12-1997

Application of Geophysical and Geochemical Techniques for the Assessment of Groundwater Recharge from Wadi Al Bih Dams, Ras Al Khaimah, United Arab Emirates

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APPLICATION OF GEOPHYSICAL AND GEOCHEMICAL TECHNIQUES FOR THE ASSESSMENT OF GROUNDWATER RECHARGE FROM WADI AL BIH DAMS, RAS AL KHAIMAH, UNITED ARAB EMIRATES

By
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A Thesis submitted to the Faculty of Science of the United Arab Emirates University in fulfillment of the requirements for the Degree of Master of Science in Environmental Science.

Faculty of Science
UAE University
December, 1997

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ACKNOWLEDGEMENTS

First of all I thank Almighty Allah for His Blessings and for providing me with the ability to complete this study sucessfully. My sincere appreciation to my supervisors, Professor Abdulrahman S. Al Sharhan, Dean of the Faculty of Science, UAE University , Professor Mahdy M. Abdul Rahman, Geology Department, Faculty of Science, UAE University and Dr. Zeinelabidin S.Rizk Geology Department, Faculty of Science UAE University who inspite of their busy workload, have contributed very actively in this study and have always given their guidance and advice. I wish to thank the Ministry of Agriculture and Fisheries for the support and valuable data provided to me. Special thanks are due to Mr. Mohammed Abdul Haq the Hydrogeologist and Mr. Tony Luis the Draftsman. My thanks are due to the Ministry of Electricity and Water for providing me with data about Wadi Al Bih well field and to the Central Laboratories of the Ministry of Agriculture and Fisheries and the Desert and Marine Research Center for the assistance they provided during the chemical analysis of the water samples. Special appreciation is also due to Abu Dhabi Company for Onshore Oil Operations (ADCO) for their efforts to process maps. I am also grateful to all those who have in some way or the other been of help to me in the completion of this study. Last but not least, a very special thanks to my great family for their patience and support during all the time of this study.

Mohamed Sager Al Asam

ABSTRACT

Groundwater from Wadi Al Bih is still a major source of water required for irrigation, industry and domestic purposes in Ras Al Khaimah area, United Arab Emirates Because of the continuous population growth, demand for pumping more water has created an imbalance in the groundwater resources of Wadi Al Bih basin, and the estimated discharge (11 million m^3/year) has exceeded the calculated natural recharge (9 million m^3/yr). To restore the balance between natural recharge and discharge and maintain a good-quality groundwater, the UAE government has built Wadi Al Bih dams in 1982.

The objectives of this study are to use the time-domain electromagnetic survey (TDEM), geophysical borehole logging, and hydrochemical measure-ments to investigate the subsurface conditions of Wadi Al Bih limestone aquifer, evaluate the aquifer's hydrochemical characters, and assess the impact of the dam on groundwater recharge.

Results of the TDEM soundings revealed the presence of four layers. Layer 1 is from 15 to 20 metres in thickness over the project area and has an average resistivity values of about 104 ohm.m, indicating a good aquifer. However, this layer is above the regional groundwater table and is unsaturated. The low resistivity areas are probably due to an increased clay content that could impede infiltration. This layer can be interpreted as loose superficial wadi gravels. The base of layer 2 is 70 to 100 m below ground level, and its average thickness is 63 m. This layer shows remarkable variations in resistivity (15 to 475 ohm.m), and is interpreted as cemented wadi gravels. The low resistivities probably correspond to clay rich areas. The lowermost portion of layer 2 may be below the groundwater table. i.e. within the saturated zone.

As the recharge water from wadi floods has to percolate through this layer, the clay rich, low resistivity areas as well as the very resistive, highly cemented sediments may reduce local infiltration rates. The average thickness of layer 3 ranges from 5 to 95 m. The shallow areas show a good correlation with surface topography, indicating that the base of this layer defines the subsurface limestone topography. The resistivities of layer 3 are generally low ranging from .7 to 60 ohm.m and representing a transition zone between the base of the alluvial gravels and the top of the weathered limestone bedrock. Layer 3 is the main groundwater producing horizon in Wadi Al Bih area and its thickest areas should yield the highest amount of groundwater. The resistivity of layer 4 is generally above 500 ohm.m. This layer can be interpreted as an extremely resistive limestone.

Geophysical borehole logging revealed that the upper unit consists of limestone gravels (70%) and boulders (30%). The caliper log also shows that the borehole wall is uneven, confirming the gravel/boulder lithology. The second layer consists of gravels cemented with about 30% clays indicated by peaks on the gamma ray log. A slightly higher resistivity ophiolitic gravels occur between the base of the cemented gravel and the top of the dolomitic limestone bedrock. This dolomitic limestone has resistivities reaching more than 2500 ohm.m in some wells. The water level at the time of logging was either within the lower part of the gravel or in the underlying dolomitic limestone layer. Porosities are low with density porosity (ϕ_D) values mostly in the range 2-10% limestone porosity, whereas the neutron porosity (ϕ_N) values are higher. The calculated true porosity of the saturated zones varies between 8% and 25%. Two fracture zones at depths of about 100 and 150m in the penetrated formations are interpreted from the caliper-log data and indicate the presence of two distinct groundwater flow systems of different salinities and water types. Groundwater movement in the fracture zones were shown by the temperature-gradient logs, and water quality was evaluated from the fluid conductivity logs.

In September 1996, the hydraulic head in Wadi Al Bih aquifer within the study area varied from 27 m above mean sea level (amsl) on the upstream side of Wadi Al Bih dams and 19m amsl in the Ministry of Electricity and Water new well field, showing a cone of depression. The groundwater salinity and concentration of ions, except HCO_3^-, show a steady increase from east to west in the direction of groundwater flow. Concentrations of chromium, cobalt, zinc, manganese, cadmium, nickel and strontium in Wadi Al Bih groundwater are below the WHO and GCC standards for drinking water, where as the concentrations on iron, lead are slightly above these standards. The calculated groundwater-dissolved salts change from $Ca(HCO_3)$in the upstream to $CaSO_4$ and $MgSO_4$ in the central area to NaCl in the west. This shows the influence of groundwater recharge in the east and the effect of saline-water intrusion in the west. The NaCl ratio indicates a brine upcoming under the MEW well field and salt water intrusion from the Arabian Gulf in the west. The calculated SAR indicated a little sodium hazard in the eastern part and medium sodium hazard in the western part if Wadi Al Bih groundwater were used for irrigation.

Evidences of groundwater recharge were revealed by the seasonal variations in groundwater temperature and salinity, fluid-temperature logs and fluid-conductivity logs. The geologic structures and karstification have the main control on groundwater recharge to Wadi Al Bih area.

A comprehensive study is needed in order to achieve sustainable development od Wadi Al Bih aquifer and maintain safe yield.

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INTRODUCTION

CHAPTER I

1 INTRODUCTION

In the past groundwater used to be the only source of water for all uses in the UAE. Recently, and due to the rapid social and economical development that started in the seventies, the demand for water has increased rapidly and groundwater resources could not meet the ever-increasing demand for fresh water. Although that now in the UAE most demand for domestic and industry is met by desalinated water, drinking water in parts of the country and irrigation water in most parts is still dependent on groundwater which is pumped out mainly from Quaternary aquifer. It was noted in recent years that the discharge from such aquifer is far exceeding the natural recharge rate. It is estimated that the annual discharge from groundwater reservoirs is about 800 million cubic meters and the average annual recharge is about 120 million cubic meters (MCM). (IWACO, 1986). Such imbalance has led to a continuous lowering in groundwater levels and deterioration of quality.

In its efforts to restore the balance between groundwater recharge and discharge, the UAE government has taken different measures. Since the early eighties many studies were conducted on the major wadies and catchment areas of the country. Since then more than 35 dams were built with a total storage capacity of about 80 MCM. Most of these dams are built with recharge facilities in order to improve groundwater quantity and quality. Among these dams is Wadi Al Bih dam which was built in 1982. Wadi Al Bih is one of the most important wadies in the northern part of the UAE. It has a catchment area of about 478 Km^2 with an average rainfall of 123.3

mm/year. Annual rainfall intensity varies from year to year in the area, for example it reached 216 mm in 1982 and it was only 21 mm in 1983 (Burayrat station).

Most rainfall causes torrential flash floods which was mostly used to be wasted to the sea before building the dam. The average annual volume of water that is added to the groundwater is calculated to be 6.86 MCM after building the dam (Abu Al Enien, 1996).

The downstream area of Wadi Al Bih is forming an alluvial fan of about 40 Km^2 in area where 20% of that area is cultivated. Wadi Al Bih is also a major supplier of water for domestic use for Ras Al Khaimah. About 2.1 billion gallons were pumped out in 1995 for domestic purposes (MEW, 1996).

1.1 LOCATION OF THE STUDY AREA

The study area is a part of the Wadi Al Bih complex which flows southwesterly through the Oman mountains of the Musandam peninsula and drains into the Arabian Gulf Ras Al Khaimah (Fig. 1.1). The mountains are composed of dolomatized limestone that have been formed by a series of major regional folds (Electrowatt, 1981). The main Wadi Al Bih dam is located about 13 km east of Ras Al Khaimah city. The surface water catchment area for the dam complex is approximately 485 km^2 (Electrowatt, 1981). The wadi rises in the mountains of Oman within the Musandam peninsula and drains south westwards into the Arabian Gulf at Ras Al Khaimah. It is deeply incised in its eastern portions and is characterized by narrow valleys and steep slopes leading down to the wadi floor of coarse alluvial gravels and boulders.

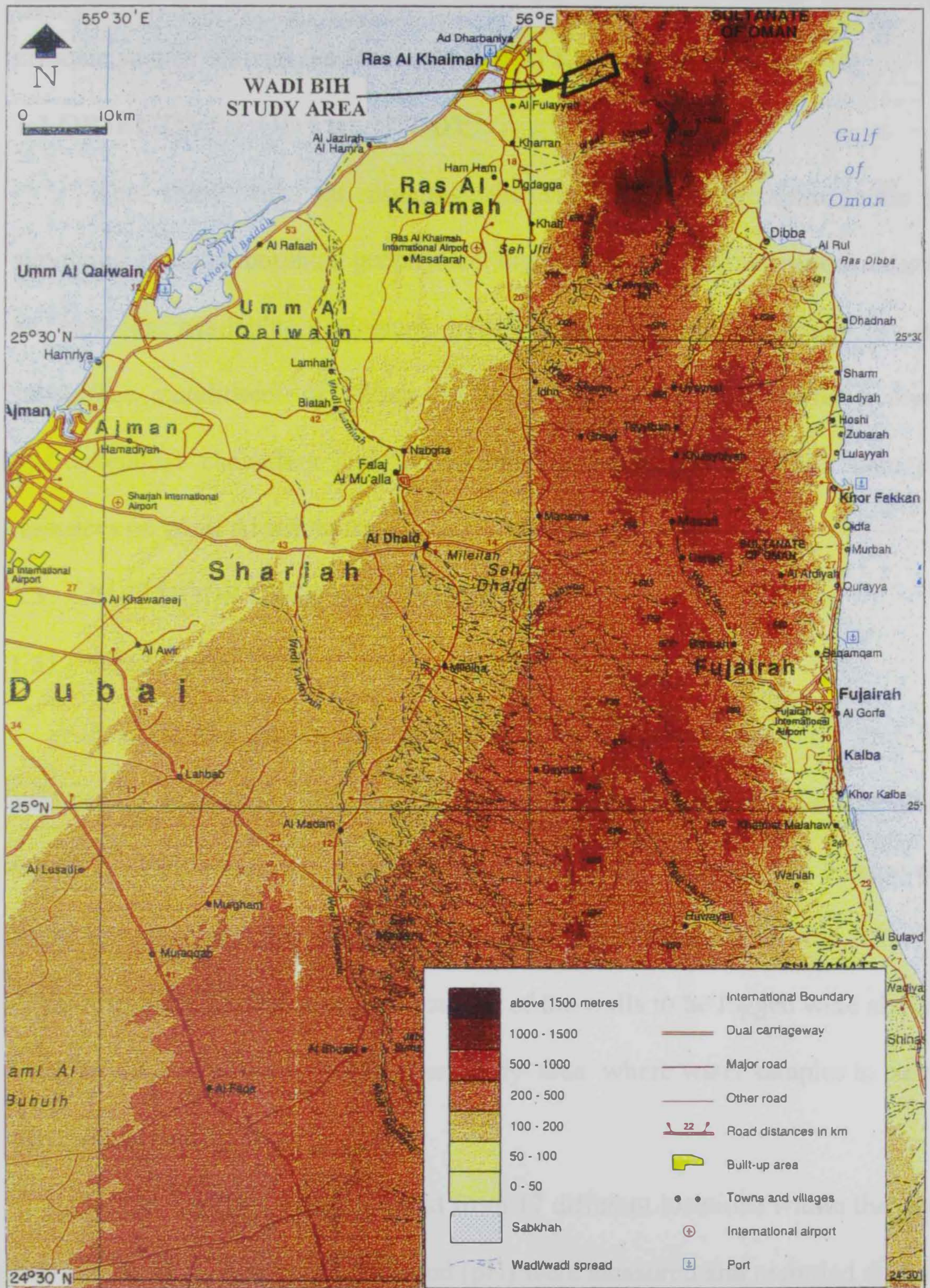

FIGURE 1.1 LOCATION OF WADI AL BIH STUDY AREA

The wadi is up to a kilometre in width at its mouth but narrows to less than 500 metres upstream of the dam. At Burayrat the wadi opens out to a broad flood plain with a crescent shaped alluvial fan leading to Ras Al Khaimah on the coast.

1.2 OBJECTIVES OF THE STUDY

The study aims at utilizing the Time Domain Electromagnetic (TDEM) surveying method, borehole geophysical logging survey, hydrochemical measurements as well as available geological, hydrological, meteorological data, to study the subsurface conditions of Wadi Al Bih area, evaluate the aquifer hydraulic and hydrochemical characters and assess the impact of Wadi Al Bih dam on water resources of Wadi Al Bih basin.

1.3 METHODS USED FOR THE STUDY

1.31 Field work

Prior to the geophysical survey and well logging a visit to the study area was arranged in September 1996 where the wadi physical features and the alluvial fan deposits were observed. The location of the main dam, the secondary dam, the retention area and the wellfield were identified. Positions of the Time Domain Electromagnetic survey lines, the position of the wells to be logged were also checked. Location of some farms within the study area where water samples to be collected were also identified.

Water samples were collected from 17 different locations within the study area. The Electrical Conductivity (EC) and (pH) were measured and recorded directly when each water sample was taken. The samples were coded and taken for analysis in the laboratory. A complete analysis for cations and anions as well as trace constituents were carried out.

Initial field trials to select the optimum loop size were conducted. The system used is called " Sirotem Mark III " which employs a transmitter and receiver within the same cable. Following initial field trials the loop size selected was 50 x 50 metres. A total of 74 soundings were completed at 74 locations. At each sounding location, a series of measurements were recorded at different gain settings designed to enhance data from greater depths. A background noise run was also recorded for environmental correction of the field data during post acquisition processing. The TDEM data acquired during the field work was downloaded to a pentium computer and processed at the field base.

Geophysical Logs were run in 5 boreholes within the study area. The boreholes were selected based on their locations upstream and downstream of wadi Bih dam within the study area. Seven different logs were run in each borehole. These logs included temperature / conductivity log, three arm caliper log, natural gamma log, formation density log, full waveform sonic log, neutron porosity log, and deep induction log. The data produced from geophysical logging for each borehole were recorded and plotted at a vertical scale of 1: 1000

1.3.2 Laboratory analysis

Water samples taken from the 17 wells were analysed in the central laboratories of the Ministry of Agriculture for (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, CO^{2-}_3 3, SO_4 Fe, Zn, Cu) by the use of flame photometer and titration techniques. The same samples were also analysed at the Desert and Marine Environment Research Center

Laboratory for (Na^+, K^+, Mg^{2+}, Ca^{2+}, Sr, Cr, Mn, Zn, Cu, Fe, Pb, Co, Ni,and Cd) by the use of atomic absorption techniques.

The result of such analysis is used to study the current hydrochemistry of the groundwater of Wadi Al Bih area. The chemical analysis data for 37 wells in Wadi Al Bih welfield for the years (1990 : 1996) were also checked and used to get a background knowledge of the change in the hydrochemistry of the study area.

1.3.3 Office activities

The office work for this study was conducted in two phases. During the initial phase, literature search was carried out on the thesis subject which included previous climatic, geologic, hydrogeologic and hydrochemical, data on Ras Al Khaimah area in general and on Wadi Al Bih drainage basin in particular. During the final phase, the office work included, interpretation of results of geophysical survey and well logging survey to construct geologic and hydrologic cross-section for the study area. It also includes the presentation of the results of these surveys on relevant maps, charts, graphs, and figures. Interpretation of result of the chemical analysis of the water samples and previous data were also conducted and the findings were presented in tables on graphs.

CHAPTER II

GEOLOGY OF WADI AL BIH

CHAPTER 2

2 GEOLOGY

The geology of Ru:us Al Jibal area where Wadi Al Bih basin is located has a great influence on surface runoff and groundwater -recharge mechanism.

In this chapter, previous investigations on the geomorphology, stratigraphy, and geologic structure were reviewed in order to define the impact of lithologic and structural controls on the flow and chemistry of groundwater in Wadi Al Bih limestone aquifer.

2.1 Geomorphic Features

The Emirate of Ras Al Khaimah, where the Wadi Al Bih lies is dominated by the northern extension of the Oman Mountain chain. The region exhibits the following geomorphic units (Fig. 2.1)

2.1.1 The Structural Ridge or Mountain region

The structural ridge or mountain region, occupies the eastern portion and rises to more than 2000 m in the northern tip close to Shaam. The major portion of the ridge is underlain by carbonate rocks, which are dominantly barren with regard to soils and to vegetation. Wadi and morphotectonic depressions are filled with ample amounts of down wash deposits which are characteristic features of the landscape.

In the area between Shaam and Burayrat the edge of the ridge rises abruptly from narrow coastal plain which is even missing at Shaam. That edge is strongly dissected by the outlets of short and rather steep wadies which add more to the complex topography of the area.

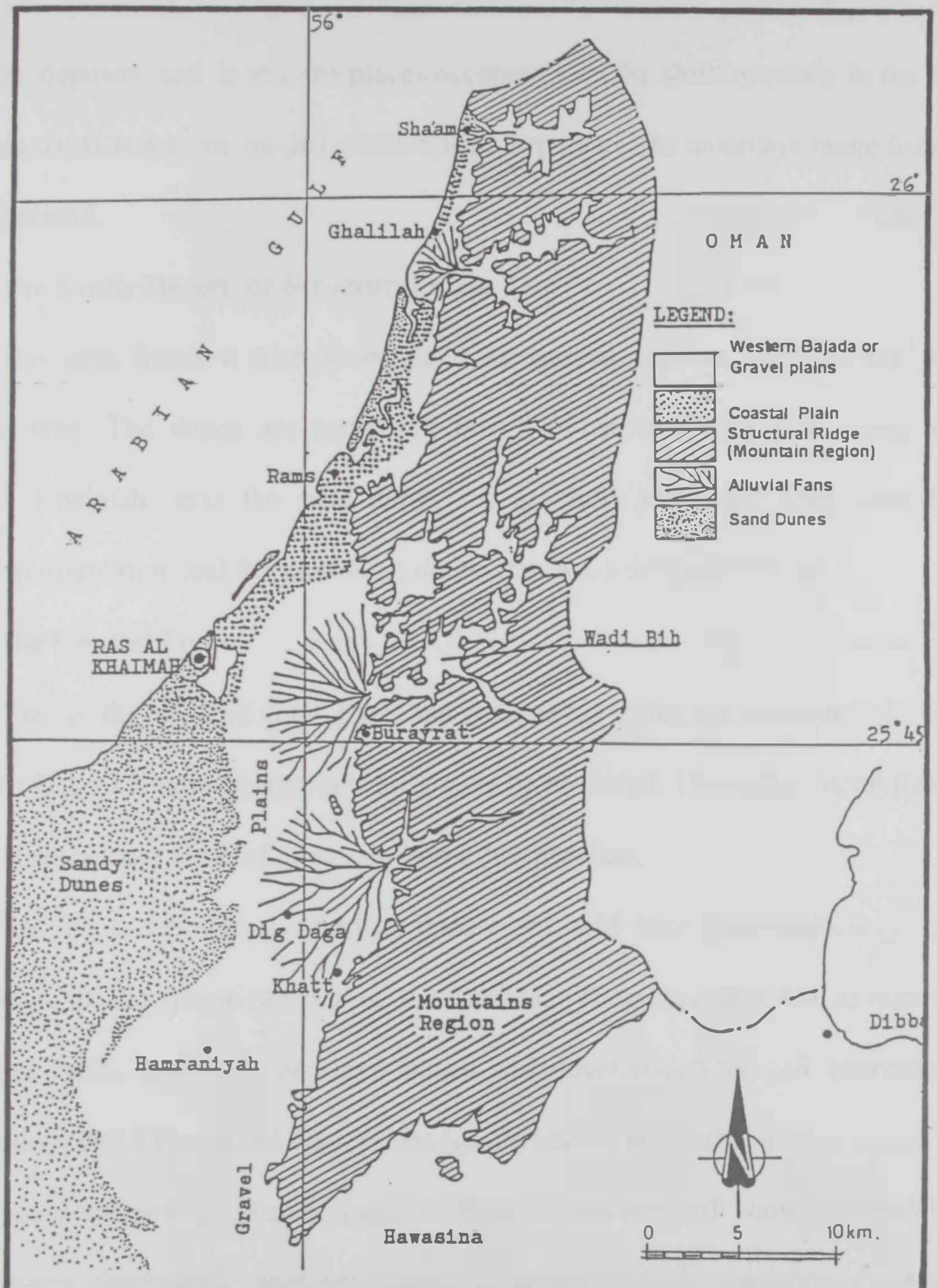

FIG. 2.1 GEOMORPHOLOGICAL MAP OF RAS AL KHAIMAH

2.1.2 The Western Bajada of the Gravel Plain

It is composed of a complex set of alluvial fans along the base of the structural ridge The surface of the Bajada is either underlain by flattened gravely deposits or by mud flat deposits and is at some places occupied with the shifting sands. In the north the plain is also known as Jiri plain which separates the mountain range from the desert foreland.

2.1.3 The Sandy Desert or Structural Plain

This area forms a triangle bounded by coastal sabkhas and the sea in the northern area. The dunes are composed mainly of carbonate and quartz sand. In the Ras Al Khaimah area the sand dunes are generally elongated with a northeast southwest orientation and the interdunal depression has a deflated bottom.

2.1.4 The Coastal Plain

This is the area of tidal flats and sabkhas bordering the Arabian Gulf. In the area near Ras Al Khaimah, littoral erosion may be observed. There the coastal flats are generally absent and cliffs of dune sand form the shoreline.

The land exhibits the typical features of arid zone geomorphology with degradation of the major portion of the surface. The area is also arid as regards to vegetation, soil, presence of sand dunes and development of salt encrustations (salinization) in the interdunal depressions locally known as " sabkha ".

Not withstanding such features the Wadi Al Bih area still shows indications of land features designating post wet-climatic conditions, which where prevailing in the Late-Tertiary time and occasionally during the Quaternary period. Wadi Al Bih lies in the extension of the Oman mountains chain, consisting of Ru'us Al Jibal mountain range or the structural ridge as defined by IWACO (1986) on the geomorphological map (Fig 2.1). The remaining areas can be classified as lowlands.

The structural setting of the carbonate rocks affects predominantly the shape of the landscape. Except in the west (thrust front) and south (Hawasina contact), the inclination (dipping) of the beds generally does not exceed 20°. This contributes to the formation of sub-vertical cuts of the deeply incised wadies in canyon like valleys, and to the development of elevated flat areas on gently-sloping beds. Different levels can be distinguished in the flat areas on gently-dipping slopes in the proximity of the two major wadies; Al Bih and Al Naqab with the elevations : 170-230 m, 500-550 m and 790 to 840 m. Sporadic small scale agricultural activities exist on these high mountain flats.

The lowlands, especially the alluvial fans, experience and intensive agricultural development. Three distinct fans are present on the western edge of the mountain range, originating from Wadi Al Naqab, Wadi Al Bih and Wadi Galillah. The slope distribution is uniform and the surface gradient is about 0.011. Most cultivations are concentrated on the foot of the alluvial cone, where the finer outwash material predominate. Where the alluvial fan changes into a gravel plain, the wadi channel courses disappear and the surface becomes irregular. These areas are used for larger scale agricultural farms and only the lowest parts are left as barren boulder fields (original surface of the gravel plain).

Two levels, having different stages of incision, can be distinguished in the area, both supporting scattered cultivation. The first level is bound to main wadi channels with direct outlets to the sea (Wadi Ash Sha'am, wadi Al Bih and wadi Al Naqab).

The elevations are between 50 m and 200 m above sea level. The other type of landscape with scattered cultivation can be found on gently sloping mountain faces, drained by minor wadis. Contributing to the main wadis, they form deep cloughs and steep cliffs, separating these two levels. Tiny cultivations can be found as far as 850 m above sea level (Hagil).

2.1.5 Mountains

The Oman Mountains comprise of a number of different groups of rock, most of which can be broken down into many smaller units. In general, however, we are concerned with only two major classes of rock (Glennie et al., 1974; Glennie, 1995).

The first is an autochthonous sequence (formed and remained in place) which ranges in age from Precambrian to Cretaceous and two allochthonous sequences (the rocks that have been moved to their present position from elsewhere). The lower sequence is composed of sedimentary rocks, and is known as the Hawasina Group.. This sequence is overlain by, the Semail suite, which consists mainly of a slab of former oceanic crust. These three fundamental units, the autochthonous sequence and the two overlying allochthonous sequences, are described very briefly in the following.

One of our prime interests in the Oman Mountains is the Upper Autochthonous, or Hajar Supergroup, a sedimentary sequence that is exposed in parts of the Oman Mountains and continues beneath the desert to the south and west. This sedimentary sequence, for the most part, was deposited on the bottom of shallow seas on the continental shelf or platform that covered much of Arabia between the mid- or Late Permian period and the Late Cretaceous time.

The allochthonous Hawasina sediments were deposited on the floor of an ancient ocean called the Neo-Tethys which, between about 270 and 70 million years ago, lay to the NE of the Arabia. During much of that time span, Arabia, which then formed the NE corner of Africa, was moving slowly westwards as the ocean on its eastern margin grew wider. As will be explained shortly, this increase in ocean width resulted from the creation of new oceanic crust in the middle of Neo-Tethys (which actually was composed of two parts: Neo-Tethys 1 and Neo-Tethys 2). Overlying the Hawasina is the other allochthonous unit, the Semail ophiolite suite. This consists of a thick slab of former oceanic crust that was created on the floor of Neo-Tethys 2 between about 70 and 105 million years ago.

These three groups of rocks used to lie side-by-side. The Arabian shelf to the west, the newly-created oceanic crust (Semail) to the east, with the Hawasina sediments overlying older oceanic crust in between. But now they exist as a thick pile, the one stacked sequence on the top of each other:

This stacking process began possibly 105 million years before the present (105 Ma BP), and took about 35 Ma to complete. At that time, the stacking did not create a mountain range, possibly because the autochthonous rocks were held down by the great weight of the overlying Semail, but rather formed a chain of essentially low-relief islands roughly along the site of the present mountains. It was not until 40 Ma later that the Oman Mountains began to be pushed up into a high mountain range. This was about the time when India started to collide with the southern edge of Eurasian (Europe plus Asia) plate to be followed by the creation of a new oceanic area beneath the Red Sea with the separation of Arabia from Africa.

2.1.6 Alluvial Fan

Alluvial fans are widespread and are significant landforms in the Wadi Al Bih area. The slope distribution is uniform and the surface gradient is about 0.011. Where the alluvial fan changes into a gravel plain, the course of wadi channel disappear and the surface becomes irregular. Near the wadi mouth the high resistivities may indicate the presence of bedrock at shallow depths.

2.2 STRATIGRAPHY

The rocks exposed in the Musandam mountains consist of shelf carbonates that are brought to overlie Hawasina sediments by a thrust fault. The rock sequence possesses a total thickness of about 3500 m.

Three Groups are distinguished, from top to base, as follows (Fig 2.2) :-

3. - Musandam Group (Jurassic - Lower Cretaceous)

2. - Elphinstone Group (Middle - Upper Triassic)

1. - Ru'us Al Jibal Group (Permian - Lower Triassic)

On the western side of the Musandam mountains, in the boundary thrust-fault zone, small outcrops of Hawasina sediments and of the autochthonous Wasia Group are present. West of the boundary thrust-fault zone clays and shales have been deposited starting from the Upper Cretaceous to the Paleocene time (Fig. 2.3). Thickness of the shales increases towards the west to more than 3 km offshore . In the gravel plain west of the Musandam mountains, two groups can be distinguished from top to base into: (2) - Aruma Group (Upper Cretaceous),(1) Pabdeh Shales (Paleocene / Eocene). The following is a brief discussion on Wadi Al Bih rock groups.

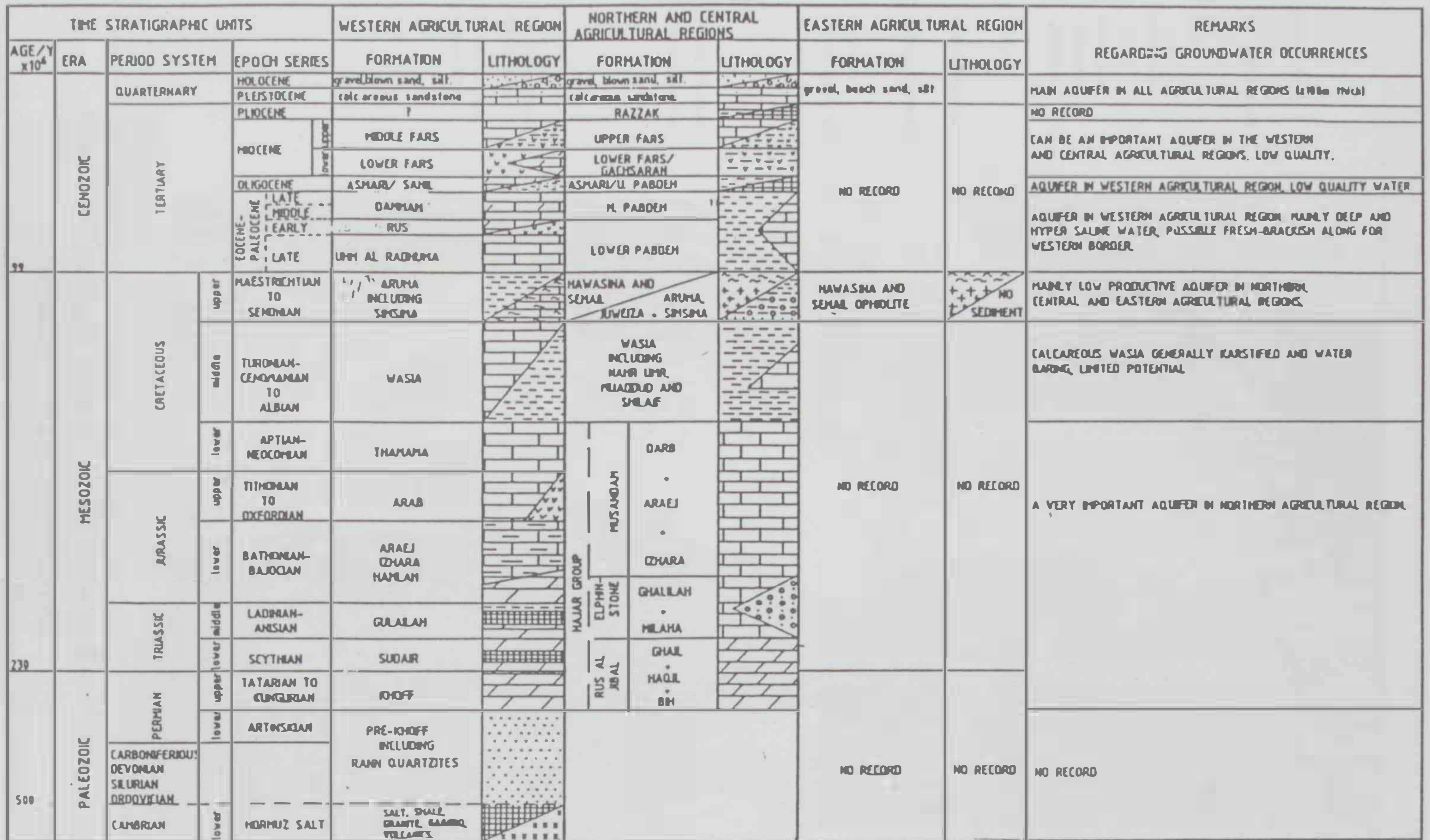

FIG. 2.2 LITHOSTRATIGRAPHIC COLUMN OF THE UAE

(IWACO, 1986)

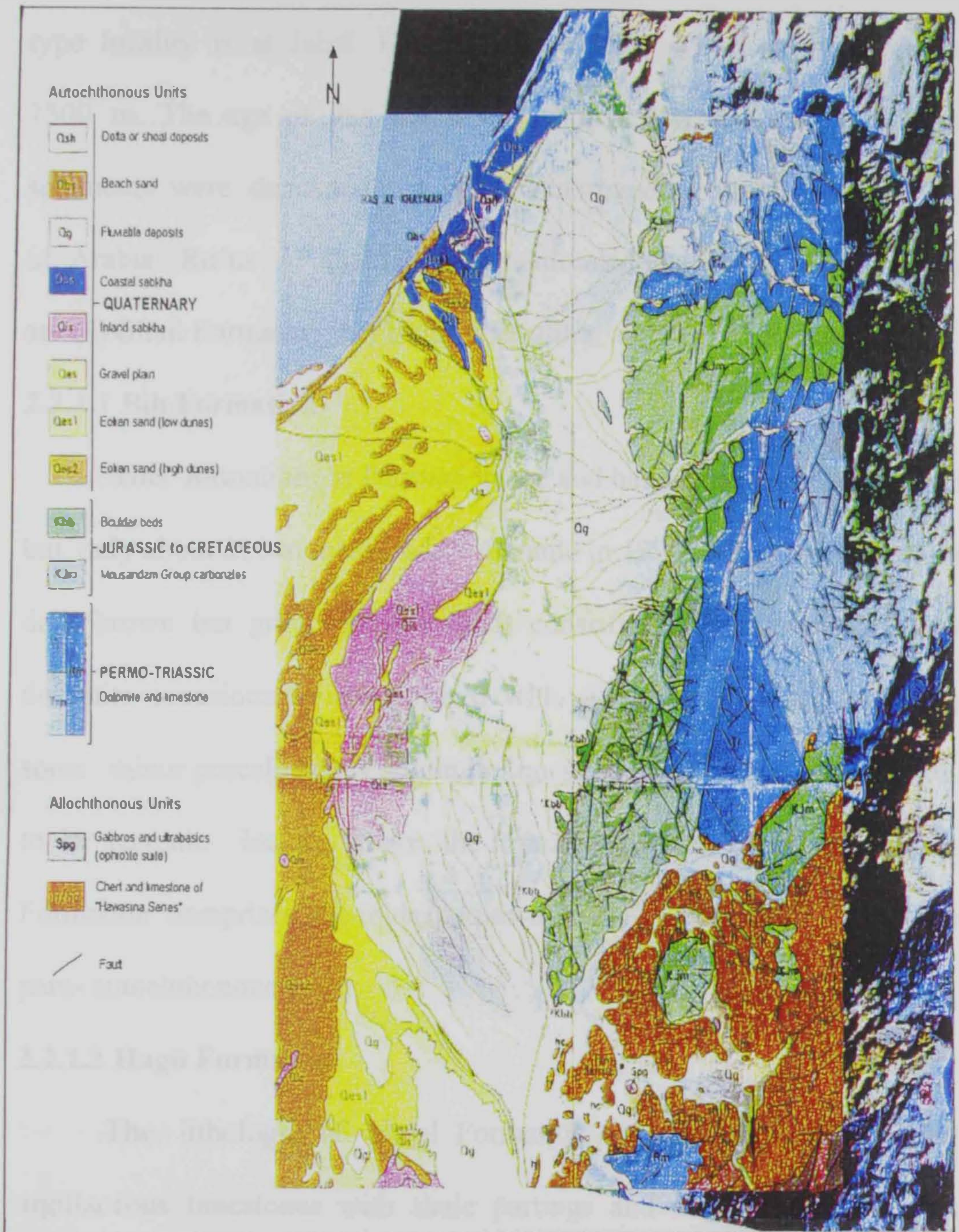

Fig. 2.3 Geologic map of the Northern Emirates, including Wadi Al Bih area (Ministry of Petroleum and Mineral Resources, 1981)

2.2.1 Ru'us Al Jibal Group

This group is characterized by dolomite and dolomitized limestone facies. The type locality is at Jabal Hagab (Hudson, 1960) where measured thickness reached 1500 m. The age of this group ranges from Permian to Early Triassic age. The sediments were deposited in a shallow marine environment on the continental margin of Arabia. Ru'us Al Jibal Group is subdivided into three formations from top to base are (3) Ghail Formation, (2) Hagil Formation, and (1) Bih Formation,

2.2.1.1 Bih Formation

This formation is Permian in age and has a thickness of 650 m (Hudson, 1960) but only about 200 m measured by Glennie in 1974. When weathered, the formation is dark brown but grey when fresh. It consists of medium to thick bedded burrowed dolomite occasionally intercalcated with skeletal and partly oolitic grainstone and some minor porcellaneous dolomitic limestone. The base is not exposed, but is known to be tectonic locally where the formation overlies the Shamal Formation. The Bih Formation comprises the oldest known rocks of the Musandam Peninsula and it is para- autochthonous.

2.2.1.2 Hagil Formation

The lithology of Hagil Formation consists of light coloured, fine-grained argillaceous limestones with shale partings and occasional shale beds, dolomitized limestone and slightly oolitic limestones. The stromatolitic lamination indicates a shallow marine environment, possibly even in the tidal zone (in the photic zone). This formation conformably overlies the Bih Formation. The thickness is 260 m (Hudson, et al., 1959) at the type locality in Wadi Hagil.

The age of the formation cannot be given with precision, but it ranges from late Permian to Early Triassic.

2.2.1.3 Ghail Formation

The formation consists of a thick to massive -bedded buff coloured sucrosic dolomite interbedded with dolomitized limestones. Relic pelletal and bioclastic structures are preserved in the dolomitized limestone of the upper half of the formation and large scale cross-bedding in the lower part of the formation.

This formation has a thickness of 500 m (Hudson, 1960). The age is stated as probably Triassic. The environment of deposition is thought to be in the tidal zone, conforming to the dolomite deposition in the present-day sabkahs in the Emirates.

2.2.2 Elphinstone Group (Searle et al., 1983, Al Sharahan and Kendel, 1986)

2.2.2.1Milaha Formation

The lithology of this formation shows a slight change from the hitherto prominent monotonous dolomites. The formation is sub-divided into three members. The lower member of 50m is thin bedded dolomitized limestone alternating with silstone and silty marls and argillaceous dolomites; weathering produces yellowish or reddish and greenish brown colours. The thickness according to Glennie (1995) is 180m and is considered mid-Late Triassic in age.

2.2.2.2 Ghalilah Formation

This unit is 250 m thick and represents the culmination of platform wide clastic deposition and occurrence of a marine regression. Like the Milaha Formation, it has three members; the lower, middle and upper members. The lower member is composed of 105 m is reddish brown quartz sandstone, buff or brown marls mudstone and sandy grainstone. The middle is 80 m of thick limestone, buff or yellow marls and massive fine-grained limestone. The upper part consists of sandstones with shale and limestone intercalations.

The clastic influx represented by the sandstone in this formation can be grouped with clastics in the allochthonous clastic of the Hawasina formations which date from the same time span approximately.

The age of Ghalilah Formation is Late Triassic - Early Jurassic (Al Sharhan, 1989)

2.2.3 Musandam Group (Lees 1928, mod. Hudson et al., 1954)

This group is a massive monotonously consistent sequence of dark grey shallow marine carbonates. The thickness is about 1475 m. The section consists of a very thick lower part in which seven regressive cycles are distinguished, overlain by a thick upper part.

According to Glennie et al. (1974), the cycles start with a massive mudstone at the base and grade upwards to thinner-bedded oolitic skeletal grainstone that are often cross-bedded and capped by a thin, burrowed and churned bioclastic lag deposit, which abruptly covered by the mudstone of the next cycle. Each cycle shows a gradual reduction in the mudstone facies and an increase in the grainstone facies, indicating a retreat of consecutive transgressions and an overall shallowing of the depositional environment. The upper part is characterized by an interval of porcellaneous to argillaceous, well-bedded mudstone at the base that is underlain by limestone conglomerate and grainstone. The porcellaneous mudstones contain radiolaria. Upwards this grade into stromatolitic calcareous mudstone and limestone with megafossils and foraminifera.

The age according to Lees (1928) is Jurassic to Lower Cretaceous which covers the bulk of the Musandam Peninsula in the northern Oman Mountains. Hudson (1960) gives the age as Rhaetic to Early Cretaceous.

The Musandam group together with the underlying Elphinstone and Ru'us Al Jibal groups, locally overlies rocks of the Hawasina allochthonous unit and Arum Group with a tectonic contact. The Musandam group is therefore considered as paratochthonous.

2.2.4 Wasia Group

The Wasia group is an important unit in the autochthonous sequence as it embraces important oil reservoirs in the subsurface (PD Ltd.) It is subdivided in the lower interval as Nahr Umr Formation and the upper thick carbonate interval as the Natih Formation. The Wasia Group has several outcrops (Biehler et al., 1975) north of Wadi Hagil. The lower quarter of the unit is a varying argillaceous muddy carbonate interval with a uniform common large foraminiferal content. Above this it is a series of shoaring-up carbonate cycles each having a variable terrigenous thin basal interval (Owen and Nasr, 1958). The thickness is 400 m descreasing to the northeast and increasing to the southwest. The age is Albian - Cenomanian age.

2.2.5 Hawasina Complex (Lees 1928)

The Shamal Formation of the Hawasina is composed entirely of pelagic sediments. It consists of red to grey/green radiolarian cherts, with some greyish mudstones and minor packstones. Thickness is probably 100 to 200 m. The age is probably Triassic to Cretaceous.

2.2.6 Aruma Group and Pabdeh Shales

West of the Musandam mountains shales of the Aruma Group and the Pabdeh shales have been deposited. The shales are absent near the mountains and the thickness increases quickly towards the west to about 500 m near the sea. The shales are overlying the limestones of the Wasia Group. The Aruma Group consists of shales with rare beds of limestones. The age is Upper Cretaceous. The Pabdeh shales consists mainly of green to yellow shale and marl sometimes silty and intercalated with silstones. The age is Paleocene to Eocene.

2.3 GEOLOGIC STRUCTURES

The interpretation of the Ru'us Al Jibal as a major thrust unit or nappe is not definitely proven. Structural features observed in the project area certainly indicate a west directed thrust. In the area between Burayrat and the confluence with Wadi Shah the tectonic structure in the limestone can be described as an antiform of regional dimension. The regional trend of the anticlinical axis appears to be north - south with a pronounced plunge towards the south. The axial depression towards the south, as well as the local rotation of bedding planes around east - west axis, conveys the impression of a superimposed transversal deformation. The symmetry of the antiform testifies to the west direction of the thrust. The eastern flank is gently inclined about 10° east, whereas the western flank is steep or even overtilted. Possibly connected with differential movement between adjacent lithologic units, a fault has developed north of Wadi Al Bih. It divides the saddle core to the east from its steeply inclined flank to the west. The fault is prominently observed at the north Burayrat running southwest - northeast. In its northward continuation it assumes a more north-south directed strike.

