UNITED NATIONS DEVELOPMENT PROGRAMME

UNITED NATIONS ENVIRONMENT PROGRAMME

UNITED NATIONS
DEPARTMENT OF TECHNICAL COOPERATION FOR DEVELOPMENT

TRANSNATIONAL PROJECT ON THE MAJOR REGIONAL AQUIFER IN NORTH-EAST AFRICA

PROCEEDINGS OF PROJECT WORKSHOP HELD IN KHARTOUM, SUDAN
12th–14th December, 1987

Under the auspices of the
National Corporation for Rural Water Development

United Nations
New York, February, 1988

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Foreword

The United Nations has for many years funded studies of groundwater in the arid areas and has contributed widely to the understanding of groundwater resources and their evolution in such areas. The eleven papers included in these Workshop proceedings are a welcome addition to arid groundwater knowledge outlining investigations carried out into the "Nubian Sandstone Aquifer" in Egypt and the Sudan with a contribution from Libya. The Department would like to acknowledge the assistance given by J.W. Lloyd in editing these proceedings.

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INTRODUCTION

Background to the Project

The Nubian Sandstone forms an aquifer underlying some two million square kilometres of Egypt, Libya, the Sudan and to a lesser extent Chad (Figure 1.1). Aridity dominates the area and the limited amount of existing cultivated land is subject to various conditions that induce desertification.

The arable land in the Western Desert of Egypt, which has provided the entire Egyptian population with wheat since time immemorial, is now reduced to small cultivated patches within the oases of Kharga and Dakhla. In the Northern Region of the Sudan the total area available for cultivation has decreased from 420,000 ha in 1960 to slightly over 100,000 ha in 1978. In particular, the most fertile land of the El Seleim-Khawi basin decreased from 100,000 ha in the late 1950s to 20,000 ha in the late 1970s, with a consequent exodus of population, which decreased from 350,000 to some 160,000 inhabitants. This decrease in land and population has resulted mainly from desert encroachment which has overcome the unutilised parts of the land and is steadily creeping towards the rest.

In order to control or reverse the process of desertification, ie. reclaiming part of the desertified land in Egypt and the Sudan, it is desirable to extend the cultivated areas beyond the Nile Valley. For this purpose, the only likely means is to develop the "Nubian Sandstone Aquifer", which is a source of large quantities of water suitable for agricultural and domestic use.

Project Design

The design of a project for the study and assessment of the groundwater resources of the "Nubian Sandstone Aquifer" was the subject of two meetings sponsored by UNESCO, held in Cairo

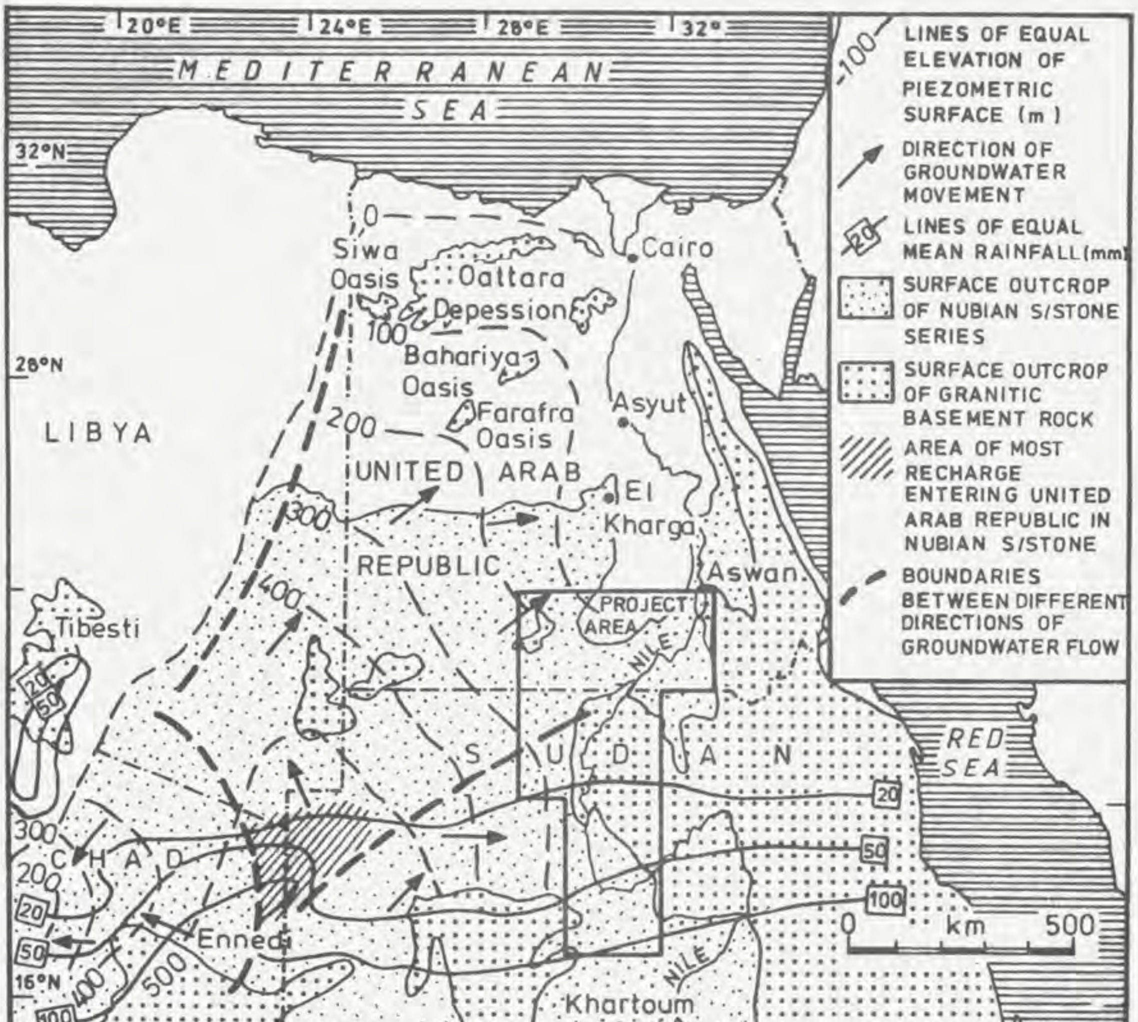

Figure 1.1 Area of the "Nubian Sandstone Aquifer"

in 1972 and 1974. Egypt, Libya and the Sudan participated in the meetings and agreed to formulate a regional cooperative programme for groundwater to be submitted to UNDP for financing.

A feasibility study on a transnational project entitled "Management of Major Regional Aquifer in North-East Africa and the Arabian Peninsula" was adopted by the United Nations Conference on Desertification held in Nairobi in 1977, and subsequently by the General Assembly of the United Nations (para. 9B of the "Plan of Action to Combat Desertification"). The implementation of the project was then recommended under the title "Transnational Project on the Major Regional Aquifer in North-East Africa", to be carried out on the basis of country components in order to facilitate bilateral technical assistance.

In summary the objects of the project were to be:

Government Development Objectives

To achieve regional co-operation in the exploitation and management of the groundwater resources of the "Nubian Sandstone Aquifer" as well as combating desertification, and practice ecologically sound agriculture and other development activities in the extremely arid areas of the region by using the groundwater from the mentioned aquifer.

Immediate Objectives

1. Upgrading of the technical abilities of national institutions in all relevant fields of water resources exploitation, assessment, development and management as well as in land use and combating desertification.

2. To have sufficient cognizance on the geographical distribution, geological conditions and hydrogeological characteristics of the Nubian Sandstone for adequate exploitation and management of its groundwater resources.

3. Establish the regional machinery for co-operation and co-ordination of studies, development, use and management of the water resources of the "Nubian Sandstone Aquifer".

4. Contribute to on-going activities related to combating desertification in the region and to select adequate modern techniques for land and water use.

Two national project components were developed, one for Egypt and the other for the Sudan. A map showing details of the areas covered by the two project components is given in Figure 1.2.

The Government of Egypt implementing agency for the project was the Research Institute for Groundwater in the Ministry of Irrigation. The Government of the Sudan implementing agency was the National Water Corporation of the Ministry of Energy and Mining. The project was administered for the United Nations by its Department of Technical Cooperation for Development (DTCD) supported by the United Nations Environment Programme (UNEP). The project's headquarters for regional coordination was established in Khartoum with a UN Project Coordinator.

The project started in April, 1984 and was completed in February 1988. Concurrently with the project a number of bilateral aid projects were carried out notably by the Egyptian General Petroleum Co., the Berlin Technical University and Bonifica-Geoexpert. Work from these projects is incorporated into this workshop report and the bilateral support is gratefully acknowledged.

Project Area Features

Although the aquifer has regional dimensions the project could only sensibly examine representative parts of the aquifer which were chosen as shown on Figure 1.2.

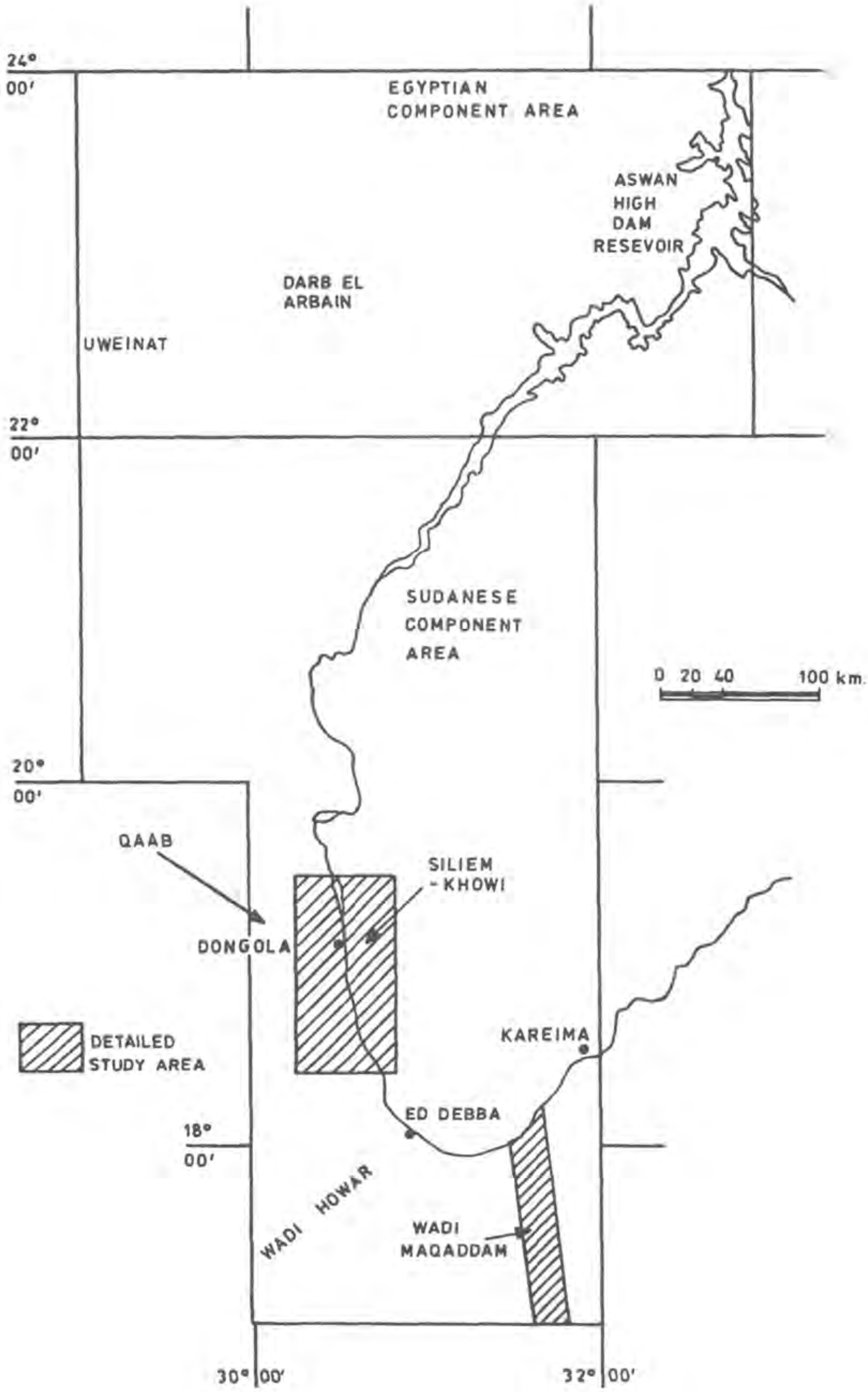

Figure 1.2 Location map of the project national component parts

The Egyptian component project area covers some 100,000 sq km in the southern part of the Western Desert between latitudes 22^{o} and 24^{o}N and longitudes 29^{o} and 33^{o}E. In the north the area is bounded by the Dakhla and Kharga Oases while the Nile flows through the eastern sector which also embraces the Aswan High Dam and Lake Nasser. Aswan is the only inhabited area but a main asphaltic road passes through from Kharga to Darb el Arbain and the Sudanese border.

The Sudanese component area borders that of Egypt and covers about 132,000 sq km between latitudes 17^{o} and 22^{o}N and longitudes 29^{o} and 32^{o}E. The area lies in the Northern Region of the Sudan and contains the Nile in its eastern sector. Dongola is the capital town for the region but other towns are present along the Nile notably Wadi Halfa, Kerma, Kareima and Merowe. Communications are via dirt roads and there is an airport at Dongola.

Climatically the project area is arid experiencing some of the highest and most continuous solar radiation in the world. Mean monthly temperatures in summer are about 30^{o}C dropping to 15^{o}C in the winter, however, daily summer temperatures frequently exceed 50^{o}C. Humidity is low (15-40%) and potential evaporation very high (10-30 mm/day). Importantly, as a factor in desertification wind speeds are consistently high of the order of 10-20 knots, trending south and south-easterly. Average rainfall in the Egyptian component area is about 1 mm per annum; this increases gradually southwards across the Sudanese area rising to about 30 mm per annum in the south.

OPENING SESSION

The workshop was addressed by Mr. O.M. Kheir, Permanent Under Secretary on behalf of Dr. Adam Madibo, Minister of Energy and Mining for the Sudan.

ADDRESS TO WORKSHOP
BY DR. ADAM MADIBO
MINISTER OF ENERGY AND MINING FOR THE SUDAN

Today we start our technical workshop about the studies in the Nubian Sandstone Aquifer. The workshop is going to continue to the 14th December and will discuss the research carried out in the aquifer in the Sudan and Egypt during the last few years. The deliberations of the workshop will also deal with the future of the present project and the development programmes which will depend on the utilisation of the groundwater from this aquifer.

The idea of studying the regional aquifer dates back to the early seventies when delegates from Sudan, Egypt and Libya met twice in Cairo and discussed the idea of participating in a joint programme financed by the United Nations to assess the groundwater development potential of the "Nubian Sandstone Aquifer" and to plan the utilisation of these resources in development projects leading to self sufficiency in cereals and legumes. With the establishment of the United Nations Environment Programme and the convention of the United Nations Conference on Desertification in Nairobi in 1977, the project was adopted as one of the regional programmes of combating desertification in north-east Africa.

The study of the regional "Nubian Sandstone Aquifer" has been carried out on a national component basis. A component was created in the Northern Region in the Sudan and another component was established across the border in Egypt. The United Nations formed a regional office in

Khartoum to coordinate the two national components and to strengthen the technical capabilities of the research institutes in the countries sharing the aquifer.

The Northern Province is considered to be one of the oldest agricultural areas where basin irrigation techniques have been practiced. After the establishment of the construction works across the upper parts of the River Nile at Roseries and Khashm El Girba, the Nile level was lowered to the extent that basin irrigation became obsolete. In addition sand migration has disturbed the irrigation systems based on the Nile so that the farmers have found it necessary to dig small open wells or mataras.

The Northern Province is ideal for growing winter crops such as faba beans, spices, citrus fruits and dates. Sand dunes have obliterated some 60% of the total irrigated land and caused exodus of 40% of the population, either to large towns or to the neighbouring countries. We have no doubts that our neighbours who share with us the desert area are suffering from the same problems which have turned them from being the world's basket of food to countries not now producing their own food.