Another major fault, also directed north-south, follows the comparatively straight stretch of the wadi opposite the mouth of Wadi Qada`ah. This fault practically limits the anticlinical core to the east. Both faults cannot be traced to the south flank of the valley, which provides further evidence of the existence of transversal tectonic elements. Such transversal elements can be observed along the narrow limestone ridge downstream of the dam. This refers to south dipping thrust faults along which the upper block has been displaced towards north.

Two additional faults directed north-south, have been observed immediately upstream of the dam. The western fault of this pair coincides with the upper limit of the Wadi Qada'ah alluvial fan. Where this fault reaches the main valley, the dip direction of the bedding planes is locally reversed. In the zone of the anticlinal core, the rock is intensively sheared. This can be indicated by the poor quality of rock exposed in the new road cut and the selective erosion and dissolution of limestone which caused a cleavage - type shear of the rock (which in fresh cuts is masked by recrystallization).

An additional complication is provided by angular unconformities in the limestone series. The unconformities represented by intraformational conglomerate sequence due to abrupt subsidence indicating stratigraphic events.

2.3.1 The Normal Fault System

The normal faults are related to the Late Tertiary uplift. Tension occurred in east-west direction caused by the overall uplift of the Oman Mountains , resulting in north-south normal faults. Due to the lateral differences in the uplift tension may have also occurred in a secondary north-south direction resulting in east-west normal fault structures.

2.3.2 The Reversed And Thrust Fault System

Most of the rock sequences in the studied area are considered to be par-autochthonous i.e., during the period of nappe emplacement some overthrust movement took place in the western direction. Front planes of these thrusts have irregular tortuous shapes. Still, the general trend is NNE/SSW and the fault systems can be followed for several tens of kilometres. Sometimes the thrusting tends to overturn the lithology, especially near the boundary thrust fault zone. In this zone dips are sub-vertical or even overturned. The exposition of the lithology at the outcrop can play an important hydrological role in relation with recharge.

2.3.3 The wrench fault system

Related to the thrust movements horizontal movements took place along northwest/southeast striking wrenching faults. A very clear location is the outlet of Wadi Naqab where sinistral movements took place along almost vertical to eastwards dipping northwest/southeast wrenching faults. In the rest of the studied area displacements are generally very small along northwest/southeast striking faults.

2.3.4 Depth To The Bedrock In The Alluvial Fans

The depth of the bedrock in the alluvial fans depends mainly upon the relative down thrown movements west of the boundary thrust fault zone. In the south, in the Al Hamranyah area, the depth to the bedrock consisting of autochthnous limestones or the Hawasina complex is generally more than 1000 m. Only within 1 or 2 km from the boundary, thrust fault zone bedrock can be expected within 500 m depth. North of

Rams the coastal plain is a narrow zone and also the character of the boundary thrust zone has changed. The main vertical displacement have taken place in thrust fault zones near the coast or even offshore. This is derived from reflection of seismic data and well logs data from oil companies. This also explains the presence of outcrops of the autochthonous Wasia group. Below the alluvial fan of Wadi Rahabah, the Wasia Group can be expected between 50 and 400 m going from east to west . Also in the alluvial fan of wadi Ghalilah the Wasia Group can be expected between about 50 and 400 m deep. North of Wadi Ghalilah the boundary thrust fault zone has again a different character. On the eastern side of the fault the layers are no longer overturned. Larger vertical displacements may have taken place again in thrust fault zones offshore.

CHAPTER III

TDEM INVESTIGATIONS IN WADI AL BIH

CHAPTER 3

TIME DOMAIN ELECTROMAGNETIC INVESTIGATIONS AT WADI AL BIH AREA

3.1. INTRODUCTION

A ground water study in Wadi Al Bih near Ras Al Khaimah, United Arab Emirates was conducted from September to October 1996. The main objective of the survey is to create maps of the subsurface geoelectrical properties of Wadi Al Bih, using the TDEM method, that could serve as a framework for the interpretation of the local geology and hydrology. (Such TDEM data were provided by the Ministry of Agriculture and Fisheries and were analyzed in this study.)

The main advantages of the TDEM method are:

1. Unlike direct current (DC) methods, TDEM has a low sensitivity to near surface lateral resistivity changes, since the induced currents flow in rings around the receiver and thus reduce noise due to small, near surface inhomogenities.

2. The transmitter loop is inductively coupled with ground and therefore contact resistance in resistive terrain (e.g. dry desert soil) does not influence the amount of current which can be transmitted. This greatly enhances data quality as compared to DC methods where high contact resistance can seriously limit current injection and impede field operations.

3. TDEM is the most accurate electrical prospecting method currently available as it possesses excellent lateral and vertical resolution in the case of conductive targets and the non-uniqueness of interpretation is significantly less than that of the DC method. The amount of data points recorded is quite significant so that simple contouring of

apparent resistivity data against time can lead to rapid interpretations in the early stages of survey.

The TDEM method is effective at :

a. Mapping the thickness of wadi gravels obscuring bedrock topography, provided that the resistivity contrast between the alluvial and the bedrock is greater than the measurement uncertainty.

b. Mapping salt and brackish water interfaces. TDEM excels at mapping conductive targets, even when covered by a thick conductor such as a clay layer. It can obtain data from formations below a saline surface.This is very useful in areas where fresh water is obscured below saline zones in multi-layered aquifers.

c. Locating vertical anomalies such as faults which can be used as drill targets for water wells.

3.2. THEORETICAL BACKGROUND

Time Domain Electromagnetic exploration techniques use electrical and magnetic fields to determine the electrical conductivity or resistivity of the subsurface layers. TDEM soundings are made with a transmitter and receiver unit attached to a transmitter and receiver loop. A primary current is passed through the transmitter loop. The primary current is then rapidly terminated and this induces a large primary magnetic field as described by the Biot-Savart law (Baker, 1979; Becker and Chang.1988; Becker, et al., 1972; Buselli, and O'Neill, 1977; West, et al., 1948).

The primary magnetic field travels downwards and outwards in closed loops below the transmitter loop. When the primary magnetic field encounters a conductor within the ground an electromotive force (EMF) is induced in the conductor, following

Faraday's Law, and this gives rise to a secondary magnetic field (by Biot's Savart Law) this field is detected and measured at the receiver where it generates a voltage in the receiver loop. Because the magnitude and distribution of the EM fields are controlled by the electrical properties of the ground, the voltages measured at the receiver provide information about these electrical properties.

As the subsurface electrical properties are highly dependent upon the porosity, saturation and pore fluid resistivity, a TDEM survey can provide valuable information about ground water quality.

The voltage recorded at the receiver is called a transient. Over one thousand transients are typically recorded and averaged at every TDEM site to reduce the effect of background EM and instrument noise. Immediately after the primary current is switched off the induced EM fields are concentrated close to the surface of the earth, and the voltage induced at the receiver is time invariant and proportional to near-surface resisitivity.

This is called the early stage . As time passes the EM field diffuses downwards and the voltage becomes proportional to $t^{-5/2}$ and $r^{-3/2}$ where "t" is time and "r" is the resistivity of the deepest layer penetrated by EM field. This is called the late stage.

During TDEM processing the voltages recorded during each time window by the receiver are converted to apparent resistivities. A theoretical geoelectrical model which generates a voltage response, that fits the observed data is then determined. The geoelectrical model assumes a uniform layered earth with resistivity varying only as a function of depth. In a simple two layer situation the apparent resistivity determined from early stage voltages, when the EM field is concentrated near the surface, correlates with the true resistivity of the upper layer. The apparent resistivity determined from late stage voltages when almost all of the EM field has diffused into the deeper layer, approaches the true resistivity of the second layer. It should be noted that, as with the interpretations of other electrical and EM methods, the principle of non uniqueness applies in that there is no unique model that will fit a particular data set.

In theory the depth of investigation is a function of time after the shut off of the primary current rather than loop radius, however in practice the late stage signal must be sufficiently strong with respect to the background EM and instrument noise to be measurable. To increase the late time signal strength and study the resistivity of deep layers, the transmitter moment must be increased.

This can be achieved by increasing the transmitter current, the loop area or both. The maximum length of time during which a transient can be recorded on the signal to noise ratio.

EM noise becomes increasingly important during the late stage, as the signal strength declines. The ambient noise (environmental noise) is recorded at regular intervals during a TDEM survey in order to determine the maximum time that can be used for the TDEM sounding interpretation.

3.3. PLANNING OF TDEM SURVEY

A base was setup in the Bin Majid Beach Hotel. The coordinates of a survey monument in Ras Al Khaimah were used to calculate the exact coordinates of a point on the roof of the hotel, which served as the base station for all the differential post processing of the GPS points measured during the survey.

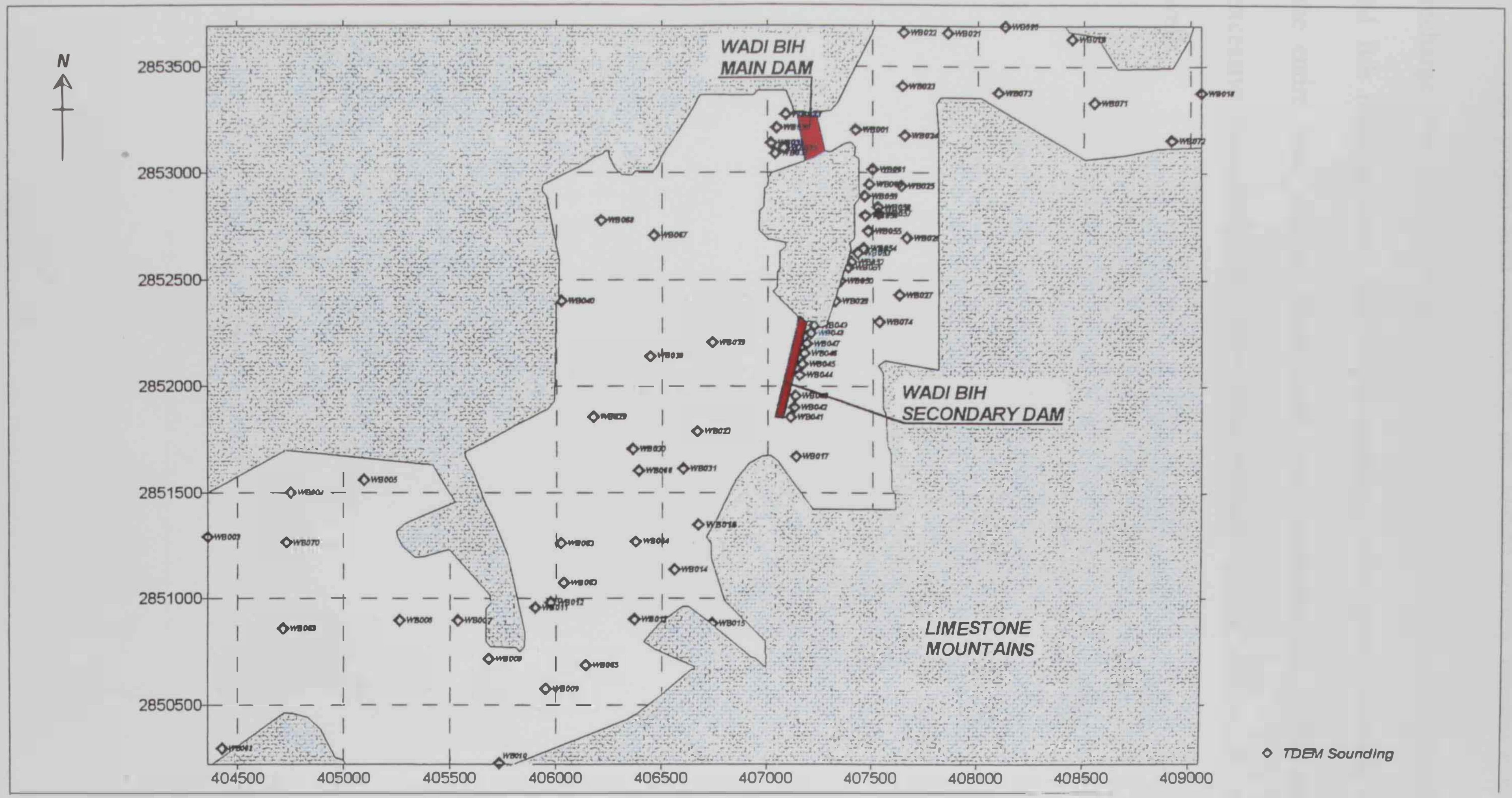

Fig. (3.1) Location map of TDEM sounding stations

The project area covered by the TDEM survey extends from the lowermost recharge dam at the base of Wadi Al Bih to 1.5 kilometres upstream of the main Wadi Al Bih recharge dam. The TDEM soundings were spread as evenly as possible over the entire wadi surface. Some areas were unsuitable for TDEM soundings, due to excessive electromagnetic noise from overhead power cables or nearby pumping wells.

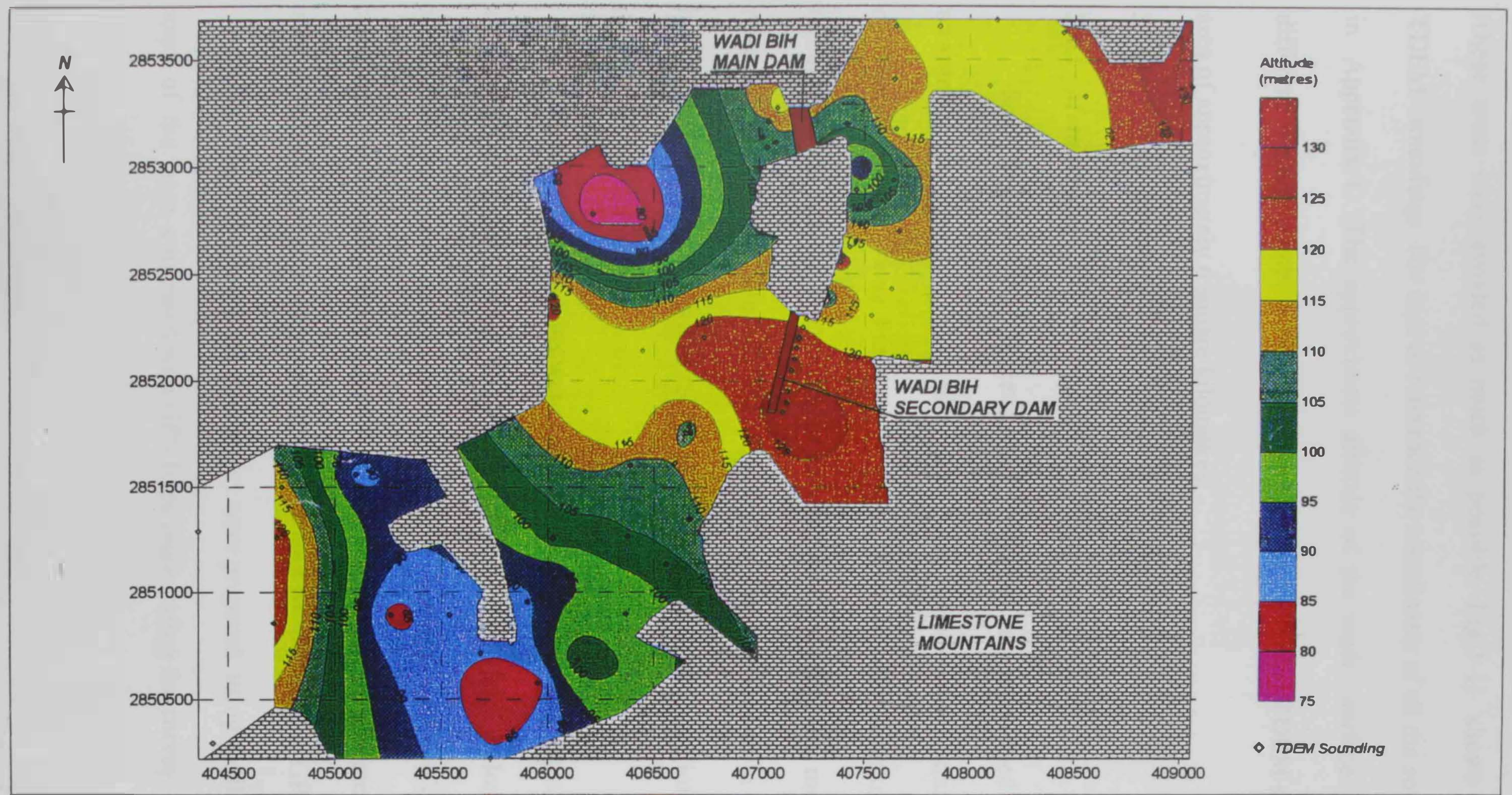

Fig.(3.2) Topographic elevations in Wadi Al Bih area on differential GPS reading

These areas were avoided as much as possible. Fig(3-1) shows the location of all TDEM soundings. For ease of reference the coordinates of all the soundings are given in Appendix C. The approximate altitude of the wadi surface calculated from differential GPS points are shown in the Fig. (3-2). The TDEM survey covered an area of approximately 6 square kilometres.

3. 4. TDEM SURVEY

3.4.1 *Methodology*

For this survey a Sirotem Mark 3 system has been used which employs a transmitter and receiver within the same cable . Following initial field trials the optimum loop size was found to be 50 x 50 metre. This loop size was employed throughout the survey. At each sounding location, a series of measurements was recorded at different gain settings designed to enhance data from greater depths. A background noise run was also recorded for environmental correction of the field data during post acquisition processing.

A total of 74 soundings were completed at 74 locations. The sounding locations are marked as WB001 to WB074 on Fig(3-1) At each sounding location north and east coordinates were recorded using global positioning system (GPS). This system calculates the position using signals received from satellites. The measurements were later corrected by post processing software, using a fixed reference GPS at the base.

The maps presented in this report were prepared using available topographic maps of the area, combined with GPS fixes taken during the survey. The TDEM data acquired during the field work was downloaded to a Pentium computer and processed at the field base, after each acquisition day.

3.4.2 PROCESSING OF TDEM DATA

The field data was processed by a transient electromagnetic interpretation software using interactive forward and inverse modeling techniques. The program calculates apparent resistivity values from normalized voltages measured in the field.

The apparent resistivity data was interpreted by geoelectric models. These models attempt to reproduce the actual values recorded in the field. As with all geoelectric models, one of the principal assumptions is that the earth can be represented by a series of horizontal layers of constant lateral resistivities and thicknesses. The departure from this generalization is demonstrated by those data points that fall outside of the predicted line. Data collected close to overhead power lines and pumping wells was generally quite noisy. The electromagnetic noise effects were masked as much as possible prior to final processing.

There is a multitude of geoelectric models that could reproduce a particular set of field data . All models were chosen so that the minimum number of layers was used to model the field data.

The sensitivity of the models to changes in resistivity and thickness was tested by an equivalence analysis. This calculates the range over which each parameter can vary either side of the modeled value that would result in an over all fitting error 20% higher than that calculated for the best fit model.

3.4.3 INTERPRETATION OF TDEM DATA

The TDEM soundings in the study area display apparent resistivity curves that could be interpreted by a four layer model. The model can be viewed in terms of simple conceptual model for the project area. This has been summarized in Table (3- 1)

Table 3--1 Summary of TDEM Geolelectric Models

Layer	Depth to Base (m)	Thickness (m)	Resistivity (Ohm-m)	Interpretation
Unit 1	Range : 15 - 20 Average : 16	Range: 15 - 20 Average : 16	Range : 25 - 269 Average : 104	**Superficial gravel**
Unit 2	Range :70 - 100 Average : 79	Range: 15 - 90 Average 63	Range : 15 - 475 Average : 225	**Cemented gravel**
Unit 3	Range :70 - 160 Average : 16	Range . 5- 95 Average : 56	Range 0.7 - 60 Average : 14	**Transition zone : cemented gravel and weathered limestone**
Unit 4			Range : 45 - 2411 Average : 925	

3.4.4 GEOELECTRIC CONTOUR MAPS

The depth to the base of the geoelectric units, their thicknesses and resistivities were gridded using the Kriging method. The Kriging method is the preferred geostatistical method in geological and hydrogeological investigations, as it can identify trends in the data. The gridded data was then contoured and presented in Figs 3-3 to 3-11 These maps should be regarded as a 'quick look' method only, and not as actual maps of the aquifer units. The groundwater in Wadi Al Bih is reasonably fresh, and therefore the main effect on the overall resistivities will be from changes in geology, rather than the presence or absence of groundwater.

It should be noted however that saline groundwater has been recorded at depth in the Wadi Al Bih wellfield. This should have the effect of lowering the recorded resistivities.

3.4.4.a.1 Layer 1

Layer 1 is generally less than 15 to 20 metres in thickness over the project area (Fig. 3-3) Although the resistivities usually exceed 40 ohm-m (Fig (3-4) which would generally point to a good aquifer, the layer is well above the regional groundwater table, i.e., it is unsaturated. Recharge events from floods in Wadi Al Bih would have to infiltrate through this layer, which would highlight the lower resistivity areas as these are probably due to an increased clay content that could impede infiltration. Layer 1 can be interpreted as loose superficial wadi gravels.

3.4.4.a.2 Layer 2

The base of Layer 2 is generally 70 to 100 metres below ground level over the project area (Fig.3-5). The thickness of this layer varies between 15 and 90m (Fig. 3-6). The resistivities show significant variations over the project area from loss of less than 50 ohm-m to highs in excess of 400 ohm-m (Fig 3-7) This layer is interpreted as a cemented gravel. The lower resistivity areas probably correspond to the clay rich areas.

In some areas, the lowermost portion of layer 2 may be below the groundwater table, i.e. within the saturated zone. As with Layer 1, any recharging water from wadi floods would have to infiltrate through this layer. The clay rich low resistivity areas as well as the very resistive highly cemented areas may reduce local infiltration rates.

3.4.4a.3 Layer 3

The base of layer 3 varies from 70 to 160 metres (Fig.3-8) The shallower areas correlate well with positive surface topographical features, indicating that the base of this Layer probably defines the subsurface limestone topography. The thickness of the third layer lies between 5 to 95m (Fig.3-9). The resistivities of layer 3 are low, generally ranging from 5 to 20 ohm-m (Fig. 3-10) This can be viewed in terms of a transition zone incorporating the basal sequence of the alluvial gravels, and the weathered top surface of the limestone basement. The predominance of vertical fractures within the limestone basement rocks would also affect the geoelectric model

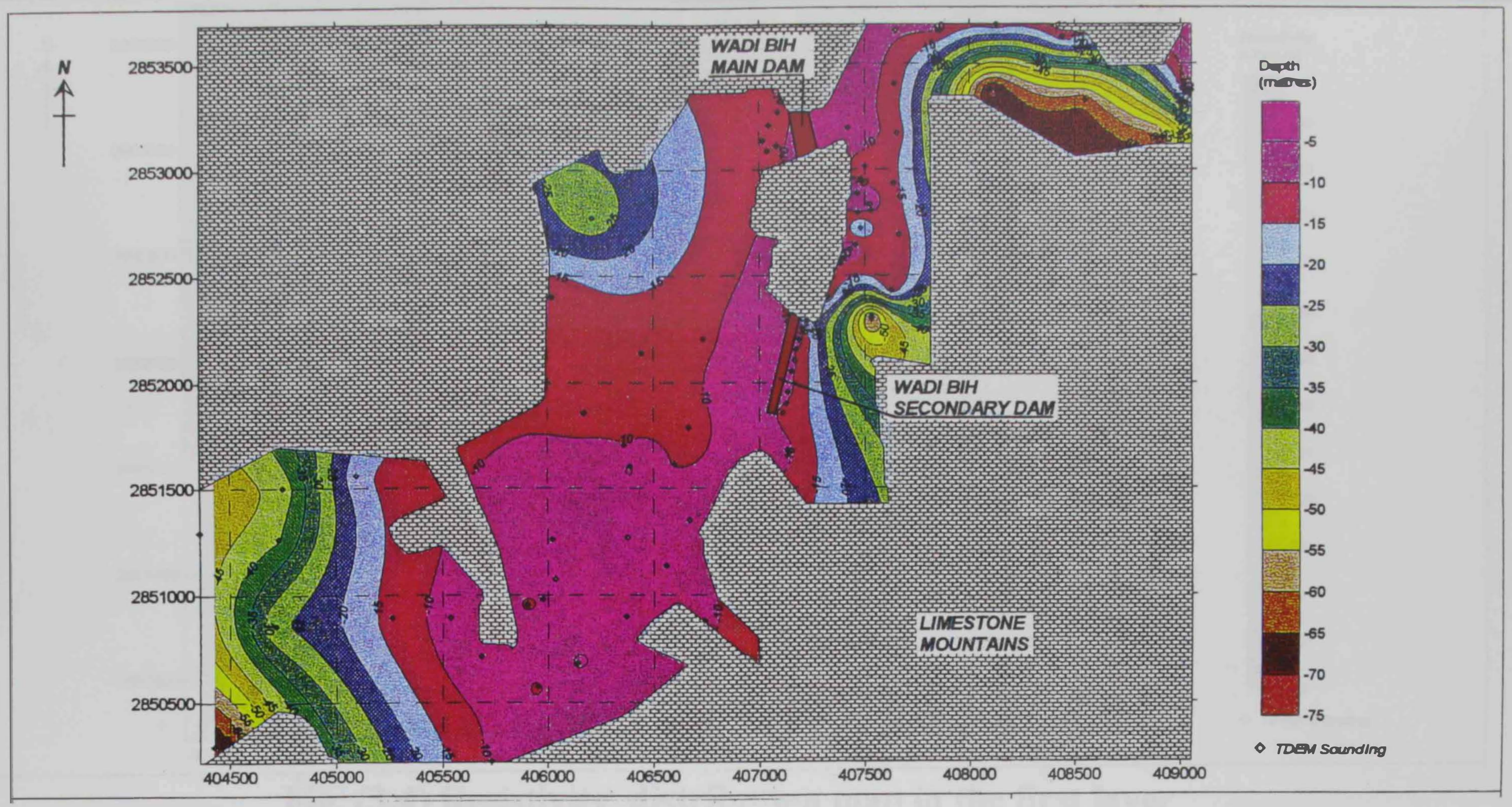

Fig. (3.3) Thickness distribution map of the first layer

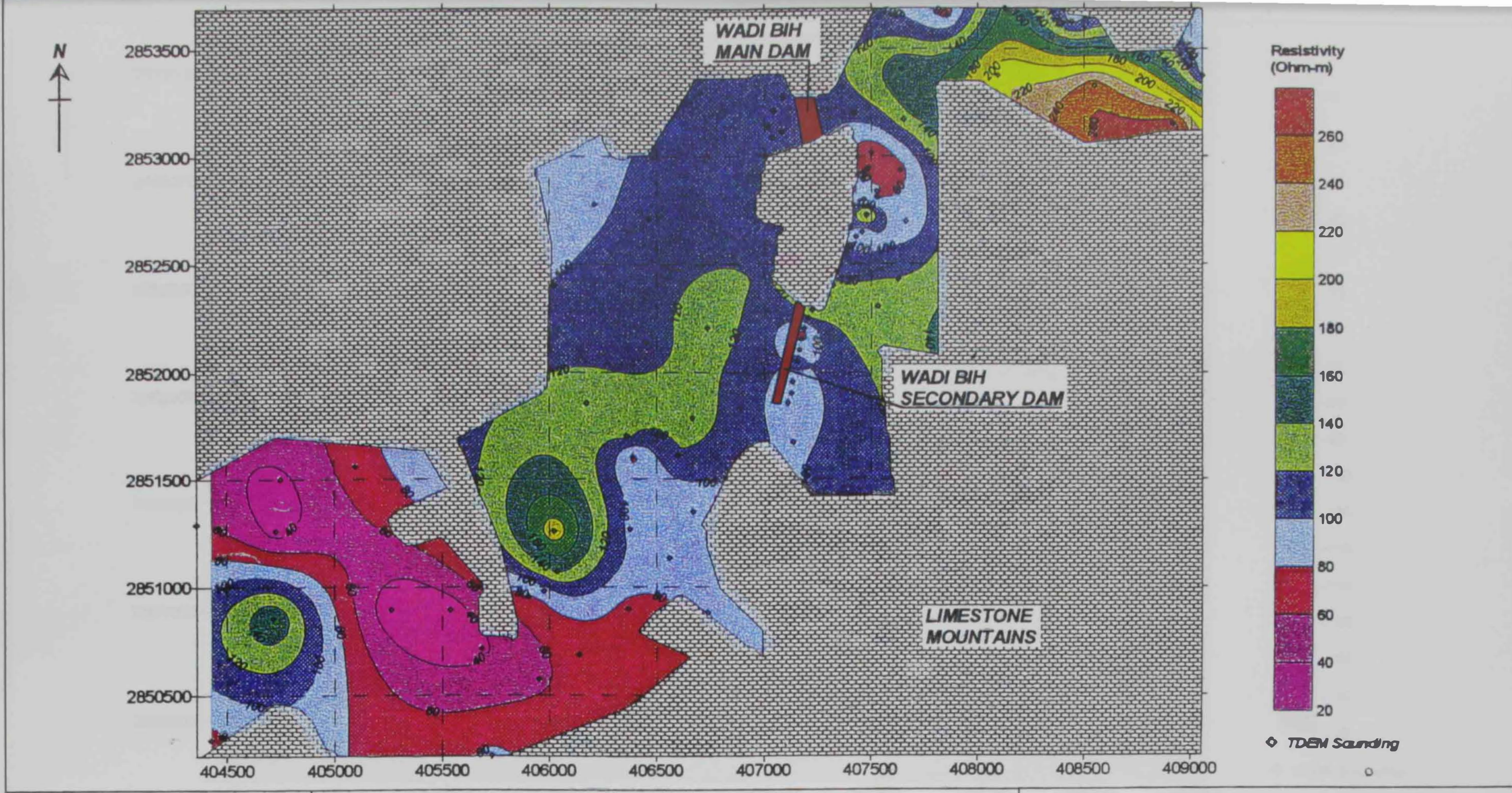

Fig. (3.4) Resistivity distribution map in the first layer

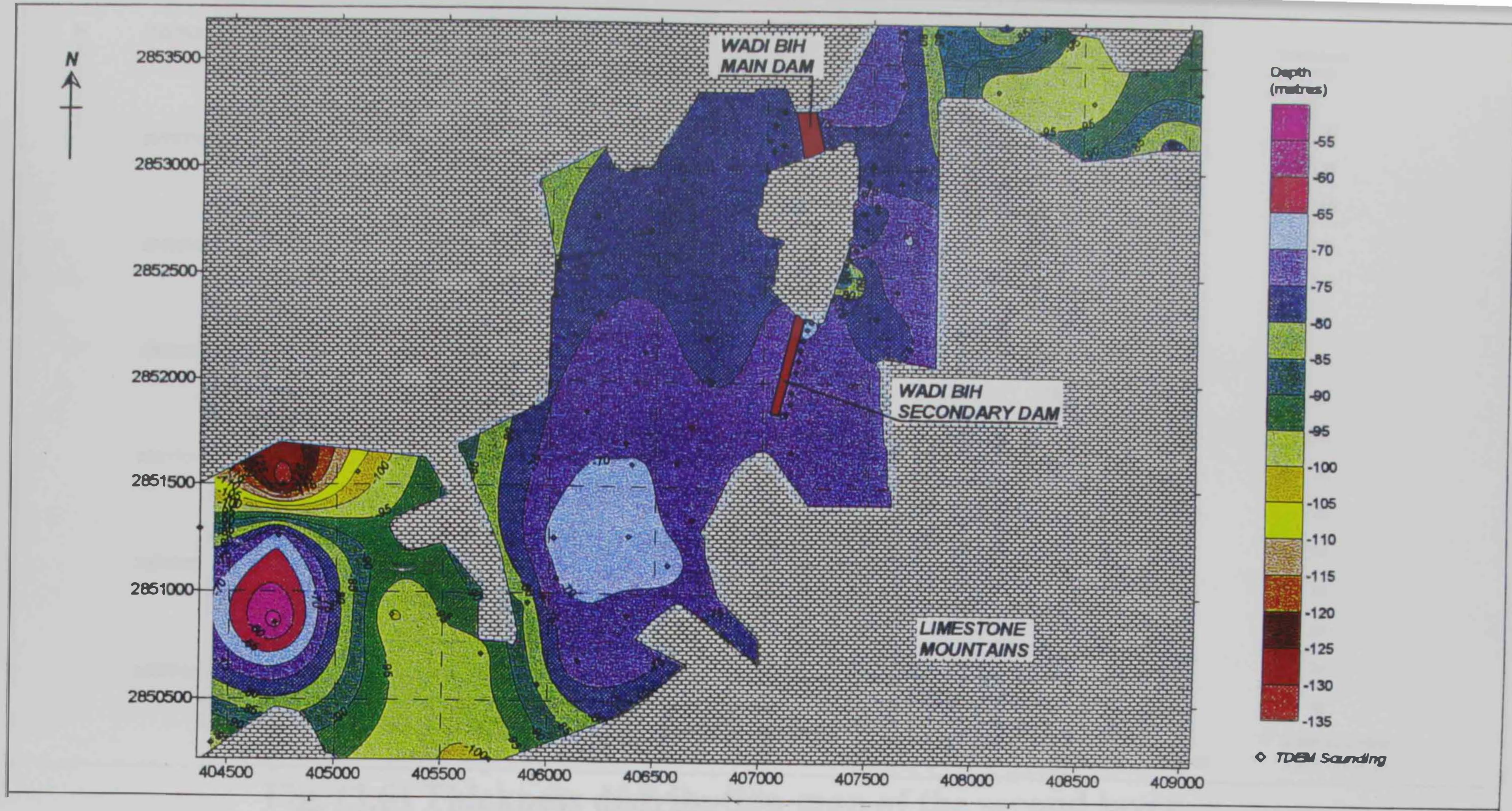

Fig. (3.5) Depths to the lower surface of the second layer

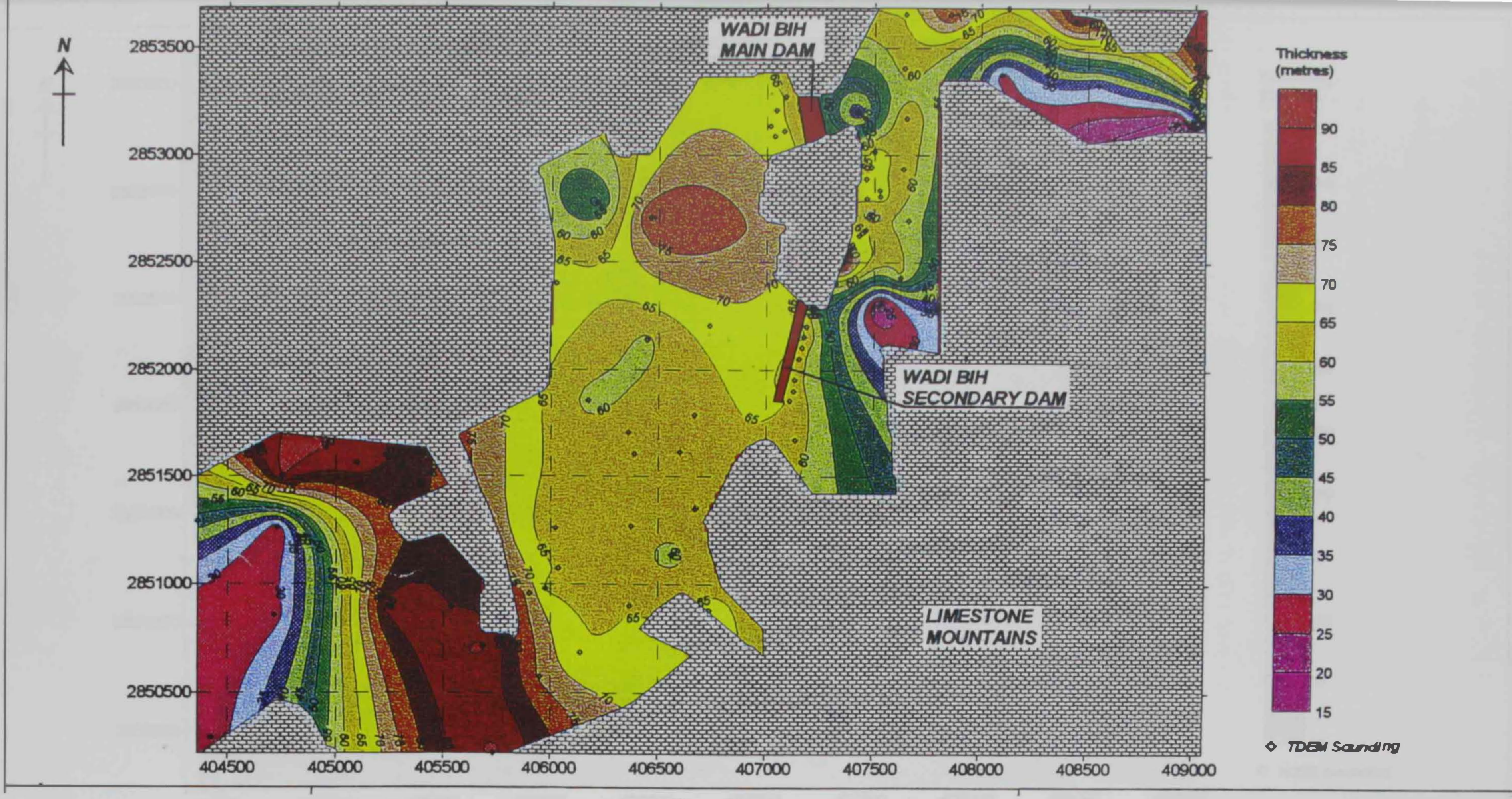

Fig. (3.6) Thickness distribution map of the second layer

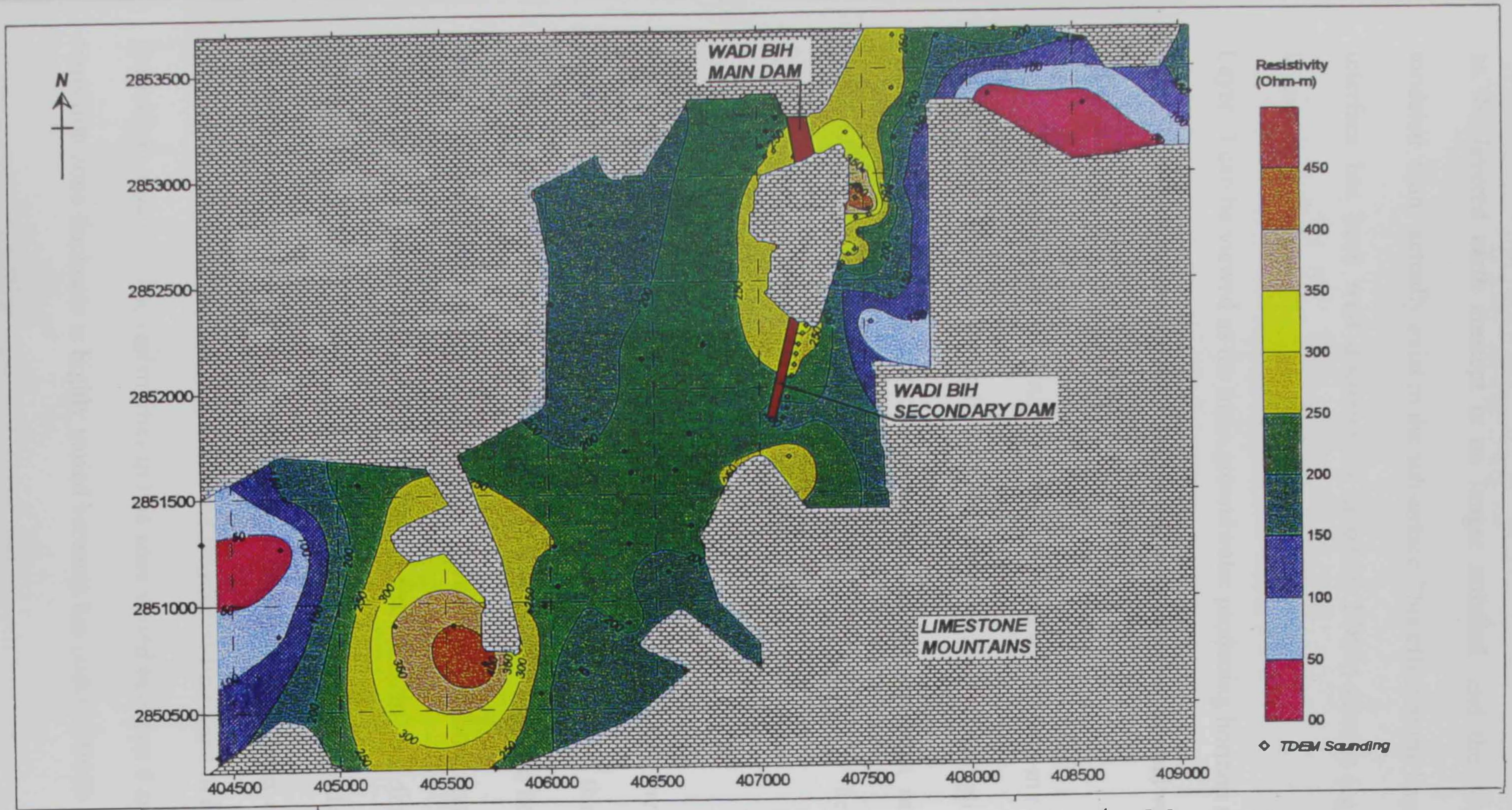

Fig. (3.7) Resistivity distribution map in the second layer as the layered earth concept is no longer satisfied, and the lower resistivities are modeled than actually exist in the subsurface.This effect at the basement /wadi gravel interface has been well documented in other TDEM surveys (eg. Wadi Ham, Wadi Wurrayah).

Layer 3 can be viewed as the main groundwater producing horizon in the Wadi Al Bih area. The thickest areas should yield the highest amount of groundwater.

3.4.4a.4 Layer 4

The resistivities of Unit 4 are generally above 500 ohm-m (Fig.3-11) The unit can be interpreted as extremely resistive limestone rocks. The high resistivity reduces the penetration of eddy currents from the TDEM soundings into this layer, and therefore represents the lowermost unit that could be explored by the survey.

3.4.5 GEOELECTRICAL CROSS-SECTIONS

3.4.5.a Geoelectric Cross-section (1)

This Cross-section strikes in the NNE - SSW direction in the frontal area of the main and secondary dams (Fig. 3-12). From the distribution of the resistivities in the vertical cross-section (1); Wadi gravels to a depth of ~ 80m can be interpreted . This can be divided into the uppermost gravel layer of ~15m thickness and the cemented gravel layer of about 65m thickness. The resistivities in the first soil layer range between 60 and 140 Ohm-m, while it fluctuates between 150 and 460 Ohm-m in the gravel layer. The cemented gravel layer is underlined by a layer of low resistivities. This layer consists of cemented gravels and weathered limestone boulders and is called (transition zone). The resistivities in this zone varied between 6 and 14 Ohm-m. The transition zone thickness is highly varied between 8m under WB049 to more than 60m

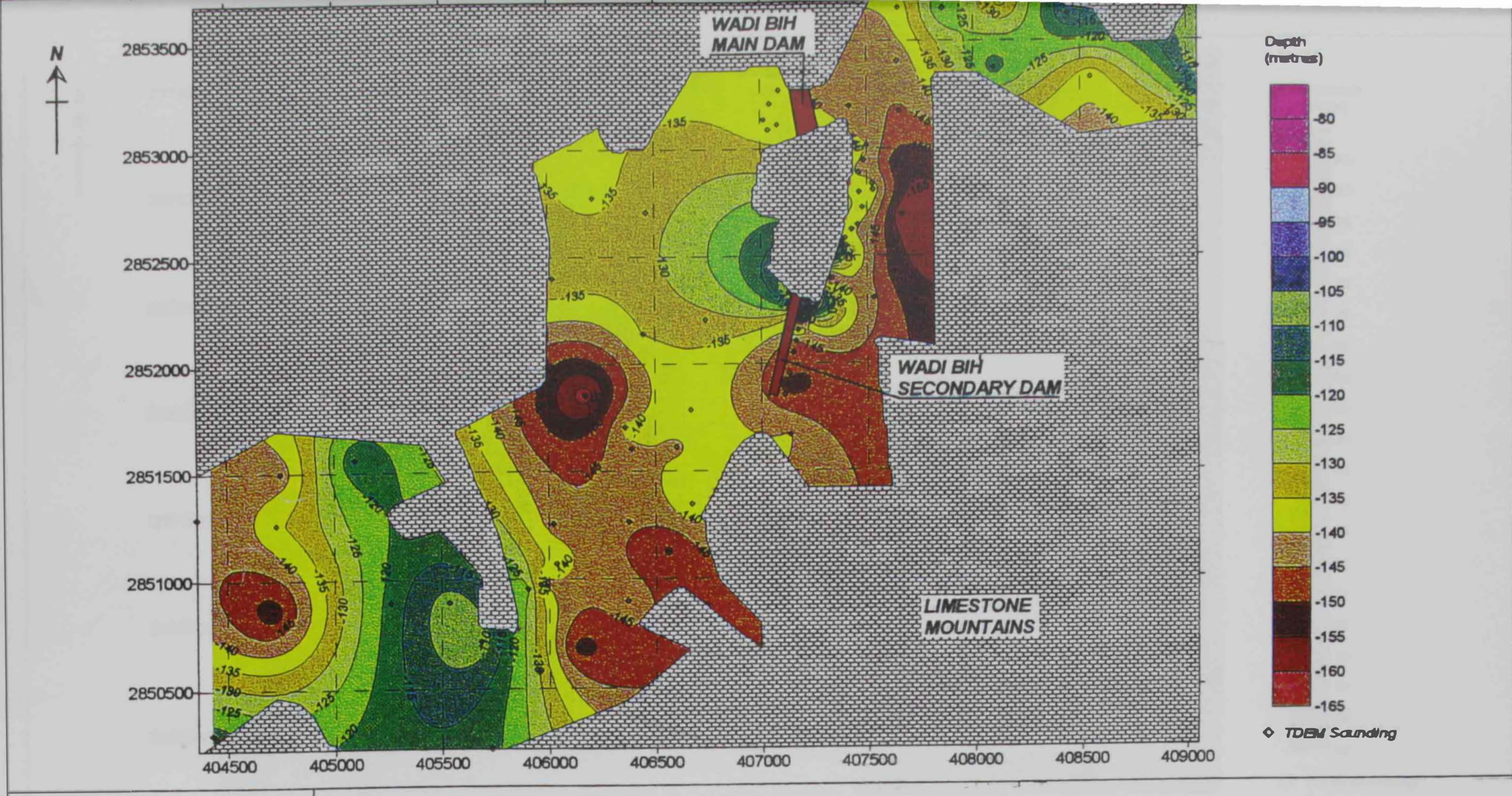

Fig. (3.8) Depth to the lower boundary of the third layer

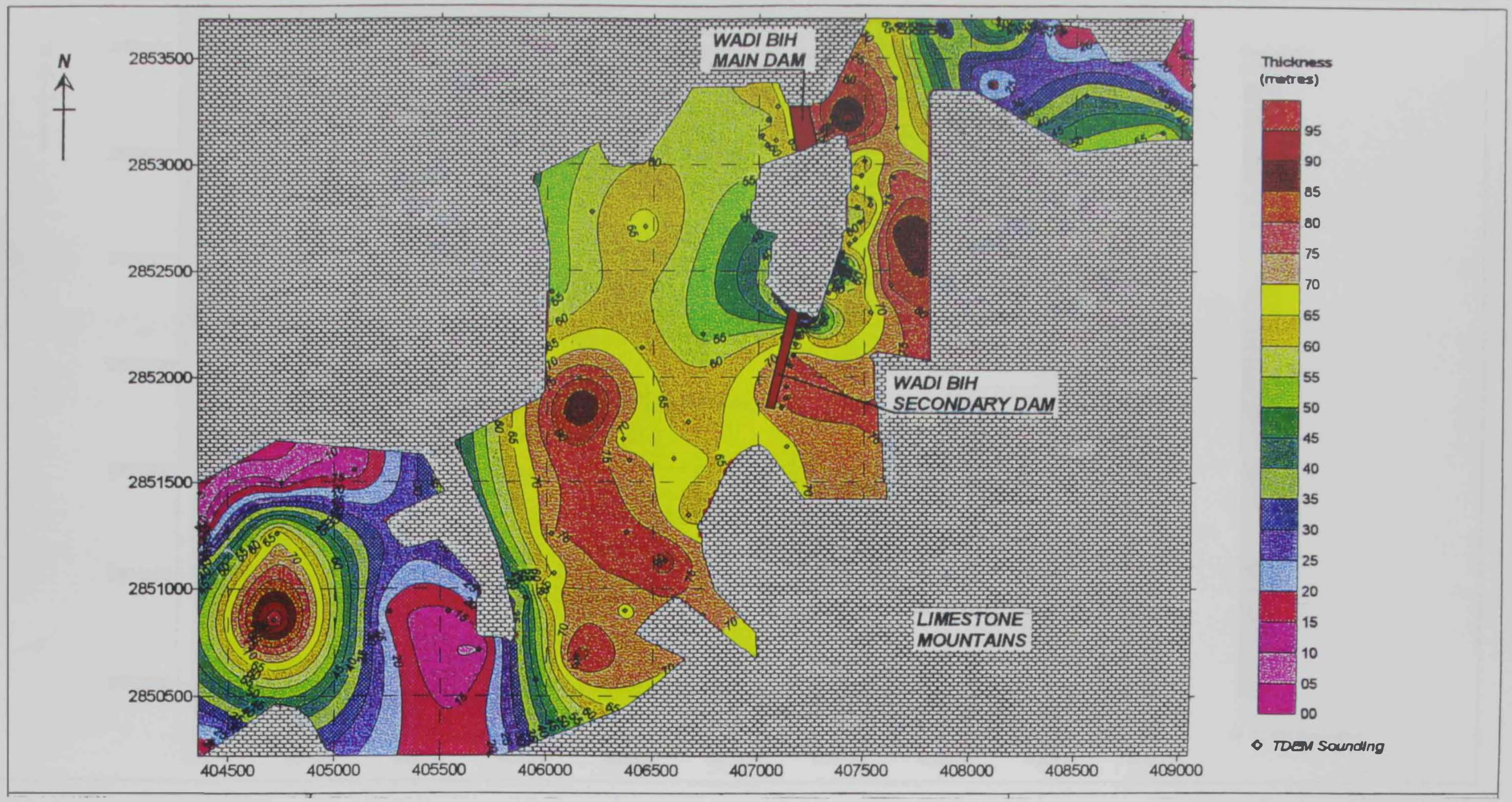

Fig. (3.9) Thickness distribution map of the third layer

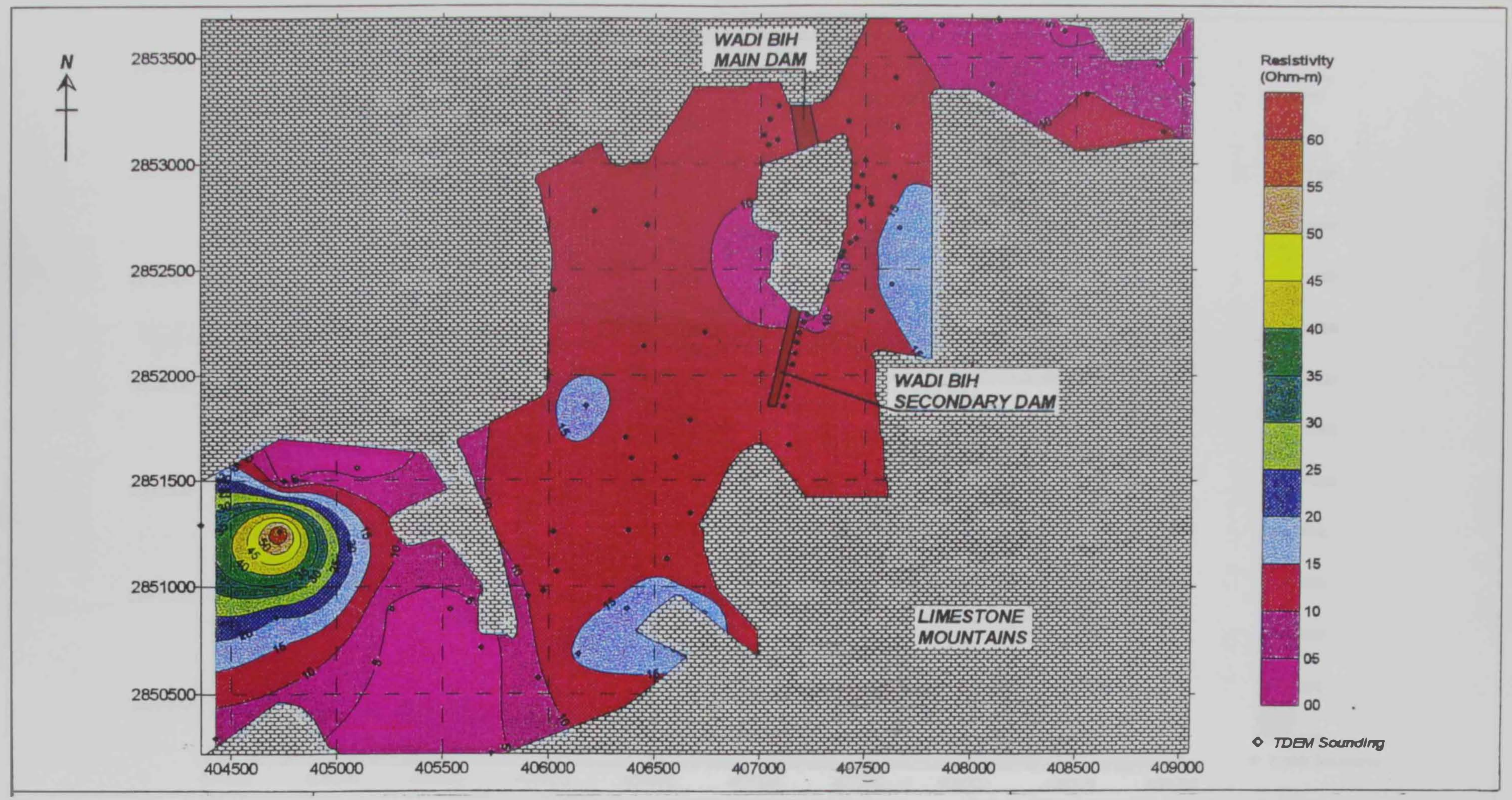

Fig. (3.10) Resistivity distribution map in the third layer

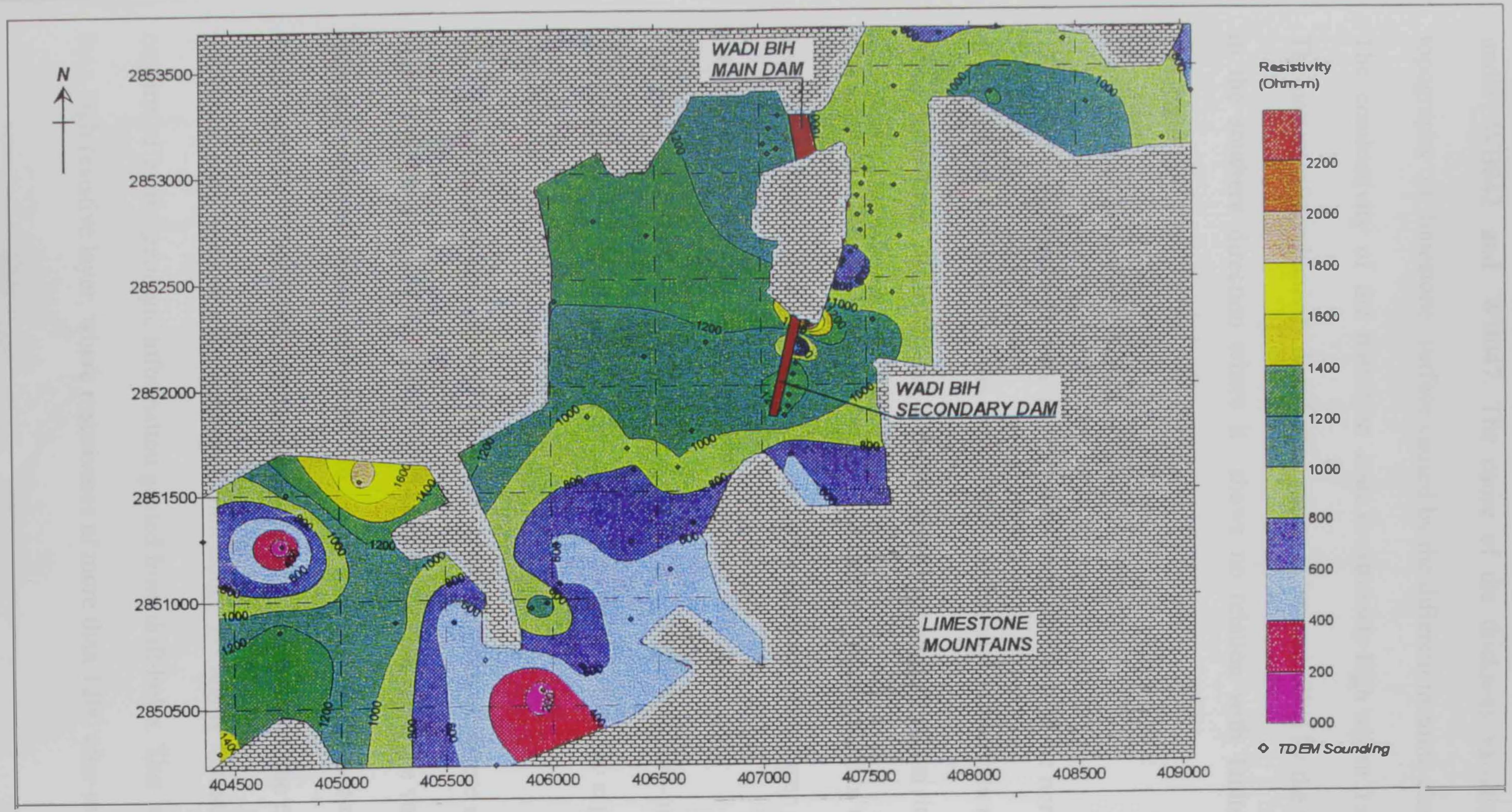

Fig. (3.11) Resistivity distribution map in the fourth layer under WB042 and WB047. The cause of the thickness variation is the rugged topography of limestone surface caused by the different tectonic elements (Fig. 3-13) The conductivity of the transition zone is extremely high where it reaches 80 mS/m. The pattern of conductivity distribution seems to be controlled by the tectonic elements in the southern direction where it shows no relation with faults in the northern direction (Fig.3-13)

3.4.5.b Geoelectric Cross-section (2)

This cross-section runs in the east - west direction in the northernmost part of the survey area (Fig.3-14). This cross-section includes the observation points WB023, WB073, WB071, WB072 and WB018. The distribution of resistivities in the vertical cross-section (2) indicates a four layer structure. The values of resistivities in the uppermost layer range between 150 and 290 ohm-m. This layer consists of wadi gravels. Its thickness fluctuates between 10m and 70m.

The resistivities in the second layer range between 20 and 290 ohm-m which indicate a cemented gravel. It seems that the cement material is the clay especially under the observation point WB073.

The third layer exhibits very low resistivity values, where under observation point WB073 a resistivity value of 5 ohm-m is calculated . The values of resistivity increases towards east and west to reach a value of 13 ohm-m under observation point WB023. This distribution indicates that the proportion of the clay cement in the transition zone (gravel and weathered limestone) is highly increased. This result is confirmed by the geologic information gained from drill-holes. This layer is underlined by a high resistive layer, where resistivities of more than 1200 ohm-m indicating a

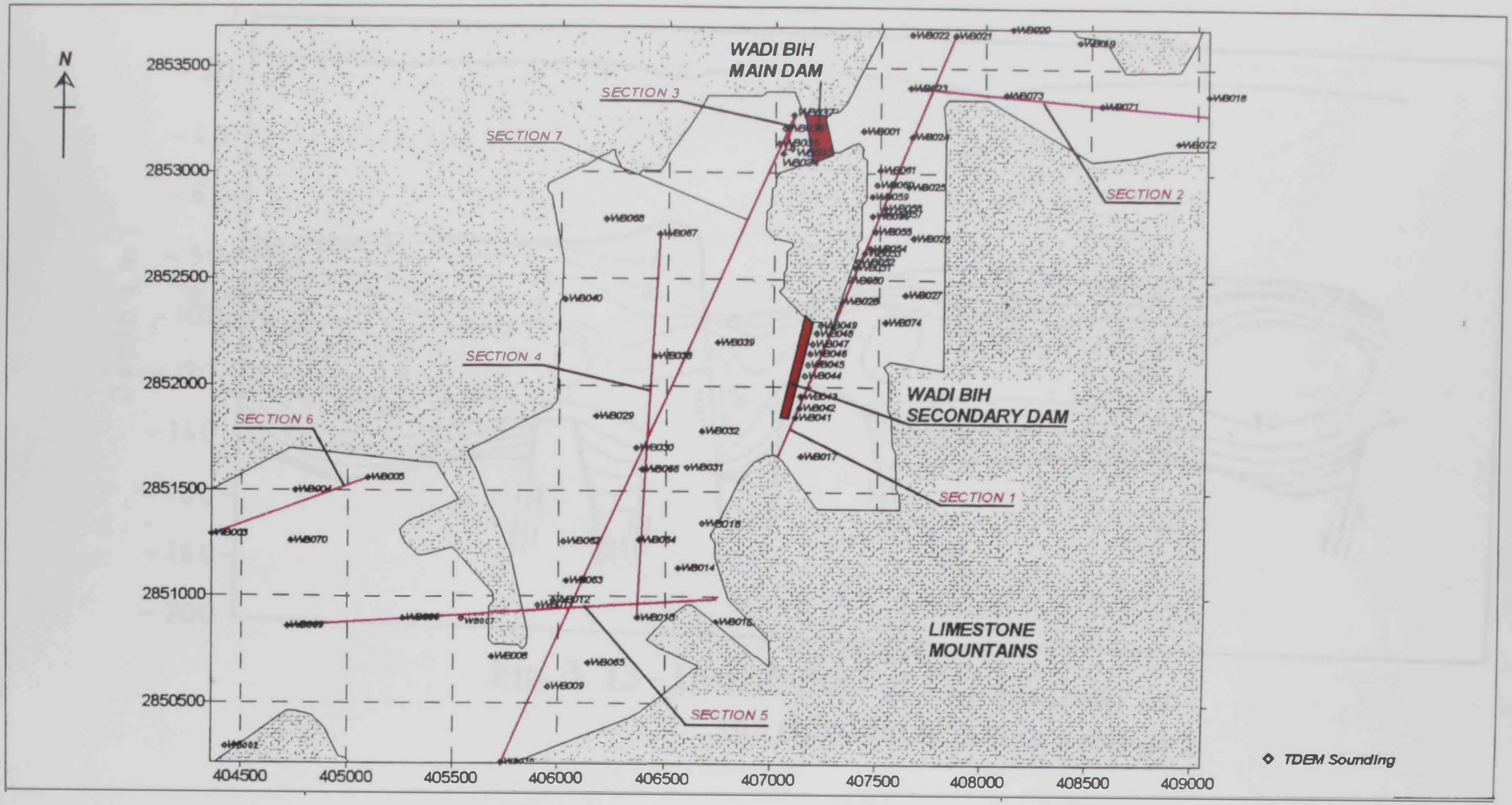

Fig. (3.12) Location map of TDEM geoelectric sections

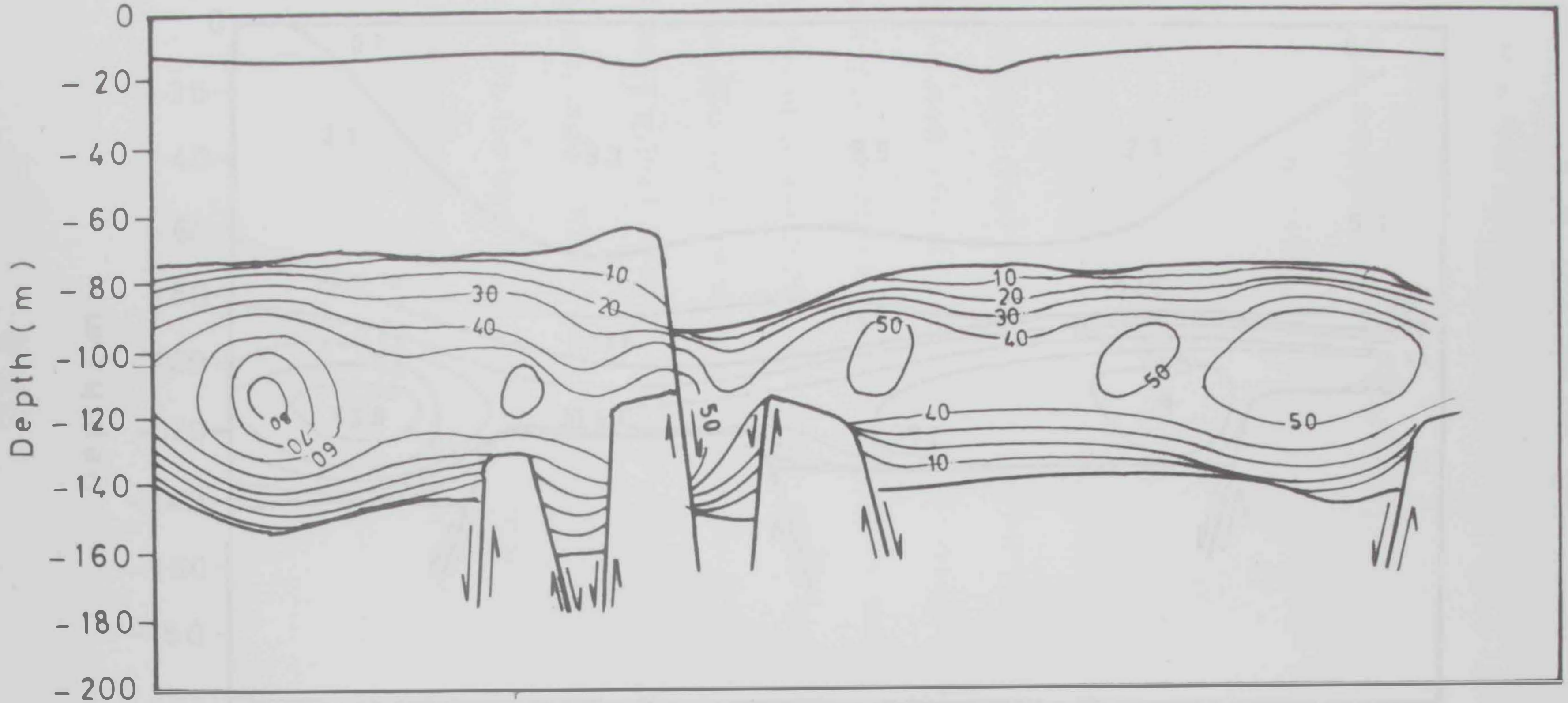

Fig. 3. 13 - Distribution of Conductivity in the third layer along section 1

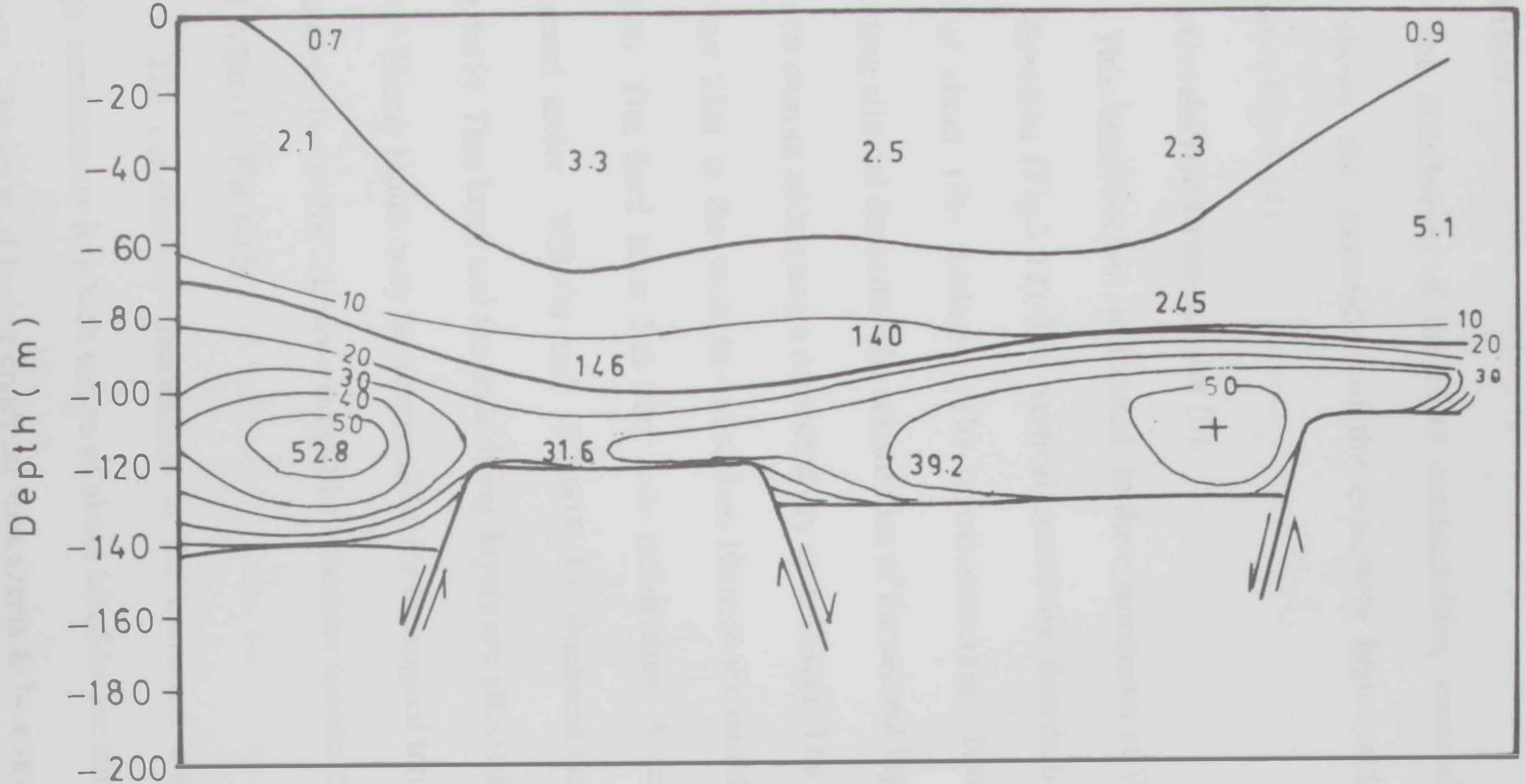

Fig. 3. 14 - Distribution of Conductivity in the third layer along section 2

compact limestone has been recorded. This section is affected by three fault elements; the western fault cuts all layers, while the other two faults affects only the top of the fourth layer.

The distribution of the layer conductivities, especially that of the secondary layer shows the association of the extremely high conductivities with the fault elements (Fig. 3-14).

3.4.5.cGeoelectric Cross-section (5)

This cross-section is located in the downstream of Wadi Al Bih. It runs in the E-W direction (Fig.3-12) The vertical resistivity distribution indicates a superficial layer of about 15m thickness. The resistivities range between 25 and 160 ohm-m indicating alluvial deposits. The resistivities of the second layer fluctuates between 160 and 400 ohm-m addressing a cemented dry gravel layer. The thickness of this layer lies between 25m at the west to more than 100m in the middle part of the section under WB006. The third layer has very low resistivities. A resistivity of ~ 5 ohm-m is measured under WB006 and WB007. Its thickness ranges between 15 and 120m (Fig.3-15). This layer and the underlying layers are affected by a number of faults.

These faults may be responsible for the rugged topography of the lowermost limestone layer that shows a ridge-like structure crosses the section between WB007 and WB011 (Fig.3-15)

The conductivity distribution in the transition zone shows that this zone has high conductivity in which values of about 60mS/m are calculated at some observation points. The areas of higher conductivities seems to be a result of lithologic variation in the transmission zone as the increase of clay proportion and not due to the intrusion of salt water across the faults.

3.4.5.d Geoelectric Cross-section (6)

This cross- section is located at the eastern end of the study area in the downstream area of Wadi Al Bih(Fig.3-12). It strikes approximately in the E-W direction. Four geoelectric layers can be interpreted from the vertical distribution of resistivities. The same characteristic features are similar to those prevailed along the parallel profile (5) where the transition zone ranges in thickness between 10m and 70m.

This zone exhibits different resistivities ranging between 2.7 ohm-m at WB004 and 187 ohm-m at WB003. The cause of such variation seems to be due to salt water intrusion as well as lithology. This is apparently because the attitude of this layer which is down-faulted from the surrounding areas by two normal faults from the eastern and western sides. These faults affect both the topography of the limestone basement and the thickness of the transition zone (Fig.3-16). An important feature of the lowermost limestone bed where a lower resistivity is recorded (~ 44 ohm-m) This lower resistivity maybe due t0 the intrusion of the salt water in the highly fractured limestone at WB070. Another very important feature is the rejuvenation of the easternmost fault in recent times where it cuts across the bottom of the surface gravel layer. (Fig.3-16)

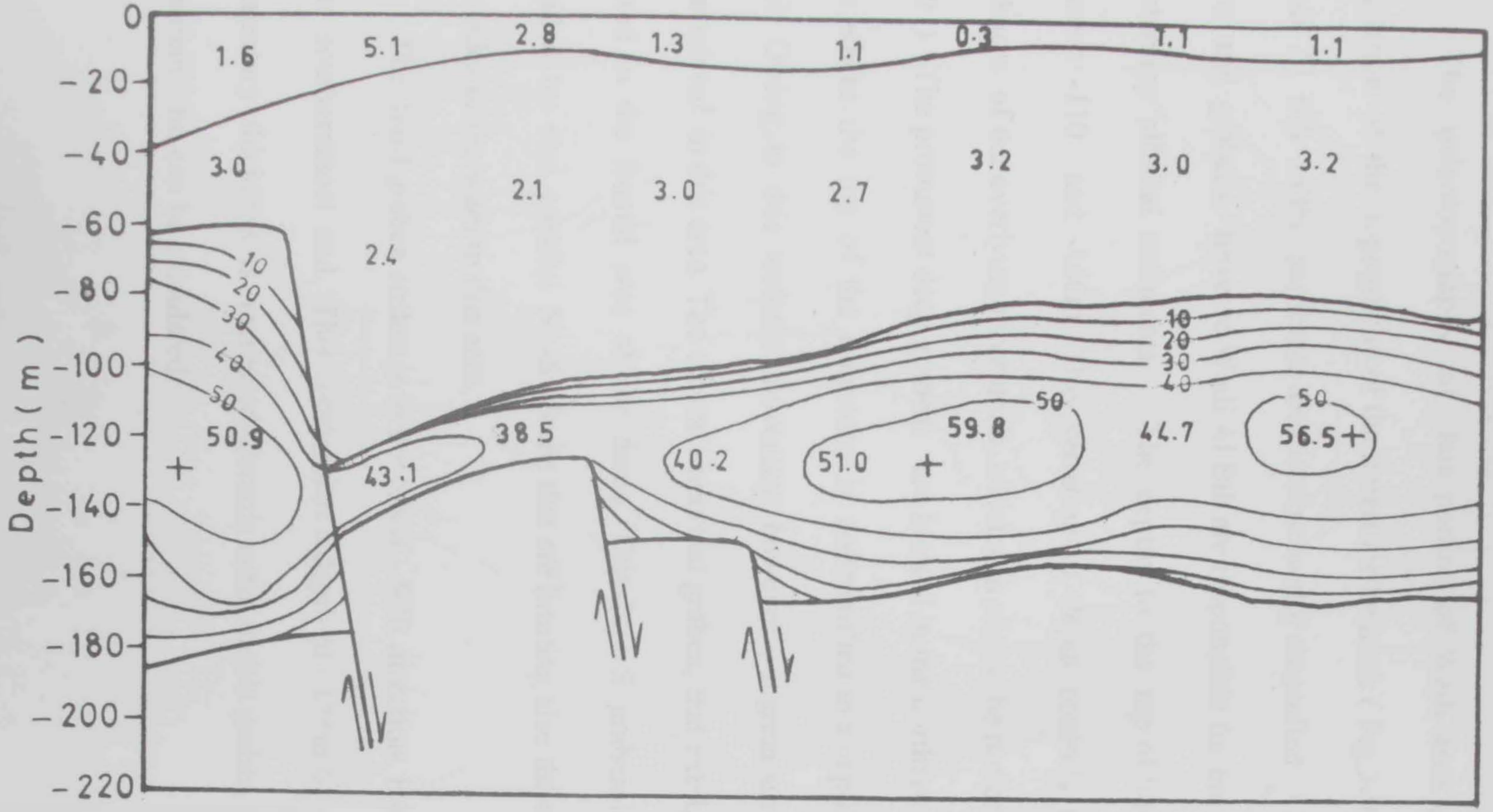

Fig. 3.15 - Distribution of Conductivity in different soil layers along section 5

3.6 Limestone Bedrock Topography

The depth to the tops of the different alluvial layers and their thicknessess have been evaluated in the area. The thicknesses of the different layers are highly fluctuated over all the survey area.

The paleotopography of this portion of Wadi area can be delineated by inspection of the topography of the limestone bedrock (Fig.3-9), where the course of Wadi Al Bih in this particular area is structurally controlled. A number of alternating horts and grabens, traverse Wadi Al Bih are responsible for the thickness variation of Quaternary alluvial sediments. The depths to the top of limestone bedrock range between -110 and -160m. This variation of depth controls to a great extent, the thickness of the overlying three units, which can easily be noticed in (Figs.3-3, 3-5 & 3-10). The prominent deep grabens are located in the northernmost part of the study area where the top of the limestone is downfaulted to a depth of ~149m below sea level. Owing to this tectonic movement however, a great amount of sediments are accumulated in this area. The second important graben, that exhibits large sediments is located in the frontal area of the dams. This N - S graben-like structure may be bounded by two parallel N -S faults that are limiting also the exposed limestone on both sides of the wadi in this area.

The third graben strikes is in the NNW - SSE direction. It includes the wellfield in its southernmost end. This graben has a depth of ~155m below the sea level. The sedimentary thickness is increased towards north in this graben where a difference of more than 20m can be calculated.

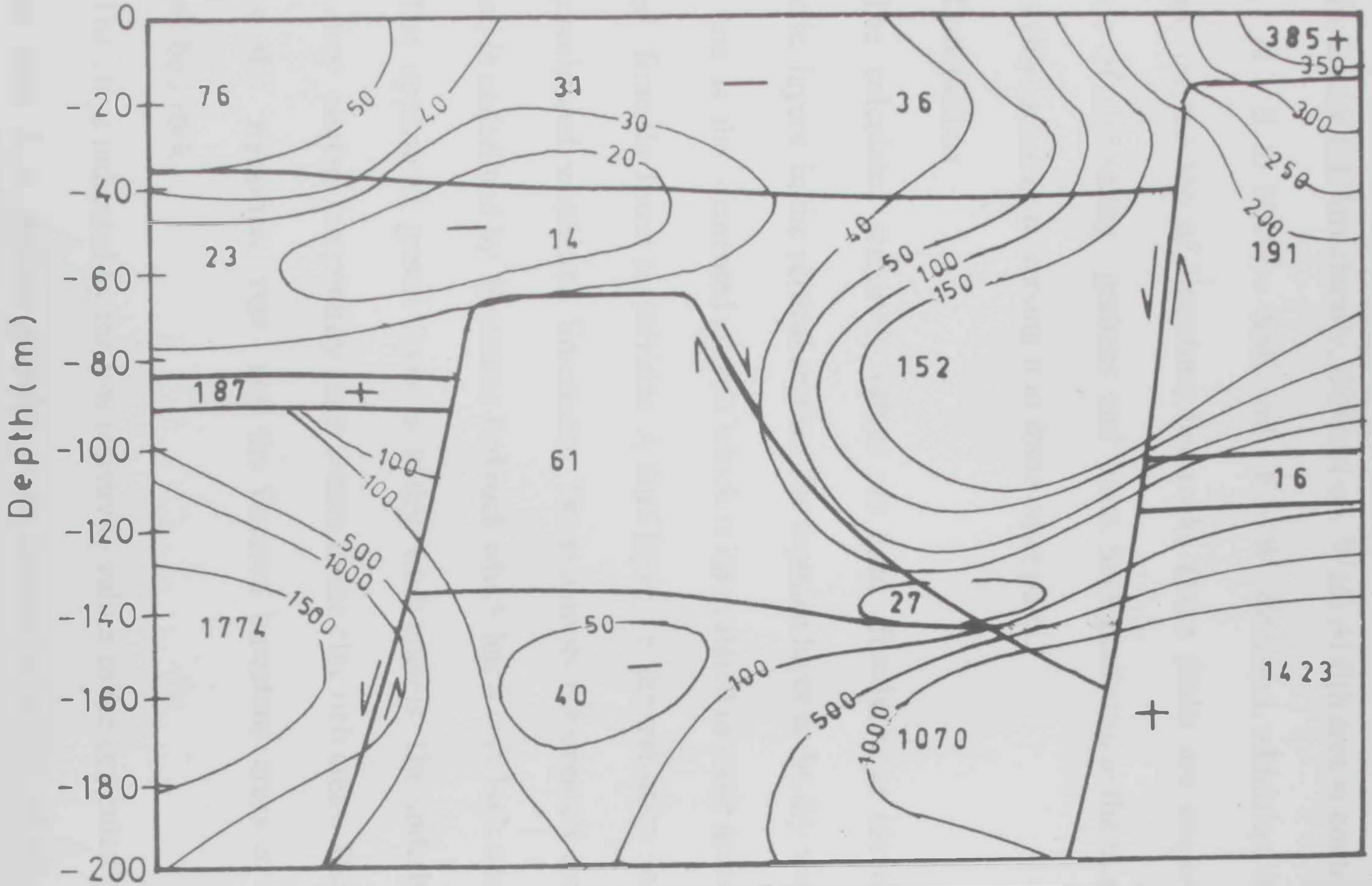

Fig. 3.16 - Distribution of Conductivity in different soil layers along section 6

The fourth graben is that located at the southwestern part of the survey area at the downstream of Wadi Al Bih. This graben is parallel to the third one. It has also the same depth magnitude of the adjacent graben-like structure, i.e. the same thickness of the sedimentary fill. Structurally, this part of Wadi Al Bih area is controlled by faults striking N - S to NNW - SSE and E - W direction, which are the main trends prevailed on the top of limestone bed-rock. These faults are responsible for the formation of alternating grabens and horts. Such faults run in the same direction of Wadi Al Bih course or traversing it in some other parts.

3.7 Conclusions

1 The calculated resistivity values are used effectively to identify four main geoelectric layers in the vertical section.The topmost layer is the dry wadi gravels, the second one is the cemented gravels which is intercalated in some areas with clays as indicated from the lower resistivities. A third layer, i.e. the transition zone consists of wadi gravels and weathered limestone. The resistivity is extremely low in this zone. This zone is underlined by limestone bed rock which has a very high resistivity .

2 The uppermost gravel layer is a dry wadi gravels. The underlying cemented gravels may contain temporarily some waters in the clay rich areas. The ground water saturates the transition zone and the fissured limestone areas in the compact limestone bed-rock.

3 The clays indicated by the low resistivity values in the cemented gravels and the transition zone is a serious candidate in the increase of salinity of the infiltrate flood waters in Wadi Al Bih area. The lack of association of faults with the abrupt increase of conductivity in some locations and the presence of solution cavities in rock samples

collected from the wells drilled through these layers confirm that the salinity there is of a local nature (i.e. due to the dissolution of salts in clays) and not due to salt water intrusions through faults.

4 There are at least three out of four grabens that have a great thickness of water bearing layer; (Fig. 3.15) the first one is located in the northernmost part of the area; The second is in the front of the dams and the third is partly occupied by the well field. These sub-basins can yield good amounts of water if they are exploited.

CHAPTER IV

BOREHOLE GEOPHYSICAL LOGGING SURVEY

CHAPTER 4

GEOPHYSICAL BOREHOLE LOGGING IN WADI AL BIH AREA

4.1 INTRODUCTION

Geophysical borehole logging is used to derive information about the sequence of rocks penetrated by a borehole (Keary and Brooks 1994). Of particular value is the ability to define the depth to geological interfaces or beds that have a characteristic geophysical signature, to provide means of correlating geological information between boreholes on the in-situ properties of the wall rock. The most useful and widely applied geophysical logging are based on electrical resistivity, electromagnetic induction, self-potential, natural and induced radioactivity, sonic velocity and temperature. Logging techniques are widely used in the investigation of boreholes drilled for hydrocarbon exploration, as they provide important properties of possible reservoir rocks. They are also used in hydrogeological exploration for similar reasons.

4.2 BOREHOLE GEOPHYSICAL LOGGING SURVEY

The geological properties obtainable from borehole logging are : formation thickness and lithology, porosity, permeability, water saturation, direction of water flow, stratal dip and temperature. Geophysical logs were run in 5 boreholes in the Wadi Al Bih area for a recent study by the Ministry of Agriculture and Fisheries and were subjected to further interpretation in this study. The aim of the geophysical logging was to produce data concerning the strata penetrated by the bore holes and information on the water quality and aquifer characteristics.