The detailed investigations carried out on the "Nubian Sandstone Aquifer" indicate the existence of plentiful amounts of groundwater in the Sudan. It is important to point out that some 750 x 10^6 m^3 of groundwater abstraction (or about 50% of the Sudanese quota of the Nile flow) should be possible without any drastic effect on the groundwater in storage or on groundwater levels in the Dongola area. Moreover, the quality of water is fresh and similar to the Nile water which means that it can be used for different purposes and specifically for irrigation.

I would like to express our gratitude to the Italian Government for granting Sudan US $ 2.7 M to cover the foreign component needed for the study which was carried out by the

Italian company Bonifica-Geoexpert jointly with the Sudanese National Corporation for Rural Water Development. I again thank the Italian Government once more for their firm promise to proceed with the project for a second phase and finance its operations through a second grant of US $ 7.5 M. This phase is scheduled to last for 3 years during which time a pilot farm will be established to experiment with the best means of the irrigation of traditional and new crops, and for arresting sand dune migration. The second phase of the project also includes the establishment of irrigated farms along the Wadi Mugaddam to settle nomads and refugees who have suffered from the drought which has recently afflicted the area. These farms will also cater for the fodder needed for their herds and the camel trade between Sudan to Egypt.

Taking this chance of addressing you I would like to extend our gratitude to the United Nations for creating the regional machinery for the project and we sincerely hope that they extend their assistance for a second phase to ensure coordination and cooperation among the countries sharing the "Nubian Sandstone Aquifer" in order that they may enrich their experience in the various ways in which the aquifer may be developed.

I would also like to thank the Relief and Rehabilitation Commission for their collaboration and support of this workshop.

Finally I wish your workshop every success for the future development plan.

With thanks

Dr. Adam Madibo.

Address by Mr. K. Shawki, Commissioner, Relief and Rehabilitation Commission of the Sudan

Mr. Shawki stressed the considerable importance that groundwater should play in future development in the Sudan, saying that to date it had been largely neglected. In view of the difficulties being experienced in controlling and utilising Nile waters quite clearly groundwater would become increasingly important. Under the drought conditions experienced in the 1980s many people had been displaced and it was anticipated that in the future such problems could be overcome by the utilisation of groundwater.

The regional cooperation of the utilisation of the "Nubian Sandstone Aquifer" is important and he hoped that Libya and Chad would join the Sudan and Egypt in studying the aquifer and that future support for such studies would be forthcoming from the United Nations and bilateral donors.

Address by Dr. K. Hefney, Project Manager for the Egyptian Component Area

Dr. Hefney said that the project had been a success in demonstrating that groundwater is not a constraint to development in the desert areas studied. He felt that the regional cooperation had been of great benefit in that it had provided an interchange of technical knowledge and experience about the aquifer.

In the future the utilisation of the aquifer would become significantly more important with major schemes envisaged in Egypt and Libya. In view of the anticipated developments he thought it essential that regional cooperation be extended.

PAPER PRESENTATIONS

Paper 1
Project Regional Coordination Machinery
W. Iskander. Project Coordinator

Introduction

The means for providing regional coordination were established by UN/DTCD in early 1982 prior to the RAB 82/013 project in an initial phase. This phase was directed specifically towards encouraging bilateral aid support for the project objectives.

Once the project became operative in 1984 coordination between the component parties was carried out through staff visits, the exchange of scientific data and reports, consultancies, fellowships and equipment allocations.

Upgrading the Technical Ability of National Institutions

The technical ability of the national institutions dealing with the studies and development of groundwater resources in both components was promoted through:-

1. Short term consultancy services
2. Training programmes
3. Provision of selected equipment

Consultancies

Ten man months of consultancies were carried out during the project. These were in:

(i)	Data Processing and Data Base	1984
(ii)	Environmental Isotopes	1985
(iii)	Modelling	1987
(iv)	Water and Land Use	1988

These followed eight man months of consultancies sponsored by UNEP before the project became operational; in:

(i)	Remote Sensing	1982
(ii)	Data Collection and Data Evaluation	1982

The contributions of the various consultants to the project's activities were most valuable. The consultants carried out appraisals of the project's needs, trained the national staff and compiled reports.

Training

Training of the national staff was carried out through the provision of fellowships, inservice training, and participation in national and international technical meetings.

Fellowships

The original intention for 27 man months of fellowships was rescheduled and increased to 36 M/m upon the recommendations of the Project Joint Technical Steering Committee. The increase was designed to provide studies in environmental isotopes in groundwater hydrology, and in water resources management. The fellowships provided were:-

(i)	Data Collection and Data Evaluation	6 M/m	USA
(ii)	Remote Sensing	6 M/m	USA
(iii)	Data Processing and Date Base	6 M/m	Netherlands
(iv)	Modelling	6 M/m	Netherlands
(v)	Environmental Isotopes	6 M/m	Austria
(vi)	Water Resources Management	6 M/m	USA
	TOTAL	36 M/m	

The programme of fellowships was timed to meet the needs of the schedule of activities of the project. The fellows selected were acquainted with the "Nubian Sandstone Aquifer" and its problems and on their return have actively participated in the on-going studies.

In addition to the fellowships sponsored by the project, the national staff in both countries benefited from 50 M/m of fellowships from bilateral and other UN sources. For the last four years, two of the project staff members from each component participated in the 2 month training course "Hydrology of the Arid Areas" arranged by UNESCO and Ein Shams University in Cairo.

Inservice Training

The geological and hydrogeological studies carried out by sub-contractors in both components offered excellent opportunities for inservice training of the national staff. The staff worked with the sub-contractors in the field and were trained in the complementary office work. Ten Sudanese nationals were sent to Italy to participate in the interpretation of the field data and the finalisation of maps and reports.

Workshops and Meetings

Two workshops were convened for three days each in the Sudan and Egypt during the visits of the consultants on remote sensing and data processing. Topics presented were directed towards the applications of both techniques in groundwater hydrology.

Project results were presented at international meetings as follows:

Fifth Congress on Water Resources, Belgium, 1985
Six Congress on Water Resources, United Kingdom, 1986
Fourteenth Colloquium on African Geology, Federal German Republic, 1987

On behalf of the project the Project Coordinator participated and submitted technical papers to:

Seminar of the Egyptian Society on Groundwater on "Groundwater Potential of the Nubian Aquifer", Cairo, 1985.

International Workshop on Sand Transport and Desertification in Arid Lands, Khartoum, 1985.

Equipment

The United Nations provided the project with computing equipment suitable for the creation of national component data bases. The equipment included four IBM personal computers, printers and plotters plus pertinent software.

To assist project field operations vehicles were also provided.

Technical Activities

Investigations and Studies

The investigations in each component were carried out either directly by the national institutions or by national or foreign specialised firms. In either case the UN project regional machinery was involved in the preparation of the methodology and provided technical help. The involvement extended to cover some of the parallel projects operating in the same areas and having the same or similar objectives.

The main projects operative within the orbit of the UN regional project are listed below with approximate funds:

Projects carried out by the Egyptian General Petroleum Co. (GPC) as part of the Egyptian Green Revolution Programme namely:

a. Assessment of Groundwater Resources of the "Nubian Sandstone Aquifer" East of Oweinat Area (value not known).
b. Establishment of a Renewable Energy Centre for Irrigating 834 ha around Bir Tarfawi from the "Nubian Sandstone Aquifer" (US $ 9,000,000).

Geoscientific Studies of Arid Areas. Berlin Technical University (US $ 20,000,000).

Establishment of Shelter Belts for the Protection of Irrigated Agricultural Land, Northern Region, Sudan (S00/84/009). UNDP input US $ 1,300,000.

Afforestation and Reforestation in the Northern Region, Sudan (UNSO/SUD/401) with a Danish grant of US $ 3,450,000.

Environmental Isotope Applications to Groundwater and Surface Water Assessments in Southern Egypt and Northern Sudan (RAF/8/010), (US $ 500,000).

The investigations in the Sudan were carried out by the Bonifica-Geoexpert Co. of Italy, and the National Water Corporation of the Sudan (NWC). They consisted of two levels of studies:

(i) Regional Reconnaissance Studies using Landsat imageries and including geological, morphological and drainage, structural and pedological mapping of the whole component area of 132,000 sq km.

(ii) Detailed Studies using aerial photography in the Seleim-Khawi-Qa'ab area and along Wadi El Mugaddam. The area covered was some 10,000 sq km and the studies included topographical, geophysical and hydrogeological appraisals, soil and land classifications, agronomic, socioeconomic and desertification analyses. A mathematical model showing the response of the aquifer for future development was constructed and a plan produced for the agricultural development of the area. 20 wells were drilled to confirm the results achieved and to provide irrigation for the proposed pilot farm.

The investigations in the Egyptian Component were carried out by the Research Institute for Groundwater and the Egyptian Geological Survey. The investigations included geological, structural, hydrogeological and geophysical studies. A mathematical model was constructed to examine the availability of groundwater for the development of the agricultural land adjacent to Lake Nasser.

The results of the investigations indicated that water will not be a constraint in the future development of the area underlain by the "Nubian Sandstone Aquifer" in Egypt and the Sudan. This is particularly evident from the groundwater modelling carried out for East Oweinat, where GPC indicate an abstraction availability of 285 x 10^6 m^3 per annum.

In the vicinity of Lake Nasser the project model indicates that 275 x 10^6 m^3 per annum can be withdrawn to develop arable land.

In the Sudanese component area the 1987 abstraction amounted to 380 x 10^6 m^3. Modelling has shown that for an increase to 760 x 10^6 m^3 per annum on a further 5 m of drawdown would be anticipated. This very advantageous condition relates to the effects of induced recharge from the Nile supporting the groundwater abstraction.

Desertification Control

The project assisted in mobilising national, bilateral and international funds to control desertification in the area. In Egypt attention was given to the generation of renewable energy necessary for groundwater irrigation. In the Sudan efforts were oriented towards establishing shelter belts to protect the irrigated agricultural lands from sand dunes migration.

The project did not draw guidelines for combating desertification although the studies carried out by the project and other parallel projects undoubtedly form the basis on which such guidelines can be formulated. Further, the project successfully created an awareness of the hazards facing the area.

Discussion of Paper

It was considered that while the project objectives had been over-ambitious it had achieved much in demonstrating the large groundwater potential of the aquifer and in the exchange of technical information between Egypt and the Sudan. The structure of the project had been such that it supplemented bilateral and multilateral aid projects without proving a hindrance.

The general opinion was that a next phase of the project was required which would implement developments using the aquifer resources. Such developments could include pilot farming and the installation of watering points on camel routes between Egypt, the Sudan and Libya, however, larger scale developments such as those in Kufra, Libya were required not only for economic reasons but also to understand the aquifer. The Kufra example was cited in which some fifteen years of abstraction at 1×10^6 m^3/day had only resulted in cone-of-depression effects extending only 25 km.

The committees formed under the encouragement of the project could provide national focal points that promote development planning. Because the project had already established regional cooperation it was felt that this could be strengthened and extended to include Libya. Funds would undoubtedly become available and it was hoped that the United Nations would support the regional activities of the committees so that coordination of bilateral aid and national projects could be carried out. In addition to the coordination of economic development it was considered essential that environmental aspects should be given a high priority.

Paper 2

Management Problems of the Major Regional Aquifers of North Africa

A. Shata. Desert Institute, Egypt. Project Consultant

Introduction

The "Nubian Sandstone Aquifer" studied by the project is only one of a regional system of aquifers extending throughout North Africa. The aquifers are variably inter-connected through their lithologies but are also to some extent structurally controlled in that regional sedimentary basins can be recognised which are analogous to groundwater basins (Figure 2.1).

Knowledge of the groundwater conditions in the aquifers is variable but generally sparse so that the management problems relating to utilisation of the resources are only just beginning.

Status of Hydrogeological Knowledge

There is in fact a wealth of general information available about the various aquifers present in North Africa. The type and quality of such information varies from country to country although it is normally possible to determine a national picture, or at least to know where to commence investigations. However, everything stops essentially at the frontiers, so that it is impossible to get an idea of the regional mechanisms of groundwater flow and of the magnitude of the resources available.

In North Africa, upto 10^{o}N latitude, the strata are mainly sub-horizontal and largely undisturbed. The basement is generally not deeper than about 300 to 500 m. Large scale folding and faulting are present north of about 20^{o}N latitude. Major uplifts and down-thrusts have severely modified the deep sedimentary basins. Aquifer depths in such basins can reach down to about 2000 m, and total aquifer thicknesses are often 500 m or more.

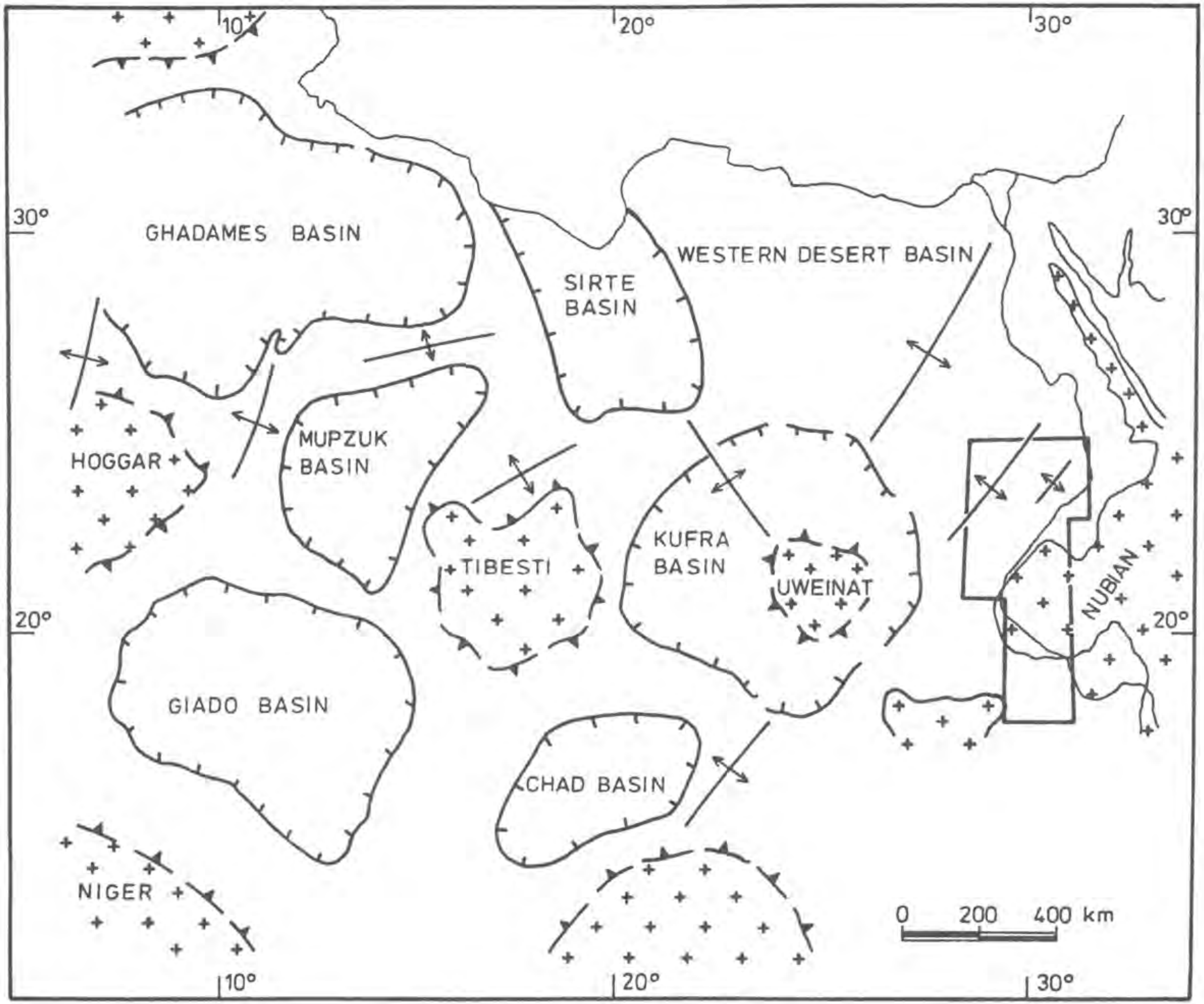

Figure 2.1 Regional geological basins in North-East Africa

Radiocarbon dating has revealed that the water contained in these basins is mainly between 20,000 and 40,000 years old. In some localities, dating yields ages in the range of 7000 to 10,000 years. Recently Burdon (1977) described the possible mechanisms, which alone or in combination, could maintain the flow of fossil aquifers under conditions of nil recharge.