The location of the 5 logged boreholes is shown in (Fig. 4 -1) A copy of the geophysical logs plotted at a vertical scale of 1 : 1000 is depicted in (Figs. 2a - 6b)

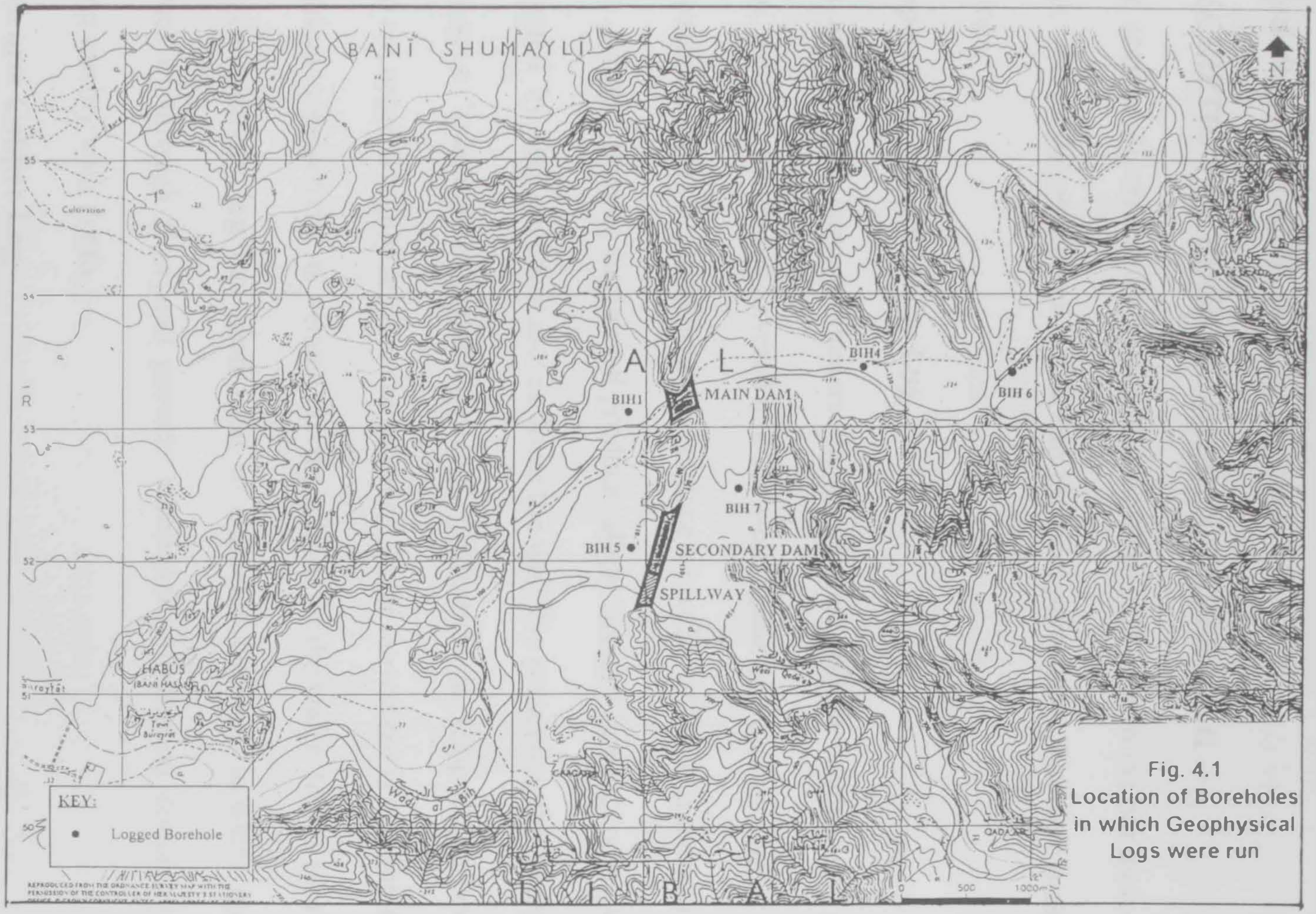

Fig. 4.1
Location of Boreholes in which Geophysical Logs were run

The logging was carried out in September and October 1996. An individual interpretation of the recorded logs in each borehole is given below and this is followed by a technical description of the geophysical logs.

4.3 DESCRIPTION OF LOGGING USED IN WADI AL BIH

This section describes the different logs that were run in the boreholes, and briefly with a brief description of the various physical parameters that were measured with these logs.

4.3.a Temperature / Conductivity Log

This tool records two parameters: the temperature and the conductivity of the fluid in the well. As the tool is lowered into the well, readings are continuously taken and then averaged over 5 cm intervals to produce a profile of fluid temperature and conductivity. Water flowing into a well produces slight changes in temperature which can be detected by the tool as it moves down the well. By presenting the changes in temperature as a "temperature differential log" (difference in temperature between samples 100 cm apart, a highly sensitive measure of water movement is generated.

Electrical conductivity is related to the salinity of the water. In this particular project the conductivity log has been used to delineate changes in water quality, identify zones of through flow and provide additional information concerning the varying water quality with depth.

4.3.b Three arm Caliper Log

The 3 arm caliper measures the internal diameter of the borehole. It is used to identify fissures and fractures in the rock formation and also to identify less competent rock formations which tend to 'wash out' during drilling.

Diameter variations measured are used for applying corrections for other logs. An additional use of the 3 arm caliper is for the precise measurement of the borehole volume, which is used for estimating the quantities required for cement or gravel pack. The caliper standard is a means for determining the stability of the well prior to running the radioactive logs (density and neutron).

4.3.c Natural Gamma Log

This log is a measure of the naturally occurring radioactive elements such as potassium, thorium and uranium. These elements are most commonly found in clay minerals and hence the natural gamma log is used as an indicator of clay content of the rock formation.

4.3.d Formation Density Log

This log measures the bulk density (RHOB) of the formation. The log can be used to identify changes in formation type, to detect features, and after processing to measure total porosity (the porosity being inversely proportional to density). This is displayed as the (DPHI) log.

4.3.e Full Waveform Sonic Log

By passing an acoustic (sound) wave through the rock formation, it is possible to measure the competence (hardness), porosity and degree of fracturing of the rock. The sonic tool passes an acoustic wave from a transmitter through the rock to a receiver on the tool. As sound travels faster through a hard material than through relatively softer material, the log can differentiate between hard and soft formations. Harder (more competent) formations give shorter sonic transit times (TT values). More porous rock formations may often show longer TT values.

4.3.f Neutron porosity Log

The neutron log is essentially a measure of the hydrogen in the rock formation and since hydrogen is an element of water (H_2O) the neutron log is thus a measure of water content of the formation. Assuming that below groundwater level the pore spaces within the rock formation are fully saturated with water, the neutron log can effectively measure total porosity (NPHI).

4.3.g Deep Induction Log

The induction tool measures the electrical conductivity (the inverse of resistivity) of the formation. The tool emits a primary electromagnetic field which induces a secondary electromagnetic field within conductors in the formation. The secondary field is detected by a receiver coil. As most rock formations are highly resistive, the measured conductivity is primarily dependent upon the conductivity and quantity of the fluid within formation.

4.4 BOREHOLE GEOPHYSICS RESULTS

4.4a Borehole 1

Borehole 1(Fig. 4-2a & 4- 2b) was drilled to a depth of 152m, and 12.5 inch casing installed to 15m. The lithology of the well comprises an upper unit of gravel and boulders, and a lower unit of limestone below 79m. Water level at the time of logging was within the lower limestone unit at 85m.

From 0m - 79m the lithology log describes gravel (70%) and boulders (30%) mostly of limestone. Below the casing the caliper log shows the borehole to have a diameter of 13 inches. The caliper log also shows the borehole wall to be uneven

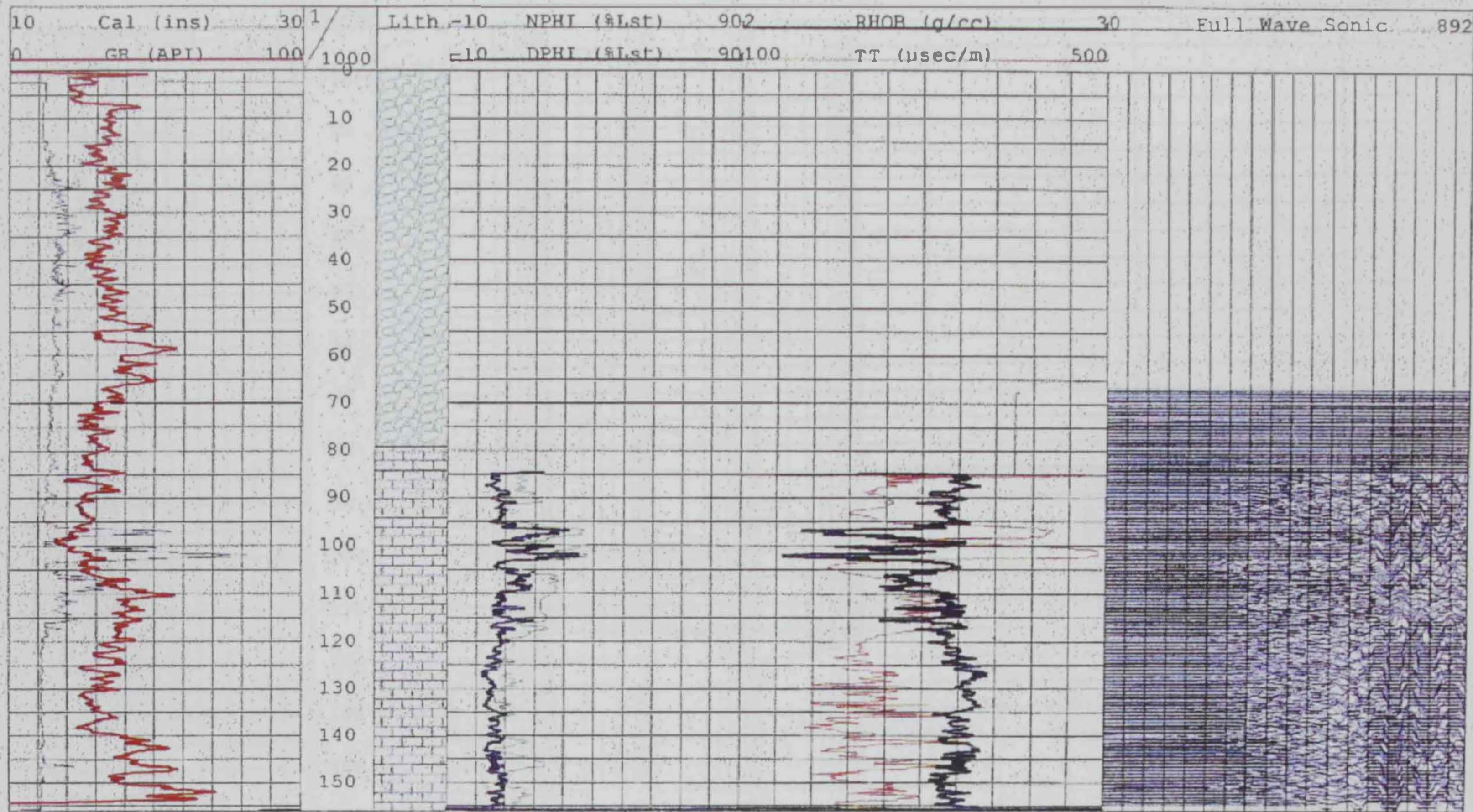

Fig.(4.2a) - A composite log of Borehole 1 of Wadi Al Bih

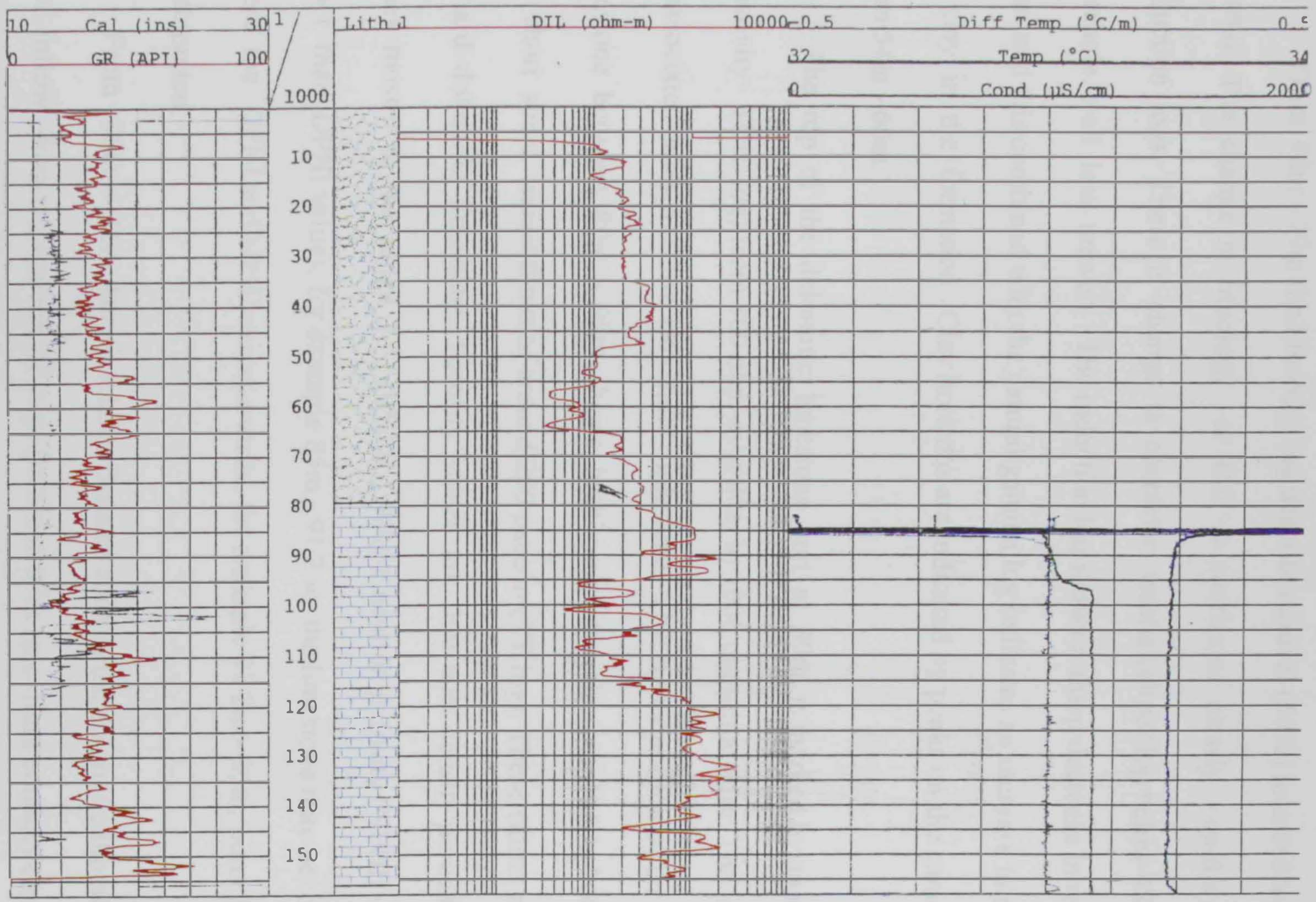

Fig.(4.2b) - A composite log of Borehole 1 of Wadi Al Bih

reflecting the gravel / boulder lithology. The induction log. (DIL) shows formation resistivities varying between 100 and 400 ohm-m.

From 48m - 79m the lithology log describes gravel (50%) interbedded with clay (50%). The change in lithology at 48m is confirmed clearly on the caliper and induction logs. There is change in character on the caliper log below 48m with the borehole wall less uneven. The induction log shows a sharp decrease in resistivity at 48m and this combined with the natural gamma log indicates an increase in the amount of clay in the formation. Clay horizons are indicated by peaks on the gamma ray log from 54m - 66m.

The top of the dolomitic limestone unit at 80m is marked by an increase in resistivity (DIL log) from 300 ohm-m at 80m to 1000 ohm-m at 85m. The latter value is associated with a dense dolomitic limestone. The upper portion of the dolomitic limestone between 80m - 90m shows high resistivity values of 1000 - 2000 0hm-m and short sonic transit times of around 250 μsec/m (TT log). These values are typical of hard dolomitic limestone. Porosity values are low with density porosity (DPHI) values mostly in the range 2 - 10%Lst. Where neutron porosity (NPHI) values are higher than DPHI values, for example 85m - 91.2 m. the limestone may be dolomitic. Where the DPHI and NPHI curves overlie, for example 91.2m - 95m, purer limestone is interpreted.

From 96m - 116m there is a large fissured zone in the dolomitic limestone with water inflow from the uppermost large fissure at 97m (see fluid conductivity log Fig. 4.2b). Water conductivity above this depth is between 1000 and 1200 μS/cm.

Over the fissured interval, 96m - 116m, the widening of the borehole diameter causes the formation logs to be influenced by 'borehole effects'. Apparent density is lower (RHOB) apparent porosity is higher (DPHI, NPHI), sonic transit times (TT) are slower and resistivity values are lower. When (DPHI) and (NPHI) limestone porosities are cross-plotted the derived porosities of the penetrated formations range between 8% and 20%. The dolomitic limestone is the type of lithology that can be indicated from such cross-plots.

From 116m - 138m the dolomitic limestone shows relatively uniform physical properties, with low porosity values between 2 - 8 % Lst, fast transit time values of round 250 μsec/m, and high resistivities in the range 800 - 3000 0hm-m. The caliper log shows the borehole to have a regular diameter of 12,25 inches and the natural gamma log has a fairly even response in the range 20 - 40 API

Below 140m the nature of the dolomitic limestone changes slightly. There is an increased natural gamma signature suggesting increased clay or marl within the dolomitic limestone and the formation resistivity is much lower at depth for example 200 ohm-m at 145m.

The main feature of this well is a large fissured zone in the limestone between 96 and 116m. There is water inflow from the uppermost large fissure at 97m. Water conductivity above this depth is between 1000 and 1200 μS/cm and below this depth the water conductivity is constant at 1200 μS/cm (Fig.4-3). The interval between 48m and 79m above the water table is cemented by clays which is responsible fo the high reduction of resistivities at that depth.

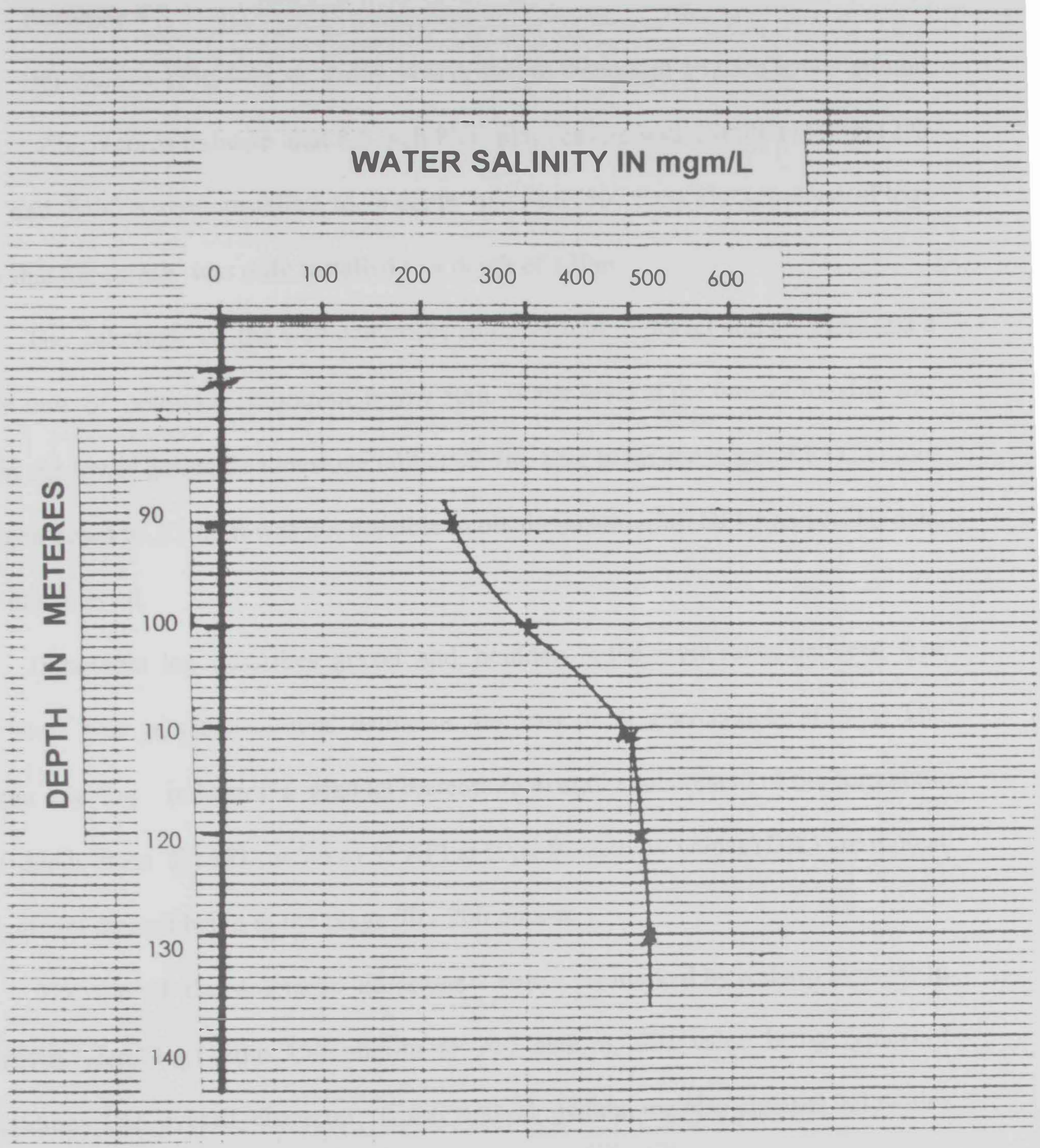

Fig. 4.3 - Vertical distribution of Water Salinity in Borehole (1) of Wadi Al Bih

4.4b Borehole 4

Borehole 4 (Fig.4-4a & 4-4b) was drilled to a depth of 152.5m below ground level. The records indicate that 8.5 inch PVC plain casing was installed to 83m (275 feet) and PVC screen installed to a depth of 152m (500 feet) The geophysical logs show that the screen was only installed to a depth of 130m.

The lithology of the well comprises an upper unit of gravel and boulders and a lower unit of dolomitic limestone below 50m. Water level at the time of logging was within the lower dolomitic limestone unit at 92.7m. Due to the presence of PVC casing / screen down to 130m it was not possible to obtain meaningful DPHI and NPHI data over this interval.

Lithologic log describes gravel and boulders in the depth range between 0 m and 54m. The geophysical logs delineate the base of the gravels to be at 54m. The gamma ray log indicates a gradual increase in overall clay content of the formation with depth from @)API at 5m to 55 API at 50m. Resistivity values (DIL) are typical for a gravel deposit being in the range 70 - 200 ohm-m.

The top of the dolomitic limestone unit is marked by a sharp increase in resistivity (DIL log) from 150 ohm-m to 700 ohm-m, this value being typical of limestome. The overall character of the natural gamma log also changes below this depth. The dolomitic limestone has a number of clay horizons, for example at 80m, 95m, 106m, and 130m-140m. These are identified by peaks on the natural gamma log.

Water level at the time of logging was 92.7m. There is water inflow within the screened section at 125m. This is indicated by a sharp change in gradient on the fluid temperature log at that depth. The sharpness of this feature indicates inflow from a

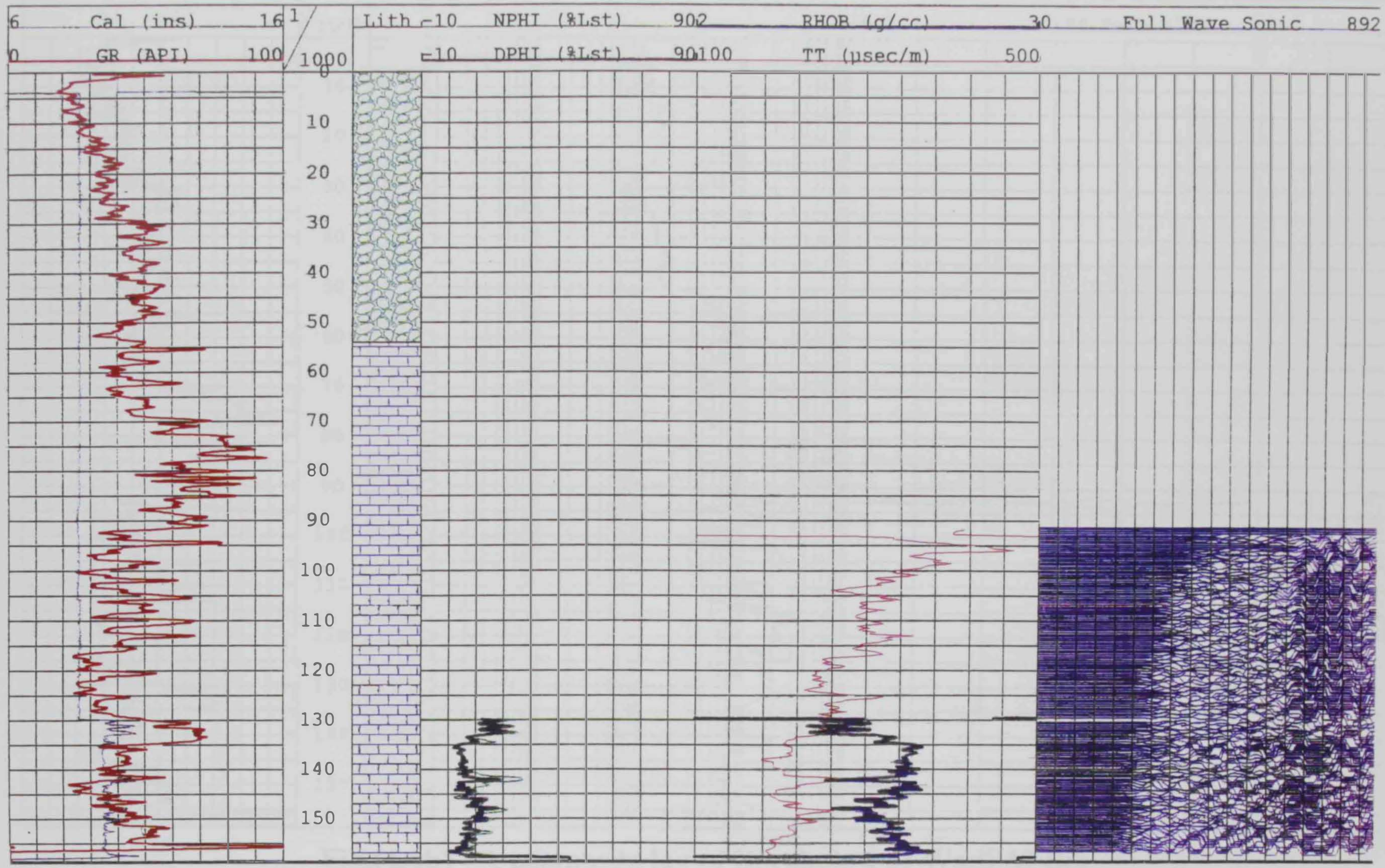

Fig.(4.4a) - A composite log of Borehole 4 of Wadi Al Bih

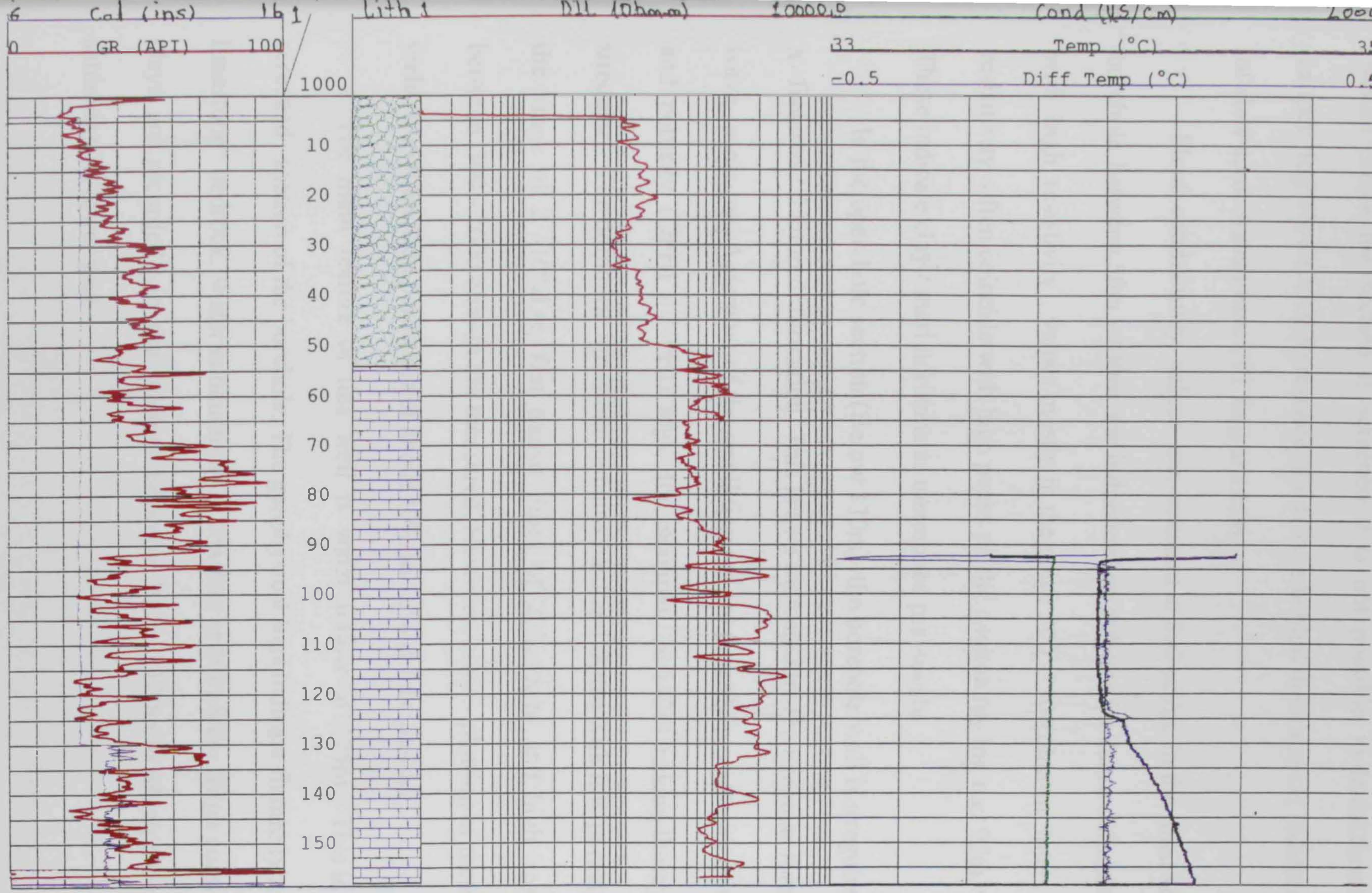

Fig.(4.4b) - A composite log of Borehole 4 of Wadi Al Bih

fissure. Since the section is screened it is not possible to detect fissures using the caliper log. However the presence of a fissure behind the screen is indicated by a peak of slow sonic transit time (TT log) at 125m.

Fluid conductivity values are constant at 800 μS/m. In the lined section of the borehole between 50m - 130m the induction log indicated a dense dolomitic limestone with high resistivity values mostly in the range 300 -2500 ohm-m. Intervals of lower resisitivity often coincide with high peaks on the gamma ray log e.g. 95m, 98m, 102m. These indicate clay / marl horizons as mentioned previously.

In the open hole section (Below 130m) the borehole wall is irregular indicating a fissured / fractured formation. This is also indicated by the irregular form of the full wave sonic log. A number of the small fissures are picked up on the density (RHOB) and porosity (DPHI / NPHI) logs, for example at 142m making these logs appear irregular. The dolomitic limestone remains hard and dense with low porosity values in the range of 2 -10%Lst, fast transit times of 200μsec/m and high resistivities of between 500 - 2000 ohm-m are measured. However, cross - plotting of these porosities yield true formation porosities of about 10% to 16% at this interval.

The main feature of this well is water inflow at 125m. This is within the screened section of the borehole. The geophysical logs indicate fissure type flow from limestone bedrock. Water conductivity is constant at 800μS/cm. High contributions of clays are recorded in the interval between 70 and 120m in which groundwatwers saturating its lower part

4.4c Borehole 5

Borehole 5 (Fig 4-5a & 4 -5b) was logged immediately after drilling was completed. the borehole was drilled to a depth of 150m and 12.5 inch casing installed to depth of 2 metres. The lithology of the well is composed of interbedded gravels of ophiolithic and limestone origin. The water level at the time of logging was 96.5 metres.

From 0m - 40m the lithology log describes ophiolite gravel. Below the casing the calipher log shows the borehole to have a diameter of 12 inches with many enlargements up to 17 inches in places. The induction log (DIL) shows formation resistivities varying between 30 and 50 ohm-m above 10m and between 50 and 90 ohm-m below 10m.

From 40m to 104m the lithology is wadi gravel composed of limestone and dolomite. Below this level there are fewer diameter enlargements suggesting a more cemented gravel. The resistivity varies between 40 and 80 ohm-m above the water level. Below the water level it decreases to 25 ohm-m.

Porosity values vary between 8 and 20% Lst. The neutron porosities (NPHI) are generally higher than the density porosities (DPHI). Sonic transit times range from 220 to 340μsec/m.

Below the limestone gravels are more ophiolitic gravels down to a depth of 137m. These gravels produce the most significant inflow at 124m. This is seen as a change in the temperature gradient (Fig.4-5 b).

The signature of the conductivity log also changes at this depth. There is a slight increase in formation resistivity at the top of this gravel unit. However, the

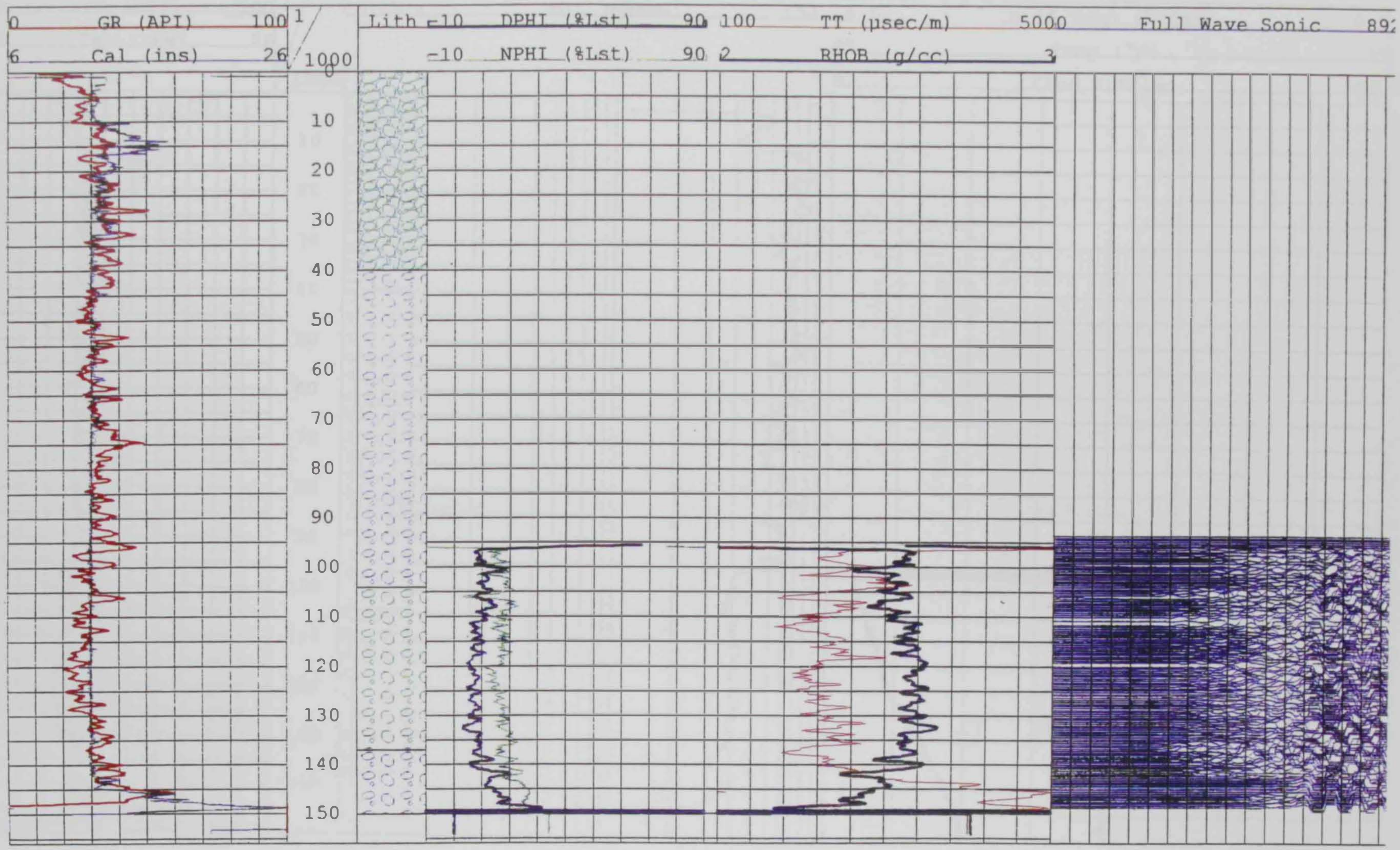

Fig.(4.5a) - A composite log of Borehole 5 of Wadi Al Bih

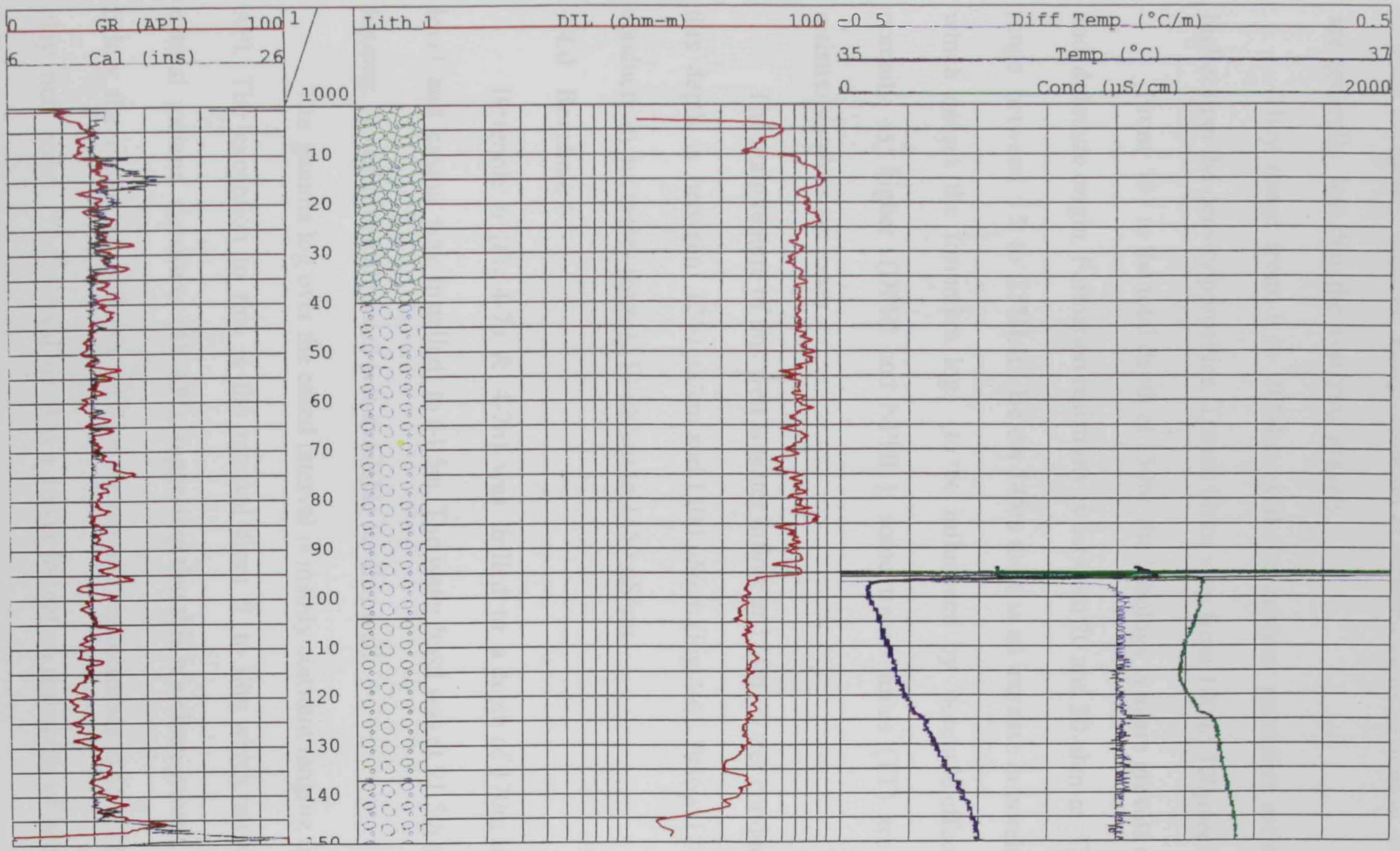

Fig.(4.5b) - A composite log of Borehole 5 of Wadi Al Bih

overall resistivity remains fairly constant at between 20 to 30 ohm-m. The porosities are generally less than the overlying gravels.

They range from 3 to 20%Lst. and the neutron porosities are again slightly higher than the density porosities. Transit times vary from 180 to 300μsec/m.

From 137 to the total depth at 150m the lithology is again gravels of limestone and dolomite origin. Formation resistivity is between 20 and 30 ohm-m. The porosities range between 5 to 25%Lst. Below 145m there is an increase in borehole diameter which causes the formation logs to be influenced by 'borehole effects'. Apparent porosity is higher (DPHI and NPHI), sonic transit times (TT) are slower and resistivity values are lower.

The main feature of this well is water inflow at 124m. Water conductivity above this depth is between 1240 μS/cm and 1300 μS/cm (Fig.4-6). Below 124m the water conductivity increases from 1350 μS/cm to 1450 μS/cm.

4.4.d Borehole 6

Borehole 6 (Fig.4-7a & 4-7b) was drilled to a depth of 170m below ground level and casing was installed to 64.5m. The water level was at 91.5m at the time of logging. No lithological record was available for this well.