Locally intensive exploitation of the fossil groundwater has occurred since the Second World War. Unfortunately groundwater levels have declined in some of the development areas with serious consequences. For example in Egypt at least 50% of the 350 deep wells drilled in the New Valley project area (Kharga and Dakhla) have stopped flowing and pumping is now necessary. Clearly this poses major management problems for the planners.

Main Hydrogeological Knowledge Gaps

Apart from the scarcity of detailed data for large areas in North Africa, there are problems related to the unreliability of much data on groundwater resources, a lack of standardisation in data presentation and the restriction on availability of certain data.

The unreliability of data for the aquifers is connected with the lack of an integrated approach to the research segments in the existing projects, as well as to the short time spans allowed for research work. Unreliability of data may also be attributed to the small number of random measurements undertaken. Due to the intrinsic vertical and horizontal variations in most aquifer characteristics, large numbers of measurements are necessary in order to arrive at statistically correct information.

A lack of standardisation in the presentation of data is a problem for comparison and correlation between the different aquifer systems. It is related to different techniques of measurement, to the use of different measuring units, and to an inconsistent variety of names and descriptions given to the same geological formations.

Although in North Africa aquifer management problems arise largely from natural conditions, the impact of man also plays a part. As examples of human impact reference can be made to the injection of saline or brackish water into oil fields and to the uncontrolled drilling and pumping of water wells. Dealing with such human problems requires legislation to regulate water allocation through controls or taxation as well as training in the technical aspects of aquifer exploitation and management. The education of water users is necessary both at the local level (each country) as well as at the regional level (more than one country sharing the same aquifer).

Finally while accepting the need for more data and integrated investigations there also needs to be a sensible resolution to the diversity of opinion regarding the aquifer characteristics of the aquifers, the age and origin of the water and also the alternative strategies for the beneficial development of the groundwater.

Reference

Burdon, D.J., 1977. Flow of fossil groundwater. Q. J. Eng. Geol. London, 10, 97-124.

Discussion of Paper

It was generally agreed that much more knowledge of the aquifer was required and that interchange of information was essential between the various countries in the region. The example of cooperation between Jordan, Syria, Iraq and Saudi Arabia in aquifer monitoring and studies of integrated development projects and social needs was cited as the way in which future work in the "Nubian Sandstone Aquifer" could proceed.

The difficulties in agricultural development experienced in Libya in the early stages of groundwater exploitation were discussed and the present Libyan policy of piping groundwater to the coast explained. Because of the presence of good land at the coast and an existing infra-structure it was found by the Libyans to be more beneficial to transport water rather than develop agriculture at the point of abstraction.

It was pointed out that differing national economies may not permit the same solutions to development of the aquifer. More understanding was needed with respect to the social and economic repercussions of in situ development particularly in Egypt where the low flow conditions in the Nile were having serious consequences for agriculture. In particular it was considered essential that more attention should be paid to reducing pumping costs from the aquifer through the development of alternative energy sources and cheap pumping systems.

Finally it was concluded that for development there was a strong need to train personnel who would be capable of living in the desert.

Paper 3

Data Collection, Storage and Retrieval for the Sudanese Component Area

S. Hamid

Introduction

One of the activities of the project was to establish a computerised data base system for the preservation and processing of the collected data, the training of Sudanese personnel in using automated data systems, and the monitoring and modelling of the "Nubian Sandstone Aquifer".

At the same time a computerised national data base system was being established supported by the Dutch technical aid. To ensure integrity of data and to prevent the dispersion of skilled staff between the two systems in the department, it was decided to merge them in one data base system but to also maintain the character of the UN project.

Computer System

The computer system provided for the project is shown in Table 3.1b, for comparison Table 3.1a shows the rest of the national system. The hardware is composed of a local area network server with 45 Megabyte storage connected to one Apple IIe, one IBM PC and two IBM AT, in addition two Apple II+ and one Olivetti M21 are used for off-line data entry and word processing systems. The output devices are dot matrix printers and a drum plotter.

The software used in handling data is the Information Master running under Apple DOS which is used as the data entry system and Dbase III+, which is a relation data base management system running under the MS-DOS operating system, and is used as the main data handling system. Programming languages used are Basic and Fortran. For word processing Easy Writer and Microsoft Word are used.

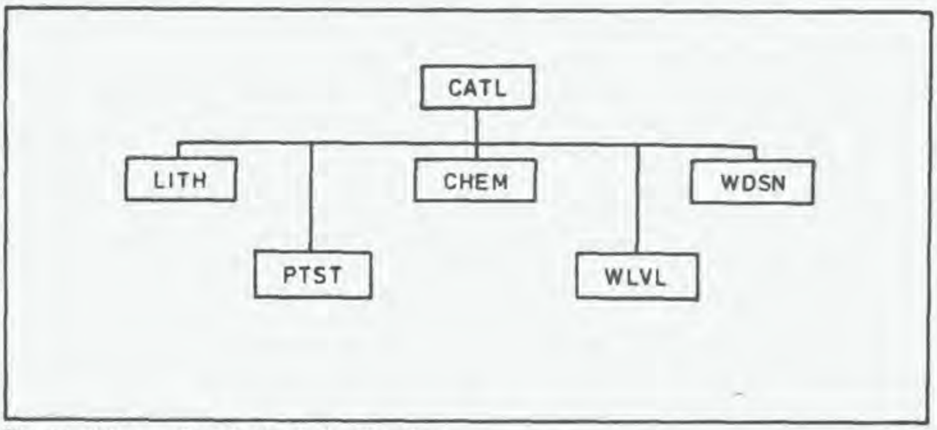

Figure 3.1 a Borehole data structure

Figure 3.1b Geophysical data structure

Name	Number	Remark
Apple II+	2	Each computer has: 64 Kb of RAM 2 * 140 Kb Floppy disc drive
Apple IIe	1	64 Kb of RAM 2 * 140 Kb Floppy disc drive
IBM PC	1	512 Kb of RAM 2 * 360 Kb Floppy disc drive math processor
Olivetti M21	1	640 Kb of RAM 360 Kb Floppy disc drive 20 Mb hard disc
Network	1	Corvus LAN with 45 Mb hard disc
Printers	3	Epson printers 8" paper width

Table 3.1a The national data base hardware

Name	Number	Remark
IBM AT	1	512 Kb of RAM 1.2 Mb Floppy disc drive 20 Mb hard disc
IBM AT	1	512 Kb of RAM 1.2 Mb Floppy disc drive 30 Mb hard disc
Plotter	1	DMP-52 Houston Instrument plotting area 24 x 36 inches
Printers	2	Okidata M193 16" paper width

Table 3.1b The Project data base hardware

Data Analysis

The geohydrological data are divided into two, conventional data which are collected during normal geohydrological processes, eg. drilling, pumping-tests, water level monitoring, geophysical surveys etc., and data collected for special purposes or data collected by other organisations such as metrological data. The conventional data are further divided into fixed data and time series, where fixed data are the data collected only once like lithological data, location, well design etc., the time series are the data that vary with time, water levels salt contents etc.

For the conventional data a special data collection form is created taking into account all the possibilities of the normal geohydrological activities. Corresponding data base files are created and inter-related within an integrated system. The general structure of conventional geohydrological data base is shown in Figures 3.1a and b where the following apply:

CATL well summary
LITH lithological description of the layers
CHEM chemical analysis of water samples
WDSN well design and location of screens
PTSP pumping-test data
WLVL water level time series
VESS vertical electrical soundings
GRAV gravity survey
SISM seismic survey

An important aspect of data analysis is the identification or numbering system, and since geohydrological data are directly related to space and time a numbering system which has space and time significance is used. This has been done by adopting and adapting the international geographic numbering system used for topographic map sheets. It gives a resolution of a quarter of a degree.

To obtain higher resolution the date of the start of the process, such as the starting date of drilling is added. This enables users of the data to make a chronological analysis as well as spatial correlation.

Data Collected

The data collected in the project have been divided into two according to their types and purpose of collection. These are:

a) Data directly concerning boreholes and groundwater.

b) Data related to economic and social activities in the project area.

Within the framework of data collection special data collection forms have been designed to help the collection of data from the field. Some of the data forms cannot be used to enter data directly into the computer because their data structure needs normalisation. For this reason data are rewritten on computer data entry forms as shown on Tables 3.2 and 3.3. These tables show the name of the data, the total number of records to be entered in the computer and the record size in Kb (in thousands of characters). The stars in the third column indicate the degree of complexity of data structure.

The agronomic and socioeconomic data are shown in Tables 3.4 and 3.5. These types of data are stored in off-line files where they can be used as required.

Data Entry and Processing

Data are entered only after all field operations have finished, also elementary processing of most of the data is done without the help of computer, except for the gravity data which are processed through the General Petroleum Corporation's computer system.

Name	Record	Level	Rec. size	File size Kb	Remarks
Driven wells					
Well inventory data	350	*	56	23.10	No coordinates
Technical characteristics	113	*	180	20.34	
Hydrologic data	339	**	50	16.95	
Physical & hydro chemical data	452	**	50	22.60	
Nile & Groundwater					
Tritium & stable isotopes of Nile & groundwater	200	*	100	20.00	No coordinates
Daily Nile elevations (masl)	40	**	190	7.60	Dongla & Merowy stations 1984-86
Daily Nile discharges (10^6 m^2/day)	20	**	190	3.80	Dongla only 1984-86
Hydrogeological data					
Well summary	197	*	200	39.40	From outcrops & wells
Chemical analyses	600	*	190	114.00	
Well design	240	*	120	28.80	48 wells piezometers
Mechanical analyses	52	**	50	2.60	Aquifer analysis
Well lithology	640	**	112	71.68	62 open & bore wells
Outcrop lithology	1995	**	112	223.44	136 Nubian outcrops
Aquifer hydrology					
Water table depth records	135	**	190	25.65	Data digitised from recorders on 20 wells
Water level monitoring	2100	**	15	31.50	Water level data for long and step test
Long duration pumping test	4080	***	25	102.00	51 pumping test & recovery test
Long duration recovery	3060	***	25	76.50	"
Step pumping test	1485	***	25	37.13	33 step test
Recovery from step test	990	***	25	24.75	& recovery test
Geophysical data					
VES resistivity soundings	4824	**	100	482.40	134 vertical electrical soundings
Gravity data	658	**	80	54.80	685 readings

Table 3.2 Data directly related to groundwater

Agronomic data					
Soil profile description	1740	**	120	208.80	497 samples
Soil profile physical & chemical data	452	**	130	58.76	113 samples
Village inventory	98	*	80	7.84	
Geology & mineralogy					
Petrographic description	359	*	35	12.50	352 samples from basement & basalts
X-Ray & chemical analyses	62	*	90	5.58	62 basement & basalts
Age determination Rb/Sr	25	*	45	1.13	25 basement only
Age determination K/Ar	15	*	45	0.67	15 basalt only
Gold & Scheelite chemical & optical separation	112	*	85	8.52	112 samples of alluvial deposits
Grain size analyses	96	*	10	0.96	Alluvial analyses
Detailed mineralogical description	96	*	270	25.92	96 alluvial samples
Radioactivity readings	208	*	50	10.40	

Table 3.3 Agricultural and mineral data

	Item	Size Kb
1)	Dongla metrological station (climatological normal (1951-80)	2.5
2)	Dongla daily wind direction	2.5
3)	Climatological parameters for ETO calculation in Dongla	2.0
4)	Crop area in the central district from 1980/81 to 84/85	1.0
5)	Sowing date, harvest time and days to maturity of main vegetable in the Northern Province	1.0
6)	Cultivation system briefings for main vegetable	1.0
7)	Number of irrigations for vegetables	0.5
8)	Vegetable production in Central district	0.5
9)	Main cultivation adopted techniques in the Northern Province	2.5
10)	Tractor availability in the study area	1.0
11)	Irrigation volumes of the study area	0.5
12)	Water requirements on ETR basis	0.5
13)	Parameters utilised for calculation of plant water requirements	2.0
14)	Crop labour requirements per feddan (0.42 ha)	2.0
15)	Total value of animal production in the study area	2.0
16)	Correlation of land sub-classes, main characteristics, salt leaching and amendments requirement	2.0
17)	Crop salt tolerance level for different crops	2.0

Table 3.4 Agronomic data

	Item	Size Kb
1)	Population trends in the Central District 1955-1980	0.5
2)	Estimated percentage of male and female population of five sample villages and Wadi Elkhawi area	0.5
3)	Population composition of the sample farming households from eight villages and Wadi Elkhawi area	1.0
4)	Manpower and employment in the study area 1983	1.0
5)	Cropped area in the centre district from 1980/81 to 84/85	1.0
6)	Cropping calendar and irrigation shifts of the main crops in the Central District	0.5
7)	Cropped area by main crop in the Central District 1984/85	0.5
8)	Area, arable land and cultivated area by Gism and by crop in the Seleim Basin in number of Feddan 1984/85	0.5
9)	Cropped area by main crop in the Seleim Basin Scheme 1979/85	1.0
10)	Farm gate prices and the value of total yearly agricultural production of the study area 1984/85	2.0
11)	Unit costs of the main farm inputs and manpower in the Dongla area for summer 1984 and winter 1984/85	1.5
12)	Input costs per Feddan of wheat, broad bean and sorghum 1985	1.0
13)	Manpower requirements for the major crops	1.0
14)	Producer and consumer prices of major crops and livestock In Dongla area 1984/85	2.0
15)	Total value of animal production in the study area in 1985	1.5
16)	Mataras of Dongla Central District	1.5
17)	Farmlands and families in the towns and villages 1984/85	2.0
18)	Farms cultivated by sample farmers	2.0
19)	Costs for the farm services rendered by the Seleim Agricultural Substation and type and number of equipment used	1.0

Table 3.5 Socioeconomic data

To date (December, 1987) the following project data have been entered in the computer:

1) Chemical data, 95% entered on the CHEM database file
2) Resistivity data, 80% entered on the VESS database file
3) 14 boreholes data entered on LITH database file
4) Gravity data, 60% entered on GRAV database file

The project data under preparation are:

1) Outcrops data
2) Well summaries
3) Well designs
4) Pumping-tests
5) Well inventories

Discussion of Paper

The data base computerisation was seen as a major advance by the project and it was important that the "Nubian Sandstone Aquifer" data were integrated with other national data although they could be retrieved as required. It was considered essential that compatibility be established between Egypt, the Sudan and Libya in order that aquifer data interchange could be achieved in the future.

Paper 4

Data Base System in the Egyptian Component

M. Hussein, S. Mansy, M. Fleifal and S. Ibrahim

Introduction

The data base collation was instituted in Egypt with the same objectives in view to those in the Sudan. Initially an inventory of all wells in the project area was made and consisted of fifty-nine drilled wells and many dug wells. Pro-forma were prepared and the data computerised.

Computer System

Two IBM computers were purchased through the project with associated peripherals. As with the Sudan it was deemed sensible to incorporate the project data base into the national system which is compiled through a software package known as DAWACO.

The DAWACO data base is developed to store and retrieve data for observation wells, in future it will include data from production wells, geophysical measurements, data of pumping- tests and other relevant hydrogeological data.

National Well Numbering System and Project System

The national well numbering system in Egypt is based on the numbering system of topographical maps on scale 1:100,000. The system uses the map sheet numbers as the first part and the second part is a sequential number. In the project area a well code number of three parts has been used. The first two numbers refer to the latitude, the second two numbers refer to the longitudes and the last two numbers are the serial numbers of the well in the area.

For example:

22	28	07
Lat	Long	Serial number

An example is demonstrated in Figure 4.1.

Data Input and Output

The input is divided into four files:

1. Characteristic file: containing the general information of a well as identification.
2. Groundwater level: containing the groundwater level measurements of a well and the date of measurement.
3. Chemical file: containing the chemical analysis of groundwater from a well.
4. The lithological description file: containing the lithological description of a well log.

Output consists of a characteristics report for a complete well and a lithological report. In addition the output can be set-up to produce groundwater level hydrographs or level tables. For chemistry, tables can be listed and data can be plotted on Piper or Stiff diagrams.

The system established is therefore versatile in that data can be stored, retrieved and analysed.

Discussion of Paper

Both the Egyptian and Sudanese papers were seen as describing powerful means of processing hydrogeological and other data. Because of the need to process the project data in the national systems the compatibility between the two country components had not been established. Nevertheless it was considered that the problem was minimised due to the commonality of the computer equipment.

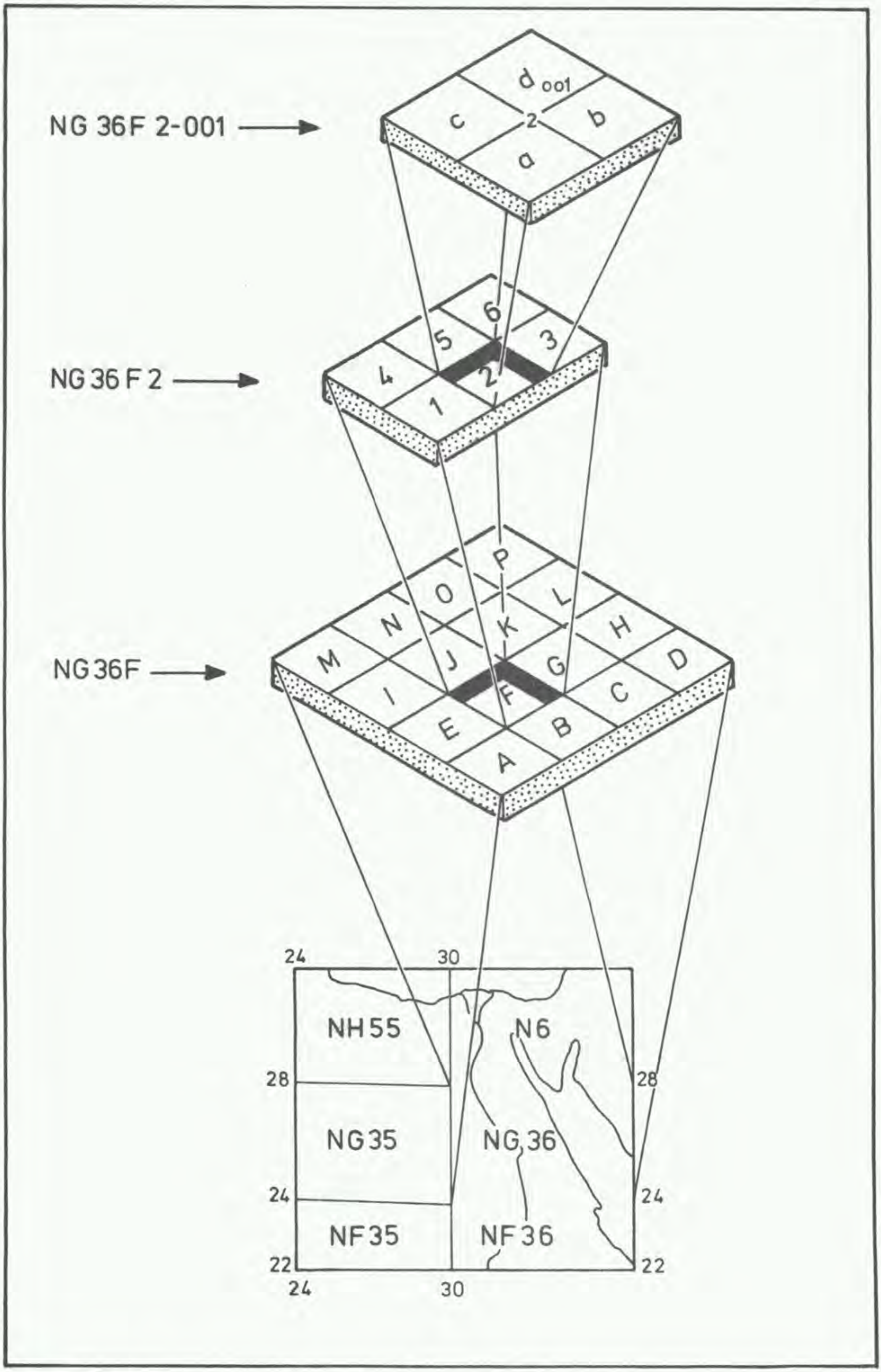

Figure 4.1 Well location numbering system for Egyptian component area

Paper 5

Geological, Geophysical and Hydrochemical Investigations in the Egyptian Component Area

M. Said, M. Mousa, R. Galal and S. Atta

Introduction

The investigations were carried out to provide a hydrogeological base for the component area. Landsat imageries and aerial photographs were used as part of the initial interpretation which was then checked by field mapping. The geological work was supplemented by geophysics and an inventory of boreholes which included hydrochemical sampling and interpretation.

Geomorphology

The western sector of the area is part of the high flat limestone plateau of the Western Desert of Egypt. The southern part of this plateau is called Sinn El Kaddab, which slopes through a series of steep scarps, to the lowland area west of the Nile Valley and south of the Kharga Oasis, and to a sandy plain in the south along the Sudanese border. The area east of Lake Nasser is characterised by basement exposures capped by sandstone and mudstone successions, highly dissected by the large valley systems of the Wadis Arr, Krusko, Gabgaba and Allaqi. West of Lake Nasser major drainage systems are observed with local drainage directed towards small internal drainage areas. Sand sheets and dunes dominate.

The Tushka depression occurs centrally in the area, and functions as a spillway for Lake Nasser. The bottom of the depression is nearly flat in the eastern side but disrupted by dunes and low hills in the west. The northern borders are clearly defined by escarpments while in the south the depression merges into the lowland desert.

Geology

Stratigraphy

The geological formations in the project area range in age from the Precambrian to the Quaternary and are given in Table 5.1. An example of the geological distribution is shown on Figure 5.1 for map NF 36-N.

Structure

The area is extensively faulted with folding playing a subsidiary role. Four fault systems have been recognised:

The east-west system: These are the most dominant faults, the lengths of these faults range from 6 km to 250 km. Fault planes dip at angles between 60^o to 80^o. Most of the faults are of normal or lateral slip type with horizontal components about 700 m.

The north-south system: The trend of the system is 5^o north, their lengths range from 4 km to 35 km. The faults are of normal type and the planes are nearly vertical.
This fault system is younger than the east-west faults as the latter are dislocated by them. The amount of offset measured in Wadi Dungul is 150 m.

The north east-south west system: These faults are fewer in number and of less importance. They range in length from 2.5 km to 30 km. At the eastern part of the area they form narrow graben and horst blocks with downthrows ranging from 10 m to 80 m. The fault planes are characterised by a comparatively gentle dip.

The north west-south east system: Of minor significance with a maximum length of about 12 km.

Epoch	Age	Formation	Lithology	Exposed thickness (m)
Quaternary		Aeolian and playa deposits, salts and calcretes, fluvial and alluvial deposits		
Tertiary	Oligocene		Basalts	
	Lower Eocene	Dungal	Limestones, shales	
		Garra	Chalky limestones, shales	
	Paleocene	Kurkar	Limestones, shales, sandstones	11-57
Mesozoic	Upper Cretaceous	Dakhla	Shales and sand-stones	35-155
		Duwi	Phosphates	0.7
		Nubian	Sandstones with shales	80-100
	Lower Cretaceous	El Borg	Massive sandstones	40-80
		Abu Ballas	Sandstones, shales, mudstones	25-30
	Lower Cretaceous - Upper Jurassic	Abu Simbil	Coarse pebbly sandstones	180
Palaeozoic	Carboniferous	Gilf	Sandstones, sandy mudstones	20-85
Precambrian			Syenites, granites, diorites, gneisses	

Table 5.1 Geological succession

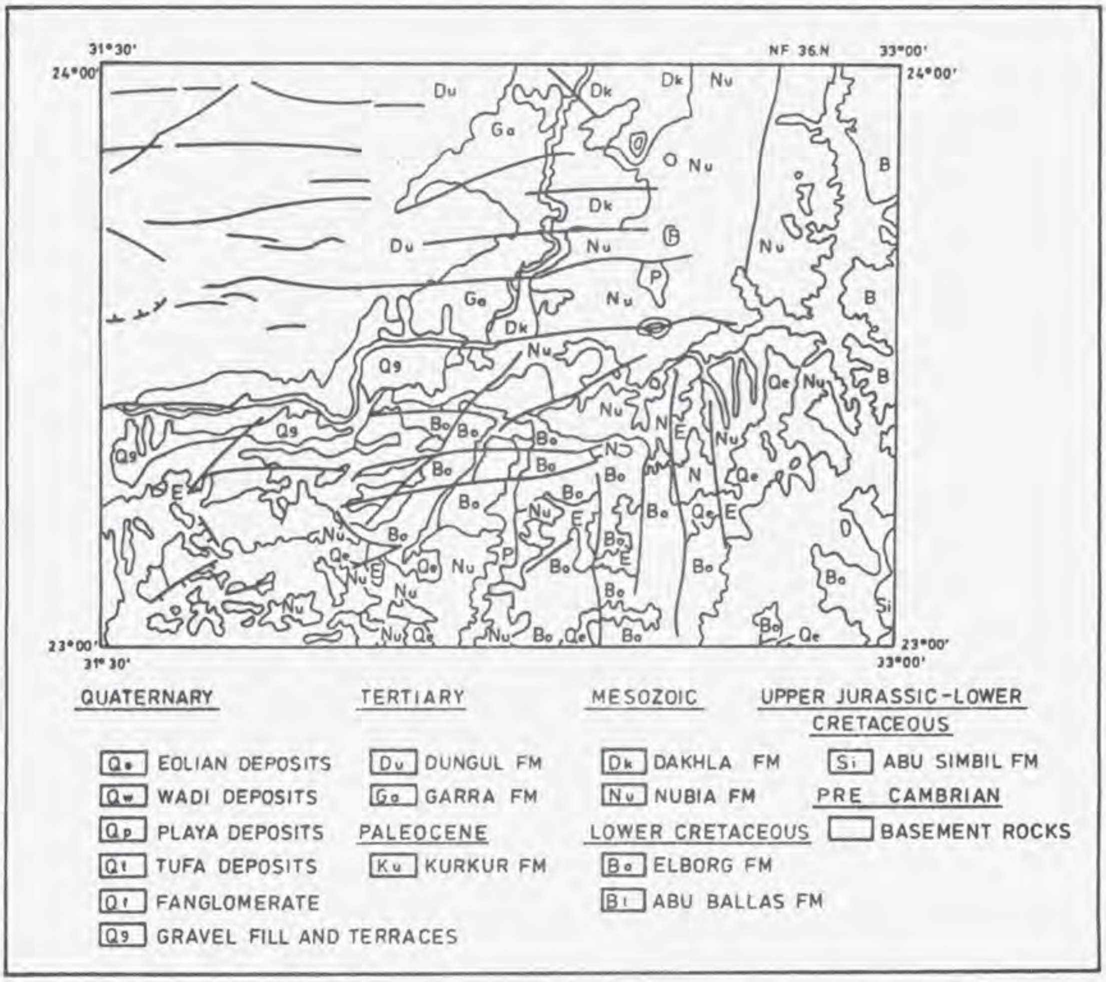

Figure 5.1 Geological map (NF 36-N) as an example from the Egyptian component area

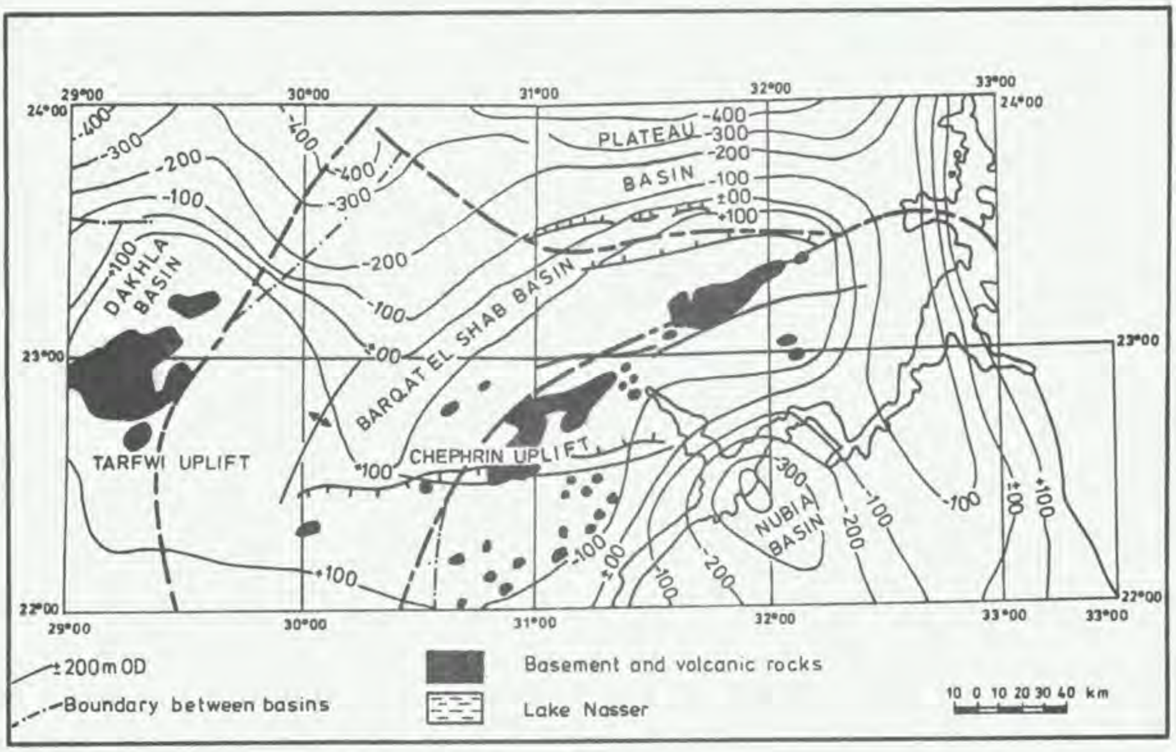

Figure 5.2 Basement structural map showing groundwater basins

In the area the basement uplift is important, especially in the areas where the overlying sedimentary cover is relatively thin. The sedimentary beds are frequently flextured or ruptured together with the basement rocks. Locally near uplifted igneous masses, the sedimentary beds are affected by heat and friction created by the uparching stresses. Basement uplifts are important in forming the boundaries between the local sedimentary basins (Figure 5.2).

Geophysics

An integrated geophysical investigation was carried out in the north-western part of the component area. Five profiles amounting to 276 km were surveyed. The field measurements undertaken were:

	Method Used	Number of Measurements	
1.	Geoelectric	102	VES
2.	Magnetic	2760	Stations
3.	Gravimetric	1380	Stations

Electric resistivity surveys were performed applying vertical electric sounding (VES) techniques, using an electronic compensator of type AE-72. The spacing between every two successive VES stations ranged between 2 to 4 km sometimes changing according to variations in geoelectric properties. The AB spacing of electrodes were some 2000 m in order to explore the relatively thick section of sediments. Interpretation was made using master curve matching techniques.

The magnetic survey was carried out using a proton magnetometer of the type 816 G, measuring the total magnetic field. The scale value is equivalent to one gamma. A base station was selected and was assumed to be away from any deformation or structural disturbance so was given an arbitrary value of 0. All measurements in the area were referred to a base station. About 10% of all measurements were checked and according to these repeated measurements, the mean square error was found to be equal to ± 0.04 m gal. The drift correction was determined graphically. The density used to calculate the Bouguer correction was chosen to be 2.4 gm/cm^3. Latitude corrections were made but there was no need to apply topographic corrections as the surface is relatively flat.

Geological Interpretation

The geological and geophysical investigations identified a number of local sedimentary basins which are structurally controlled. The basins are shown on Figure 5.2 and are discussed in hydrogeological terms below.

Groundwater Basins

The structurally controlled basins are variably interconnected hydraulically but can be considered as entities. Four basins have been defined.

Dakhla Basin

The Dakhla Basin occupies the western part of the area, covering some 30,000 sq km. The Tarfawi-Abu Bayan High bounds the basin on the eastern side and extends northwards to Kharga. Igneous outcrops delineate the southern boundary and the basin becomes gradually deeper to the north. The base of the basin is 0-600 m below sea level.

Three main aquifers are identified within the basin, there are:

The Gilf Formation and undifferentiated Palaeozoic rocks
Abu Simbil Formation sandstones
Nubia Formation sandstones

The intervening rock types are all of low permeability so that the aquifers are essentially confined.

Plateau Basin

The Tarfawi-Abu Bayab High does not completely separate the Dakhla and the Plateau Basins as they are interconnected through the Nubia Formation aquifer.