The gamma log over the cased interval is mainly constant ranging from 30 to 40 API. The exception to this is the interval from 9 to 18m which has a much lower natural gamma signature (18 API), suggesting that this is a clean gravel. Immediately below the casing to a depth of 71m the gamma log increases to 55 API indicating a clay rich zone. The interval also has a lower formation resistivity of between 10 and 30 ohm-m. This agrees with the high gamma activity. From 71m down to 89m the

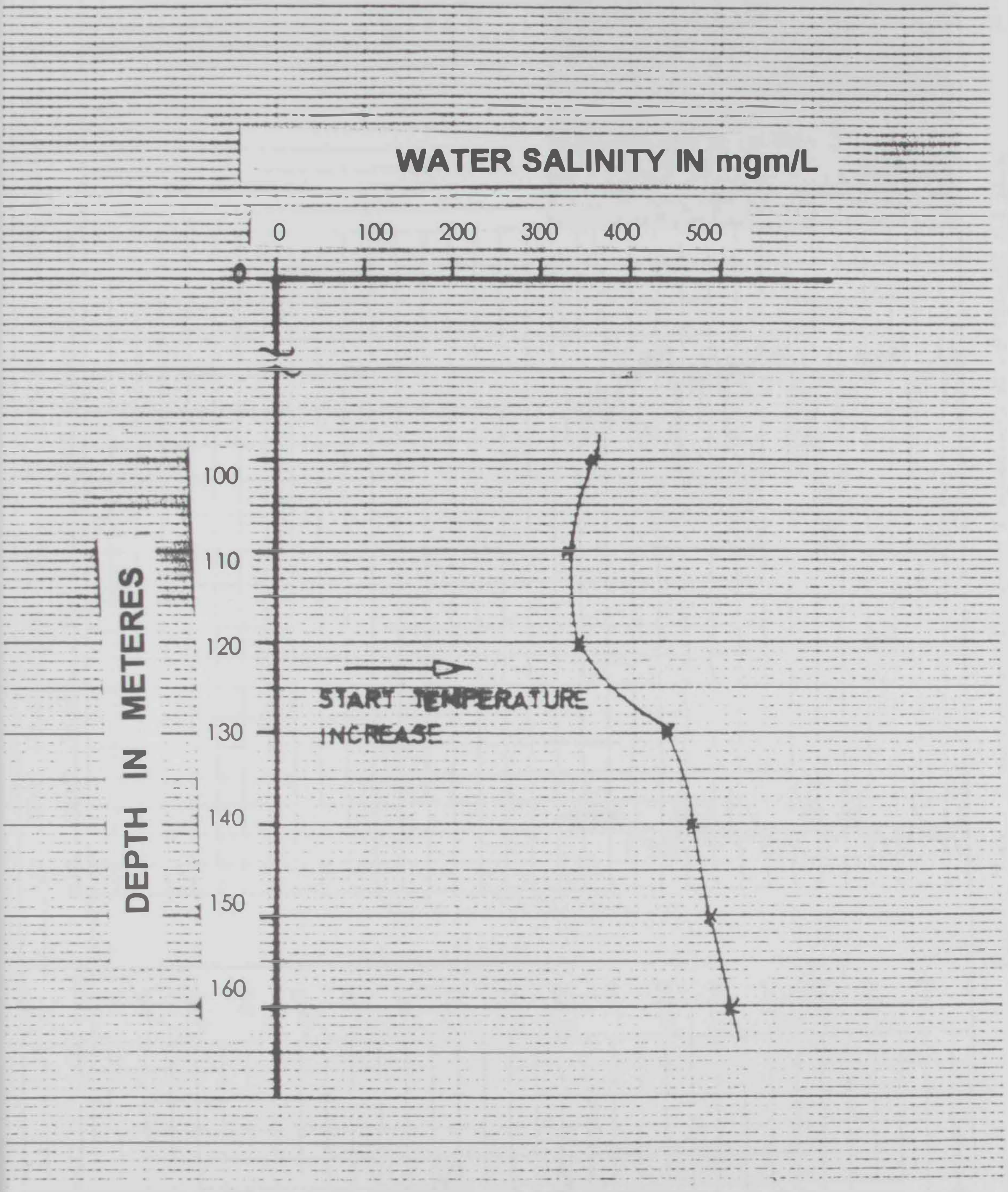

Fig. 4.6 - Vertical distribution of Water Salinity in Borehole (5) of Wadi Al Bih

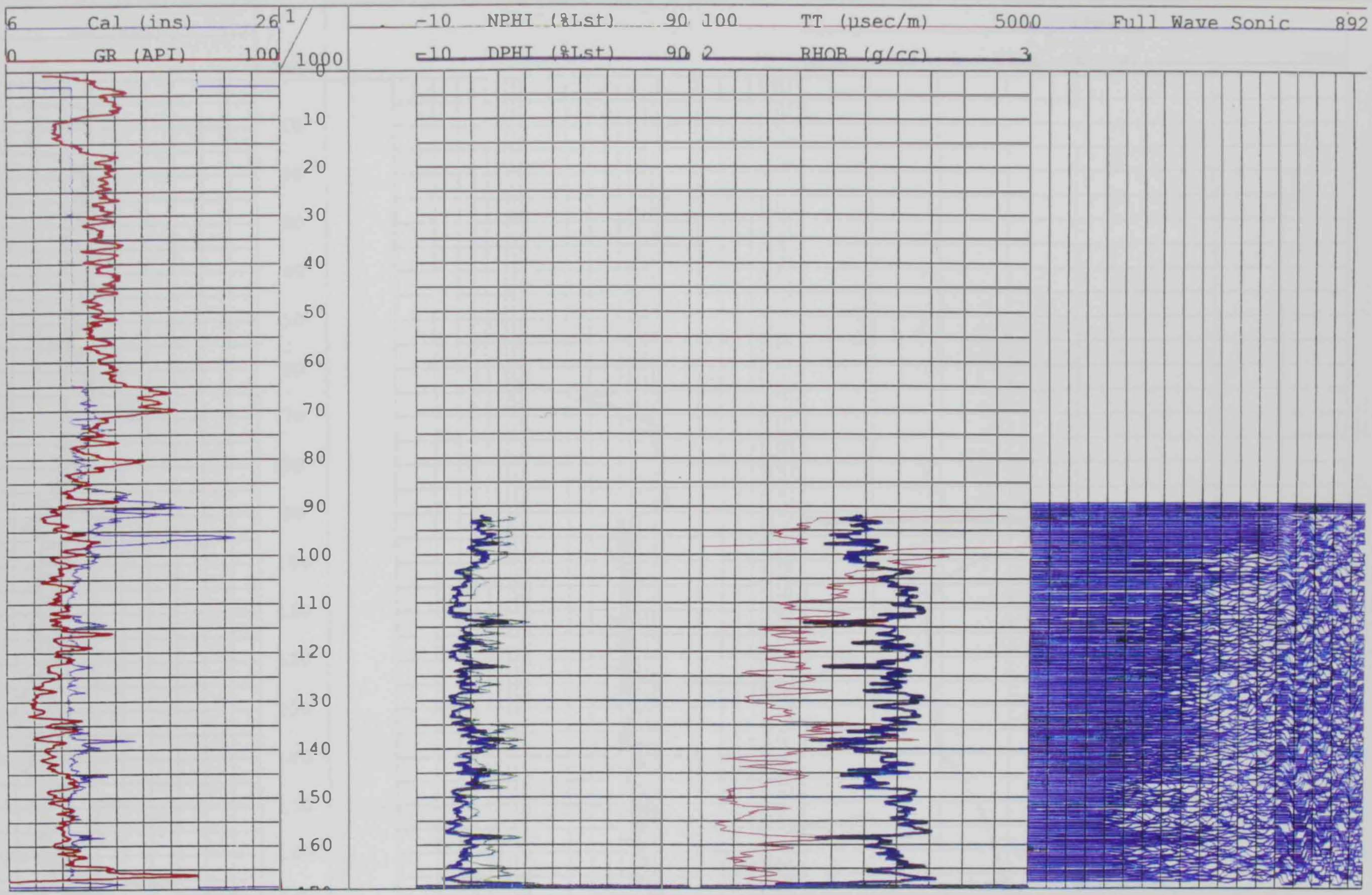

Fig.(4.7a) - A composite log of Borehole 6 of Wadi Al Bih

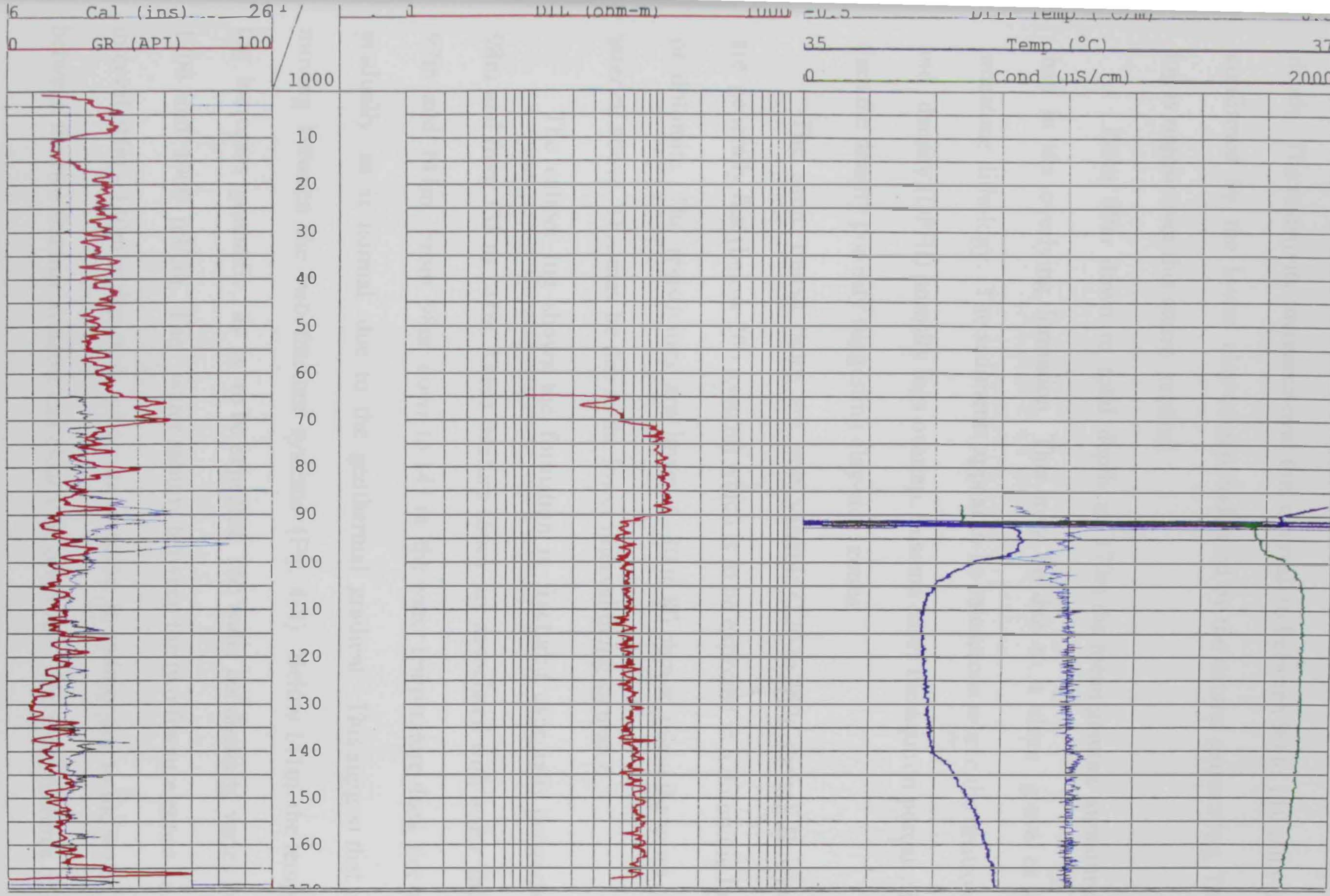

Fig.(4.7b) - A composite log of Borehole 6 of Wadi Al Bih

overall gamma signature gradually decreases implying a decrease in clay content with depth. The resistivity increases over this interval, to between 90 to 110 ohm-m. This is confirmed by the lower clay content indicated by the natural gamma log. The caliper log is rugose over this entire section.

From 89m down to total depth at 170m the mean gamma signature is lower than in the overlying formation. This may be due to a clean gravel or dolomitic limestone lithology. The sediments appear to be calcareous where the neutron (NPHI) and density (DPHI) porosity logs overlap. In some cases the neutron porosity is higher than the density porosity suggesting clay-rich zones.

The sonic transit times are very variable (120 to 380 μsec/m). However, they are generally fast (below 200 μsec/m) which is to be expected in a dolomitic limestone or dolomite. The resistivities are lower (30 to 80 ohm-m) than the more clay-rich interval above. This may be due to the lower interval being saturated.

The caliper log shows the formation is fractured, especially between 95 and 98m and from 138 to 141m. These fracture zones are associated with water inflows at 97m and 141m. From 98m down to 141 m the water temperature does not increase gradually, as is normal, due to the geothermal gradient. This suggest that water is moving between the two fracture systems (Fig. 4-8) Below 141m the temperature log increases gradually, as is to be expected. The water conductivity varies between 1700 and 1900 μS/cm. The water salinity between the two fracture zones i.e. in the interval 95m - 140m is depicted where an increase in salinity due to the water inflow between the two fracture systems can clearly be observed. The main features of this

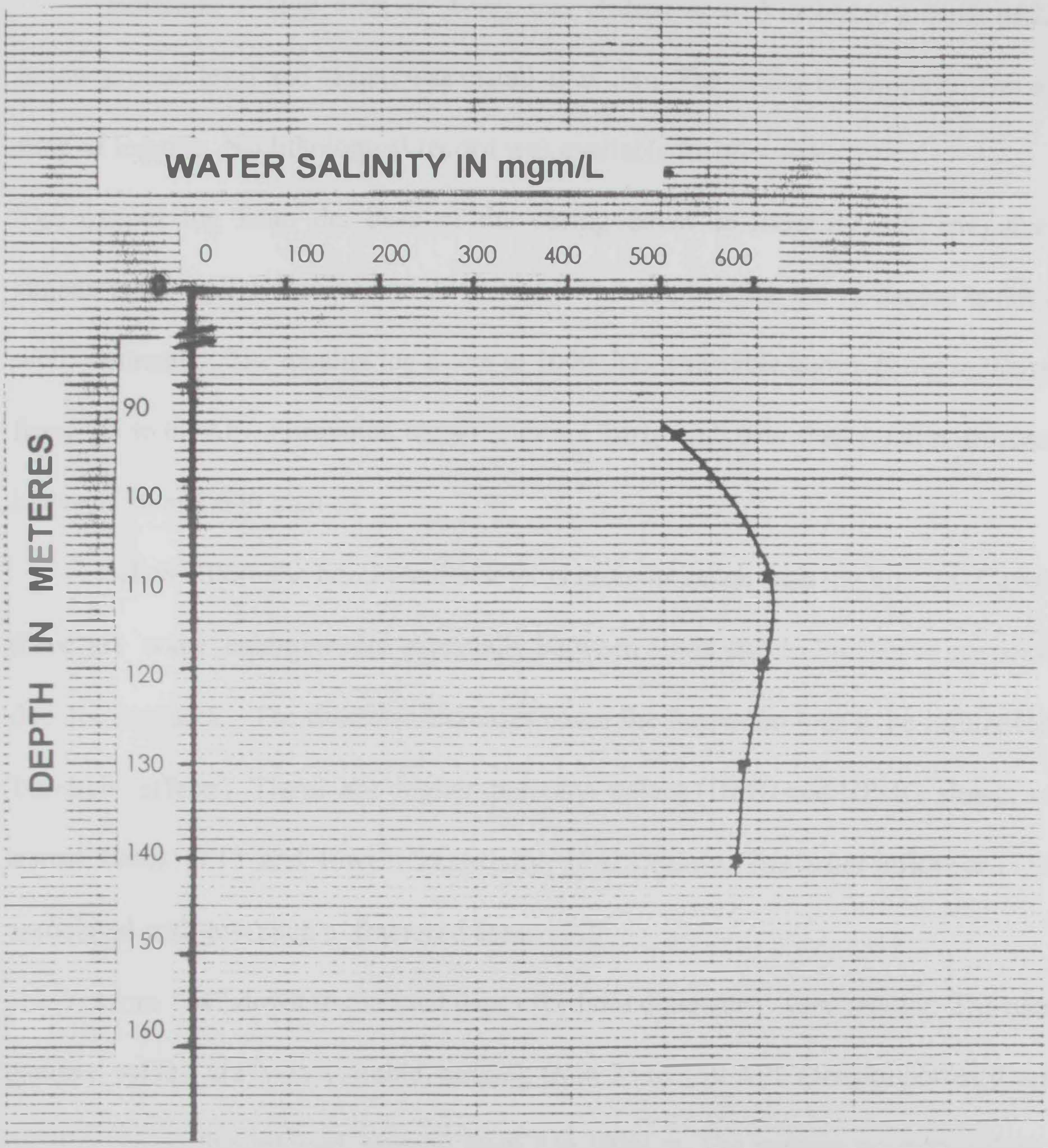

Fig. 4.8 - Vertical distribution of
Water Salinity in Borehole (6) of Wadi Al Bih

well are the water inflows from fractures at 95 m - 97m and 141m. The water conductivity decreases below the top fracture from 1900 μS/cm at 170m.

4.4.e Borehole 7

Borehole 7 (Fig 4-9a & 4-9b) was drilled at 10.5 inches to a depth of 238m below ground level and casing was installed to 19m. The water level was at 99m at the time of logging. No lithological record was available for this well.

The caliper log from the base of the casing down to 100m is highly irregular and rugose (varying between 11 and 22 inches). This implies that the formation is not very well cemented. The gamma log down to 100m has a variable nature being in the range from 25 to 60 API. Formation resistivities are fairly high over this section, fluctuating between 70 and 600 ohm-m.

Below 100m the borehole diameter is more in gauge with the bit size. However, there are some enlargements especially between 100m and 147m. These are possibly due to fractures. The diameter increases cause the formation logs to be influenced by 'borehole effects'. These are higher porosity values (DPHI and NPHI), slower sonic transit times (TT) and lower resistivity (DIL) values. The water inflow at 115m is associated with just such a fractured area.

From 147 down to the total depth the hole diameter is very regular. The natural gamma values are very variable, ranging from 25 to 150 API. Density porosity values are low over this interval, ranging from 2 to 10%Lst. The neutron porosity values are far more variable at between 10 and 50%Lst. The higher neutron porosities are between 160m and 218m. These coincide with `the high gamma values and indicate clay-rich zones. Transit times vary between 200 and 340 μsec/m.

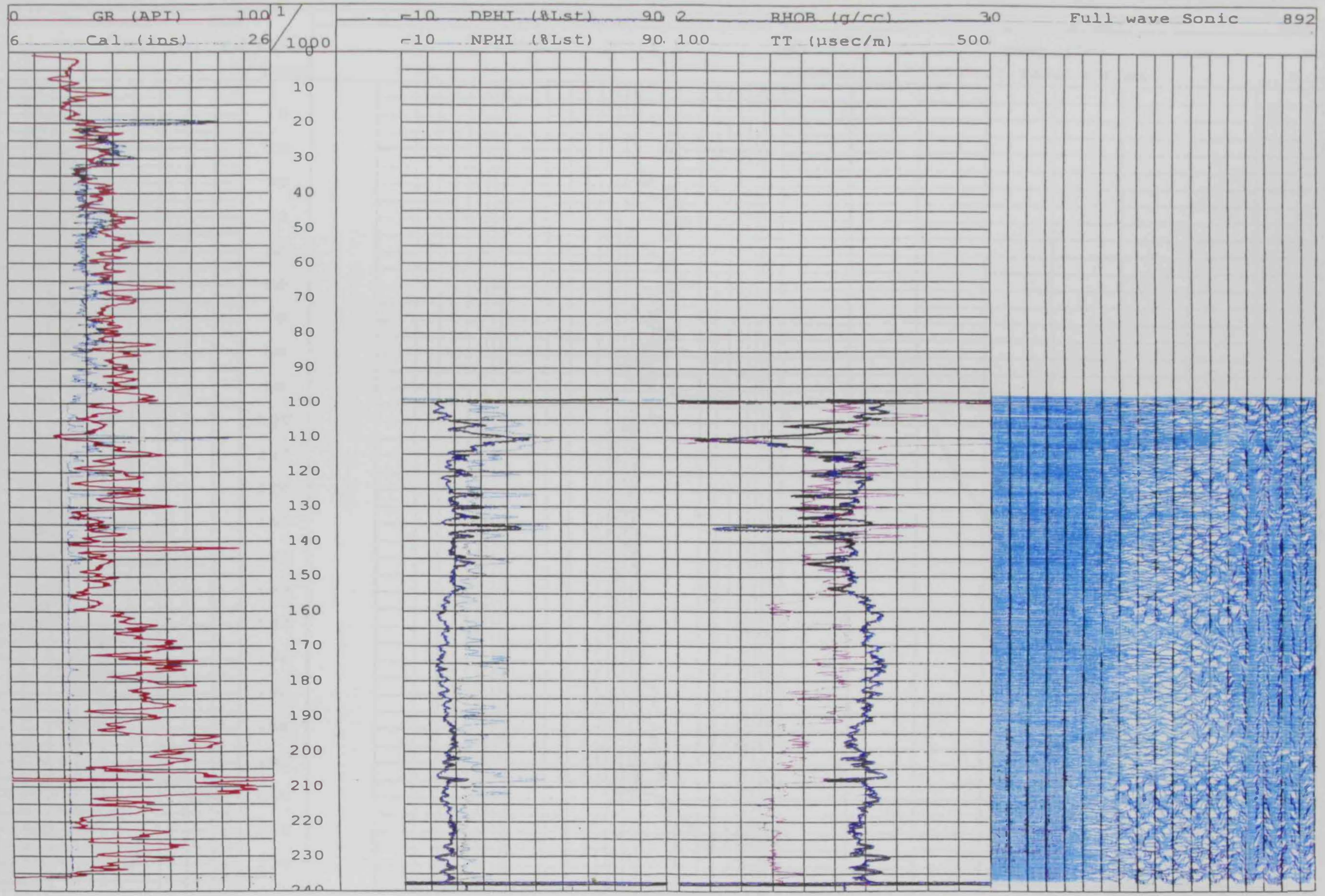

Fig.(4.9a) - A composite log of Borehole 7 of Wadi Al Bih

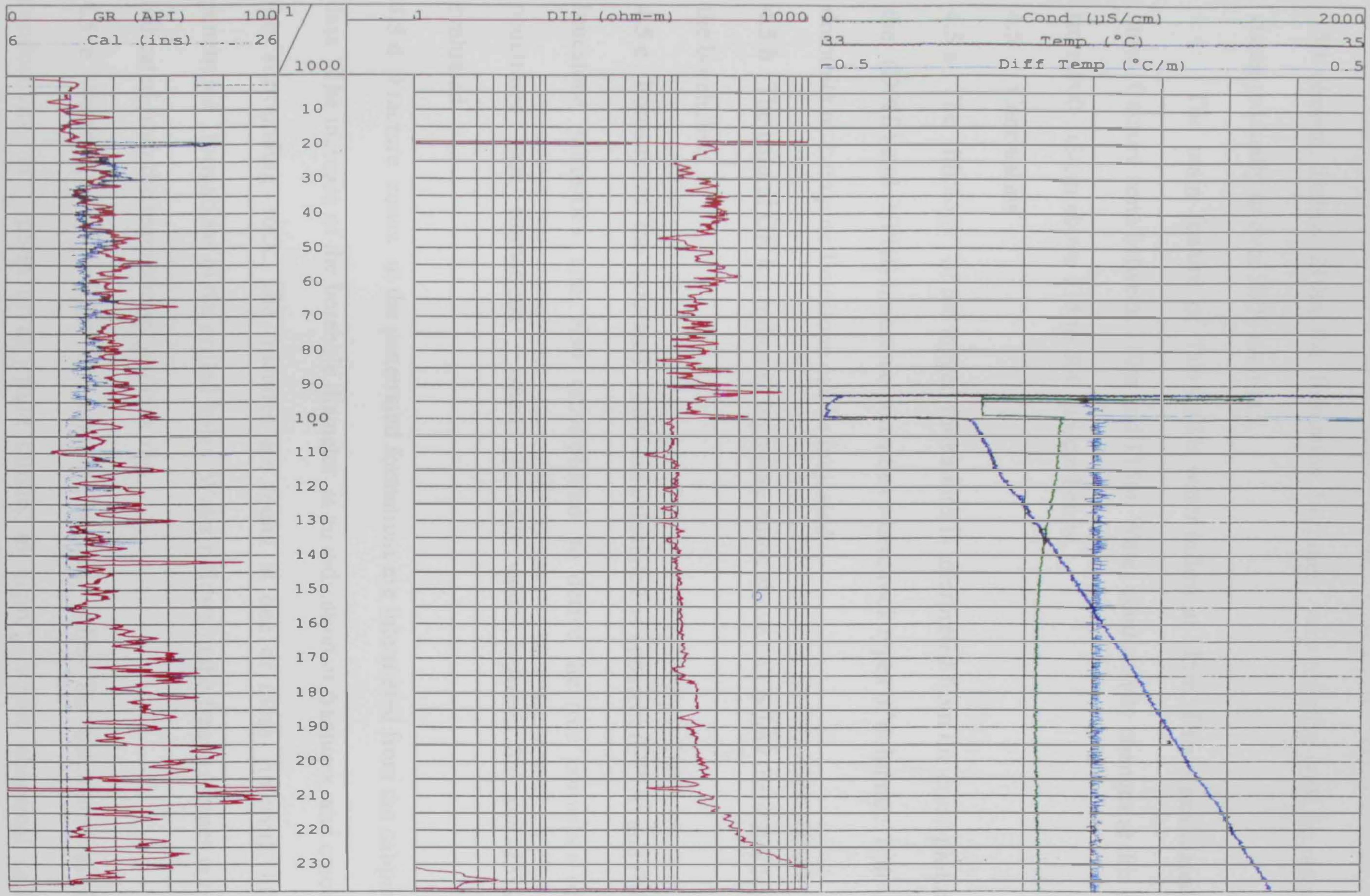

Fig.(4.9b) - A composite log of Borehole 7 of Wadi Al Bih

The rsistivities of the depth range between 147 to 210m vary between 50 and 150 ohm-m. Below 210m the formation becomes very resistive with the resistivity rising gradually to over 2000 ohm-m.

The main feature of this well is water inflow at 115m. This is associated with large fracture zone between 110m and 115m. Water conductivity changes at this depth from 900 μS/cm above 115 to 800 μS/cm below.

4.5 Conclusions

4.5 a The lithology of the logged formations is interpreted from the cross-plotting of the (DPHI) and (NPHI) limestone porosities where rock types of dolomitic limestone, dolomite or even pure limestone can be indicated.

4.5 b The natural GR log indicates high clay ratios above and below the water level in the boreholes.

4.5 c Porosity of the saturated zones are calculated as apparent (DPHI) and (NPHI) limestone porosities and also cross-plotted to derive the true porosities of the penetrated rock formations where porosity values between 8% and 25% are evaluated.

4.5 d Fracture zones in the penetrated formations are interpreted from the caliper log data. The increase of the borehole diameter is an indication of fractures and cracks of the surrounding rock. The fractures are found at one or more intervals of the penetrated formations in the drilled holes. Water inflows in the fracture zones are also indicated from the temperature gradient logs.

4.5 e Water quality in the different wells can either be calculated as fluid conductivity in μS/m or as fluid salinity in mgm/L, where abnormal salinity distribution in the wells can be interpreted as the result of water inflows through the fractures encountered in a particular well.

CHAPTER V

HYDRO-GEOCHEMISTRY

CHAPTER V

HYDROGEOCHEMISTRY

The objective of this chapter is to interpret the results of chemical analysis of the groundwater samples collected from Wadi Al Bih during September 1996 in terms of chemical characteristics, dissolved salts and suitability for different uses. It also intends to evaluate the changes in groundwater chemistry which may indicate recharge induced by wadi Wadi Al Bih dams.

Samples were analyzed for major ions in Al Oha Central Laboratories of the Ministry of Agriculture and Fisheries and for trace chemical constituents in the Desert and Marine Environment Research Center of the UAE University in Al Ain. The electrical conductivity (EC) in micro-Siemens per centimeter (μS/cm), pH and temperature (°C) were directly measured in the field.

5.1 Sampling

Table 5.1 and Figure 5.1 show the locations of groundwater samples collected for this study from Wadi Al Bih area in September 1996.

5.2 Field measurements

Temperature (°C) and pH were measured using portable pH-meter, model HI-8314. The EC in (μS/cm) was measured by Myron-L EP-meter, which has the following specifications :

Range	0 to 5,000 μS
Accuracy	± 2% of full scale
Repeatability	± 1%
Temperature Compensation	0.00 to 49 (°C)

Table 5.1 Groundwater samples collected from Wadi Al Bih area in September 1996

Sr. No	Code	Location	Time Taken
1	HAAH BH1	Farm borehole	09.45
2	AMH BH 1	Farm borehole	18.00
3	SF BH 1	Farm borehole	18.18
4	SAR BH 1	Farm borehole	09.30
5	MEW - BNOB4	Farm borehole	17.40
6	MEW- BNOB3	Farm borehole	09.00
7	SSF BH 1	Farm borehole	12.40
8	SSF BH 2	Farm borehole	11.10
9	SSF BH 3	Farm borehole	12.20
10	HAAH BH2	Farm borehole	11.50
11	RMH BH1	Dug well	15.00
12	SAH BH 1	MEW boreholes	17.20
13	MEW BH 24	MEW boreholes	10.27
14	DW1	MEW boreholes	16.20
15	MEW 38	MEW boreholes	10.05
16	MEW 10	MEW boreholes	17.50
17	MEW BH 1	MEW boreholes	17.18

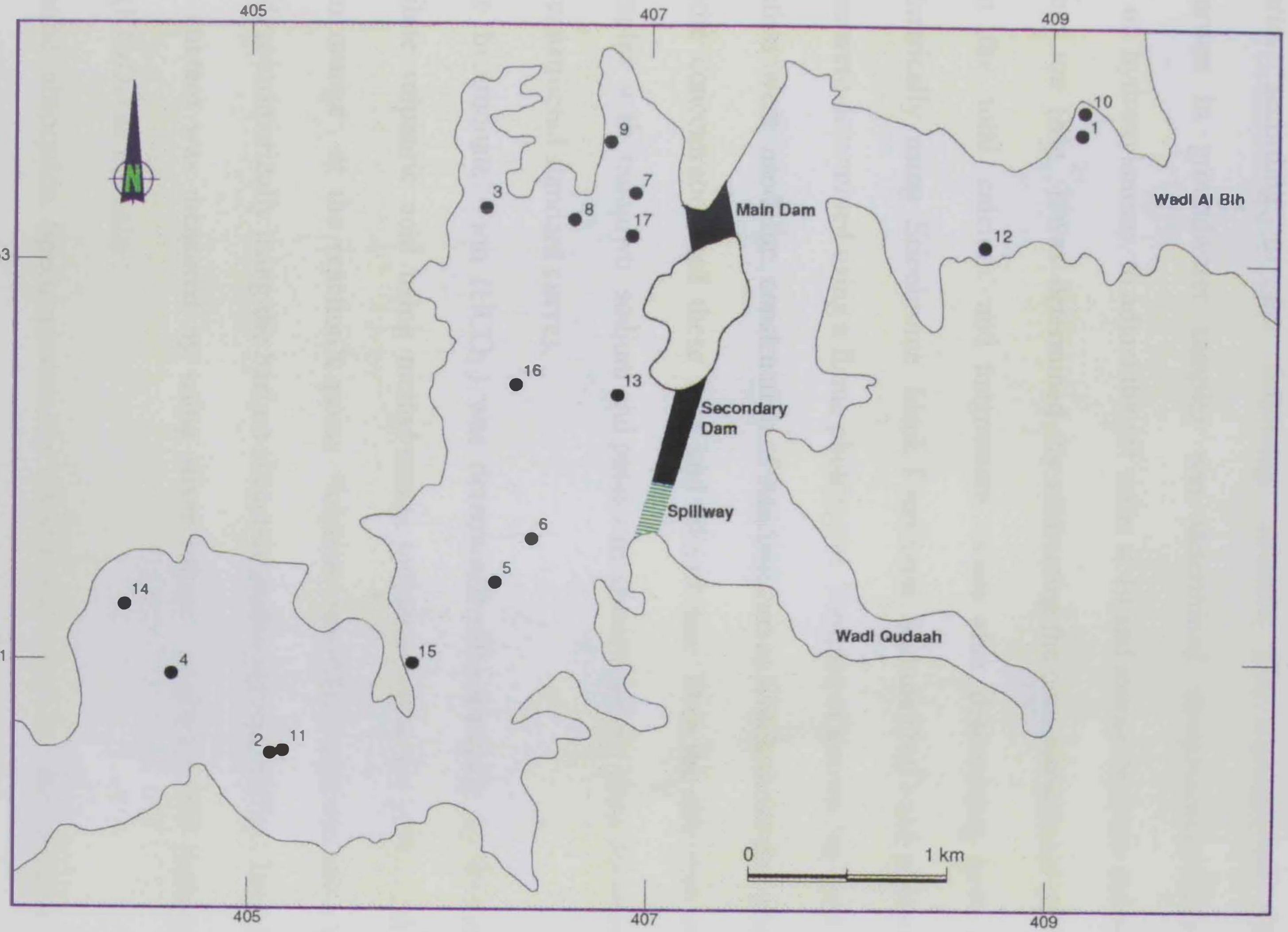

Figure 5.1 Location Map of Wadi Al Bih Basin Showing Water Wells Used in this Study.

GD-4472

5.3. LABORATORY ANALYSES

The chemical analysis of water samples for major ion cations : Ca^{2+}, Mg^{2+} Na^{+} and K^{+} and anions : CO_3^{2-}, HCO_3^{-}, $SO4^{2-}$ and Cl^{-} , were analyzed in Al Oha Laboratories according to the following scheme: The Calcium-ion (Ca^{2+}) concentrartion in groundwater samples was determined complexometrically by addition of hydroxylamine to adjust the pH value at 10 and murexide as an indicator. Magnesium ion (Mg^{2+}) was determined by subtracting the concentration of calcium ion from the total calcium and magnesium values after determining both ions complexmetrically using Eriochrome black T indicator. Sodium (Na^{+}) and potassium (K^{+}) ions were determined using a flame photometer. Samples of known Na^{+} and K^{+} concentration were used for construction of standard curves which show the relation between the concentrations of these ions and absorbence. Then the absorbences of water samples with unknown sodium and potassium concentrations were determined using the constructed standard curves.

The bicarbonate - ion (HCO_3^{-}) was determined volumetrically by tritration against dilute sulphuric acid using methyl orange indicator, where the yellow colour changes to orange at the reaction's point. Sulphate -ion (SO_4^{2-}) concentration was determined colorimerically using the barium chromate method (FAO, 1970) Chloride - ion (Cl^{-}) content was measured by using silver nitrate ($AgNO_3$) and potassium chromate ($KCrO_4$) as indicator.

Atomic absorption Spectrophotometry (AAS) was used for the analysis of several trace metals (Fe, Sr, Cr, Zn, Pb, Ni, Cu, Co, Cd, and Mn). For determination of total metals in water, the water sample is acidified with nitric acid (8ml/l) and boiled for 4-5 minutes and then filtered, if necessary. Simultaneously a blank, preferably in duplicate with deionized water having the same amount of nitric acid, should be run in identical conditions. This blank to some extent takes care of the errors due to reagents and / or environment. The contamination of iron, chromium, copper, nickel and zinc from different equipments of the laboratory is very common. The samples are then spirated to double beam Atomic Absorption Spectrometer (GBC- 906) equipped with autosampler and and direct background corrector.

5.4 RESULTS AND DISCUSSION

The results of chemical analysis are given in Appendix A (Tables A1 and A2). Tables from A3 to A5 show the results and calculated indices such as hydrochemical ratios, hypothetically dissolved salts and sodium absorption ratio (SAR).

5.4.1 Field Measured Parameters

Because their values change with time, the temperature (°C), hydrogen-ion concentration (pH) and electrical conductivity (μS/cm) of collected water samples were directly measured in the field. The depth to groundwater measured at seven boreholes along with, topographical elevation were used for construction of a hydraulic head map of Wadi Al Bih limestone aquifer in September 1996 (Fig. 5.2). The following is a brief discussion on field measured parameters :

5.4.1.1 Temperature

The temperature of the collected groundwater samples varied between 32.3°C in Well No.12 on the upstream of Wadi Al Bih main dam and 37.4°C in Well No.16 within the Ministry of Electricity and Water well-field in the downstream of Wadi Al Bih dams. The iso-temperature contour map shows a gradual increase in groundwater

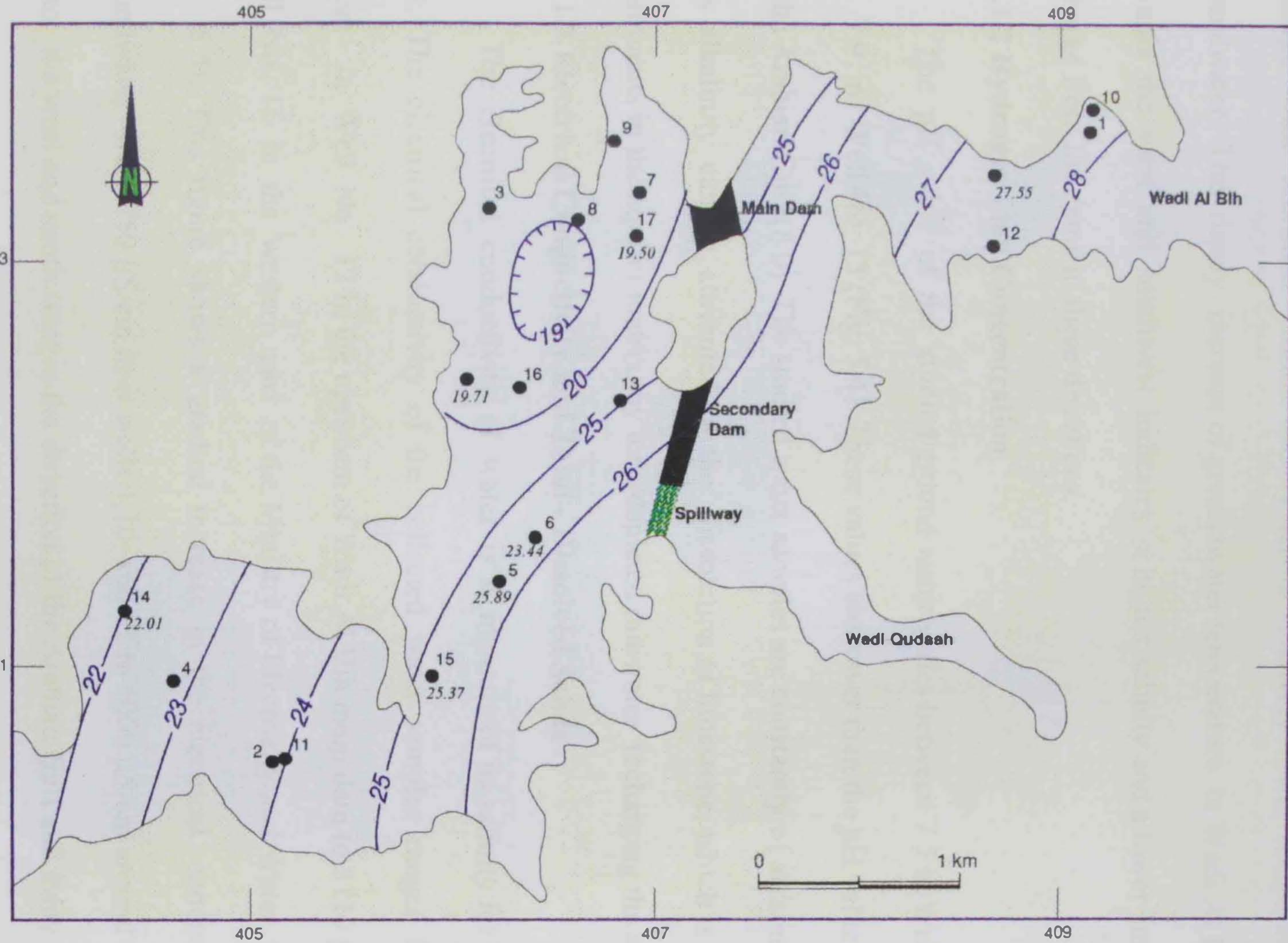

Figure 5.2 Hydraulic Head Contour Map in Meters Relative to Sea Level, September 1996

GD4472a

temperature from east to west in the direction of the Arabian Gulf (Fig. 5.3). The low groundwater temperatures close to the main dams may be related to groundwater recharge with rainwater which usually has a relatively lower temperature than groundwater. The steady increase of groundwater temperature in Wadi Al Bih basin towards the west and southwest indicates a higher salinity and a lower amoount of recharge from the dams in these directions.

5.4.1.2 Hydrogen - ion Concentration

The pH value of the studied ground water varies between 7.5 in Well No. 16 and 7.9 in Well No. 13 (Fig. 5.4). These values are lower than the pH value of water in the Arabian Gulf (8.0). The studied water samples are constantly of alkaline nature. This alkalinity can be attributed to the dissolution of limestone, which is the main constituents in the aquifer matrix, by ions-depleted rainwater recharging the aquifer.

5.4.1.3 Electrical Conductivity and Total - Dissolved Solids

The electrical conductivity of water is a measure of its salinity for different uses. The electrical conductivity of the collected water samples ranges from 679 μS/cm in Well No. 12 in the upstream of Wadi Al Bih main dam to 5110 μS/cm in Well No. 16 in the western part of the Ministry of Electricity and Water wellfield (Fig. 5.5). This figure shows a gradual increase in the electrical conductivity of groundwater from 750 μS/cm near wells 1,10, and 12 to 5000 μS/cm around well No. 16 to the west and south west in the direction of the Arabian Gulf and away from the main dam. This reflects the limited groundwater recharge in these areas.

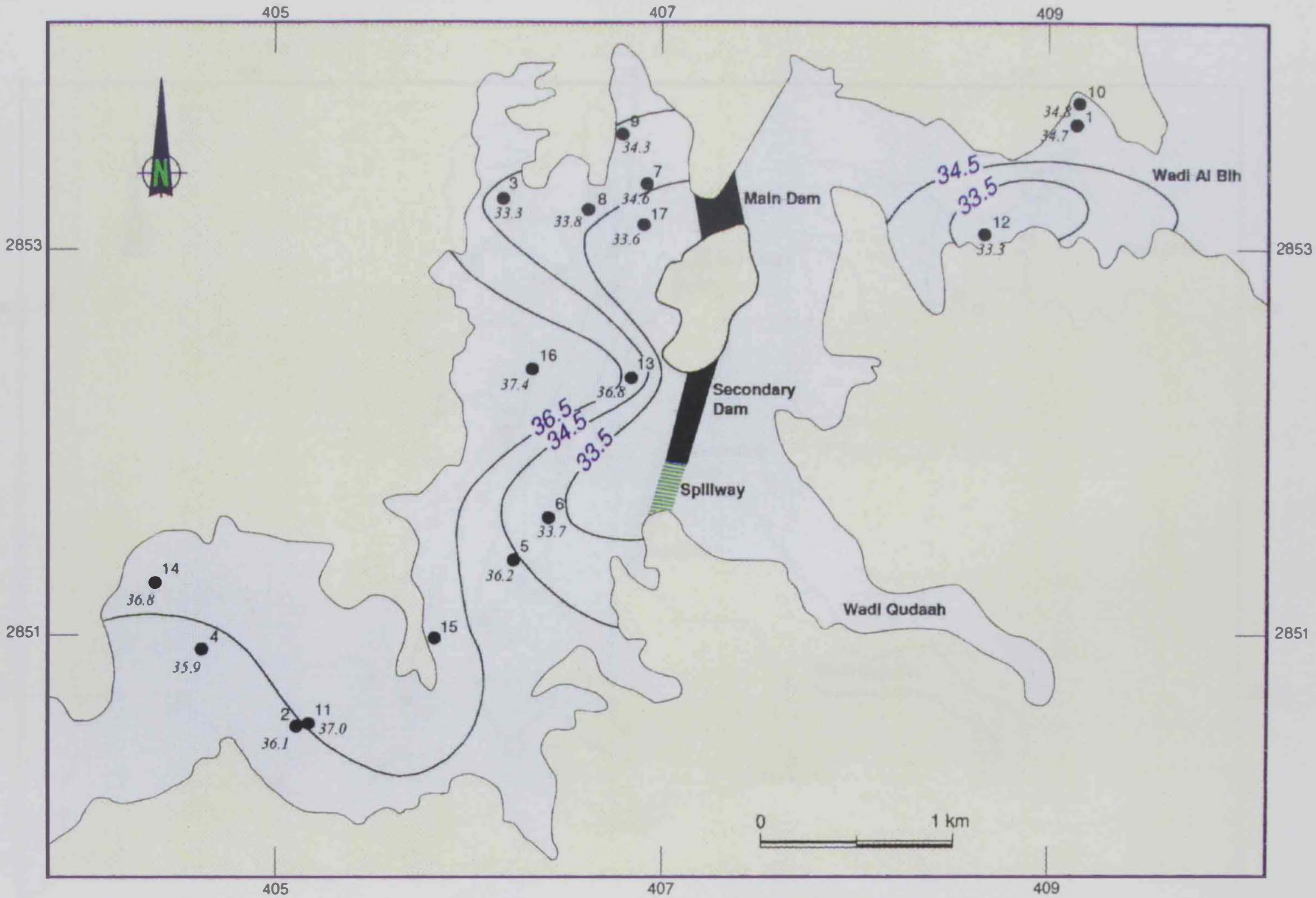

Figure 5.3 Iso-temperature Contour (˚C) Map of Ground Water in Wadi Al Bih Aquifer, September 1996.