The Plateau Basin occurs in the north-east part of the project area, between the Nile Valley to the east and Dakhla Basin in the west. The basin is 15,000 sq km and is bounded by an igneous ridge (Chephren-Aswan High) on the east and south-east. It is partially separated from the Dakhla Basin by the Abu Bayan High. The basin becomes gradually deeper in a northerly direction, with the base ranging in altitude from 0-600 m below sea level.

The Plateau Basin contains the Abu Simbil and Nubia Formations which correspond to the middle and upper aquifers in the Dakhla Basin. Both aquifers are confined.

Nubia Basin

The Nubia Basin occurs in the east of the area. The Red Sea Hills bound the eastern part of the basin and the Chephren-Aswan High the north-west. The basin occupies about 35,000 sq km in Egypt with the major part of the basin lying in the Sudan.

The Nubia Basin is deepest beneath the Tushka depression where the depth to basement is more than 400 m below sea level. The Gilf and Abu Simbil Formations form the aquifers.

Barqat El-Shab Basin

This basin occurs to the south of the Plateau Basin and is defined by the Tarfawi and Chephren Highs. Its base ranges in altitude from 0-200 m below sea level.

The Barqat El-Shab Basin contains the Abu Simbil and Nubia Formation aquifers.

Well Nos.	Salinity mg/l	Cations			Anions		
		K + Na	Ca	Mg	Cl	SO_4	HCO_3
P1 Tarfawi	1288	350	28	19	319	400	142
P3 Tarfawi	1413	438	38	18	525	257	137
P1 Misaha	270	31	37	10	50	31	105
P4 Misaha	331	19	33	32	57	51	139
P3 Sahara	742	145	74	19	206	198	100
P5 Abu Husein	1154	302	71	18	376	272	115
P4 Abu Husein	1016	130	120	41	184	531	10

Table 5.2 Chemical analyses of groundwater samples from the Dakhla Basin

Well Nos.	Salinity mg/l	Cations			Anions		
		K + Na	Ca	Mg	Cl	SO_4	HCO_3
P1	6941	2400	150	44	3814	301	183
P2	1652	592	27	5	553	331	256
P3	948	330	18.4	8	248	224	219
P4	3962	1445	35	20	1868	311	341
P5	3220	1091	19	10	1242	425	299
P6	3698	1385	9	8	1775	214	283

Table 5.3 Chemical analyses of groundwater samples from the Nubia Basin

Throughout the four basins defined the Quaternary deposits form potential aquifers which can locally contain intermittent groundwater.

Hydrochemical Studies

Samples of groundwater were collected form the seven wells in the Dakhla Basin and from six wells in the Nubia Basin. The analyses are shown in Tables 5.2 and 5.3.

The data show that the salinity in Dakhla Basin ranges between 270 and 1413 mg/l, increasing in a northerly direction. In the Nubia Basin salinity increases in a westerly direction from 983 mg/l in the Tushka Depression to 6941 mg/l in the north-east.

The groundwaters are dominantly sodium chloride in character but are of meteoric origin.

Discussion of Paper

The work raises the question of geological and hydrogeological terminology. It was pointed out that prior to the recent mapping in Egypt the term "Nubian" was applied to all the pre-Dawi sandstones. The paper demonstrates the modern accepted definition of "Nubian" so that in reality the manner in which the project uses the "Nubian Sandstone Aquifer" is incorrect. A call was made to resolve geological nomenclature and correlations within the region.

It was considered that the groundwater chemistry would need more investigation as the data presented show variations that were difficult to explain in groundwater flow terms and also had inference for agriculture.

Paper 6

Geological, Geophysical and Isotope Investigations in the Sudanese Component Area

M. Salih

Introduction

The studies were carried out jointly by the Italian company Bonifica-Geoexpert and project staff from the National Water Corporation. The fieldwork lasted for two years (1984-86) and an extensive set of reports were produced.

The geological and hydrogeological investigations were carried out at two levels:

(i) Regional reconnaissance studies covering the whole area (132,000 sq km) using landsat imageries and intensive field checks.

(ii) Detailed studies over an area of 8000 sq km in two locations namely the Seleim-Khawi-Qa'ab area and the Wadi El Mugaddam area using aerial photographs.

Regional Reconnaissance

The regional reconnaissance included:

Geological, structural, geomorphological, drainage and soil studies.
Evaluation of the Nubian Aquifer.

The mapping and studies were carried out using remote sensing techniques through the interpretation of landsat imageries covering the whole area and at the scales of 1:1000,000, 1:500,000, 1:250,000 and 1:100,000. Three types of imageries were chosen for the study:

- band 7 for the study of drainage and geomorphology
- band 4 for the study of soils
- false colour composition of bands 4, 5 and 7 for geology.

The area is covered by 10 images each with a coverage of 25,600 sq km, and an over-lapping of 10%. The interpretation of landsat imageries was followed by intensive field investigations.

The types of maps produced were:

Geological and structural maps
Morphological and drainage maps
Soils maps

Geological and Structural Mapping

The maps were produced by interpretation of the black and white band 7 imageries with the false coloured composits of bands 4, 5 and 7 imageries. Field checks were made of the Basement Complex outcrops in the Nubian Desert and included taking 321 rock samples for petrographic examination, chemical analysis and for absolute age determination using Rb/Sr (rubidium/strontium) or K/Ar (potassium/argon) methods. The boundary between the Basement Complex rocks and the younger sediments was verified radiometrically using an airborne (helicopter) scintillometer.

The field work on the area of the Nubian Sandstone Formation included the examination of 78 stratigraphic sections to study the different lithostratigraphic units. 1000 rock samples were obtained for petrographic examination of the various lithotypes and, where possible, age determinations were made. Because of the scarcity of macrofossils in the formation, 40 samples were collected at different localities to examine pollen grain indices.

As a result of the studies five geological units were delineated in the Nubian Sandstone Formation:

Alternating sandstones and mudstones (Units D and E)
Sandstones (Unit C)
Sandstones and conglomerates (Unit B)
Conglomeratic sandstones (Unit A)

The geological distribution for the project area is shown on Figure 6.1.

The structural setting of the area indicates that the Nubian Sandstone was deposited in elongated north-west to south-east depressions after a long period of intense peneplanation. Late Mesozoic and Tertiary tectonics produced vertical displacements with two faulting systems in north-east and north-west directions.

Morphological and Drainage Mapping

The maps were produced using the interpretation of the landforms and drainage from the black and white band 7 imageries, the false colour composite of bands 4, 5 and 7 and field checks. The maps show divisions of the area into its main geomorphological units of both accumulation and erosion zones such as demonstrated by sand dunes and escarpments etc. The main drainage elements, their catchment areas, hydrographic network and possible hydrogeological basins are also shown.

Soils Mapping

Soils maps were produced by the analysis of band 4 imageries, together with the false colour composite of bands 4, 5 and 7. Field mapping was carried out and six major soil types identified which have formed the basis for agronomic work.

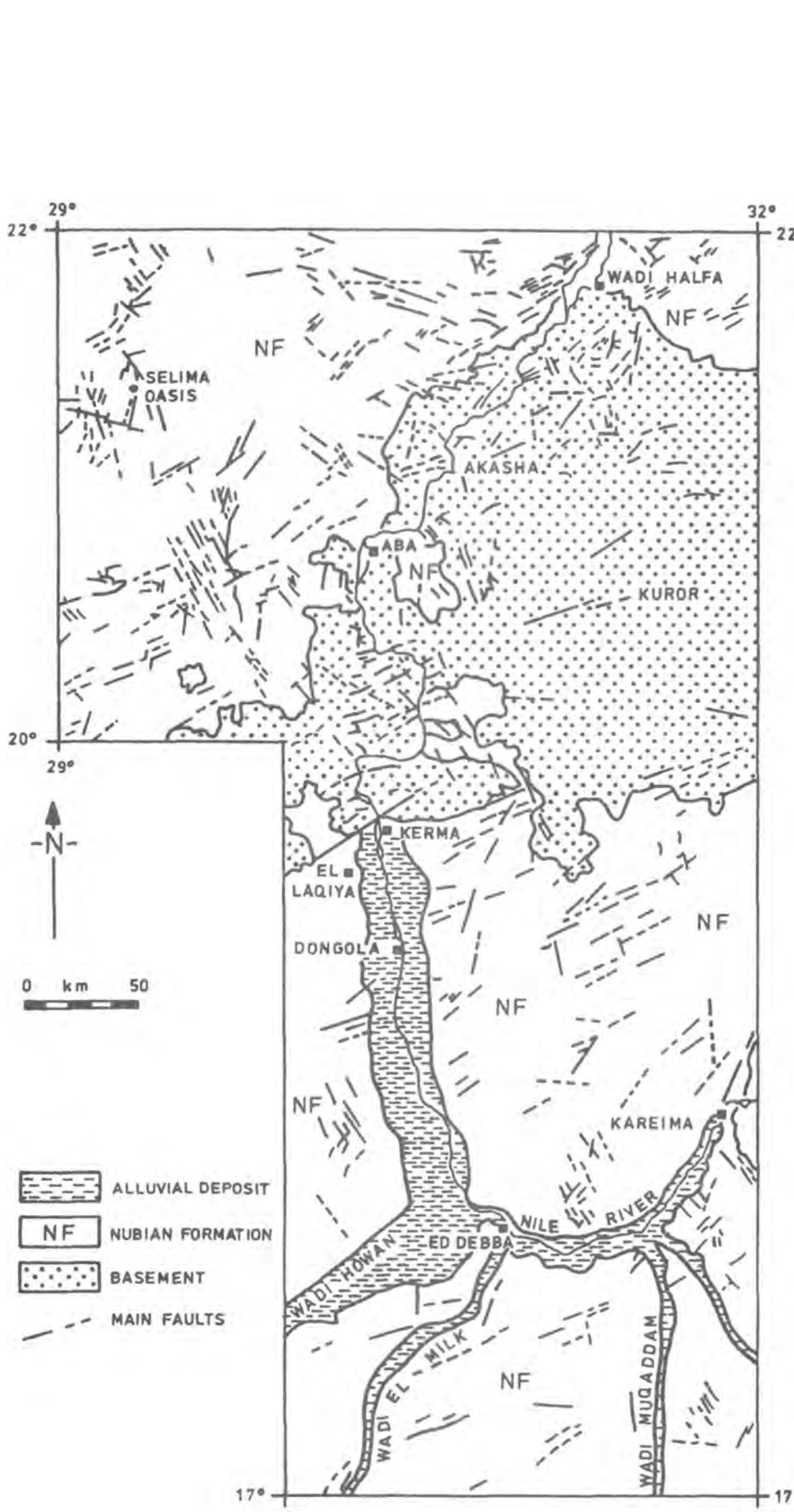

Figure 6.1 Geological distribution in the Sudanese component area

Detailed Studies

The detailed studies over the two selected areas include:

Aerial photography, topography, pedology, socio-economic, and agronomic surveys and studies of the Seleim-Khawi-Qa'ab area.

Hydrogeological investigations of the Seleim-Khawi-Qa'ab area.

Hydrogeological and agronomic investigations of the Wadi Mugaddam area.

The detailed studies were mostly based upon 1983 aerial photography with a scale of 1:20,000. Geological mapping was carried out and extensively supplemented by geophysics.

Geophysical Investigations

Aero-magnetic, gravity and electrical resistivity surveys were carried out.

The aero-magnetic survey was made by Philips Oil Co. as a part of their exploration in the Northern Region. The survey covered most of the area underlain by the Nubian Sandstone Formation north of latitude 17^{O}N. The work confirmed the presence of the north-west trending troughs. Calculated sedimentary thicknesses, however, eventually proved to be over-estimated.

Gravity measurements were taken at some 800 stations by the staff of the National Water Corporation using a Worden gravimeter. The interpretations were carried out by the consultants.

The field measurements were based upon the International Gravity Station at Merowie with (978467-966 m gal). The first station measured in a traverse was repeated again every 3-4 hours to correct for the instrumental drift. The altitude measurements were carried out using two sensitive altimeters, which were calibrated at a bench mark elevation. Temperature corrections were carried out at the base station and then matched with the readings along the profiles.

The results obtained indicate that the Nubian Formation is gently dipping to the south-west. The Bouguer anomaly map indicates the occurrence of dip structures, probably related to lateral variations in the lithology and linear structures associated with the faulting system in the formation.

Electric resistivity surveys were carried out using the vertical electric sounding (VES) method. 167 VES measurements were conducted in the area using an ABEM SAS 300 and a booster 2000 with a maximum spread of 4000 m. Steel bars were used as feeding electrodes and copper electrodes were used to measure the difference in potential. To minimise the error, two measurements were taken in each station after changing the voltage. Curve matching interpretation was used.

The resistivity results were found to be conformable with those obtained by the gravimetric survey and show that the Nubian Formation is getting gradually thicker in a southerly direction and is always carrying highly fresh groundwater.

Drilling Operations

To confirm the geological and geophysical work and to allow testing of the "Nubian Sandstone Aquifer" eleven tube wells and thirteen piezometers were drilled. Rotary mud techniques were used for the tube wells. Slim holes were drilled initially and geophysically logged for resistivity and natural gamma. The holes were then reamed to 12¼" diameter and cased and screened as appropriate.

The holes were drilled to basement with the sedimentary thickness range shown to vary from 68 to 300 m. In Qa'ab two flowing wells were drilled.

The piezometric holes were drilled with a cable tool rig and to variable depths below the water table. Each tube has one or two adjacent piezometers located at variable distances to measure the response of the aquifer to pumping. The pumping-tests carried out indicated transmissivities ranging from 2150 to 3900 m^2/day and storativities ranging from 1×10^{-4} to 3×10^{-2} showing a groundwater occurrence varying from typical confined to free water table conditions.

Groundwater Isotope Analyses

A total of 112 groundwater samples were taken for isotopic analyses of tritium, D, ^{18}O, ^{13}C and ^{14}C. Some wells were sampled more than once to determine any variations.

The study showed that the Nile is the main source of recharge to the aquifer locally. The isotopes show that recharge decreases from 100% close to the river bank to almost nil some 40 km away from the river. The mixing ratio does not substantially change with time suggesting a strong hydraulic connection between the Nile and the aquifer. The age of the groundwater in the aquifer ranges from modern, to some 26,000 years in the parts of the aquifer away from the Nile.

Discussion of Paper

The paper was considered to be very informative and quite clearly a lot of very worthwhile data had been collected. The lack of correlation between the Sudanese and Egyptian areas' geology was criticised although it was appreciated that the age of the Sudanese "Nubian" was not clearly established. The work demonstrated the need for regional geological and hydrogeological correlation. It was generally felt that the investigations provided an excellent base for water resources development particularly with respect to the Nile-aquifer inter-relationship.

Paper 7

Groundwater Resources Assessment and Groundwater Modelling in the Egyptian Component Area

M. Hussein and A. Fekry

Introduction

The geology of the area is described by M. Said et al. in Paper 5 of the proceedings of this Workshop and has been used as the basis for the groundwater resources assessments.

Groundwater Occurrence

In the project area, groundwater of good quality (500 to 1000 mg/l) is contained within several hundred metres of porous sandstone.

The geological succession can be divided into two main aquifers separated by intermediate confining beds varying in thickness from a few metres to 130 m. The upper aquifer consists of alternating layers of gravel, sand, silt and clay, and has a thickness ranging between 100 and 250 m. The lower aquifer consists of coarse to medium grained sandstones with fine grained sandstone interbeds. Basal conglomerates are usually found at the contact between the basement and the sedimentary rocks. The maximum thickness of the lower aquifer is 300 m and it is the principal source of groundwater. In some places, especially at the Nasser Lake area, the lower aquifer may be separated into two where thin shales and silts are present.

The groundwater flow pattern in the project area is controlled by major north-east trending swells or arches on the Precambrian surface and major north-east faults. There are two main uplifts, Nakhli-Aswan and Tarfawi-Abubayan, as well as the Kalabsha Fault, which partially separates hydrogeological flow systems. Four hydrogeological basins are defined (Figure 5.2).

Dakhla Basin: This contains two aquifers, the lower confined aquifer is very permeable (average permeability 10 to 20 m/day), the transmissivity ranges from 945 to 2,746 m^2/day. The upper aquifer is unconfined. The maximum depth to the basement is about 650 m. The maximum groundwater salinity is 800 mg/l.

Plateau Basin: The depth to the basement varies from 0 to 600 m and the basin is completely isolated from others by igneous rocks. Groundwater salinity varies from 550 to 2,000 mg/l, suggesting the presence of connate water. The Nubian and Abu Simbil Formations are the two exploitable aquifers present.

Barget El Shab Basin: The depth to the basement ranges from 0 to 200 m. The aquifer is the Nubian Sandstone Formation with a thickness of 200 m or more and is multi-layered. Several thin sandstone layers are present containing groundwater of different salinities. The variable salinities indicate that the layers are not well connected and that the water may well be connate in origin. The salinity ranges from 2,000to 7,000 mg/l.

Nubia Basin: An effective hydrogeologic boundary to the basin is formed by the Kalabsha Fault in the north. The depth to the basement ranges to 500 m. The lower aquifer is well developed and can be separated into two layers locally. Shale and sandy chalk separate the two layers. The thickness of the lower aquifer reaches 300 m and has an average permeability of 1 to 4 m/day. The transmissivity ranges between 500 and 1,200 m^2/day. The upper aquifer has a thickness of 200 m and is unconfined.

Groundwater Head Distribution

Groundwater flow in the "Nubian Sandstone Aquifer" is generally towards the north-east (Figure 7.1). The depth to groundwater in the project area ranges from a few metres to 90 metres. In the east groundwater levels in both the shallow and deep aquifers show seasonal fluctuations which are caused by recharge to the Nubia Basin from Lake Nasser.

Before the construction of the Aswan High Dam, the static water level of the deep aquifer was much higher than that of the shallow aquifer. After the formation of Lake Nasser the relative groundwater levels were reversed and the shallow aquifer is now recharging the deeper aquifer (Figure 7.2). The two aquifers are variably hydraulically interconnected through lateral changes in facies.

Aquifer Characteristics

Pumping-test data in the Nubia Basin indicate transmissivity values ranging between 500 and 1,200 m^2/day. In the west in the Dakhla Basin, transmissivity ranges between 945 and 2,746 m^2/day and hydraulic conductivity from 10 to 20 m/day. Storativity is 0.0002 to 0.0008 in the confined aquifer and 0.16 to 0.23 in the unconfined area.

Mathematical Modelling

The objective of the modelling was to properly evaluate the groundwater resources and their development potential. Two models were constructed, one of the Nubia Basin around Lake Nasser and the other on the north-west side of the project area in the vicinity of Oweinat.

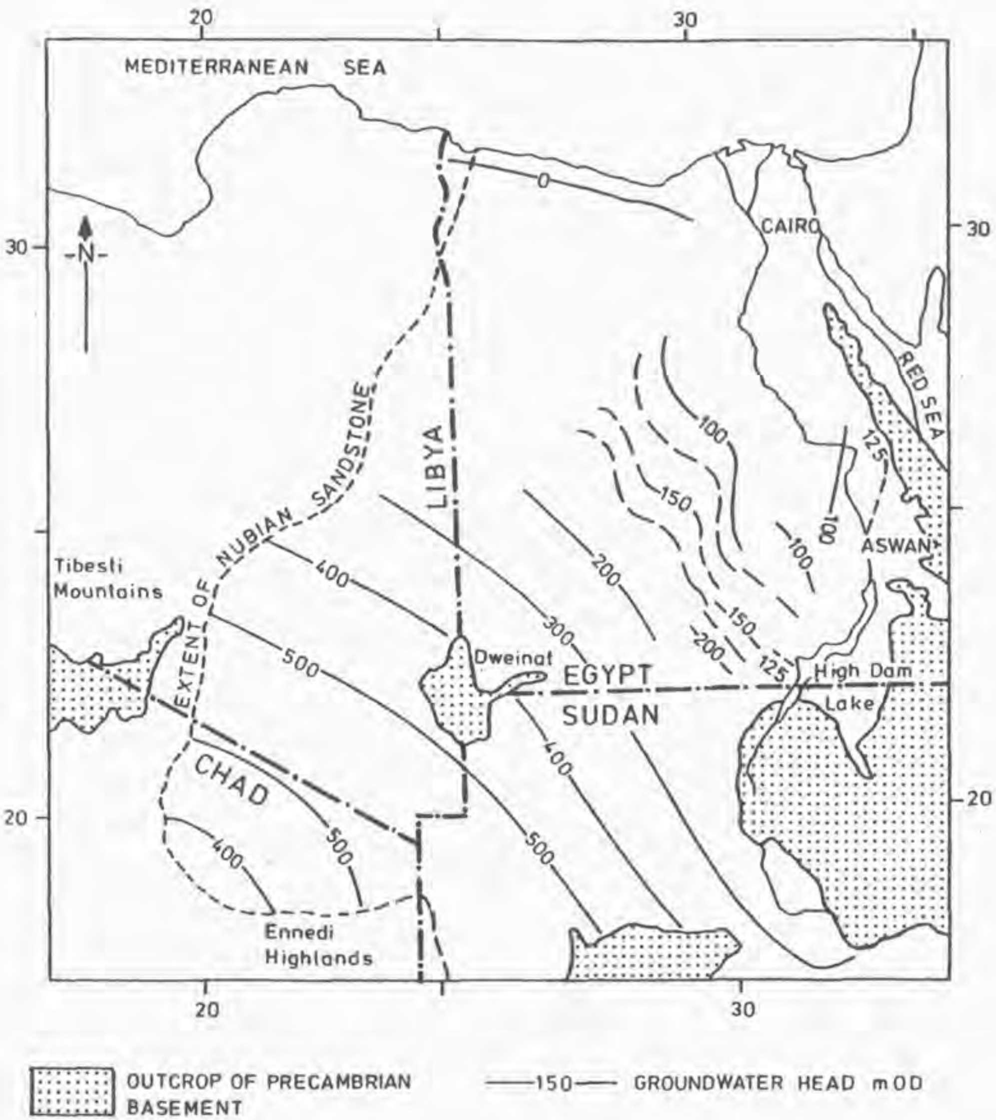

Figure 7.1 Groundwater head distribution for the "Nubian Sandstone Aquifer"

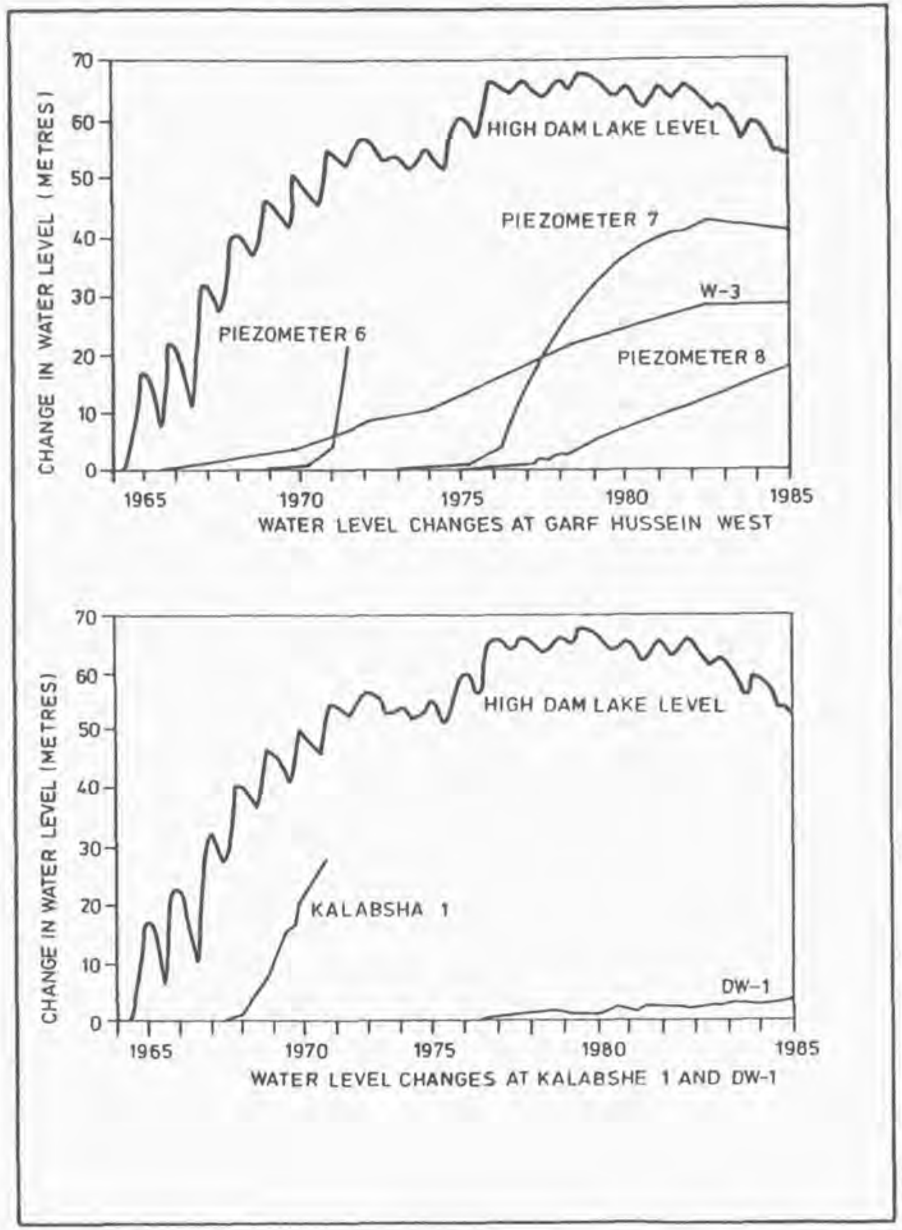

Figure 7.2 Groundwater head changes after the construction of the Aswan Dam

Nubia Basin Model

The water balance for Lake Nasser for the period 1975 to 1981 indicates seepage losses ranging from 2.2 to 8.4 x 10^9 m^3 per annum. The lake is underlain by the Nubian Aquifer which is subdivided into three layers that have various degrees of hydraulic interconnection. The upper part of the aquifer is unconfined and is in hydraulic continuity with the lake. The middle part of the aquifer is 100 to 250 m thick, and is very promising for development. This layer is separated from the top one by a sandy clay and from a bottom part of the aquifer by shale. The aquifer has a transmissivity ranging from 130 to 205 m^2/d and a hydraulic conductivity ranging between 3.22 to 4.56 m/d. The electrical conductivity of the groundwaters is less than 1500 µS/cm and the water is suitable for agriculture.

A two dimensional finite element model was constructed for an area of 31,000 sq km around Lake Nasser (Figure 7.3).

The aim of the model was to determine the safe yield of the aquifer at periods of low floods when the level of the lake is at its lowest and hence the recharge to the aquifer is at a minimum, ie. under the worst conditions. The lowest level of the lake has been considered to be 150 m above sea level and the critical period of low floods taken as seven years.

The model consisted of 102 elements and 65 nodes. The calibration was carried out using an average transmissivity of 180 m^2/day. The results of the model indicate that the safe discharge from the aquifer at the various locations selected for irrigated agriculture can total 257 x 10^6 m^3/annum.

The main wellfield development is proposed for Adindan which lies on the western bank of Lake Nasser (Figure 7.3). The aquifer thickness at the proposed wellfield is about

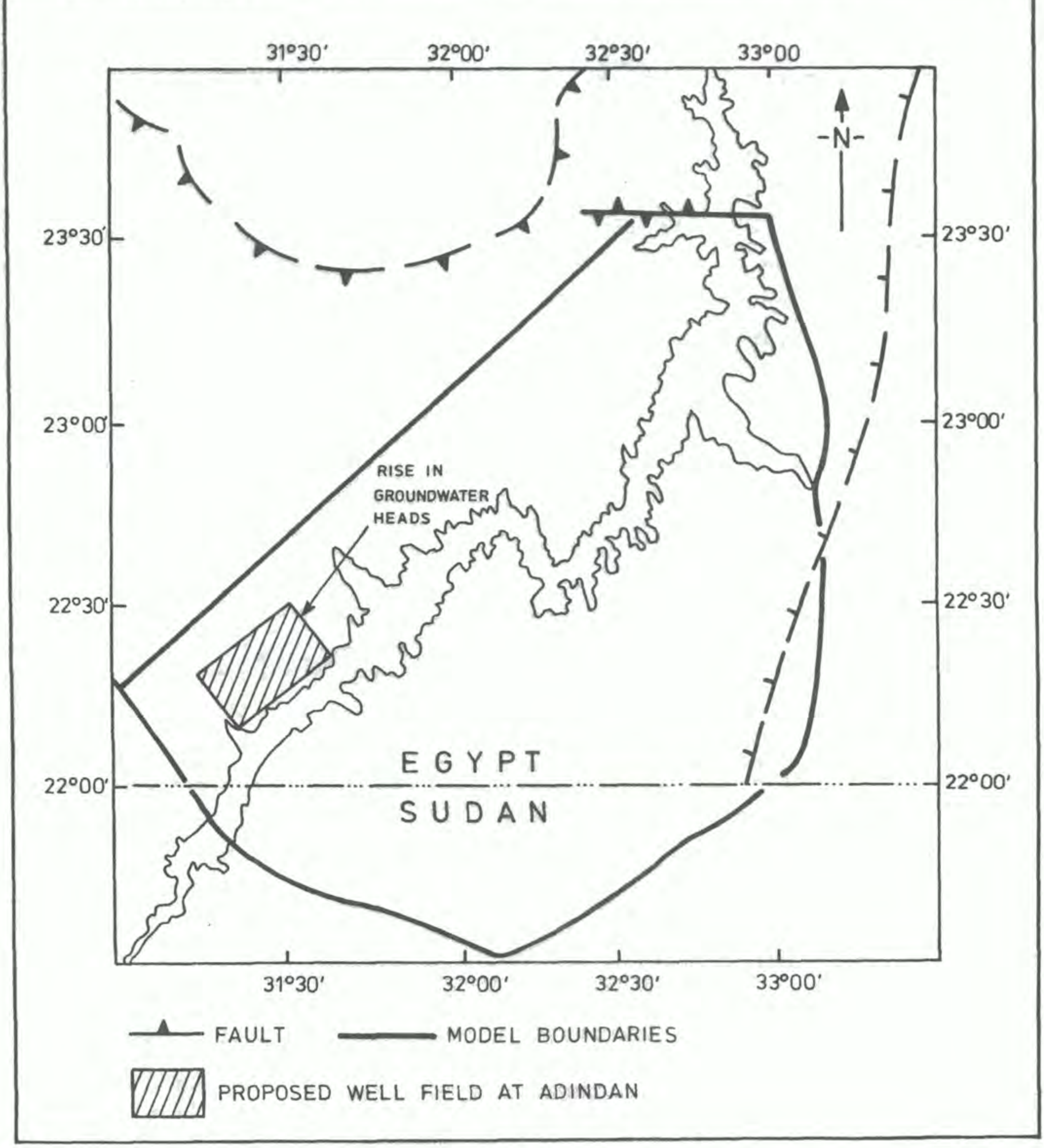

Figure 7.3 Area of groundwater model adjacent to Lake Nasser

265 m with the depth to water some 123 m below the ground surface. The average permeability close to the lake is 4.56 m/day and the specific yield is 0.05.

The proposed wellfield consists of 20 wells located 1 to 3 km away from the lake and with well spacing of 2 km. Each well will be of 16" diameter and will fully penetrate the aquifer. Design discharges are 76 l/sec which is enough to irrigate a plot of 100 ha.

To predict the drawdown in the wellfield a model of 38 x 60 nodes each having an area of 2 x 2 km covering an area of 9.120 sq km was used. The lake leakage was simulated by placing leakage nodes near to the lake. Other sources of recharge to the aquifer were not considered.

A numerical solution was obtained using the Strongly Implicit Procedure (SIP). Two scenarios were used to show the effect of the leakage parameters from the lake, namely 7×10^{-5} m/sec and 3.5×10^{-5} m/sec or 50% of the first as the worst case scenario. The mass balance calculation for the first 20 years simulation indicated that the volume of water obtained from leakage will be approximately three times that obtained from storage. For the 50 years simulation, the leakage value will be six times that of storage, which means that the wells will start by extracting water from storage and then will draw more and more from leakage.

After continued pumping of 20 years, 883×10^6 m^3 can be extracted with a maximum drawdown of 14-16 m and after 50 years of pumping, 2.2×10^9 m^3 can be extracted with a maximum drawdown of 14.85 m, without accounting the well losses which are expected to be 7 to 10 m.