GD4472c

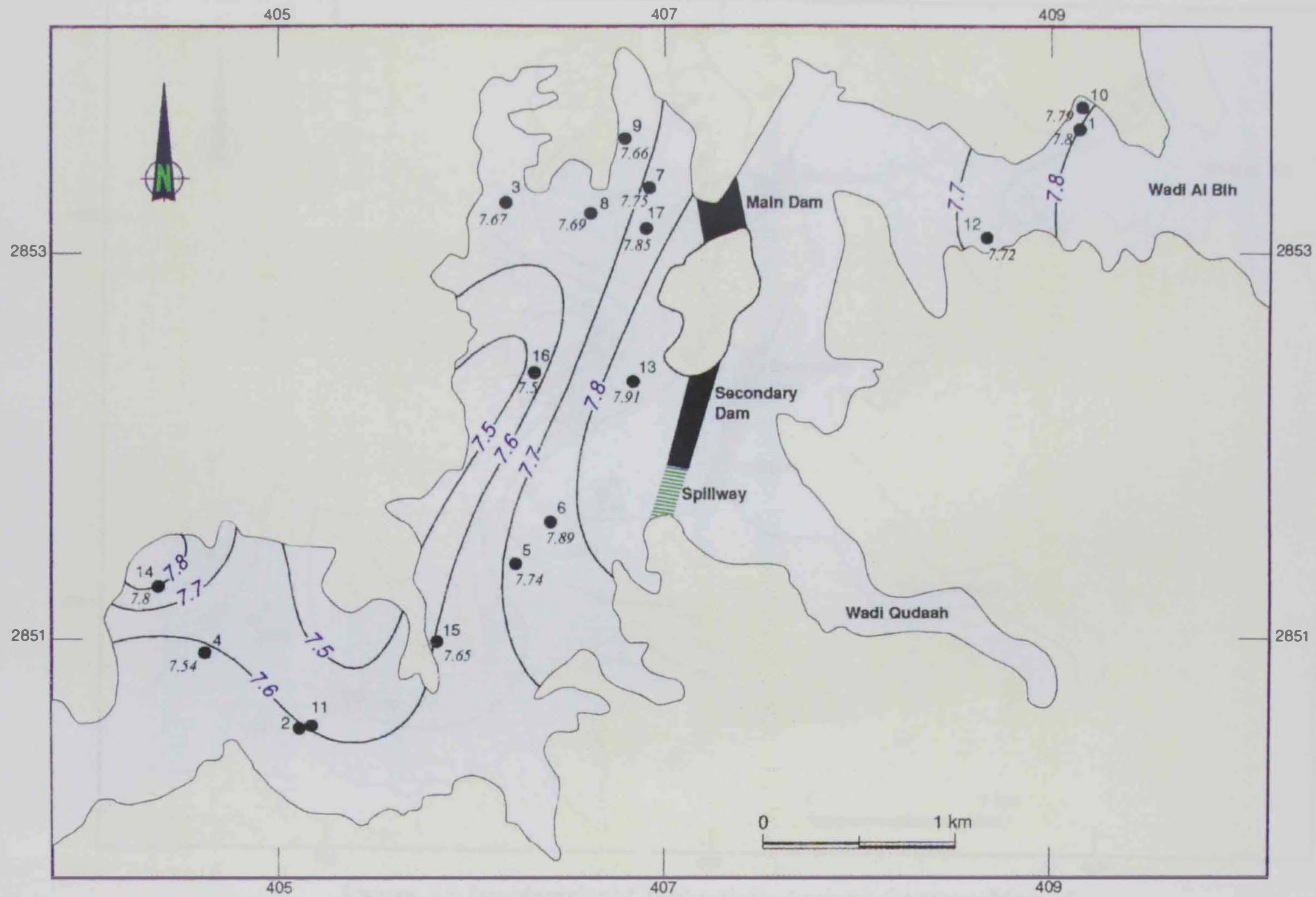

Figure 5.4 Iso-hydrogen Ion Concentration (PH) Contour Map of Ground Water in Wadi Al Bih Aquifer, September 1996.

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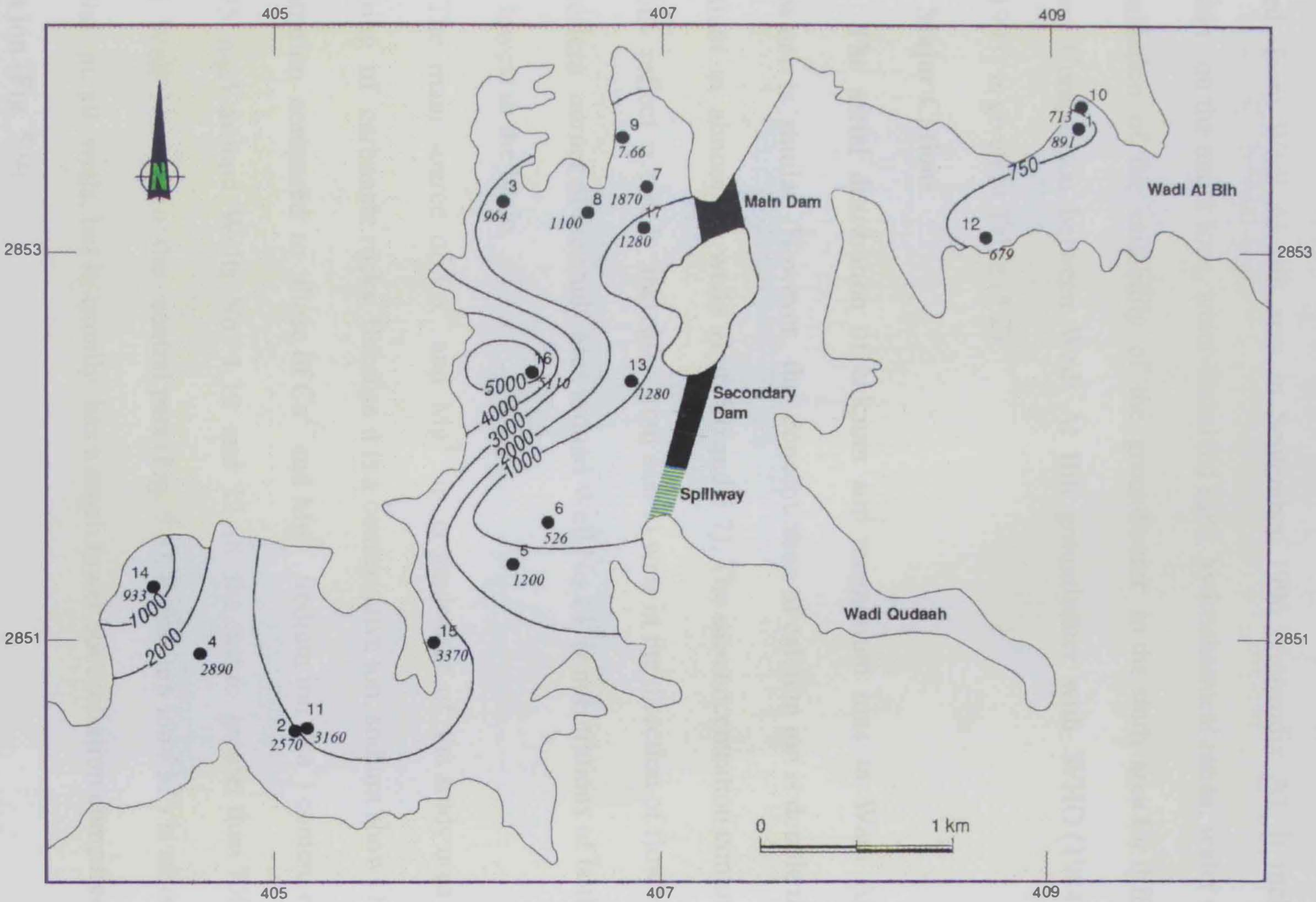

Figure 5.5 Iso-electrical Conductivity (μs/cm) Contour Map of Wadi Al Bih Aquifer, September 1996.

GD4472e

5.4.2. Lab measured parameters

The following discussion is based on the chemical analysis of water samples collected from Wadi Al Bih area in September 1996 (Appendix A). It includes discussion on the major ions, water-dissolved salts, hydrochemical ratios, water types and evaluation of the suitability of the groundwater in the study area for different purposes. Comparison between Wadi Al Bih groundwater with WHO (1984) and GCC (1993) is given in Table (5.2).

5.4.2.1 Major Cations

The aerial distribution of calcium and magnesium ions in Wadi Al Bih groundwater is similar. However, the concentration of calcium ion is double that of magnesium in almost all wells (Fig. 5.6 and 5.7). The iso-concentration contours of both ions reflect a steady increase from east to west in the direction of flow. In the southwestern corner of the study area around Well No.14, concentrations of both ions are the lowest in the basin.

The main source of Ca^{2+} and Mg^{2+} in groundwater of the study area is the weathering of carbonate rocks. Because it is a conservative ion, sodium shows higher concentration compared to those of Ca^{2+} and Mg^{2+}. Sodium ion (Na^+) content ranges from 75 mg/l around Wells No. 1,10 and 12 in the east to greater than 750 mg/l around Well No. 16 in the central part (Fig. 5.8). Potassium ion (K^+) is associated with Na^+ in all wells, but it usually has a much lower concentration compared with sodium ion (Fig. 5.9)

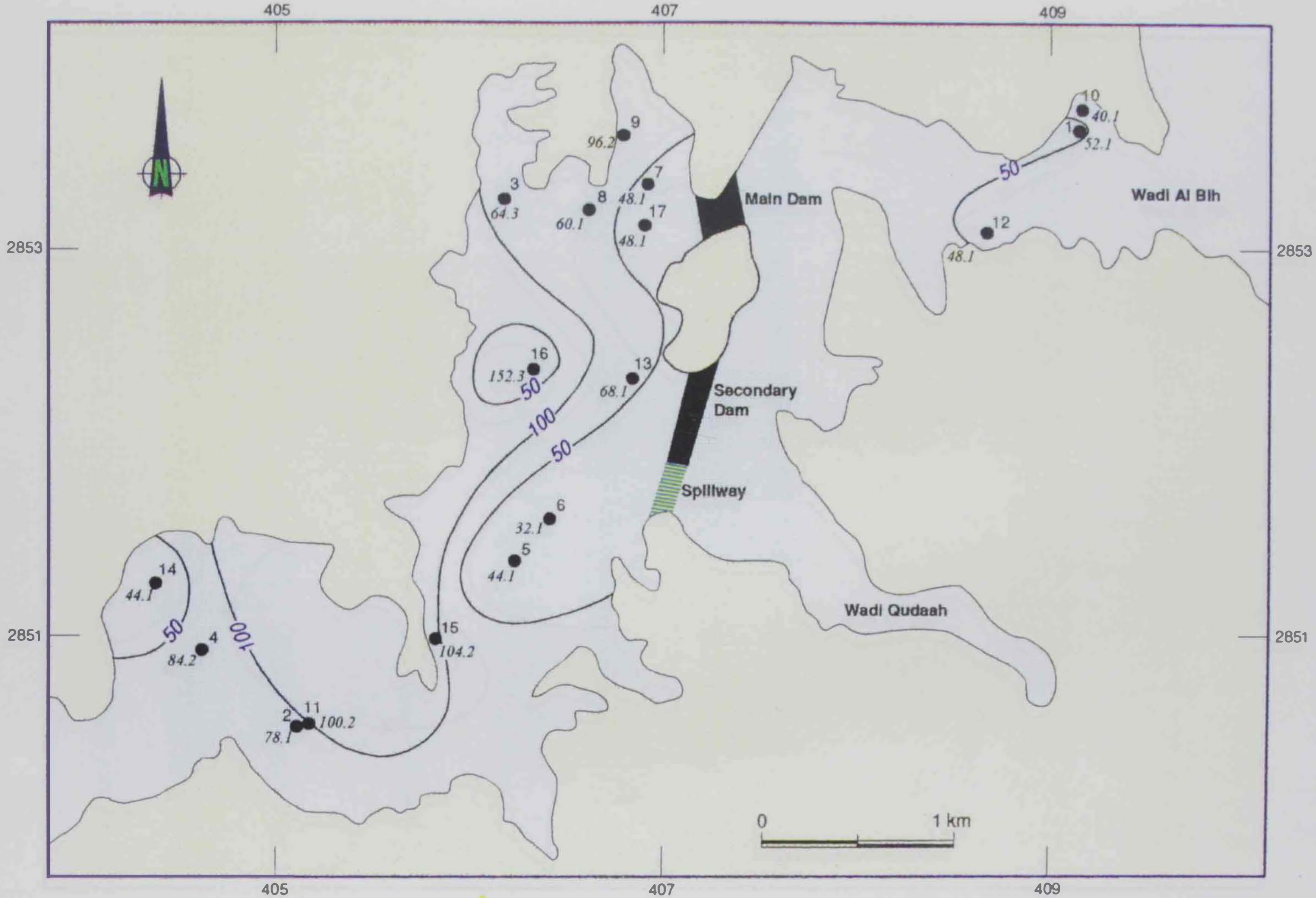

Figure 5.6 Iso-concentration Contour Map of Calcium Ion (mg/l) in Wadi Al Bih Ground Water, September 1996.

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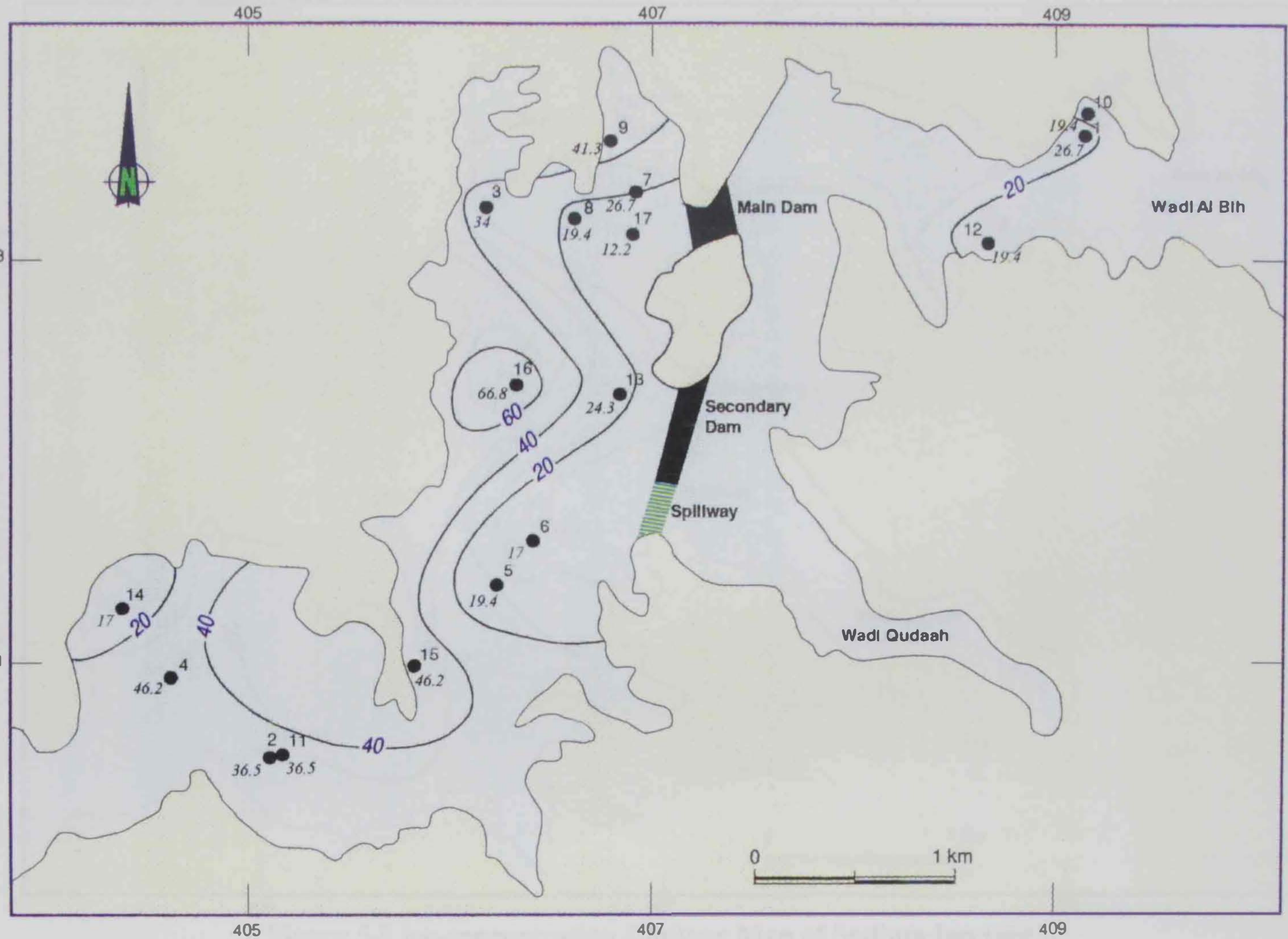

Figure 5.7 Iso-concentration Contour Map of Magnesium Ion (mg/l) in Wadi Al Bih Ground Water, September 1996.

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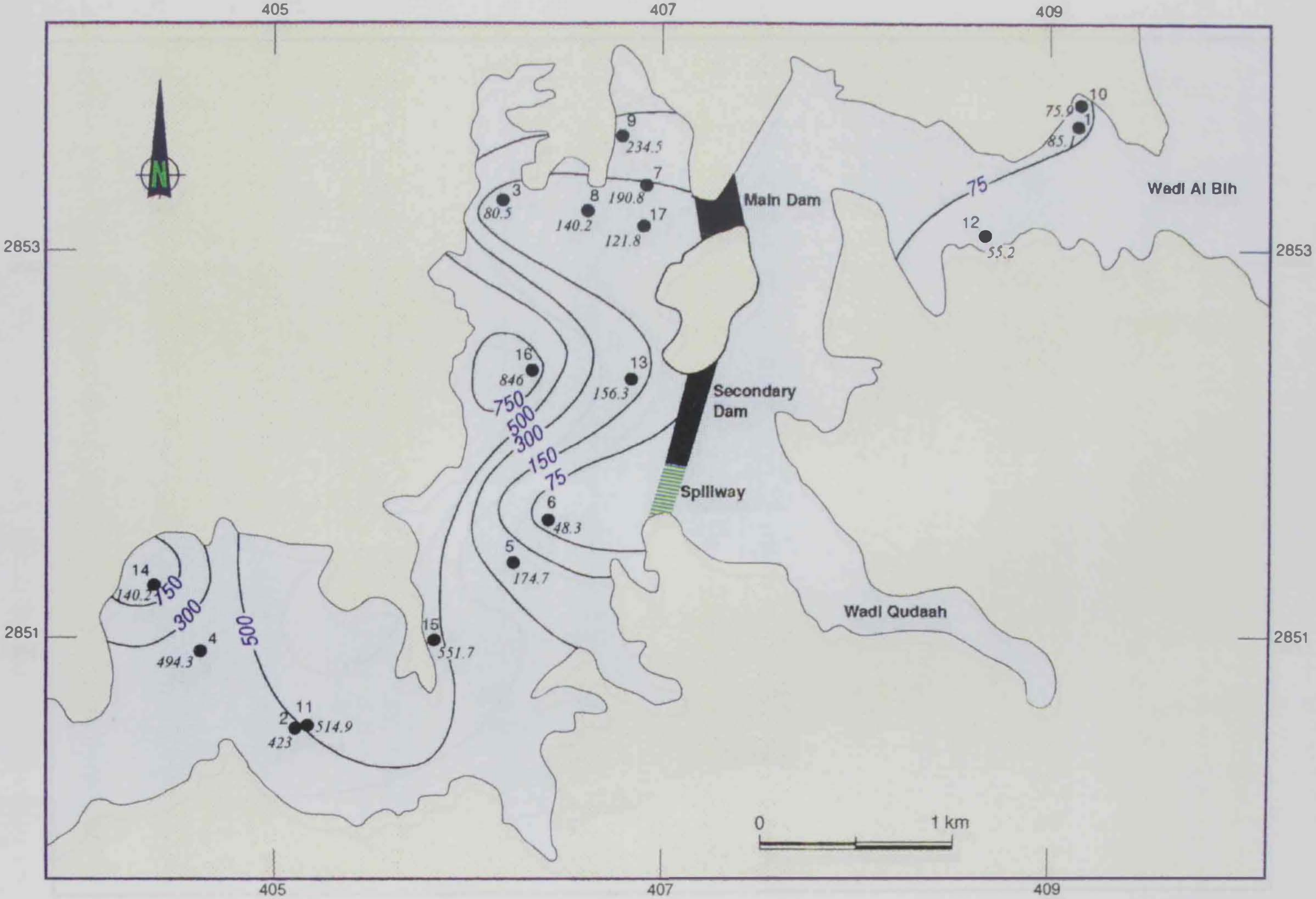

Figure 5.8 Iso-concentration Contour Map of Sodium Ion (mg/l) in Wadi Al Bih Ground Water, September 1996.

GD4472h

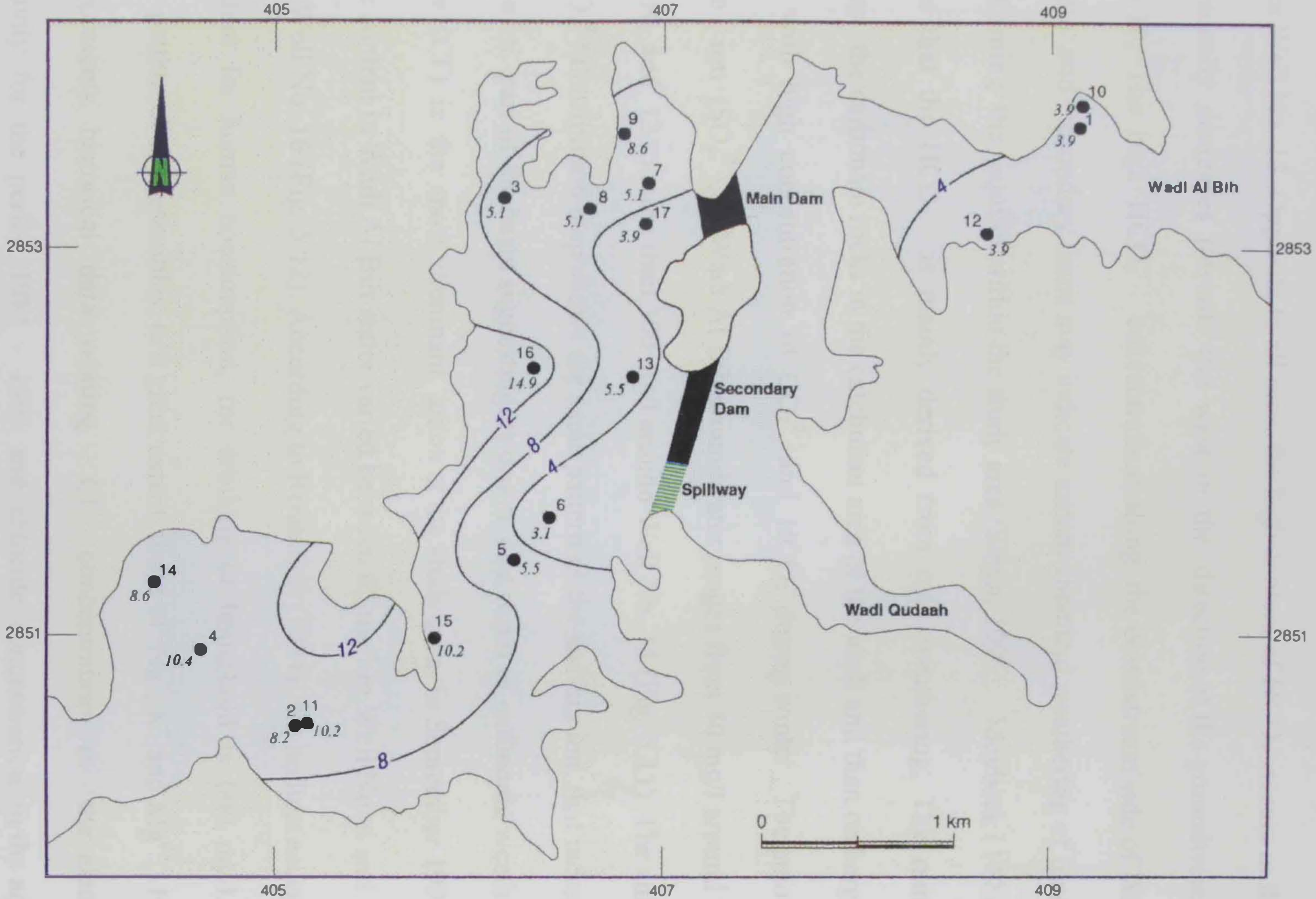

Figure 5.9 Iso-concentration Contour Map of Potassium Ion (mg/l) in Wadi Al Bih Ground Water, September 1996.

GD4472p

5.4.2.2 Major Anions

Bicarbonate-ion content (HCO_3^-) ranges from 61 mg/l in Well No. 14 to 256 mg/l in Well No. 13. Opposite to all ions, the high content of HCO_3^- occurs in the east and gradually decreases towards the west in the direction of the groundwater flow (Fig 5.10) The high HCO_3^- concentrations along the downstream side of Wadi Al Bih main and secondary dams may indicate instant chemical weathering of limestone rocks forming the aquifer within the study area (Singh, 1996). Meybeck (1979) also believes that the HCO_3^- is mainly derived from rock weathering. The rainwater dissolves the carbonate rocks in the catchment area of the wadi and then recharges the aquifer with high concentration of CO_3^{2-} and HCO_3^- during winter . The amount of sulphate ion (SO_4^{2-}) in Wadi Al Bih groundwater ranges from 50 mg/l around Wells No. 1, 10, and 12 to more than 300 mg/l around Well No. 14 (Fig. 5.11). The sulphate ion (SO_4^{2-}) distribution map shows the same pattern as the sodium ion, that increase in the western part of the basin suggesting its origin as a result of carbonate weathering. Chloride (Cl^-) is the most dominant anion at the study area. In September 1996, the chloride content in Wadi Al Bih water varied between 85 mg/l in Well No. 6 and 1,546 mg/l in Well No. 16 (Fig. 5.12). According to Rosenthal (1994), the highest acceptable Cl^- content for human consumption, for drinking or household is 600 mg/l. The contour pattern of Cl^- resembles, to a great extent, those of Na^+, K^+ and Mg^{2+}. Figure 5.12 represents historical data relating Cl^- concentration to the electrical conductivity for the period 1981 - 1993 and chloride concentration in the aquifer during the last 15 years, which runs parallel with the groundwater development in the basin.

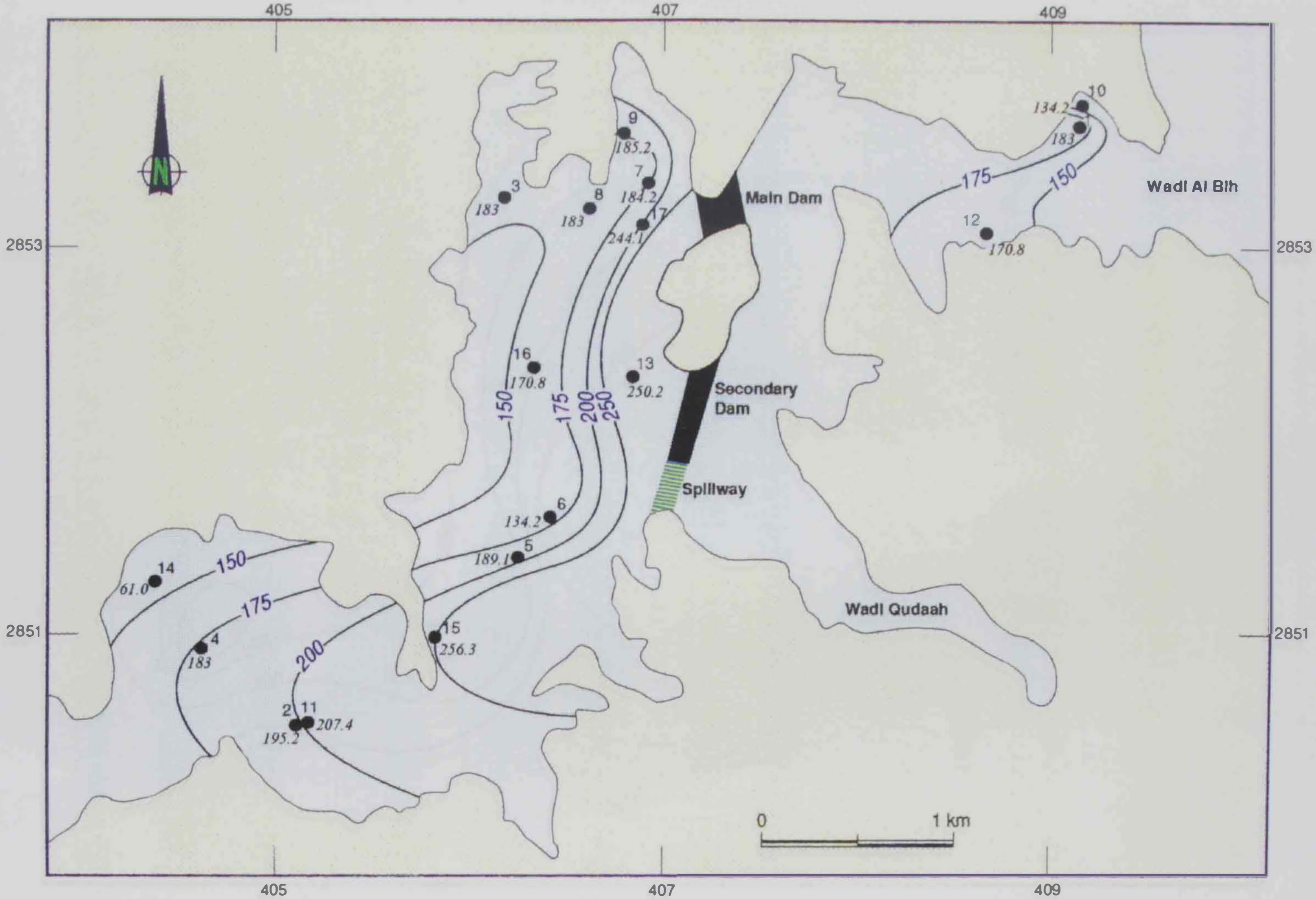

Figure 5.10 Iso-concentration Contour Map of Bicarbonate Ion (mg/l) in Wadi Al Bih Ground Water, September 1996.

GD4472s

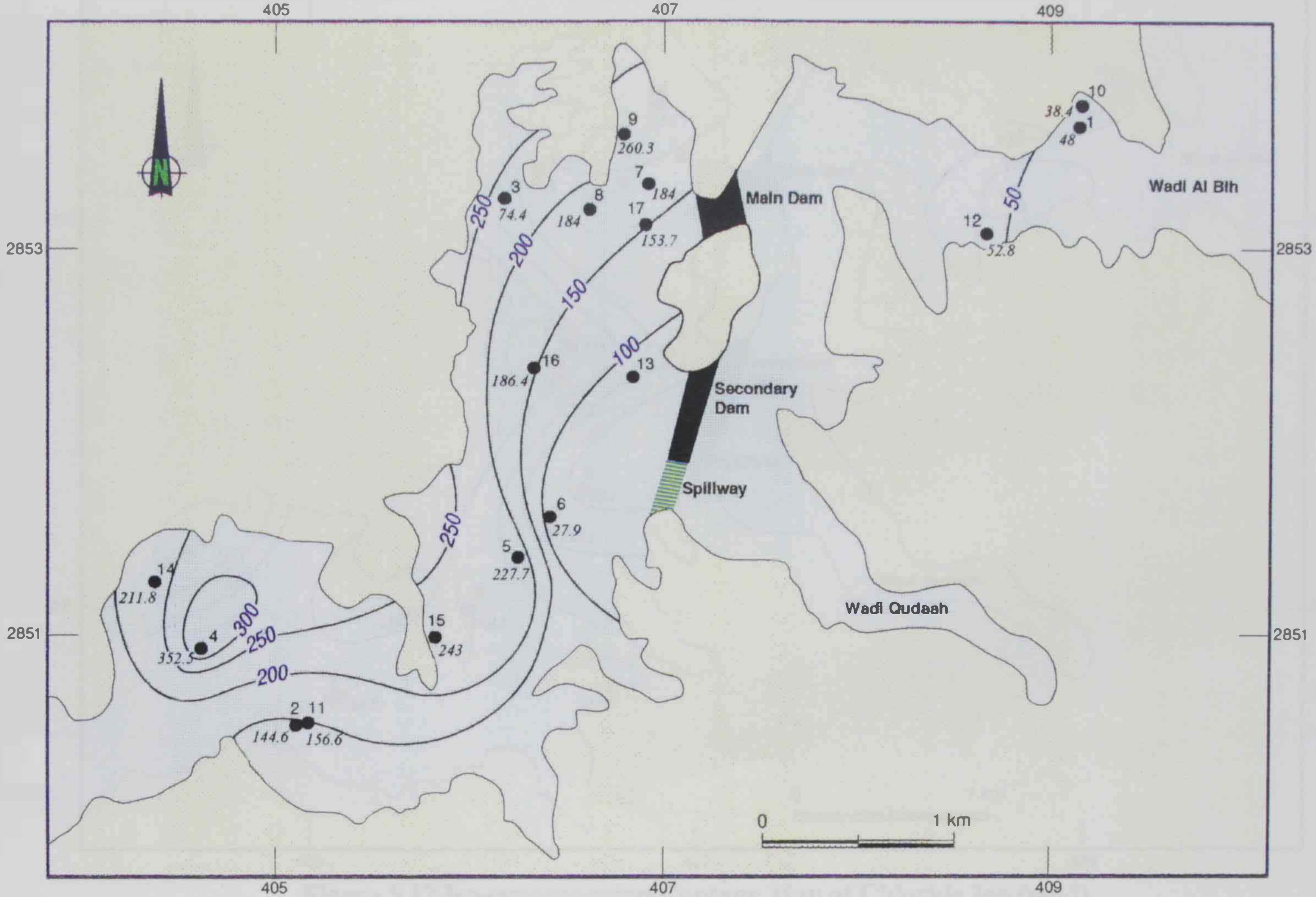

Figure 5.11 Iso-concentration Contour Map of Sulphate Ion (mg/l) in Wadi Al Bih Ground Water, September 1996.

GD4472r

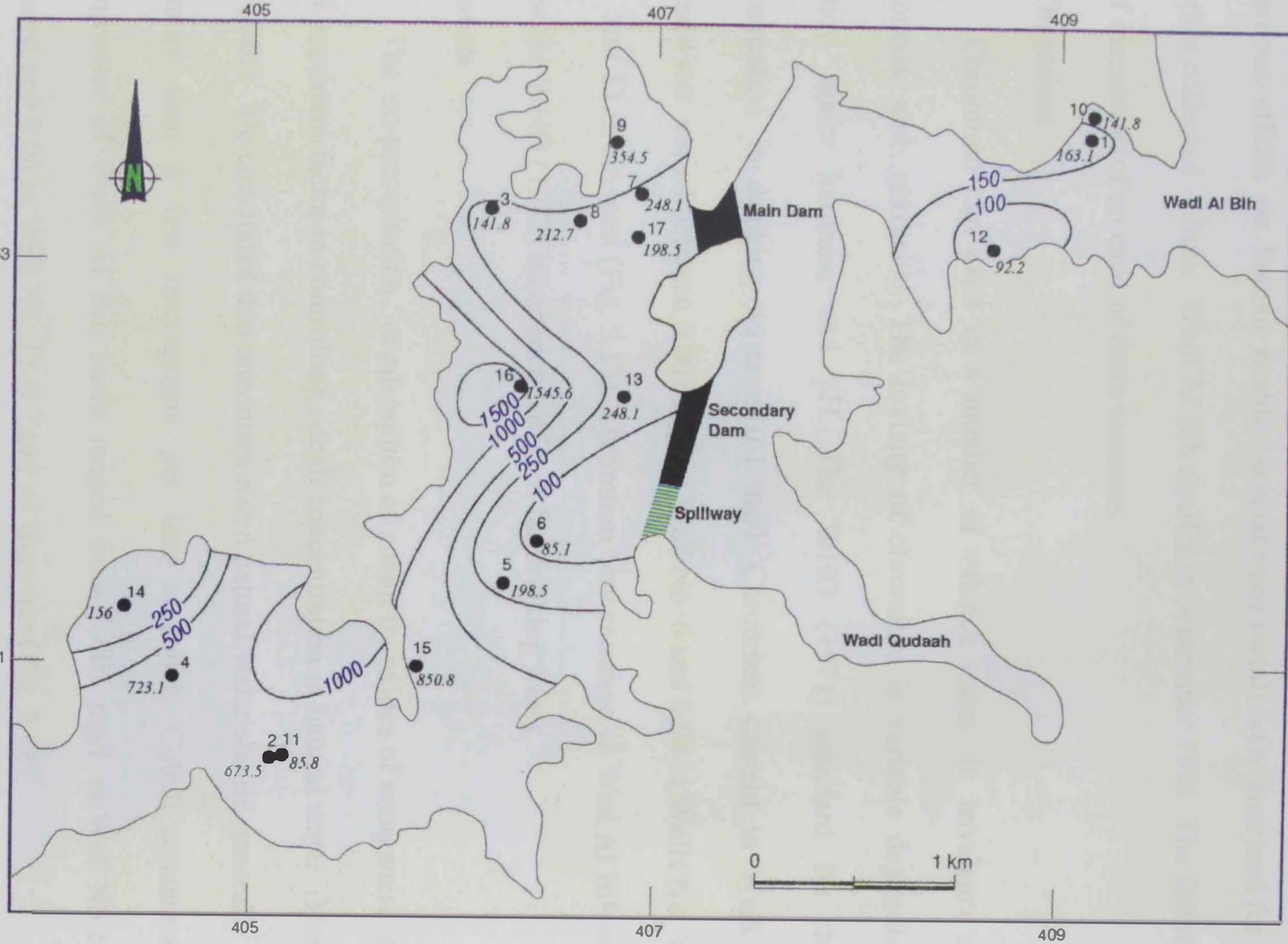

Figure 5.12 Iso-concentration Contour Map of Chloride Ion (mg/l)
in Wadi Al Bih Ground Water, September 1996.

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5.4.2.3 Trace Elements

Because of their presence in groundwater at high concentrations has serious hazardous effects on human health, several trace metals were analyzed for in water samples collected from Wadi Al Bih aquifer in September 1996. The following is a brief discussion of on each of these elements

a. Chromium

Chromium can exist in a number of valence states. In trivalence state it is poisonous and corrosive. The toxicity of chromium is variable depending upon valency, water hardness and pH. The WHO (1971) standard for chromium concentration in drinking water is 0.1 mg/l. Chromium content in Wadi Al Bih groundwater varied between 0.001 mg/l in Well No. 6 and 0.04 in Wells No. 10 in the east and 13 in the west (Fig. 5.13). Chromium concentration in Wad Al Bib aquifer is below the WHO (1983) recommended limit for drinking water.

b. Cobalt

The co-precipitation or adsorption of cobalt by oxides of manganese and iron is an important factor in controlling cobalt concentration in natural water (Hem, 1978 and 1980). He concluded that uncontaminated natural water should generally contain no more than a few micrograms per litre of cobalt. Cobalt concentration in groundwater of Wadi Al Bih basin ranged from 0.001 mg/l in Well No.10 in the northeast and 0.06 in Well No. 11 at Tawi Al Burayrat (Fig. 5.14).

c. Iron

Iron is toxic to some aquatic species at concentrations of 0.32 to 1.00 mg/l. A water quality criterion for iron of 0.3 mg/l has been suggested for domestic uses. For

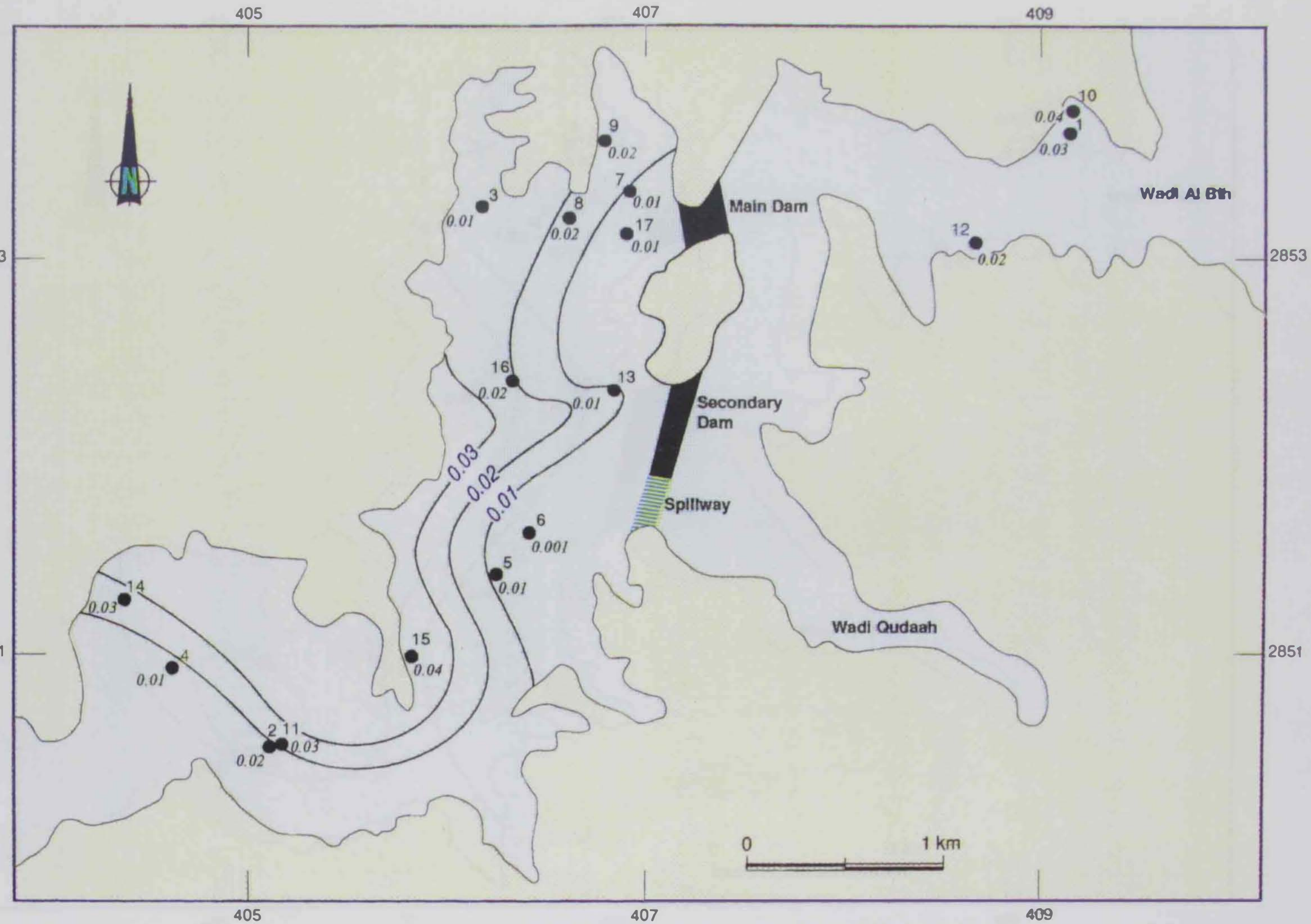

Figure 5.13 Iso-concentration Contour Map of Chromium (mg/l) in Wadi Al Bih Ground Water, September 1996.