East Oweinat Model

This model was made by the General Petroleum Company. In the study leading upto the model 29 wells were drilled to depths ranging from 22-140 m. A three layered system was modelled using the following values:

	First layer	Second layer	Third layer
K ; m/d	13	1	9
T ; m^2/d	1950	130	800
S	0.18	1×10^{-3}	6×10^{-3}
Thickness : m	150	130	87-100

The abstraction simulation in the model indicated that 3×10^7 m^3 can be withdrawn.

Discussion of Paper

The modelling was seen as a distinct advance in understanding the groundwater resources of the "Nubian Sandstone Aquifer". Whereas water was clearly not a constraint it was considered that there was a need for more understanding of the socioeconomic conditions related to the proposed groundwater developments. More attention also needed to be paid to environmental issues and the cost of abstraction.

The problem of wellfield interference was discussed but it was considered that the abstraction areas such as Kufr and Oweinat were too distant to pose such problems, particularly as the Kufr data show a limited cone of depression. However, in purely hydrogeological terms the need for more understanding of aquifer storage and natural recharge clearly exists.

Paper 8

Water Resources Assessment and Groundwater Modelling in the Sudanese Component Area

A.R. Mokhtar, Sudanese Project Manager.

Introduction

Except for the area north of Kerma where the Nile passes through the Third and Second Cataracts (locally known as Ard El Hagar), the river is contained in a floodplain some 5 to 30 km in width. The plain is cultivated but the agricultural land is gradually becoming inundated by sand. To the west of the Nile is the Selima Oasis, and the Qa'ab Hillal and Qa'ab El Hashi both of which are topographically lower than the Nile and represent a former Nile course.

The Northern Province is the most arid area in the Sudan. The Nile is the only permanent surface water course although it is joined by a few ephemeral wadis, the Howar, El Milk and Mugaddam, which drain an area of some 20,000 sq km in northern Kordofan and Darfur.

The water resources assessment in the project area was made for the detailed study area (Figure 6.1) described by Salih in Paper 6 of this Workshop. The objectives of the assessment were to study the groundwater and its relationship to the Nile in a typical floodplain area, and to consider the use of groundwater in combating desertification.

Groundwater Occurrence

The Nubian Sandstone Formation is the main aquifer and underlies 70% of the project area. The water-bearing sediments are mostly composed of medium to coarse weakly cemented sandstones which change both laterally and vertically into fine grained sandstones and mudstones. Accordingly the aquifer can be considered as a multi-layer system with various degrees of hydraulic continuity. The aquifer is also connected with the river through the Nile floodplain deposits.

The aquifer lies over the uneven weathered basement surface. A north-east to south-west basement ridge separates the aquifer into two sub-basins, the Nubian Sahara Basin in the west and the Nubian Nile Basin in the east. With the exception of Salima Oasis, the project area lies within the Nubian Nile Basin. The sedimentary thickness ranges from 200 to 600, increasing in a southerly direction. In Salima the sediments are 400-450 m thick.

Groundwater occurs dominantly under unconfined conditions although flowing artesian conditions are encountered in the Qa'ab areas.

The data indicate no significant changes in the overall water table of the aquifer for the last 16 years. Seasonal fluctuations of upto 2 m occur in the wells close to the Nile and this corresponds to 6 and 9 m fluctuations between the high and low levels of the river in Dongola and Merowie. Away from the Nile true seasonal fluctuations are not recognised.

Lowering of water table as a result of abstraction by 4 m in El Seleim is recorded during the cropping season. However, once pumping has ceased, the water table returns to its original level.

<u>Groundwater Head Distribution</u>

The regional groundwater flow direction is from north to south.

The water table contour map shows that the groundwater of the "Nubian Sandstone Aquifer" is recharged from the Nile.

The effect of river recharge to the aquifer or the bank storage extends to several hundred metres on both banks but varies gradually with the changes of the river level.

Within the regional picture of groundwater movement the El Qa'ab Depression is also important and acts as a discharge zone through expotranspiration losses. A stagnant zone of saline groundwater beneath the Wadi Mugaddam also points to locally complex flow conditions.

Aquifer Characteristics

The transmissivity of the aquifer ranges from 700 to 3900 m^2/day. The El Seleim Basin and El Qa'ab Depression are the two areas underlain by the high transmissivity, 2255 and 3400 m^2/day respectively. The hydraulic conductivity of the water-bearing sediments varies from 105 to 35.7 m/day with an average value of 23 m/d.

The coefficient of storage ranges from 4×10^{-4} to 3×10^{-2}. This indicates free water table to confined conditions. The two flowing wells drilled at the El Qa'ab Depression have a head of one metre above the ground surface. The specific capacity of the wells reaches 3000 m^3/day/m indicating that each well may be capable of irrigating 40 ha.

Groundwater Quality

The groundwaters are generally fresh, electrical conductivities range from 215 to 3000 µS/cm increasing away from the Nile. Close to the Nile, the composition of groundwater is similar to that of the river.

Sodium and calcium bicarbonate waters predominate. They are bacteria free and do not contain any toxic elements so are suitable for domestic use. The quality of the groundwater is excellent for irrigation in that it can be used to irrigate any crops on the soils of the area without any salinity or alkalinity hazards. In fact irrigation using groundwater is preferred to the Nile water as the former contains more calcium than sodium and hence improves the permeability of the alkaline soils, which form the arable land throughout much of the project area.

Mathematical Modelling

A mathematical model was constructed of the detailed study area of Seleim-Khawi-Qa'ab (5000 sq km) to assess the groundwater resources potential. A two dimensional finite element model was used representing the "Nubian Sandstone Aquifer" and the overlying Nile alluvium.

The following average parameters were used in the simulation:

- Groundwater conditions : Semi-confined to unconfined
- Transmissivity : 1500 m^2/day
- Storativity : 5 x 10^{-4}
- Depth to water level : 3-20 m below the ground surface
- Groundwater abstraction : 380 x 10^6 m^3/annum
- Nile discharge : 40-800 x 10^6 m^3/day
- Losses by evaporation : 3 x 10^6 m^3/annum
- Vertical permeability : 5 m/day

On Figure 8.1 the groundwater head distribution is shown for the recorded abstraction conditions at its peak (380 x 10^6 m^3/annum). The maximum drawdown amounts to 2.5 m. To examine the resource potential abstractions of 456 and 760 x 10^6 m^3/annum were modelled. For the first case drawdowns were increased a further 2-3 m and in the second case a further 7 m demonstrating a very high potential. The head distribution for the 760 x 10^6 m^3/annum abstraction is shown on Figure 8.2.

The model shows that the manipulation of the aquifer storage in conjunction with induced recharge from the Nile

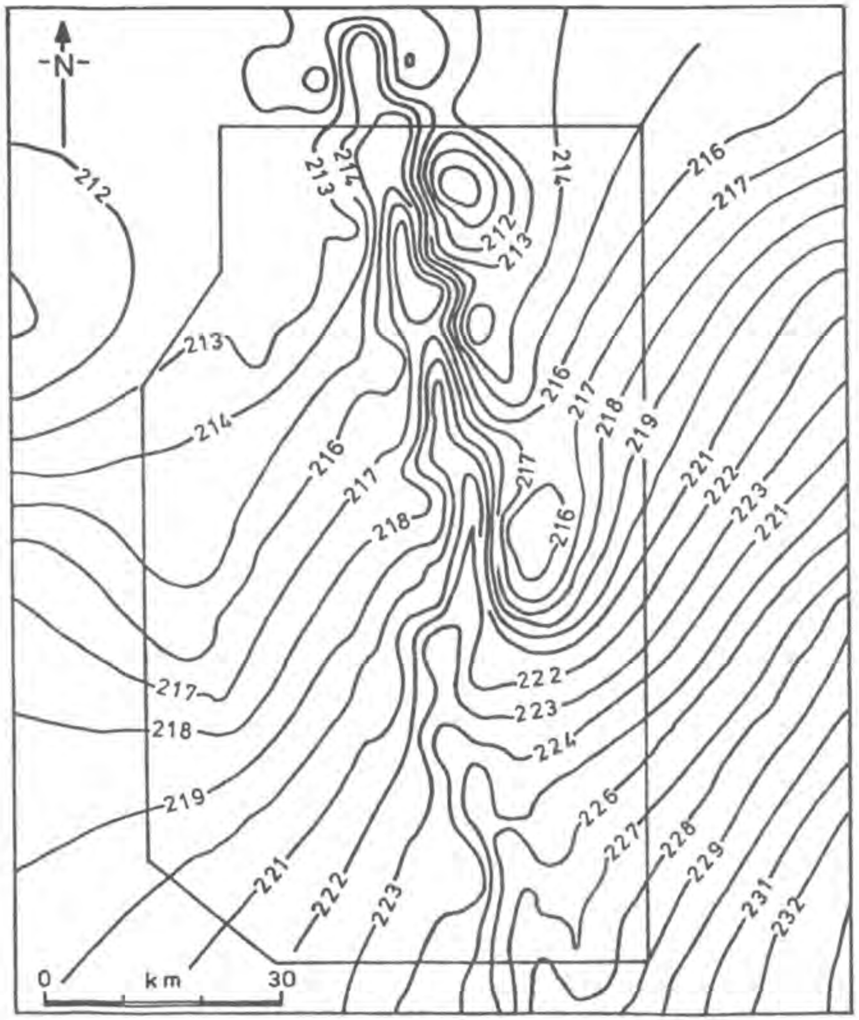

Figure 8.1 Groundwater head distribution adjacent to the Nile near Dongola at peak abstraction (380 x 10^6 m^3/annum).

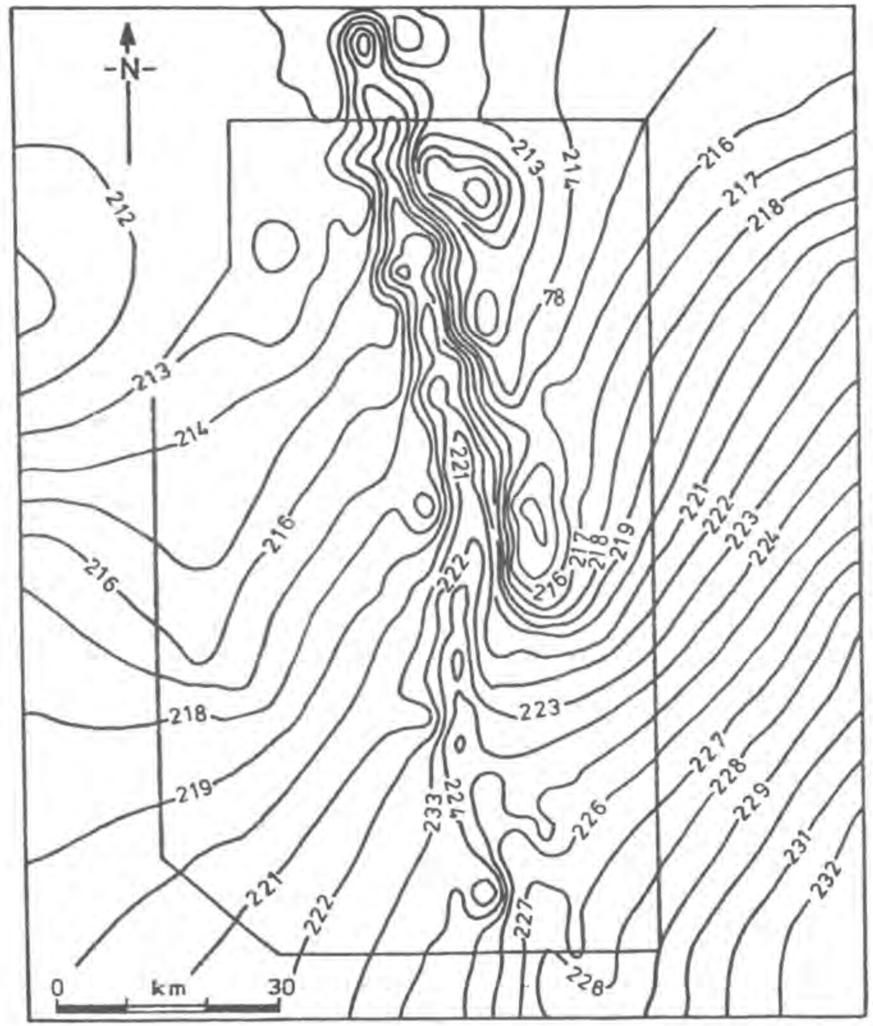

Figure 8.2 Groundwater head distribution adjacent to the Nile near Dongola simulated for abstraction of 760 x 10^6 m^3/annum

would be a realistic resources development approach. It is clear that the availability of groundwater at a reasonable cost will not be a constraint in the overall development of the area. However, lowering of the water level by an additional 7 m will drastically affect the existing dug wells which use suction pumps. Accordingly the existing pumping system would have to be changed to high yielding turbine or submersible pumps.

Development Issues

The principle development issues in the area are:

(i) The present difficulties in communication and transportation are the most severe limiting factors for the development of the area. The construction of a road link between Dongola and the rest of the country is vital.

(ii) The choice between the groundwater and Nile water as a source for irrigation depends upon the pace of development and investment envisaged for the area. Groundwater exploita- tion is more consistent with slower paced development and higher and quicker profit.

(iii) The management of privately owned groundwater irrigation schemes would be easier and more effective than Nile irrigation schemes, depending upon government funding.

Future Development Options

Five options were examined for the Seleim-Khawi area making use of groundwater, and two using Nile water for irrigation. The overall net irrigable area, in all options, amounted to 32,430 ha with water requirements of 80 x 10^6 m^3/annum.

Of the groundwater options, the best on both technical and economic grounds proved to be the use of small diameter drilled wells, each capable of producing 30 l/sec and feeding clusters of three farms.

The capital cost for such well schemes was calculated as US $ 2300 per ha as opposed to US $ 5000 per ha for pumped Nile water. Moreover the use of well schemes allows a gradual development more suited to local requirements and investment availability than would be the case with a major river irrigation scheme.

Discussion of Paper

The paper provided an excellent example of a very important localised study, however, more attention needed to be paid to the regional hydrogeology as it was still not clear how the Nile influences the aquifer regionally. Further, the groundwater flow relationships between the Sudan and Egypt had not been adequately established.

While the model showed very encouraging results no sensitivity had been carried out on the parameters and the multi-layered aquifer had not been represented, so it was considered that the results should be treated with caution. Nevertheless, the concept of using induced Nile recharge was very attractive and clearly would allow groundwater resources development to proceed in the area. It was felt that any shortcomings with the model could be rectified as development progressed.

The shallow groundwater distribution throughout much of the area was considered to be very advantageous for the purposes of combating desertification through the use of shallow wells and small pumping lifts. The techniques of shelter belt implementation, however, needed to be integrated with the irrigation schemes envisaged by the project.

Paper 9

Water and Land Use in the Egyptian Component Area

A. Khafagi

Introduction

The groundwater resources studies carried out by the General Petroleum Company and the project show the presence of an abundance of groundwater at manageable depths in the project area. The quality of the groundwater is generally suitable for irrigation purposes and adequate sandy and gravelly sand land is present. Pedological studies show that 500,000 feddans (1 ha = 2.4 feddans) of such lands occur of which 190,000 feddans have been identified for irrigation from groundwater.

As part of the project studies the cost of irrigating the land has been investigated. Both the capital investment and recurrent costs have been examined.

Capital Costs

The costs for the irrigation system are shown in Table 9.1.

Item	US $/feddan
Main canals	145
Small canals	292
Land leaching	32
Levelling	332
Electrical works	77
Transportation	123
Administrative buildings	63
Housing	252
Social services and amenities	48
TOTAL	1364

Table 9.1 Irrigation system costs

An area of 100 feddans can be irrigated by water pumped from one deep well on the basis that a deep well gives 750,000 m^3/annum and the water requirements per feddan is 7500 m^3/annum. The cost of drilling is US $ 90,900, accordingly the capital cost per feddan is US $ 909. The economic life of the well is estimated as 20 years so that wells will need to be replaced once within the envisaged 40 year life of the irrigation scheme. The pump life is estimated at 10 years with a capital cost of US $ 273 per feddan.

Recurrent Costs

Operational and maintenance costs were taken as 10% of the capital costs for the economic analysis.

Economic Analysis

The purpose of the economic analysis was to study the minimum benefits which can be gained from the project after establishing the irrigation system. Owing to the shortage of data on costs and benefits in the study area, the figures from experimental projects already established such as that at East Oweinat were used.

$$\text{The benefit/cost ratio} = \frac{\text{Present worth of benefits}}{\text{Present worth of costs}}$$

was used as a measure of social benefit in the economic analysis, and in particular for studying the economic viability of water resources development. In practice, it is probably more common not to compute the benefit/cost ratio using gross costs and gross benefits, but rather to compare the present worth of the net benefits with the present worth of the capital investment plus operation, maintenance and replacement costs. This reflects United States government practice where the benefit/cost ratio has been a common measure applied to assess the "national economic development" effect of water resources projects.

In principle, the discount rate should be set at a level at which the total cost of all the potential projects in a country could show a positive present value (however small), at that rate. In practice it is very difficult to estimate the rate so that in this analysis, discount rates of 10%, 12%, 14%, 16%, 18% and 20% are used to show the effect of changing rates on the project's economy.

The details of the benefits of the project in terms of agricultural production are not included here. Nevertheless, the study shows the limiting economic benefits in which the total present worth of costs equals the total present worth of benefits.

These limiting economic benefits are:

at Discount Rate of	10%	=	4322	US $/feddan
"	12%	=	3844	"
"	14%	=	3482	"
"	16%	=	3199	"
"	18%	=	2969	"
"	20%	=	2782	"

The economic analysis shows that the agricultural development will have to be based upon high value cash crops. The development of these remote areas should be carried out in stages and should be preceded by proper realistic feasibility studies indicating the modalities of development, the irrigation technique, the cropping system and the social economic impact.

Discussion of Paper

While the paper was considered to be a start to understanding the economic problems of development in the deserts much scepticism was expressed about the results obtained. The chief criticisms concerned the omission of data relation to costs of seeds, plants etc. and the requirement of fertilisers which had been found to be large in Libya.

Although the costings included in the paper may be realistic for many of the items, it was felt that there was need for more in-depth studies of marketing and transportation costs. Further, it was pointed out that the interest rates were far too high and much lower rates could be obtained through aid packages.

Unfortunately without more understanding of crop data from desert areas little could be done to resolve the economics. Sensible pilot schemes were therefore required but should not pose a deterrent to development. As was pointed out the only way to understand the situation is to abstract water and see what happens as has been the case in Libya.

Paper 10
Water and Land Use in the Sudanese Component Area
S. Ibrahim

Introduction

Water and land use have been studied in three areas during the project:

The Kerma-Khawi area on the east bank of the Nile in the Dongola District
The Wadi Qa'ab depression 40 km west of the Nile
and The Wadi Mugaddam in the Merawi District.

The Kerma area is a strip parallel to the Nile, 60 km long, and 10 km wide. The area used to be irrigated by the floods of the Nile through a canal, however, for the last 30 years the Nile levels have lowered and a large part of the area became abandoned and desertified. The drastic reduction of the Nile irrigation resulted in the farmers turning to dug well or matara irrigation. East of Kerma is the Khawi plain which includes the Borgaig Nile irrigation scheme. Some 2000 mataras have been constructed on the plain each supporting approximately 4 ha of irrigation. In the south of Khawi sand dunes are encroaching on villages and farm land.

El Qa'ab is a typical desert area with several scattered small oases. Only one of them, El Lagiya, is presently inhabited and flourishing. The others are small in size, and have been practically abandoned because of severe sand encroachment.

The wadi Mugaddam is a former tributary of the River Nile. The wadi is located in the southern part of the study area in the Merawi district. The wadi is sparsely vegetated. The main economic activity is livestock raising which supports most of the wadi's population. Groundwater is the only source of water in the area. The existing wells along the wadi have depths ranging from 30 to 40 m.

Land Resources

The fertile soils in the Northern Province are mostly confined to the narrow alluvial strip close to the Nile. This strip consists of basin soils on the floodplain and levee soils on the river banks. Most of these soils are cultivated to some degree. Future agricultural expansion must therefore be on to the river terraces, where land is flat and suitable for irrigation. However, the soils are locally saline and/or alkaline. Much of these lands are covered with aeolian sand in the form of sheets and sand dunes, which inhibits the conveyance of the Nile water through open channels.

To study the soil conditions surveying was carried out mostly at a reconnaissance level. Some 290 pits to a depth of 20 m were dug and 196 auger holes to a depth of 3 m were drilled. A total of 1274 soil samples were taken for identification and mechanical analysis out of which 288 samples were chemically analysed.

The chemical analyses of the soil indicate that the soluble salts and electric conductivities are very high in the study area. Leaching tests, carried out on a number of representative samples, show that the salts are leachable with economically viable quantities of water. Permeability values of these soils are higher than 15-20 mm/h. The soils are very poor in their organic matter, nitrogen and phosphorous. However, they contain modest amounts of exchangeable potassium and because of their high exchange capacity, they respond adequately to the application of fertiliser.

Water Resources

The available water for irrigation in the project area includes the Nile and groundwater. Recently, considerable development of groundwater has taken place in Kerma and other parts of the area. Such development forms an important alternative to river Nile pump schemes. The main advantages of using groundwater for irrigation are:

(i) It allows the development of small scattered areas of good soil.

(ii) It avoids the problem of siltation and erosion of banks associated with river pump stations.

(iii) It does not affect Sudan's allocation under the Nile Water Agreement.

Surface Water

Irrigation from the Nile is practiced either by exploiting seasonal floods through irrigation canals, eg. Seleim canal, or by pumping directly from the Nile as in the case of the Borgaig Scheme and many other private schemes. The Seleim canal was constructed in 1949 with a total length of 30 km and used to provide flood irrigation for about 55 km^2. The Borgaig Scheme occupies an area of about 2746 ha and was established in 1944. Water is drawn from the Nile by two pumps, each with a capacity of about 600 m^3/h.

Groundwater

Groundwater is pumped from the "Nubian Sandstone Aquifer" the water table of which is generally within 3 to 12 m of the ground surface. The depth to water depends on topography and hence increases away from the Nile.

Groundwater for agricultural use is tapped either from small open mataras or tube wells. Mataras are equipped with 3 inch centrifugal pumps and 6 hp engines. Discharges are of the order of 10 l/sec. Tube wells are normally fitted with turbine pumps which can discharge about 50 l/sec and can irrigate about 25 ha.

The quality of groundwater is generally suitable for agriculture. Reclamation of soil can be achieved by using either surface or groundwater, depending on economic and logistic considerations.

Cropping Systems

The agricultural year is divided into three planting seasons:

(i) Winter or "Shita" from October until February, the crops grown in this season are: broad beans, wheat, fenugreek, water melon and vegetables (garlic, onion, fennel, tomato, peas and minor ones).

(ii) Summer or "Seif" the normal planting starts in April but is generally postponed to May or June. The main crops are: sorghum, maize, seasonal fruits (melon, water melon), Sudan grass, vegetables (okra, cucumber etc.).

(iii) Flood or "demira". Crops grown are: sorghum, maize, cucumber, okra, onion (for fresh use) and melons. Due to the decline in importance of the flood cultivation and the consequent predominance of winter growing season there has been a shift towards cash crops such as broad beans, fruits, spices and vegetables.

Irrigation Systems

The cultivated fields are subdivided into plots of 25-40 sq m where small basin irrigation is practiced. Some farmers specialise in vegetable production and apply furrow irrigation.

Table 10.1 indicates the cropping pattern and average water requirements for each crop.

Crop	Cropped area (ha)	Seasonal volume m^3/ha	Total year volume 10^6 m^6
Wheat	8,700	14,000	121.8
Broad bean	7,500	14,000	105.6
Alfalfa	1,450	33,600	48.7
Horticultural crops	1,450	39,200	56.8
Vegetables	1,450	28,000	40.6
Sorghum	2,900	12,600	36.5
Dates	5,510	33,600	185.1
TOTALS	29,000	175,000	595.1

Table 10.1 Irrigation requirement of Sileim and Khawi cultivated areas

The Borgaig Scheme attained the highest rates of cropping intensity in the whole area. During the last 10 years, however, due to the low levels of the Nile, siltation of the pump site and the frequent breakdown of the engines, irrigation from the Nile became unreliable. Several years, farmers lost their seasonal crops and fruit trees were endangered. To solve the problem farmers constructed mataras for supplementary irrigation, and they now claim that their wells are more dependable than Nile irrigation water.

Although groundwater has added a new dimension to land utilisation in the project area it has brought problems. Difficulties with Nile water supply prompted local farmers to move to Wadi Khawi, where their use of traditional farming practices was unsuitable for the soil conditions, as a result partially developed land became abandoned and desertified.

The difficulties of Khawi land are mainly due to the salinity and the alkalinity of the soils. Further, the low productivity and the need for large amounts of water to counter balance the high evapotranspiration, forced many farmers to abandon Wadi Khawi mataras. The rate of abandonment was increased by high fuel prices and fuel scarcity.

Leaching is a requirement for many of the soils away from the immediate vicinity of the Nile and needs to be co-ordinated within the irrigation systems. Both Nile and groundwater are suitable for land reclamation. However, the latter contains more calcium and is hence more favourable, as the soil to be reclaimed contains no gypsum. Sodium clays when irrigated with pure water tend to disperse and reduce in permeability. If calcium salts are present in the irrigation water the dispersion is less likely to occur.

The deep sandy terrace soils with high permeability provide good drainage which can remove the leached products. For the reclaimed soils an additional irrigation is recommended in order to remove the remaining salts before starting a new crop.

Prospects

The project studies have indicated that some 45,000 ha of reclaimable land are present in the detailed study area. This is in addition to the 29,000 ha cropped in 1984-85. Ground- water will be the principle means of reclaiming land but can, under the right circumstances, be used beneficially in conjunction with Nile water.

In the Qa'ab depression, the Lagiya Oasis can be developed by improving the agricultural techniques and reclaiming new areas. A large-scale development does not seem feasible due to the limited arable land. The small oases should be conserved for cultural and environmental reasons.

A different situation is at Kerma where favourable potential exists and at Seleim where the passage from individual wells to centralised or co-operative irrigation schemes should be implemented. These schemes could be irrigated either by Nile water or by groundwater, depending upon the technical and economic considerations. The main issue, however, is to ensure adequate fuel supplies and reduce pumping costs. Collective irrigation schemes could ensure availability of fuel and undertake afforestation of marginal soils and the sand affected areas. Research and piloting in new sources of energy is strongly recommended, especially in view of the high potential of the area in solar and wind energy. Parts of Khawi are similar to Seleim in potential and the same development principles can be applied.

For the purpose of experimental agriculture and soil reclamation techniques different irrigation systems, trials in farm management, and the implementation of an experimental farm are recommended.

Discussion of Paper

The co-operation with the local people in the area was considered to be a major achievement of the project. Unfortunately as was pointed out severe migration had occurred from the area because of desertification. People are obviously a vital resource and there is a major need for properly trained people to live in the desert in order that development may occur. The work presented showed that water could be obtained, however, the lack of infra-structure and understanding of the socio-economics of desert development is an over-riding constraint.

It was believed that the socio-economic factors should be concentrated upon and coupled with environmental studies to combat desertification. If the latter was to be achieved a comprehensive knowledge of the "Nubian Sandstone Aquifer" was essential.

It was concluded that while it was very important for groundwater studies to continue the emphasis should be placed upon land use studies in conjunction with groundwater development. The infra-structure problems should be pursued with the respective governments.

Paper 11

Groundwater in the "Nubian Sandstone" in Libya

Synopsis of paper by M.A. Fadel, Director General of the Water and Soil Department, Libya

Introduction

The "Nubian Sandstone Aquifer" is important in two regional basins in Libya. The Murzuq basin in central Libya and the Kufra basin in the south-east connecting to western Egypt.

Regional Basins

The "Nubian Sandstone Aquifer" is considered as the upper aquifer in the Murzuq basin. It is separated from Palaeozoic aquifers by a thick shaly carboniferous aquitard. At the centre of the basin, the "Nubian Sandstone Aquifer" is covered by thick aeolian deposits of Quaternary age, mainly in the form of sand dunes and sand sheets.

The aquifer reaches its maximum thickness at the centre of the basin (about 1000 m) and decreases to about 200-300 m towards the margins. It is apparently not receiving current recharge. Carbon-14 analyses from shallow wells in the north-eastern zone show the water to be more than 21,000 years old without tritium.

The groundwater flow in the aquifer is from south-west to north-east. When the aquifer comes into contact with the Hun Graben, it terminates with part of the flow taking a north-western direction and part flowing through the fault zone to the Sirt basin. Transmissivity values range from 1.3×10^{-2} to 2.8×10^{-3} m^2/s and storage coefficients are in the order of 2.0×10^{-4}. The aquifer contains very good quality water.

In the Kufra basin the static water level of the Nubian aquifer is only a few metres below ground surface. The hydraulic gradient indicates flow from south to north and north-east. Within Libyan territory, the hydraulic head difference within the Nubian aquifer is in the order of 400 m between the southern and northern limits of the basin.

Water wells constructed in the aquifer have relatively high discharge rates (135 to over 300 m^3/hr) and medium to high specific capacities (10-50 m^3/hr/m). Transmissivity values range from 300 to 3500 m^2/day and storage coefficients from 1.1 to 10^{-4} to 1.5 x 10^{-2}. Regional drawdown as a result of pumping is closely monitored through a network of observation wells within and at the periphery of the well fields. Maximum decline in the water level of about 25 m was observed at the centre of both fields up to April 1985, decreasing rapidly away from the abstraction zone to only 20 to 25 cm at a distance of 30 km. This decline is in response to an annual discharge currently put at 90 to 120 million m^3. Pumping began in 1968 but only since the mid-1970's have discharges reached these levels.

Water quality for use in the aquifer is very good although it is classified as corrosive due to the presence of high CO_2 and low pH values. Amounts of free CO_2 range from 34 to 57 mg/l near Kufrah, considerably affecting the lifetime of the irrigation wells and installations and increasing construction and maintenance costs.

Discussion of Paper

The wide ranging discussion concluded that the most important factor of the work in Libya was the fact that significant groundwater had been abstracted and long-term effects had been monitored. Although corrosion had posed a problem this could be countered but significantly the aquifer responses had been excellent backing the conclusions reached in Egypt and the Sudan that groundwater was not a constraint to development.

WORKSHOP FINDINGS

As a conclusion to the Workshop a closing session was held to discuss the participants views on the findings. It was generally agreed that the Workshop had been a success and reflected the success of the project.

It was concluded that the project had provided an invaluable impetus to cooperation between Egypt, Libya and the Sudan in understanding the "Nubian Sandstone Aquifer". While the objectives of the project had been over-ambitious the achievements had been considerable in data acquisition and interpretation. Further, the project demonstrated the need to continue cooperation and collation of data between the interested parties.

As with any major project is was found that more information was required but it was emphasised that future investigations should not be a deterrent to groundwater resources, rather an adjunct. A number of topics were proffered for future investigations notably geological correlation, recharge, flow distributions with respect to structural basin controls, aquifer characteristics particularly specific yield and hydrochemistry.

The requirement for groundwater modelling was discussed and while the value of regional models for ascertaining boundary conditions was accepted it was felt that the small modelled areas as adopted by the project might be more meaningful for future development.

For development three main scenarios were identified; unconfined, confined, and induced recharge adjacent to the Nile. The first two scenarios are both dependent upon long-term mining with the unconfined conditions having been assessed very favourably by the East Oweinat study in the project area and demonstrated by long-term abstraction at Kufra in Libya. The confined groundwater development scenario is well understood in Egypt in the major oases areas, but in groundwater management terms may pose more difficulties than the unconfined conditions. The use of recharge induced from the Nile together with groundwater in the aquifer as studied as part of the project in the Sudan promises to be an excellent groundwater development for the aquifer particularly with the current problems of Nile river flows.

The main finding of the Workshop and the project was that groundwater from the "Nubian Sandstone Aquifer" should not pose a constraint to development. It was stressed that development should take account of environmental factors and priority should be placed upon using the aquifer groundwaters to counter desertification.

While it had been shown that groundwater could be obtained there remained many unanswered questions concerning the viability of its uses. Development in the desert environment not only requires facilities but also trained personnel prepared to accept the environment. In Libya projects are underway to transport waters to coastal areas where an adequate infra-structure exists. Clearly this is expensive but perceived to be preferable to in situ development in Libya. The connotations are obvious to neighbouring countries so that future work must concentrate upon socio-economic factors in addition to groundwater resources development and environmental control.