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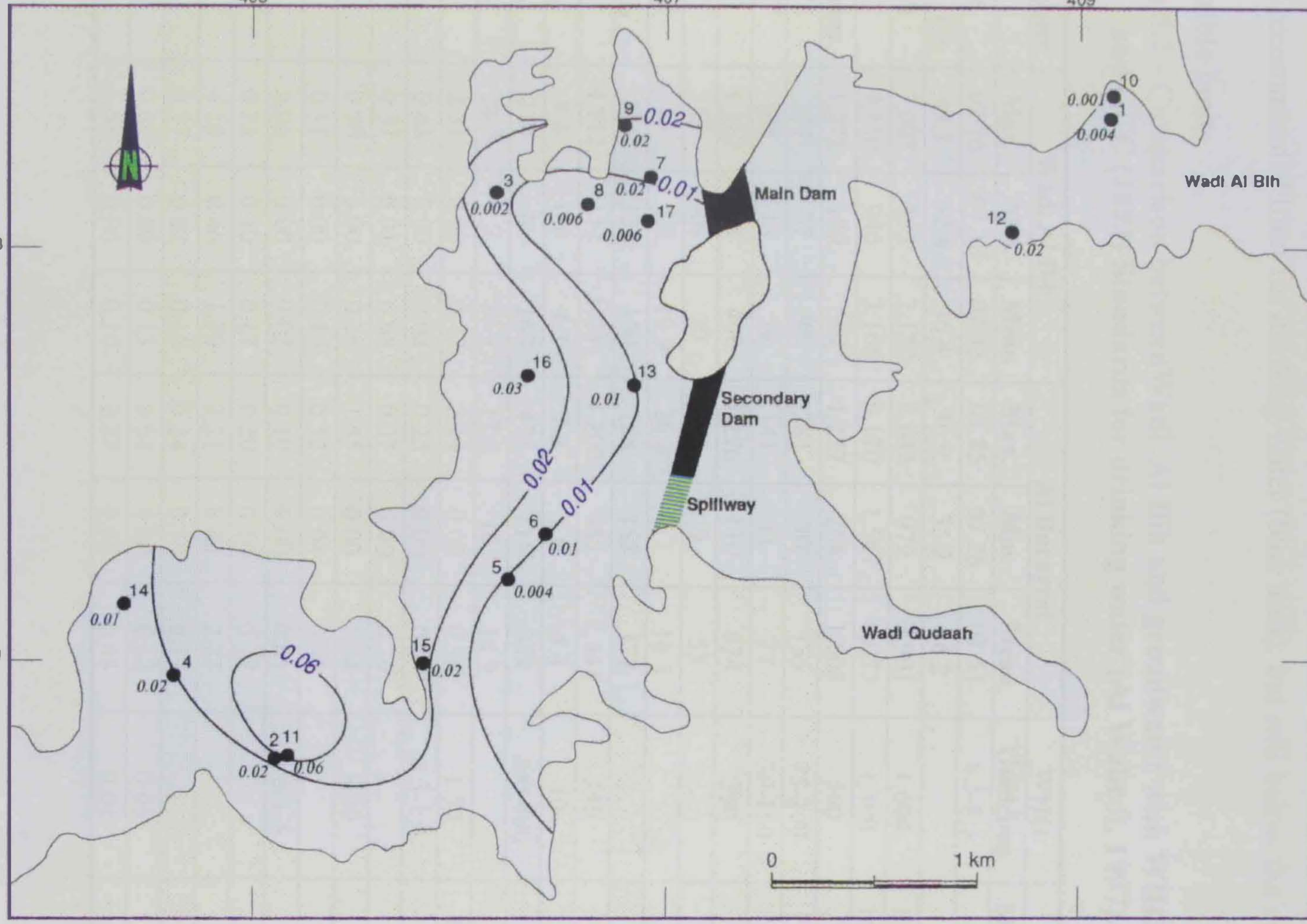

Figure 5.14 Iso-concentration Contour Map of Cobalt (mg/l) in Wadi Al Bih Ground Water, September 1996.

GD4472o

aquatic life, a maximum iron content of 1.0 mg/l is the criterion. Iron contents in Wadi Al Bih groundwater ranges from 0.1 mg/l in Wells No 6,7,12,13 and 14 and 0.7 mg/l in Well No. 16 (Fig. 5.15). The iron concentrations are above the WHO (1983) recommended limit for drinking water (blue area), but still below the maximum permissible limit.

Table 5.2 - Comparison betweenWadi Al Bih and groudwater with WHO (1984) and GCC (1993) Standards for drinking water (Al Wahedi, 1997).

Parameter	Wadi Al Bih			Al Burayrat			WHO	GCC
	Max.	Min.	Mean	Max.	Min.	Mean	Guideline	Max. level
pH	07.76	07 10	07 43	07.85	07.26	07.51	6 5-8.5	6.5-8 5
Temp. C°	43 3	32 8	36.4	36 9	35 2	36 2		
TDS	7,007	593	2,122	6,642	979	3,901	1,000	100-1,000
EC	9,330	940	3,166	9,170	1,567	6,073	1,400	160-1,600
Hardness	1,272	189	502	1,277	264	1,008	500	500
Ca^{++}	277	37	96	281	30	135	75-200	200
Mg^{++}	108	13	39	141	11	77	30-150	30-150
Na^{+}	1,362	88	400	1,276	110	674	200	200
K^{+}	87	10	30	111	9	53		
CO_3^-	19	3.6	10 9	26 3	7.2	16.3		
HCO_3^-	204	131	160	188	153	172		
Cl^-	4,712	112	1,201	4,200	482	2,441	250	250
NO_3^-	9 4	0 0	4 7	7 9	1.6	5.4	10	10
SO_4^-	270	74	162	475	115	309	200-400	400
SiO_2^-	18 7	9 3	16.1	17 5	16	16.9		
F^-	2.31	0 00	0.47	2 44	0 00	0.94	1.50	0.6-1 7
Fe	0 48	0.00	0 08	0 25	0 00	0.07	0 3-1 0	0 3
B	0.37	0.01	0.08	0.37	0 00	0.10		
Zn	0 90	0 00	0.26	1 55	0.00	0.34	5 00	5.00
Ni	0 51	0 00	0.16	0 52	0 04	0.30		
Cu	0 06	0 00	0 02	0 10	0 00	0 01	1 0-1 5	1 0
Li	0 33	0 10	0.17	0 20	0.14	0.17		
Sr	4 28	0 46	1 70	3.21	0.88	2.27		
Ba	0.37	0.02	0.16	0 24	0.10	0.17		
Pb	0 60	0 00	0 13	0 34	0 00	0.12	0 05	0 05
Se	1 56	0 00	0 20	2 27	0.00	0.44	0.01	0.01

d. Zinc

Zinc is an essential trace element necessary for human metabolism, synthesis of protein and enzymes Zinc can be toxic, causing gastrointestinal distress if ingested in

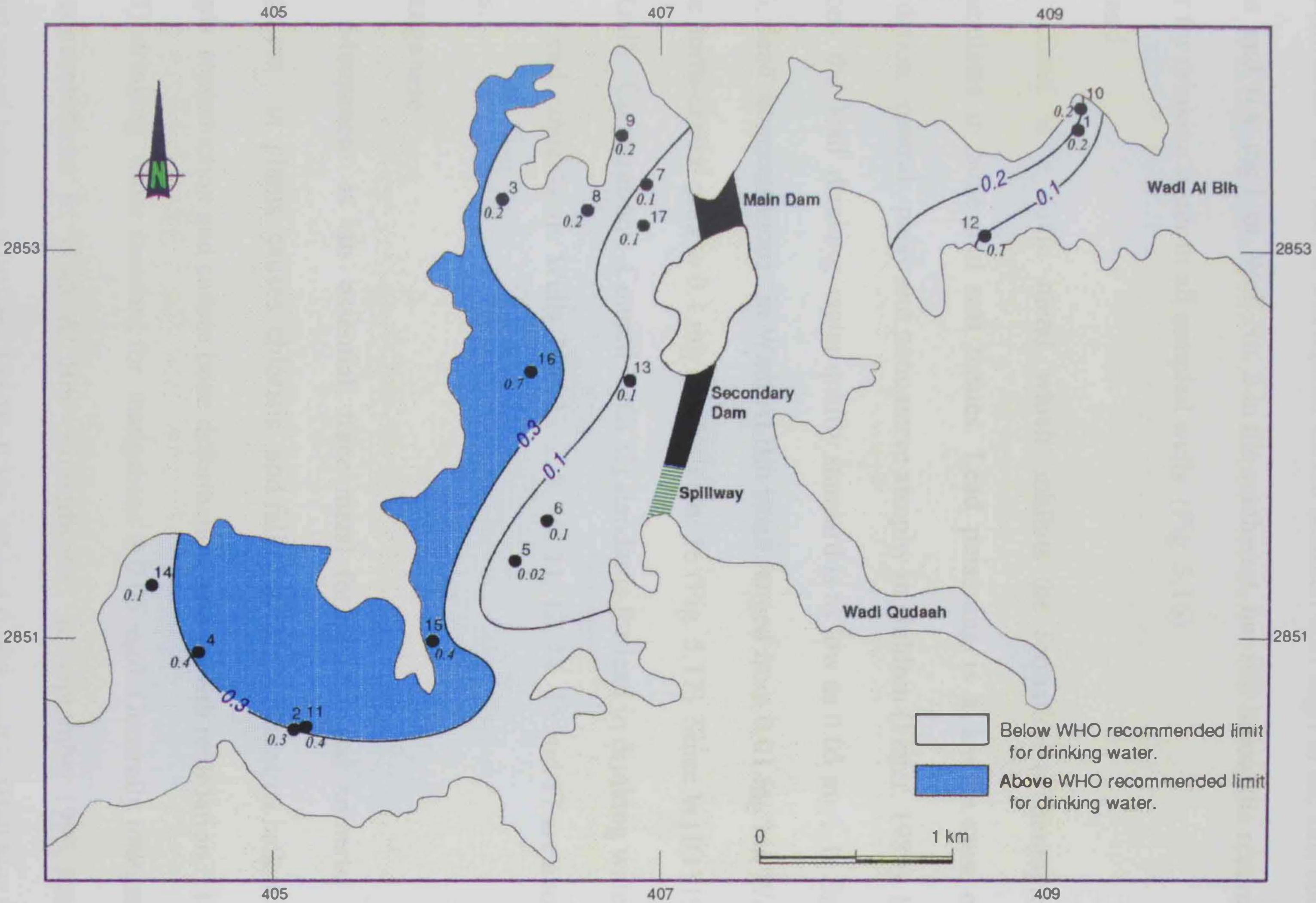

Figure 5.15 Iso-concentration Contour Map of Iron (mg/l) in Wadi Al Bih Ground Water, September 1996.

GD4472c1

large quantities. Toxicity varies with pH, alkalinity and water hardness. Suggested WHO (1983) standard for zinc concentration in drinking water is 5mg/l. Zinc concentration in Wadi Al Bih aquifer varied between 0.01 mg/l in the east and central areas and 0.6 mg/l in Well No. 2 in the southwest, but still below the recommended limit for drinking water in all sampled wells. (Fig. 5.16)

e. Lead

Lead is a toxic metal which inhibits the formation of hemoglobin and accumulates in bone and soft tissues. Lead poisoning is a known cause of mental retardation, central palsy and potic nerve atrophy in children (Fetter, 1980). For these reasons the lead drinking water quality standard is as low as 0.05 mg/l. In September 1996, lead concentrations in Wadi Al Bih basin ranged from 0.01 mg/l in Well No. 9 in the north-central area to 0.1 mg/l in Well No. 16 (Fig. 5.17). Since WHO (1993) and the Gulf Cooperation Council (GCC) standards for lead in drinking water is 0.05 mg/l. Lead contents in Wells No. 1, 2, 8, 10, 11, 12, 14, 15 and 17 are above these limits.

f. Manganese

Manganese is an essential trace metal for plants and animals. Lack of manganese in plants causes chlorisis and fall of leaves; whereas its lack in animals disrupts reproduction and causes bone deformation and growth retardation. The WHO (1993) drinking water standard for manganese is 0.05 mg/l. Generally manganese has low concentrations in Wadi Al Bih groundwater. In September 1996, manganese content varied between 0.001 mg/l in Well No. 17 and 0.005 mg/l in Well No .14 (Fig.

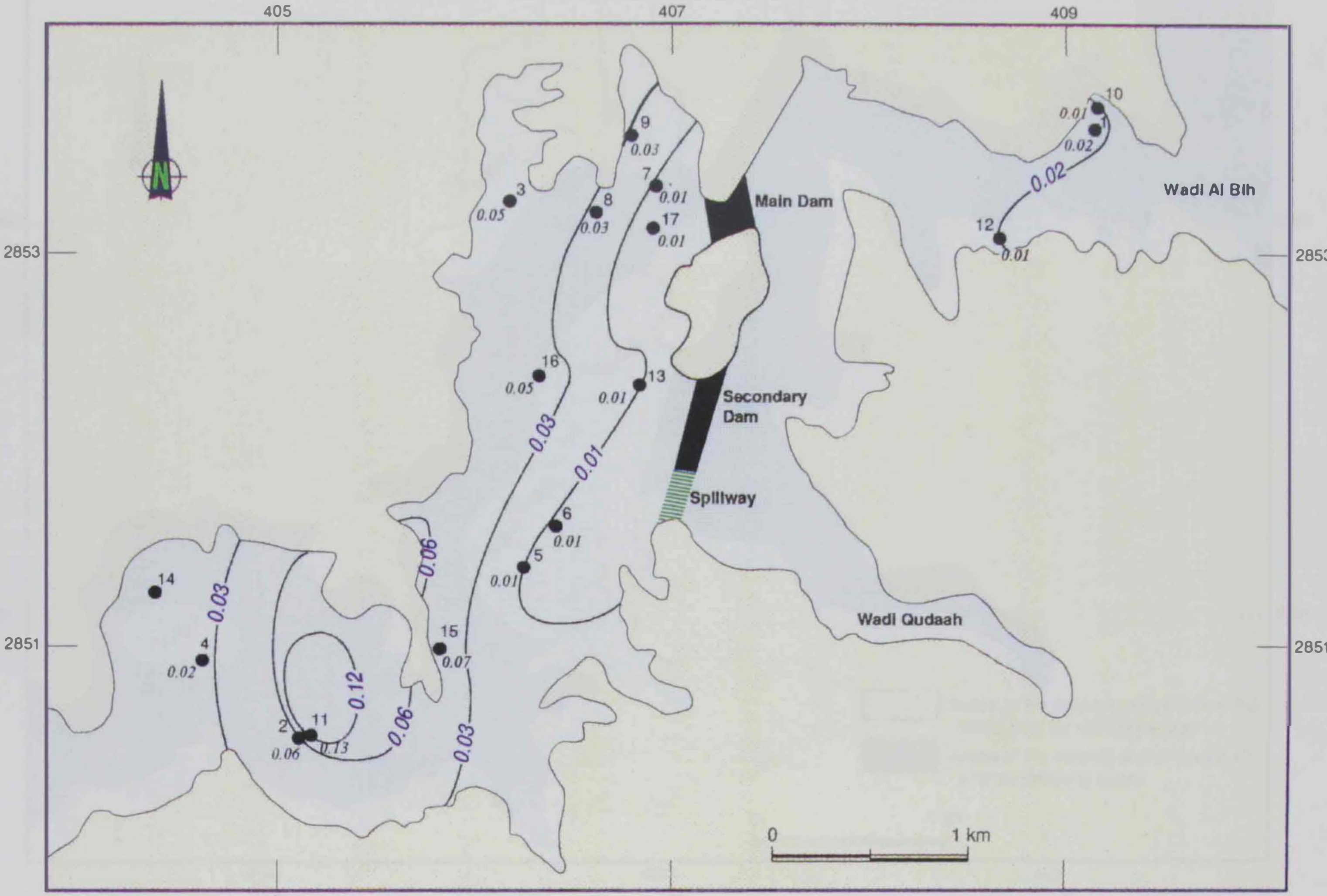

Figure 5.16 Iso-concentration Contour Map of Zinc (mg/l) in Wadi Al Bih Ground Water, September 1996.

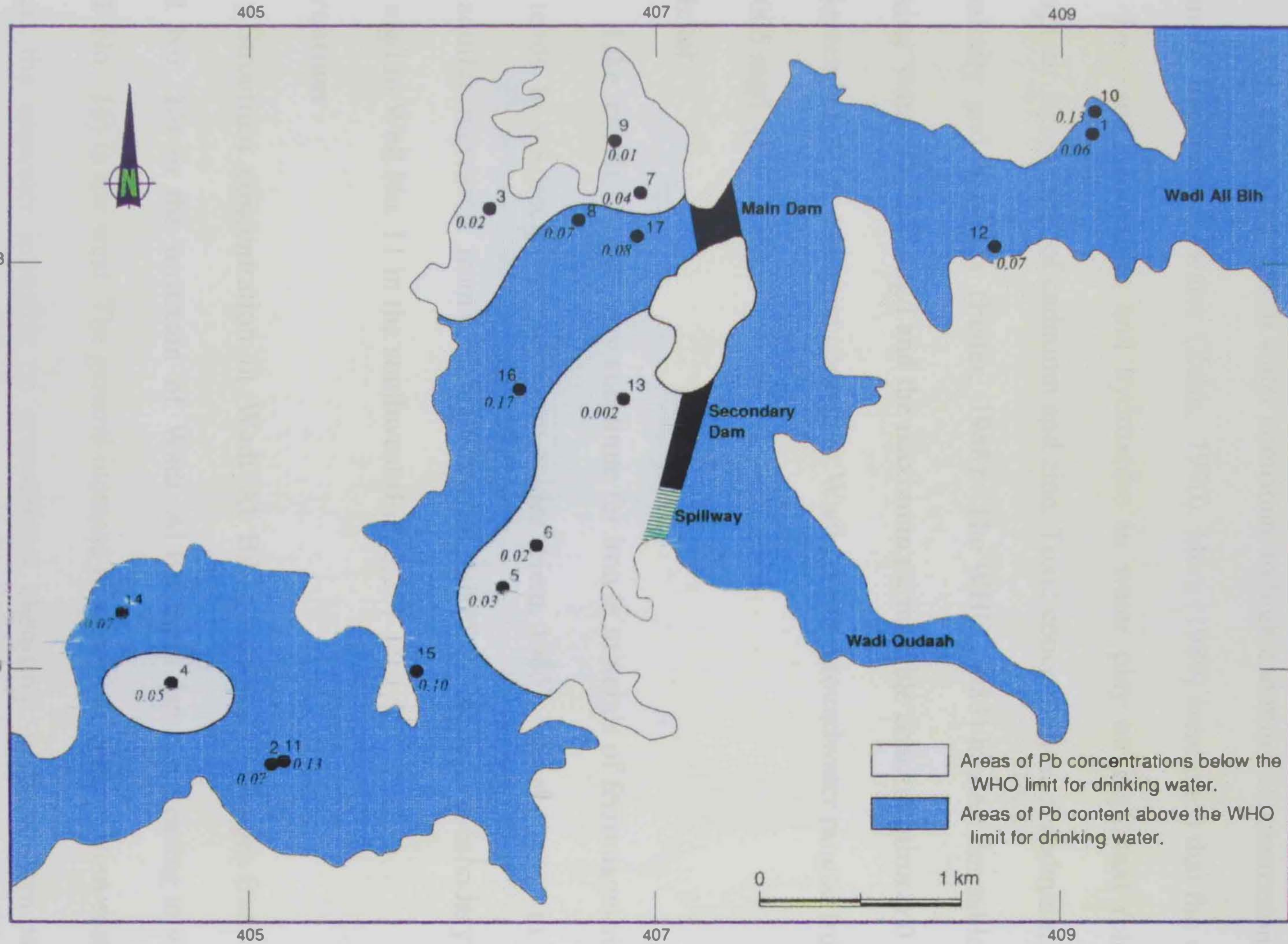

Figure 5.17 Iso-concentration Contour Map of Lead (mg/l) in Wadi Al Bih Ground Water, September 1996.

GD4472d1

5.18). The manganese in Wadi Al Bih aquifer is below the WHO (1983) recommended limit for drinking water.

g. Cadmium

High content of ions in water contribute to high cadmium concentration and fast cadmium transport in water (Zahn, 1990). Merz (1989) mentioned that the values of pH, Fe, and Mn-oxides and hydroxides in water play an important role in the adsorption behaviour of cadmium and zinc. Toxic concentration of cadmium depends on salinity and hardness (Fetter, 1988). The WHO (1983) highest desirable level in drinking water is 0.01 mg/l and the maximum permissible concentration is 0.05 mg/l. In September 1996, cadmium content in Wadi Al Bih groundwater ranged from 0.001 to 0.005 mg/l (Fig. 5.19)

h. Nickel

Like cobalt, nickel may substitute for iron in minerals of ferromagnesian rocks and tends to co-precipitate with iron oxides (Hem, 1985). Nickel content in Wadi Al Bih aquifer increases from 0.02 mg/l downstream of the main and secondary dams to 0.15 mg/l in Well No. 11 in the southwest (Fig. 5.20)

I. Strontium

Strontium concentration in Wadi Al Bih groundwater ranges from 1.2 mg/l (Well No. 10) in the upstream of Wadi Al Bih main dams, increasing to 4.93 mg/l (Well No. 16) in the west. The general increase in strontium content from east to west reflects the seawater intrusion on groundwater chemistry in the western part of the study area (Fig. 5.21).

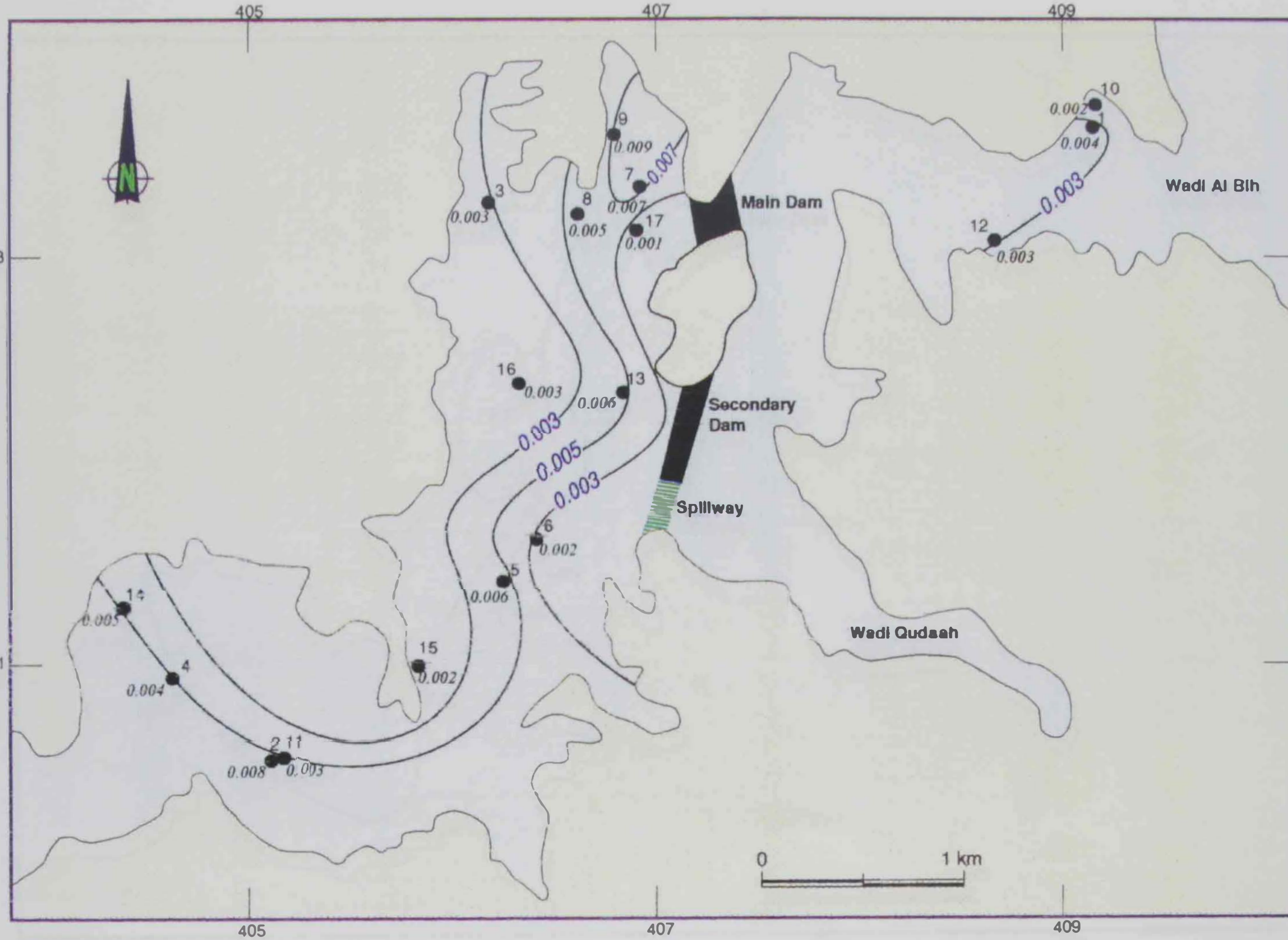

Figure 5.18 Iso-concentration Contour Map of Manganese (mg/l) in Wadi Al Bih Ground Water, September 1996.

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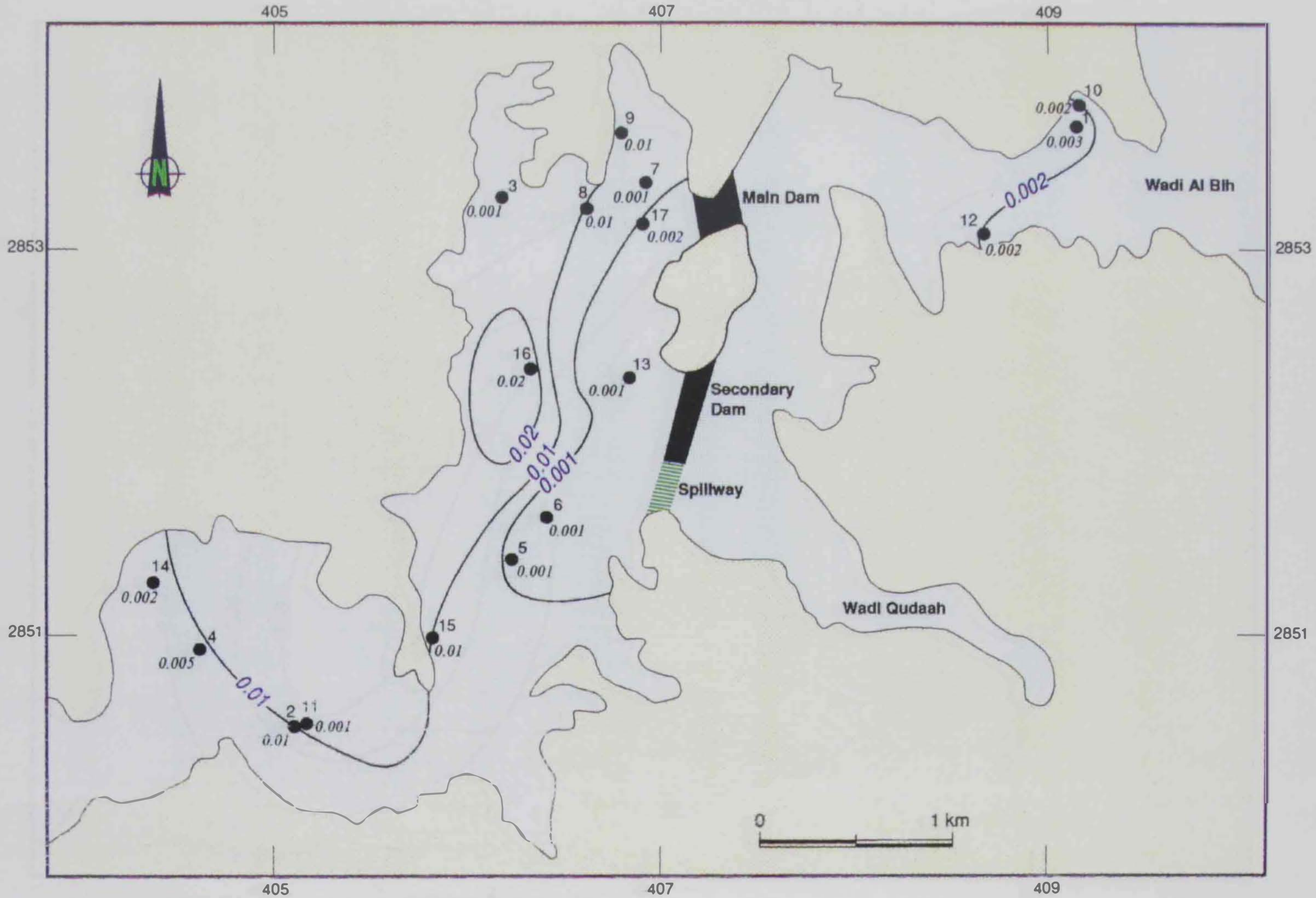

Figure 5.19 Iso-concentration Contour Map of Cadmium (mg/l) in Wadi Al Bih Ground Water, September 1996.

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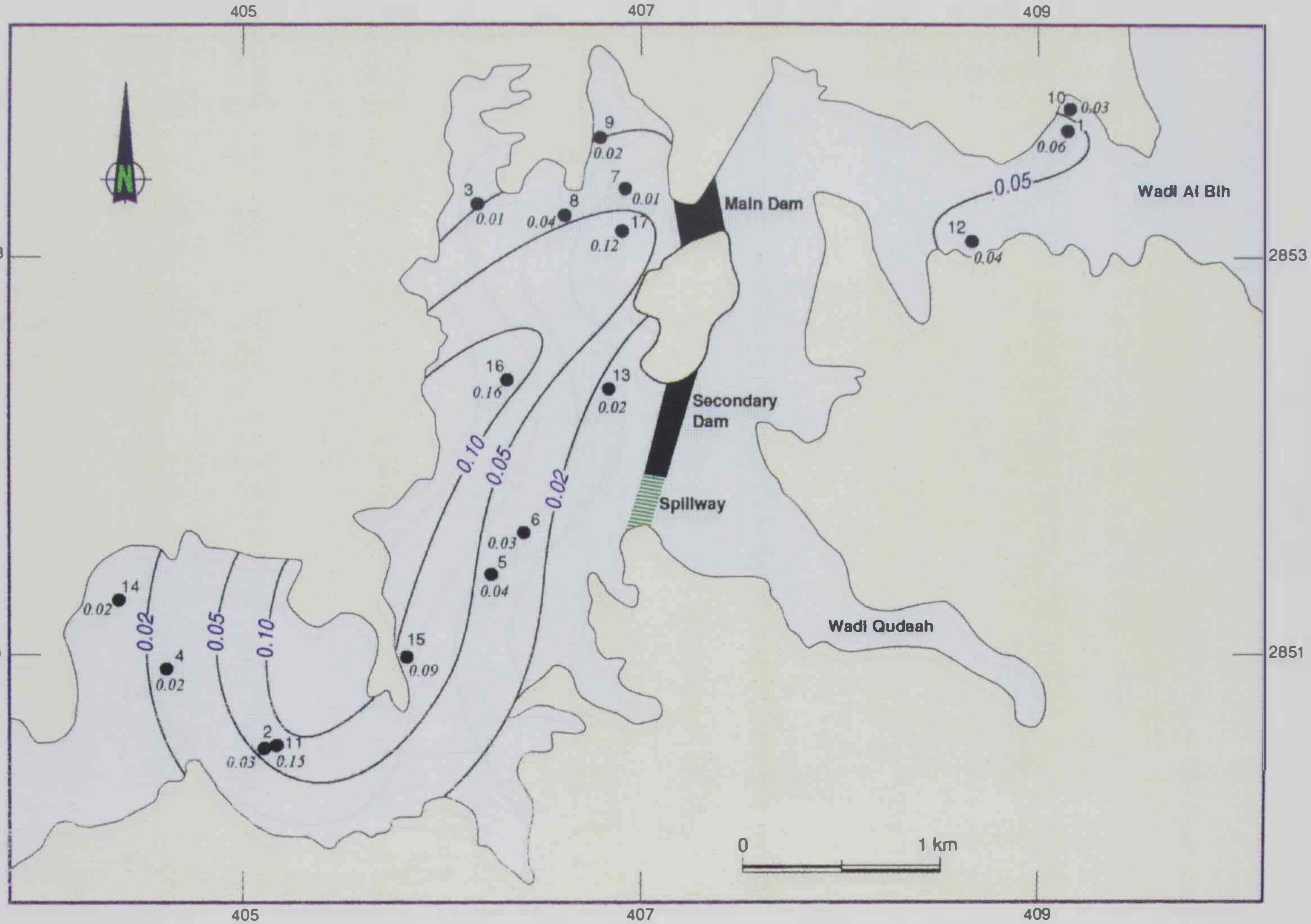

Figure 5.20 Iso-concentration Contour Map of Nickel (mg/l) in Wadi Al Bih Ground Water, September 1996.

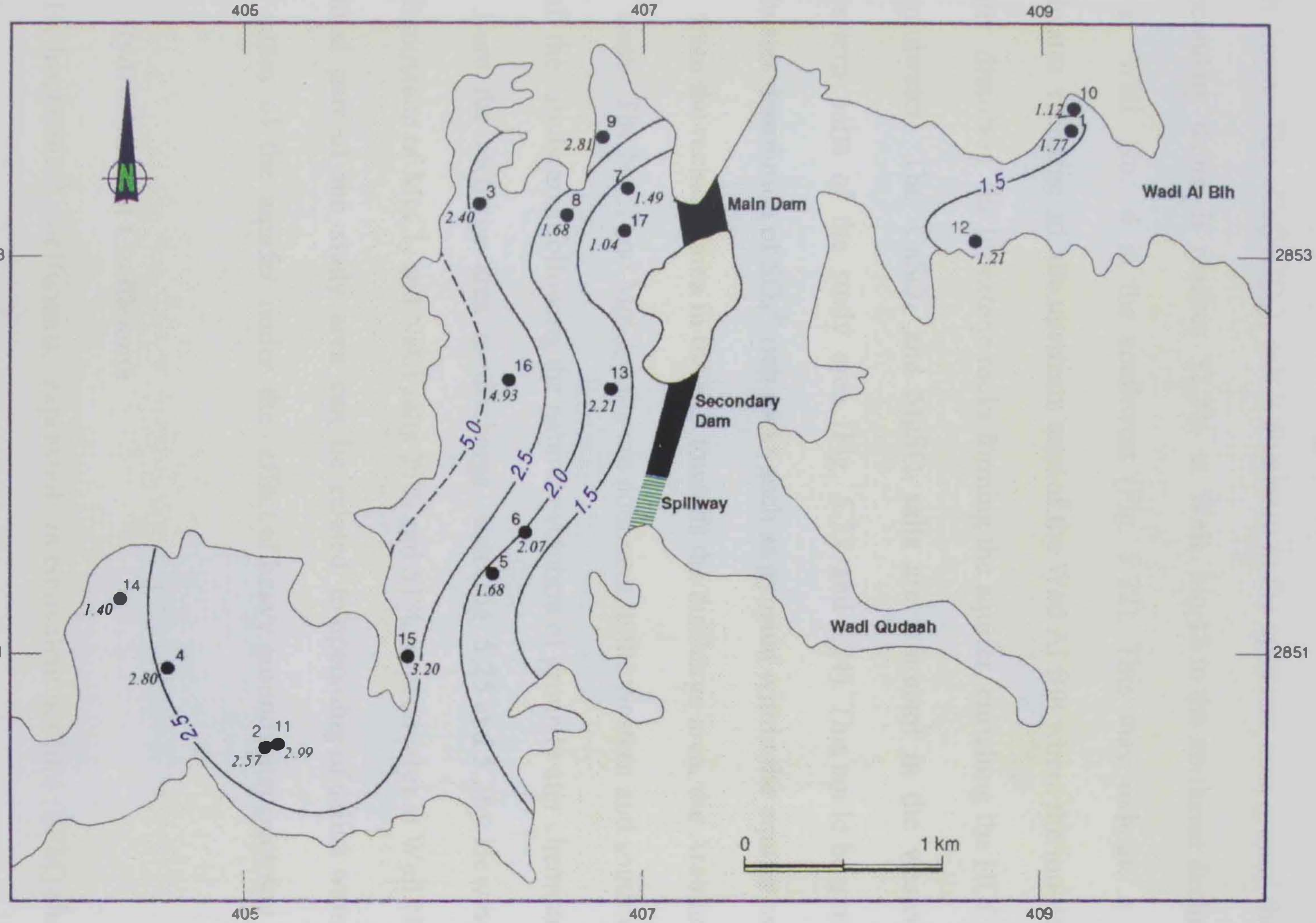

Figure 5.21 Iso-concentration Contour Map of Strontium (mg/l) in Wadi Al Bih Ground Water, September 1996.

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5.4.2.4 Water dissolved solids

The calculated water-dissolved salts in Wadi Al Bih aquifer are $Ca(HCO_3)_2$, $CaSO_4$, $MgSO_4$, and. The dominance of these salts exhibits a wide variation in Wadi Al Bih basin. The $Ca(HCO_3)_2$ salt is dominant in the upstream area around the main and secondary dams. It reaches 32.2% at Well No.12 in the northeast declining to 6.3% at Well No. 4 in the southwest (Fig. 5.22). This may indicate a higher groundwater recharge in the upstream area of the Wad Al Bib where the ion-depleted rainwater dissolves the limestone rocks forming the aquifer, enriching the HOC_3^- salts in groundwater. The $CaSO_4$ and $MgSO_4$ salts are dominant in the western and southwestern parts of the study area (Fig. 5.23 and 5.24). This could be a result of groundwater dissolution of SO_4^{2-} rich rocks such as gypsum within the aquifer as water moves from the recharge area in the east towards the discharge area, the Arabian Gulf, in the west. The NaCl and $MgCl_2$ salts are dominant in the western and southwestern parts of the study area following the natural evolution of groundwater chemistry as it moves from the recharge area to discharge area (Fig. 5.25 and 5.26). However, the local dominance of $MgCl_2$ and NaCl salts 26% and 51% respectively) at Well No. 6 in the central part of the study area can be related to upcoming of saline water from deeper zones of the aquifer under the effect of heavy groundwater pumping in this area.

5.4.2.5 Hydrochemical Coefficients

Hydrochemical coefficients, expressed in equivalent per litre (EPM) show the relative concentrations of various ions and can be used to indicate the predominance of a particular ion and to define locations of salt-water intrusion.

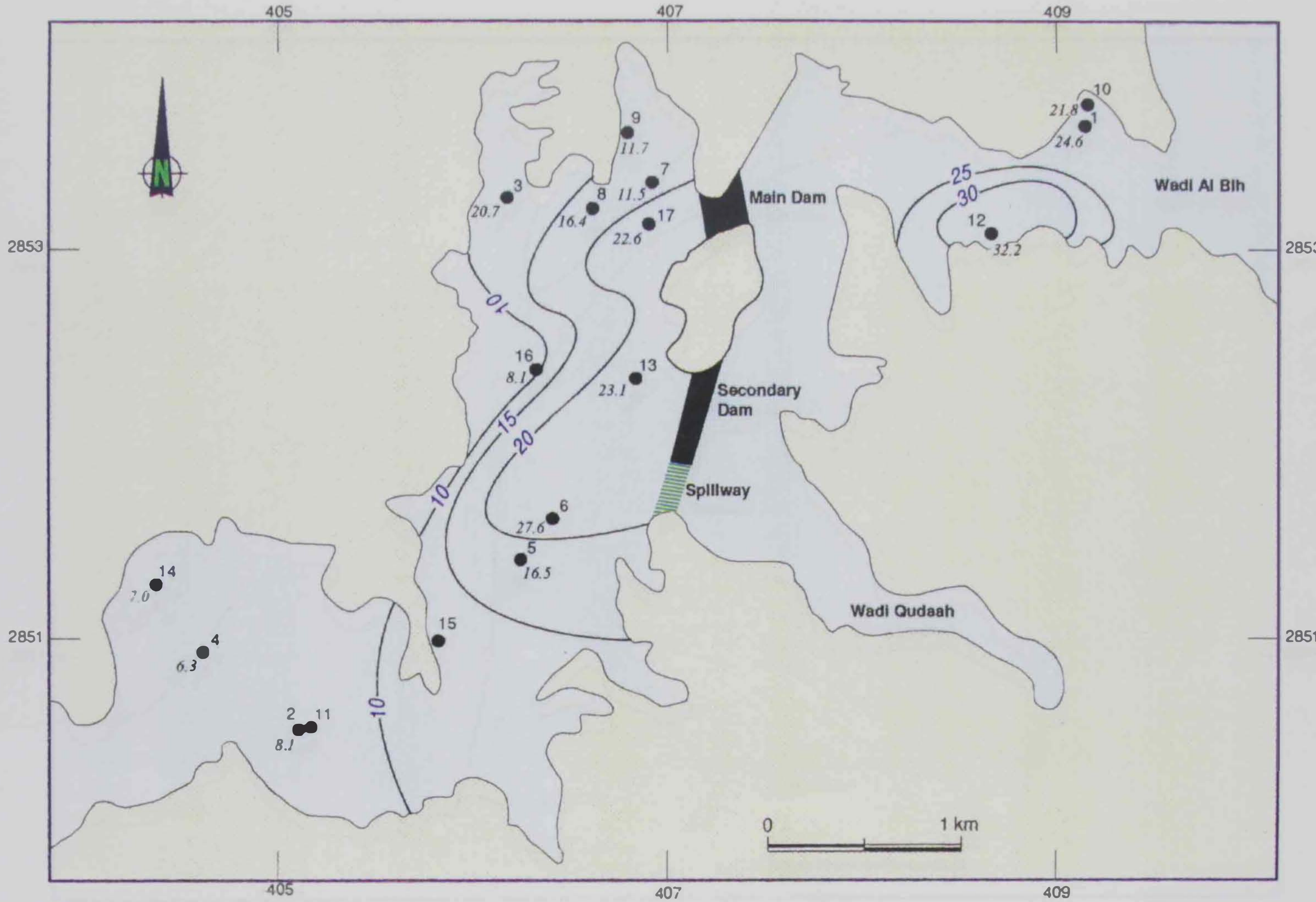

Figure 5.22 Iso-percentage Contour Map of Calcium Bicarbonate (mg/l) in Wadi Al Bih Ground Water, September 1996.

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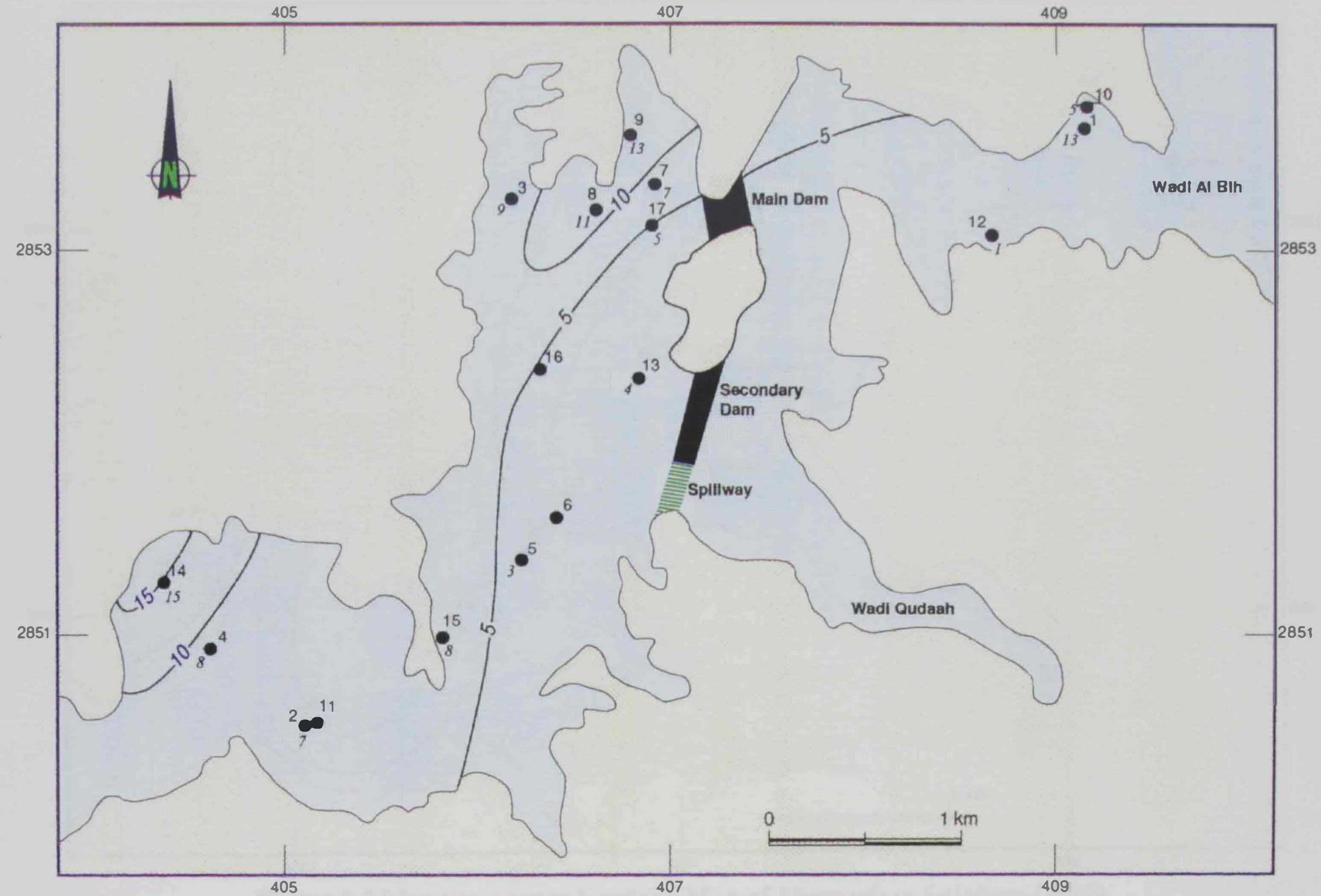

Figure 5.23 Iso-percentage Contour Map of Calcium Sulphate in Wadi Al Bih Ground Water, September 1996.

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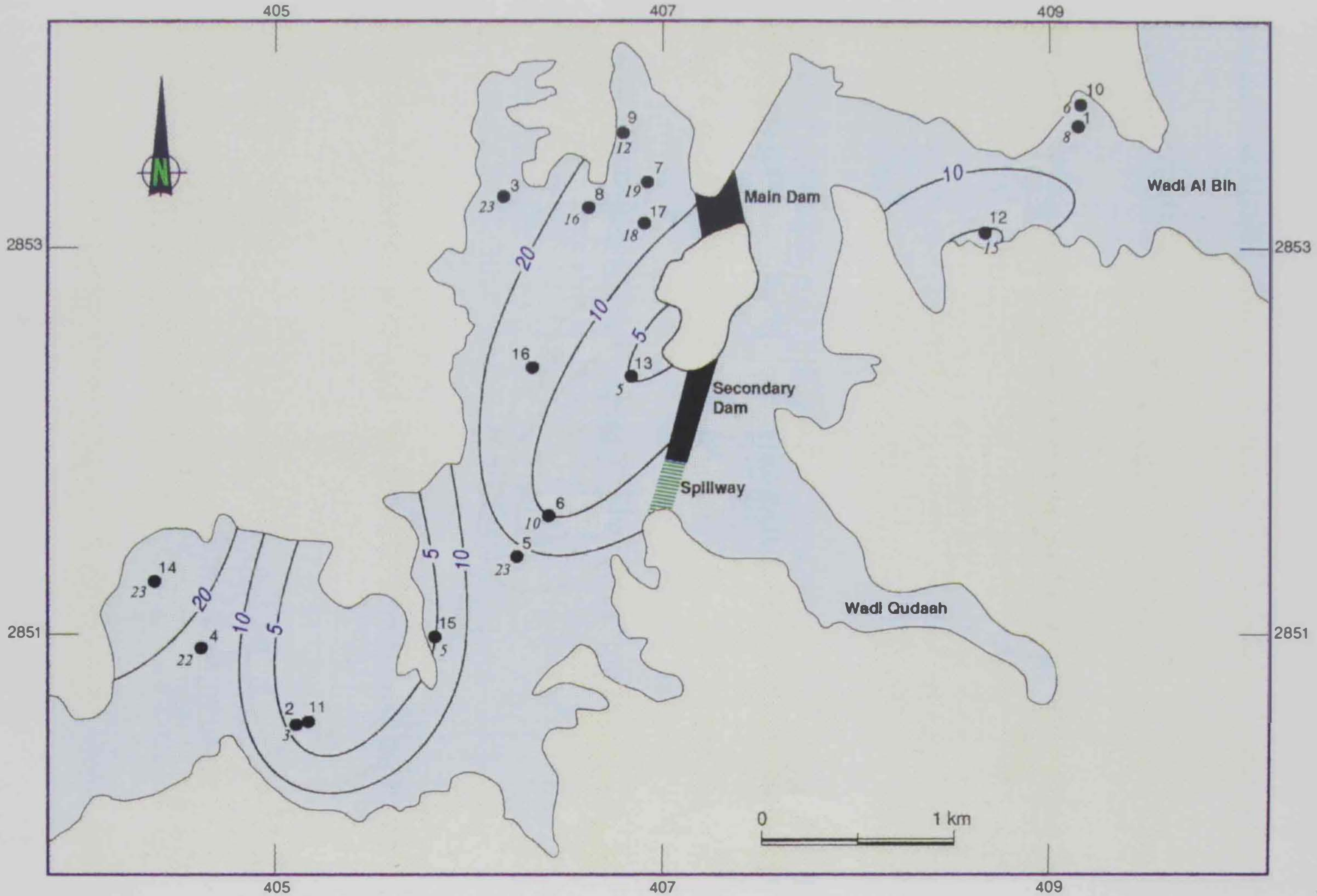

Figure 5.24 Iso-percentage Contour Map of Magnesium Sulphate (mg/l) in Wadi Al Bih Ground Water, September 1996.

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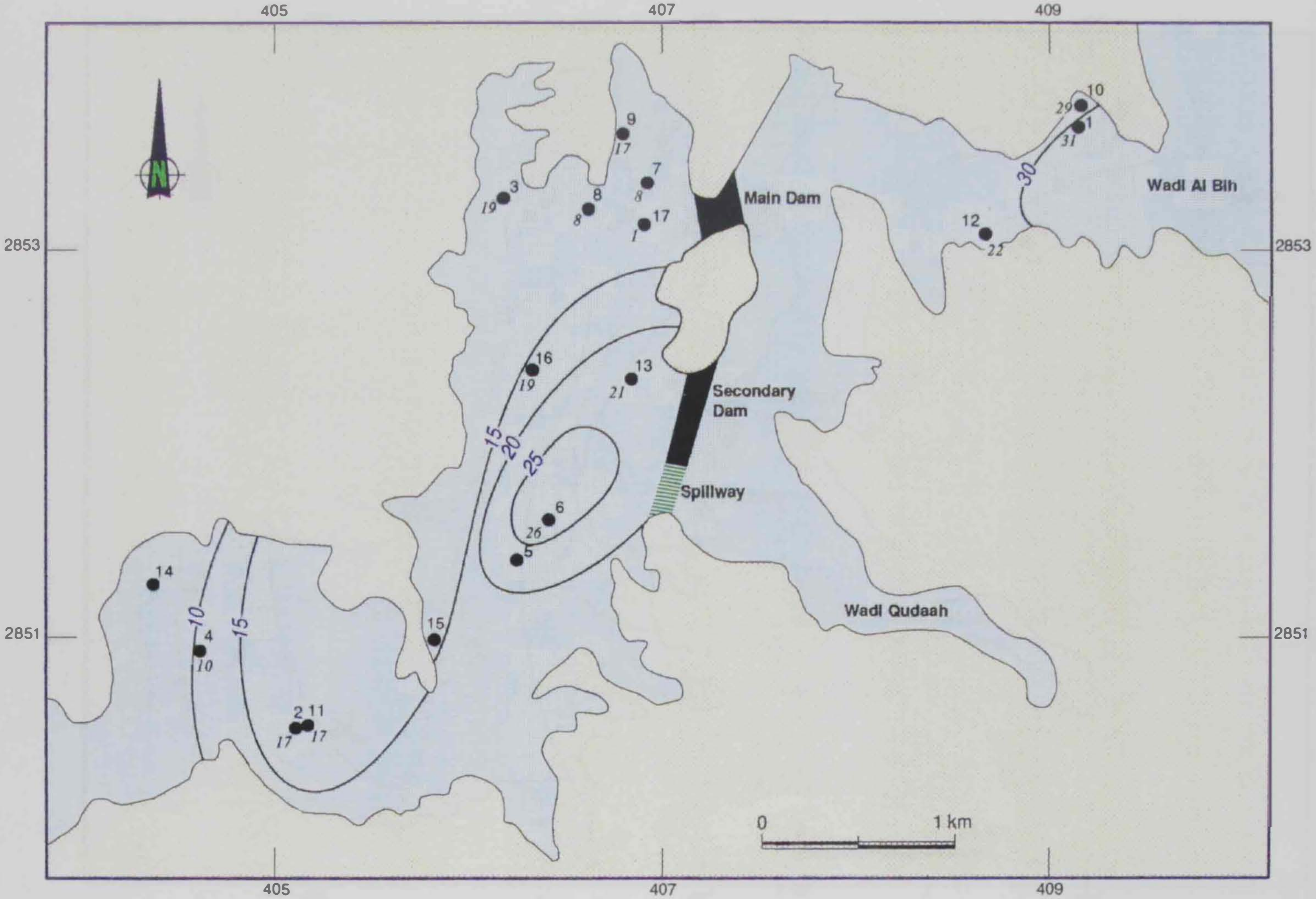

Figure 5.25 Iso-percentage Contour Map of Magnesium Chloride in Wadi Al Bih Ground Water, September 1996.

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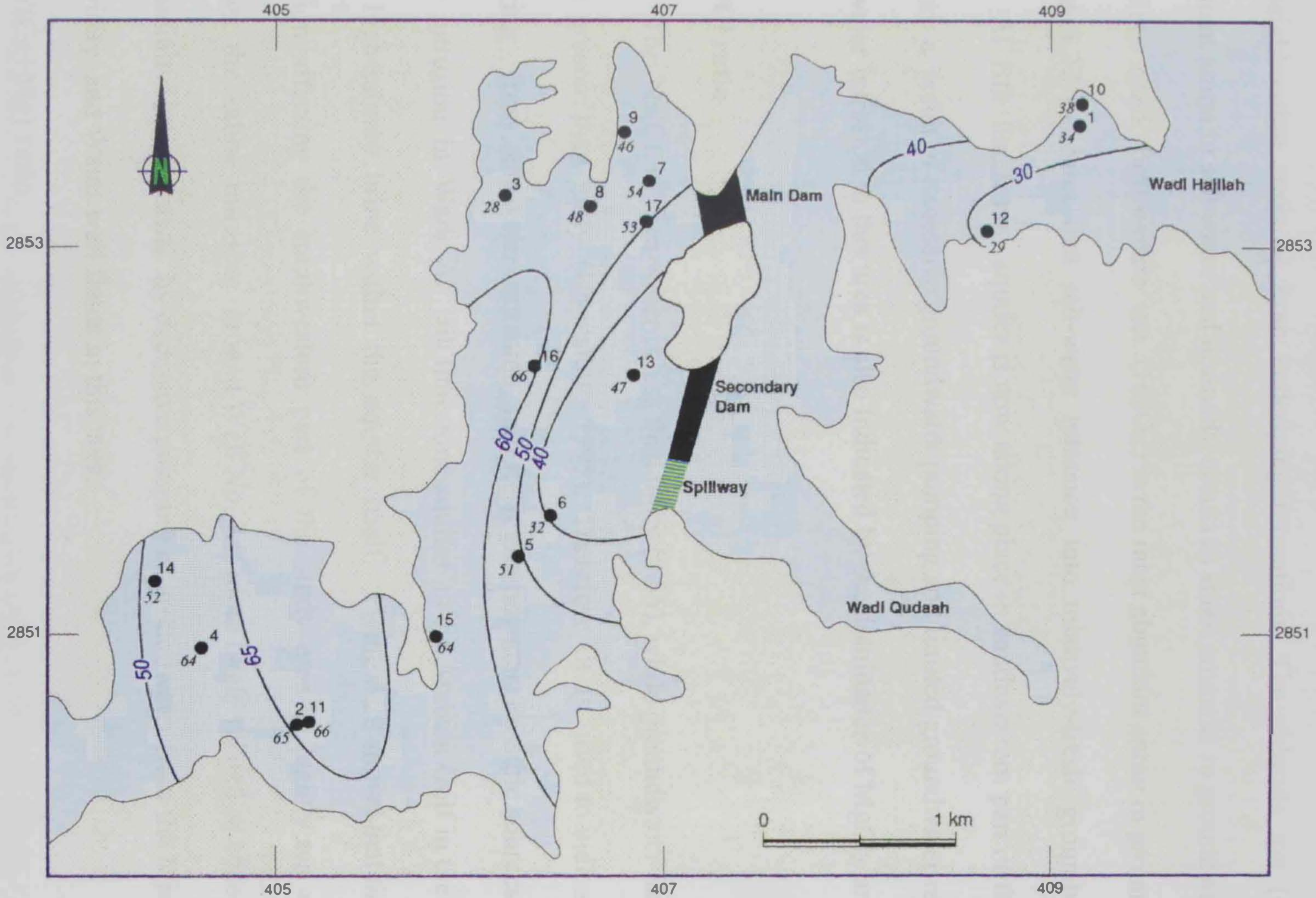

Figure 5.26 Iso-percentage Contour Map of Sodium Chloride (mg/l) in Wadi Al Bih Ground Water, September 1996.

GD4472x

a. $Cl/(CO_3+HCO_3)$

The $Cl/(CO_3+HCO_3)$ ratio is used to evaluate salt-water intrusion, either from the neighbouring areas or from underlying formations. The chloride ion (Cl^-) is a dominant anion in salt water and normally occurs in small amounts in groundwater. On the other hand, bicarbonate ion (HCO_3^-) is the most abundant anion in groundwater. Figure 5.27 indicates that salt-water intrusion into relatively-fresh groundwater of Wadi Al Bih limestone aquifer is now taking place in southwestern part of the study area as a result of excessive groundwater pumping and limited groundwater recharge. Salt-water intrusion in this area is also indicated by the dominance of $MgCl_2$ and NaCl salts.

b Na/Cl ratio

The Na/Cl in sea water is less than unity (0.85), while groundwater has Na/Cl ratios greater than unity (Hounslow, 1995). Therefore, it is used to indicate areas suffering from salt-water intrusion into fresh groundwater. Possible sources of salt-water intrusion in Wadi Al Bih limestone aquifer is the Arabian Gulf in the west or deep high-salinity brine within the aquifer itself. Figure 5.28 shows that the saline intrusion affecting the southwestern part of the study area is mainly sea water. In contrast the saline intrusion around Well No. 7 is more likely related to upcoming of high-salinity brine drawn by excessive pumping of groundwater from the Ministry of Electricity and Water well fields in this area.

c. Na/(Ca+Mg) ratio

The Na/(Ca+Mg) ratio in the groundwater of Wadi Al Bih aquifer shows the dominance of Ca^{2+} and Mg^{2+} over Na^+ in the upstream areas (ratio <1). Westwards the

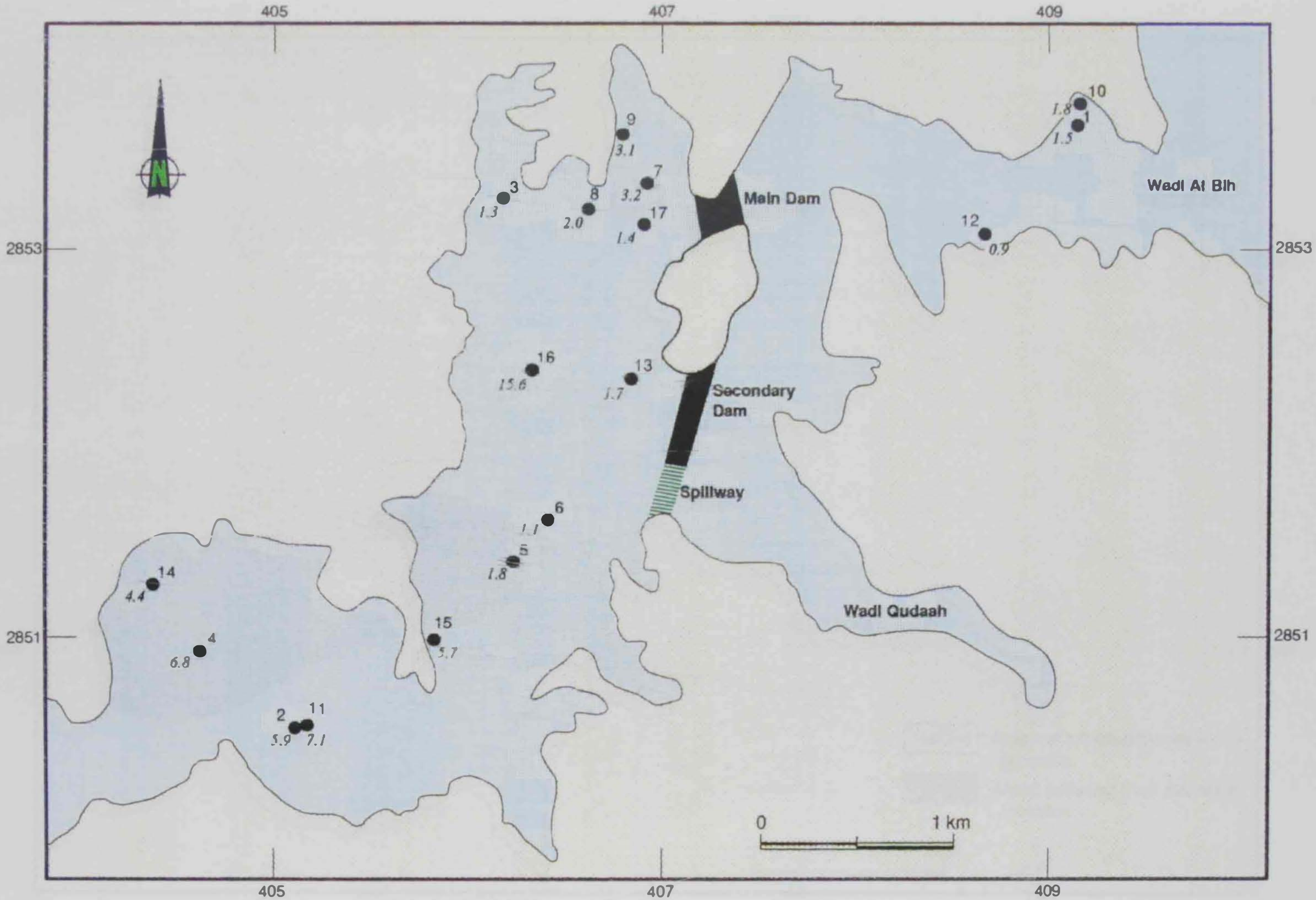

Figure 5.27 Chloride/Carbonate+Bicarbonate Ratio in Wadi Al Bih Ground Water, September 1996.

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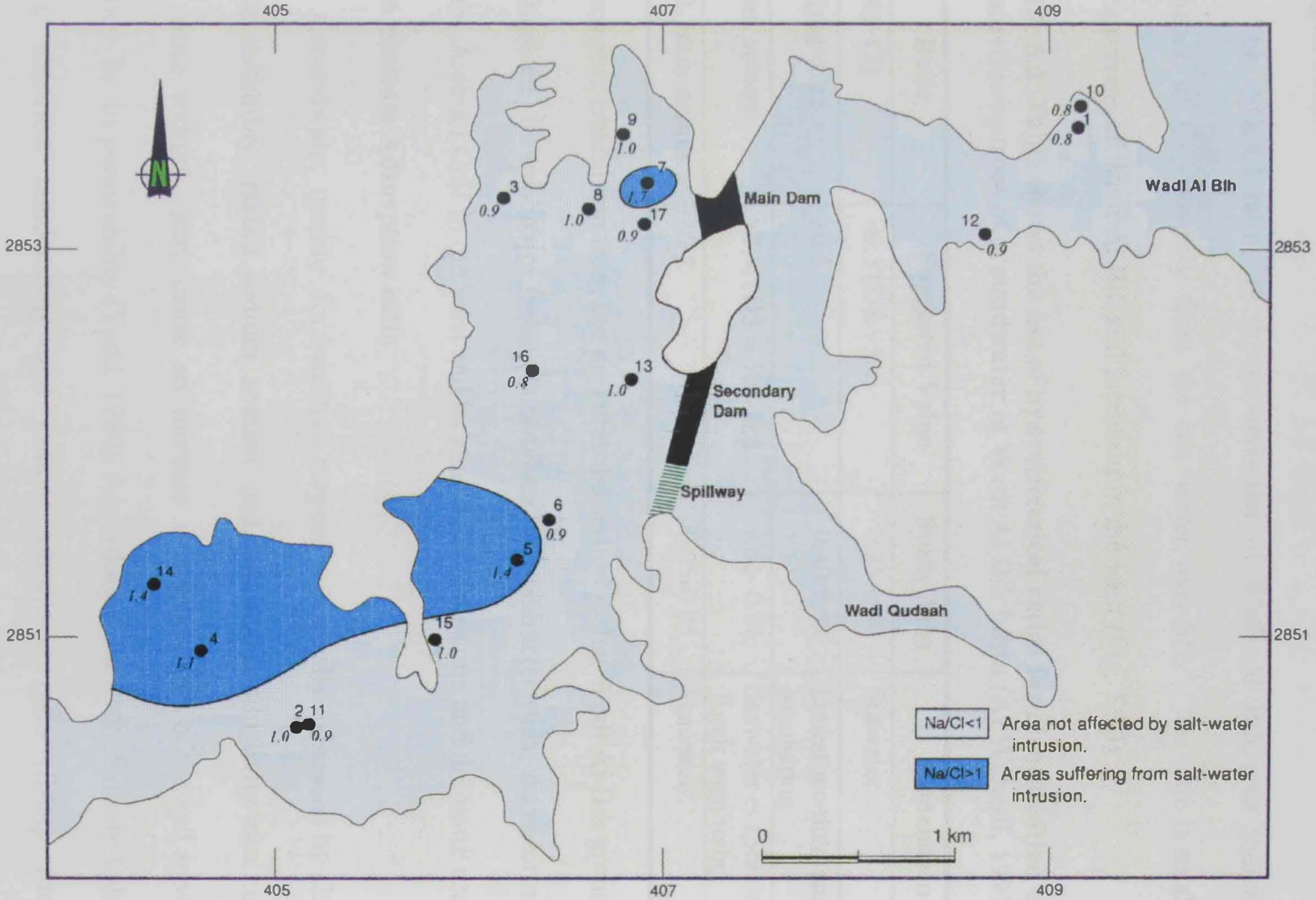

Figure 5.28 Sodium Chloride Ratio in Wadi Al Bih Ground Water, September 1996.

GD4472a1

ratio gets progressively larger indicating greater contribution of Na^+ from the sea in this direction (Fig. 5.29)

d. SO_4/Cl ratio

The SO_4/Cl ratio in the groundwater of Wadi Al Bih area indicates the dominance of Cl^-, possibly from the sea water, over SO_4^{2-}. The ratio is small in the upstream areas of Wadi Al Bih and increases in the west (Fig. 5.30).

Table 5.3 Table shows the use of hydrochemical ratios for identification of the possible sources of groundwater in Wadi Al Bih basin (Al Wahedi, 1997).

Ratio	Suggested Value	Study Area	Conclusion
Na(Na+Cl)	<0.5TDS >500	0.25-0.40	Seawater
Mg/(mg+Ca)	<0.5	0.40-0.49	Limestone-dolomite weathering
Cl/sum anions	>0.8,TDS > 500<0.8	0.62- 0.	Seawater evaporates, Rock weathering
HCO_3^-/sum anions	<0.8	0.05-0.25	Seawater

The possible conclusion from the previous discussion is that Wadi Al Bih groundwater is influenced by two major factors controlling their characteristics; seawater intrusion from the Arabian Gulf in the west and weathering of limestone and dolomite rocks.

5.4.2.6 Sodium Adsorption ratio

Groundwater quality for irrigation purpose is generally expressed by classes of relative suitability, taking sodium content and electrical conductivity into consideration, since sodium may cause an increase in the hardness of the soil as well as a reduction in its permeability (Todd, 1980). According to the U.S. Salinity Laboratory (1954), electrical conductivity and sodium adsorption ratio (SAR) should be considered in determining the suitability of water for irrigation use. According to the

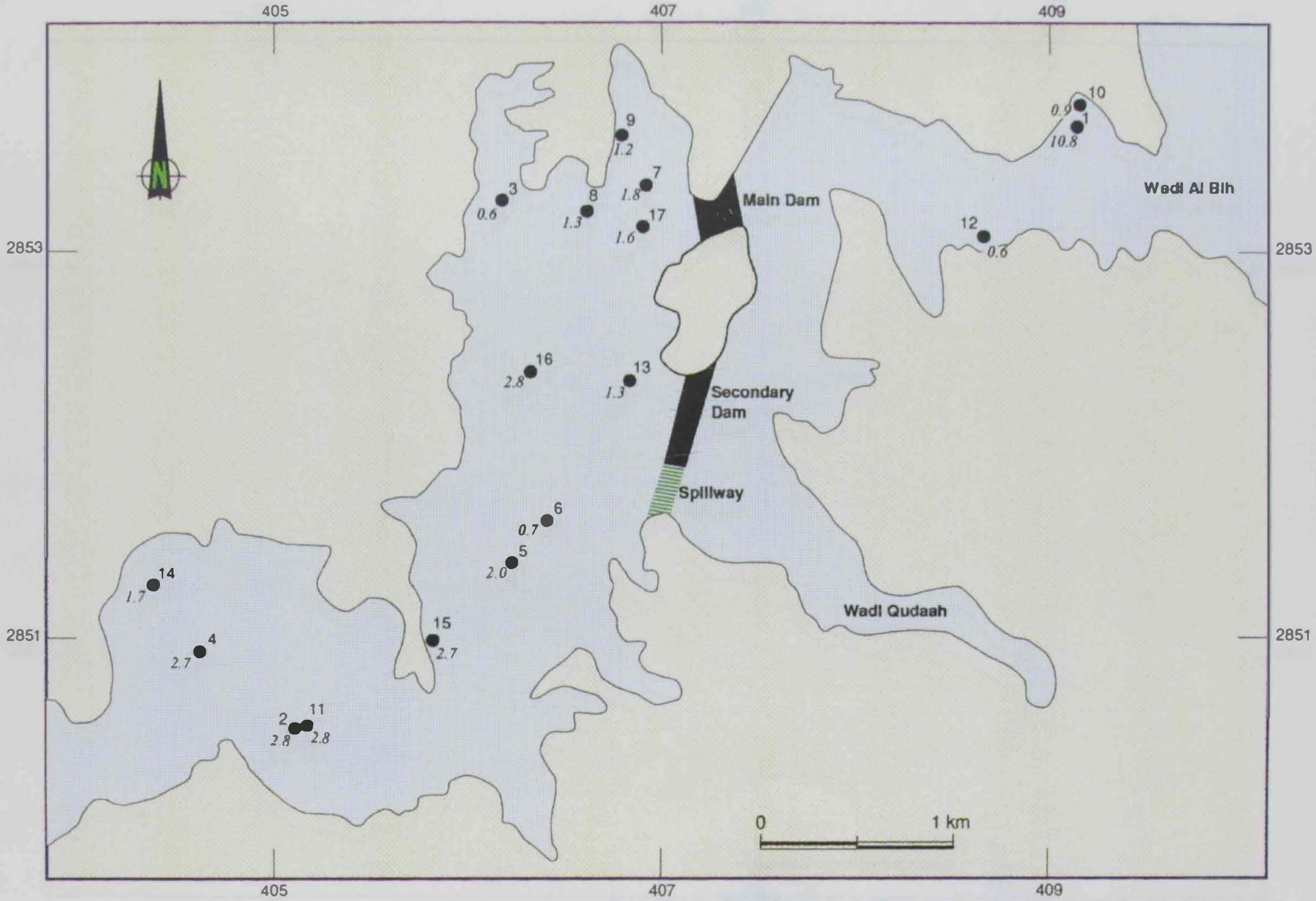

Figure 5.29 Sodium/Calcium+Magnesium Ratio in Wadi Al Bih Ground Water, September 1996.

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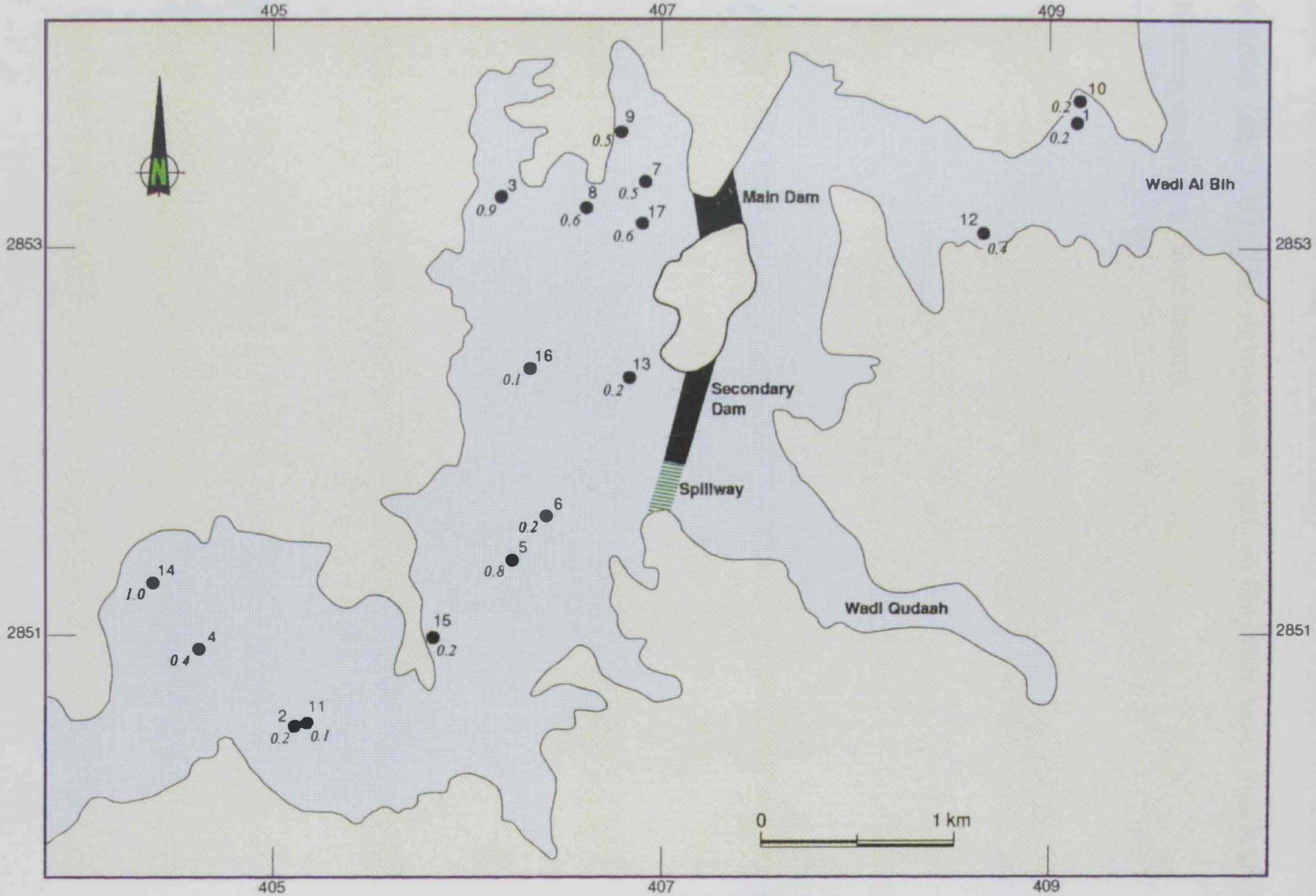

Figure 5.30 Sulphate/Chloride Ratio in Wadi Al Bih Ground Water, September 1996.

GD4472k

SAR values, the study areas were subdivided into two parts; the upstream and downstream. The upstream part is characterized by SAR values <10, a little danger from sodium (fig 5.31). The downstream part, on the other hand , has SAR values >10, indicating medium sodium hazard.

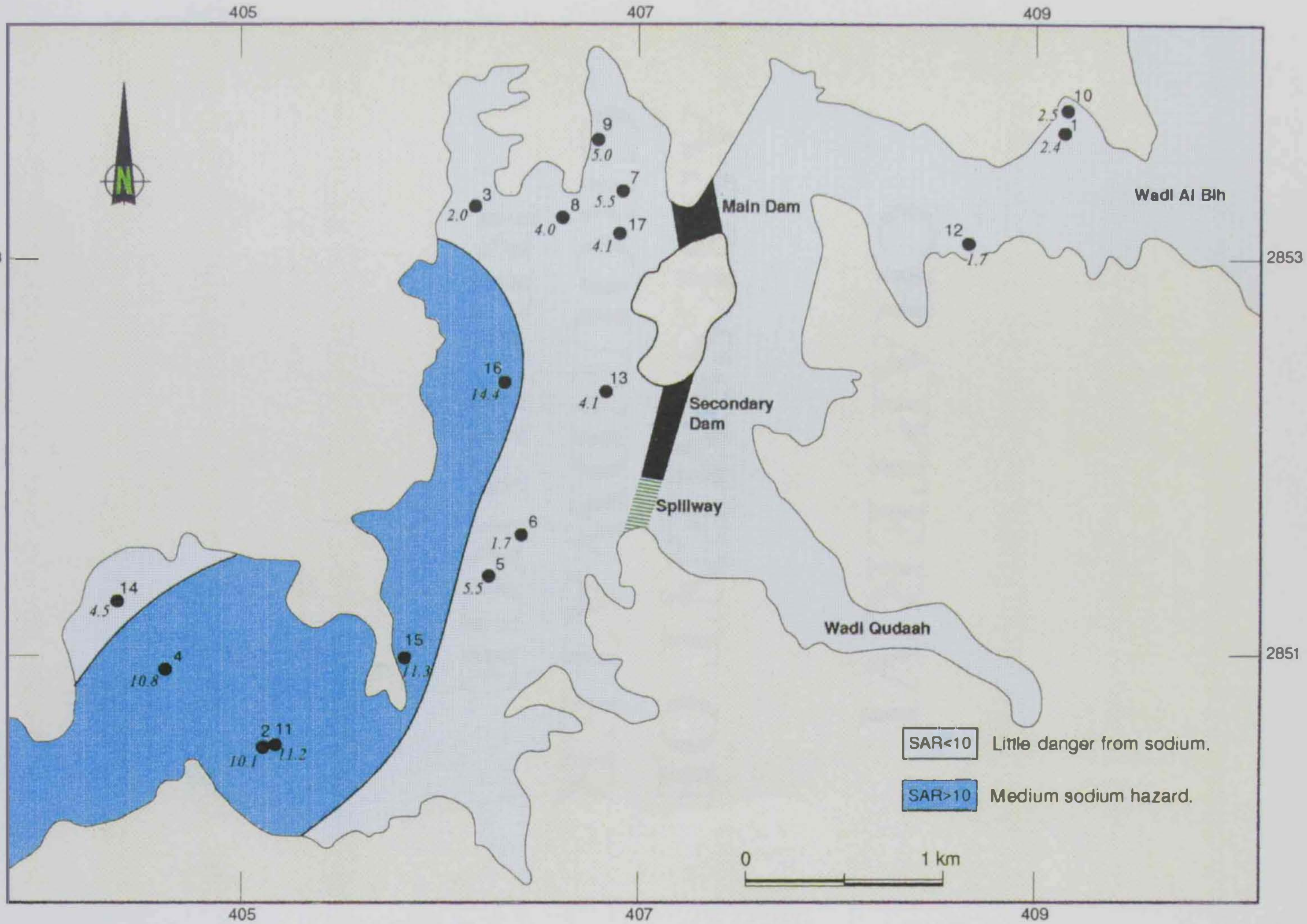

Figure 5.31 Sodium Adsorption Ratios of Wadi Al Bih Ground Water, September 1996.

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CHAPTER VI

ASSESSMENT OF GROUNDWATER RECHARGE

CHAPTER VI

ASSESSMENT OF GROUNDWATER RECHARGE

6.1 Introduction

Interpretation of the results of water chemistry, TDEM survey, and Borehole logs provide valuable evidences on groundwater recharge. However, the amount of groundwater recharge can only be estimated from the records of rainfall intensity and surface runoff, measurement of infiltration, and groundwater hydrographs. This is outside the scope of the present study.

In this chapter, the results of chemical analysis of groundwater samples, TDEM survey, and borehole logs were applied to assess groundwater recharge for Wadi Al Bih limestone aquifer.

Evidences on groundwater recharge within the study area were indicated by the seasonal changes in groundwater temperature, fluid-temperature logs, groundwater salinity, fluid-conductivity logs, and concentration of groundwater-dissolved ions. The pathways of recharge water were uncovered by the TDEM survey and borehole logs. The following is a summary of the evidences and controls on groundwater recharge in the downstream area of Wadi Al Bih basin :

6.2 Evidences of groundwater recharge

The groundwater recharge of Wadi Al Bih limestone aquifer was indicated by the seasonal change in groundwater temperature between winter (rainy) and summer (dry) seasons of 1996. Salinity decreased in April compared to September because of the groundwater dilution by low-salinity rainwater which recharges the aquifer from the upper reaches of the basin. Concentration of groundwater-dissolved ions, except bicarbonates, were also lower in April 1996 than September 1996 as a result of groundwater recharge.

6.2.1 Groundwater temperature

Al Wahedi (1996) showed that there is a seasonal variation in ground temperature of Wadi Al Bih aquifer (Fig. 6.1). In 1996, the temperature of collected groundwater samples varied between 32.8° C and 38.4° C except in one well the recorded temperature was 43.3°C., with averages of 36.1°C during the winter and 36.3°C during the summer. A noticeable decrease in ground temperature was observed in Wadi Al Bih well-fields during April. This is more likely related to groundwater recharge with rainwater which usually has a relatively lower temperature than groundwater. The steady increase in ground temperature in Wadi Al Bih basin towards the west and southwest indicates a higher salinity and lower recharge from dams in these directions.

6.2.2 Fluid-Temperature Logs

Movement of relatively cooler groundwater into boreholes was indicated by fluid-temperature logs. The sharp temperature gradient at depths of 125m in the boreholes BIH4 and BIH5, and 97m and 147m in borehole BIH6, indicates that the groundwater moves through fissures passing by these boreholes (Fig. 4.4b, 4.5b, 4.6, and 4.7b). The movements of water at depths of 97 and 141m in borehole BIH6 suggests that the groundwater in Wadi Al Bih aquifer within the study area is moving through two fracture systems.

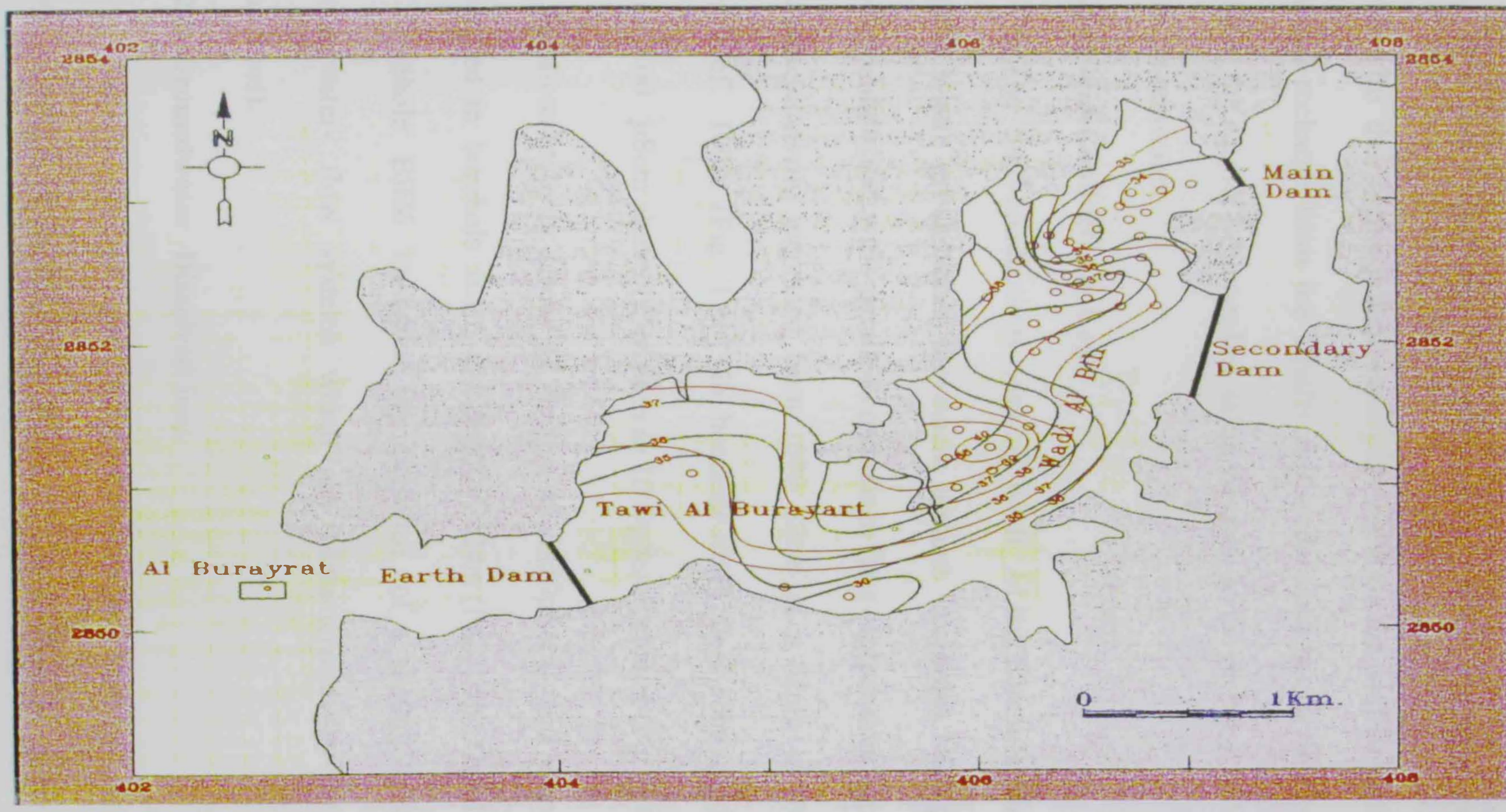

Fig. 6.1 Iso-temperature (°C) contour map of groundwater in Wadi Al Bih limestone aquifer in April (blacklines) and September (red lines)1996 (Al Wahedi, 1997)

6.2.3 Groundwater Salinity

The average TDS contents of groundwater in Wadi Al Bih aquifer increased by 28% during September 1996 compared to April of the same year (Fig. 6.2). This is related to the higher groundwater pumping from the well-fields in summer and lower natural recharge from the aquifer during the same period. In April , the groundwater within the aquifer becomes less saline because of the recharge of the aquifer with low-salinity rainwater.

6.2.4 Fluid-Conductivity Logs

The fluid-conductivity logs of Wadi Al Bih boreholes show sharp changes at depths where groundwater movement through boreholes takes place. Usually, these changes coincide with parallel contrasts in fluid-temperature logs. In borehole BIH1, fluid-conductivity increased from 1000 μScm at a depth of 90m to 1200μScm at a depth of 100m (Fig. 4.2b). In borehole BIH4, fluid-conductivity increased sharply from 800 μScm above 125m deep to 1000μScm below it (Fig. 4.4b). Parallel changes in fluid-conductivity (from 1259μScm to 1450μScm) and temperature gradient was observed in borehole BIH5 at a depth of 124m (Fig. 4.5b).The fluid-conductivity log of borehole BIH6 indicates the presence of a shallow (95m) and deep (140) groundwater- flow systems which are characterized by different conductivites (salinities).

6.2.5 Groundwater -Dissolved Ions

Except bicarbonate ions, all groundwater-dissolved ions increased in September 1996 over April of the same year (Fig. 6.3). The decrease of the ion concentrations in

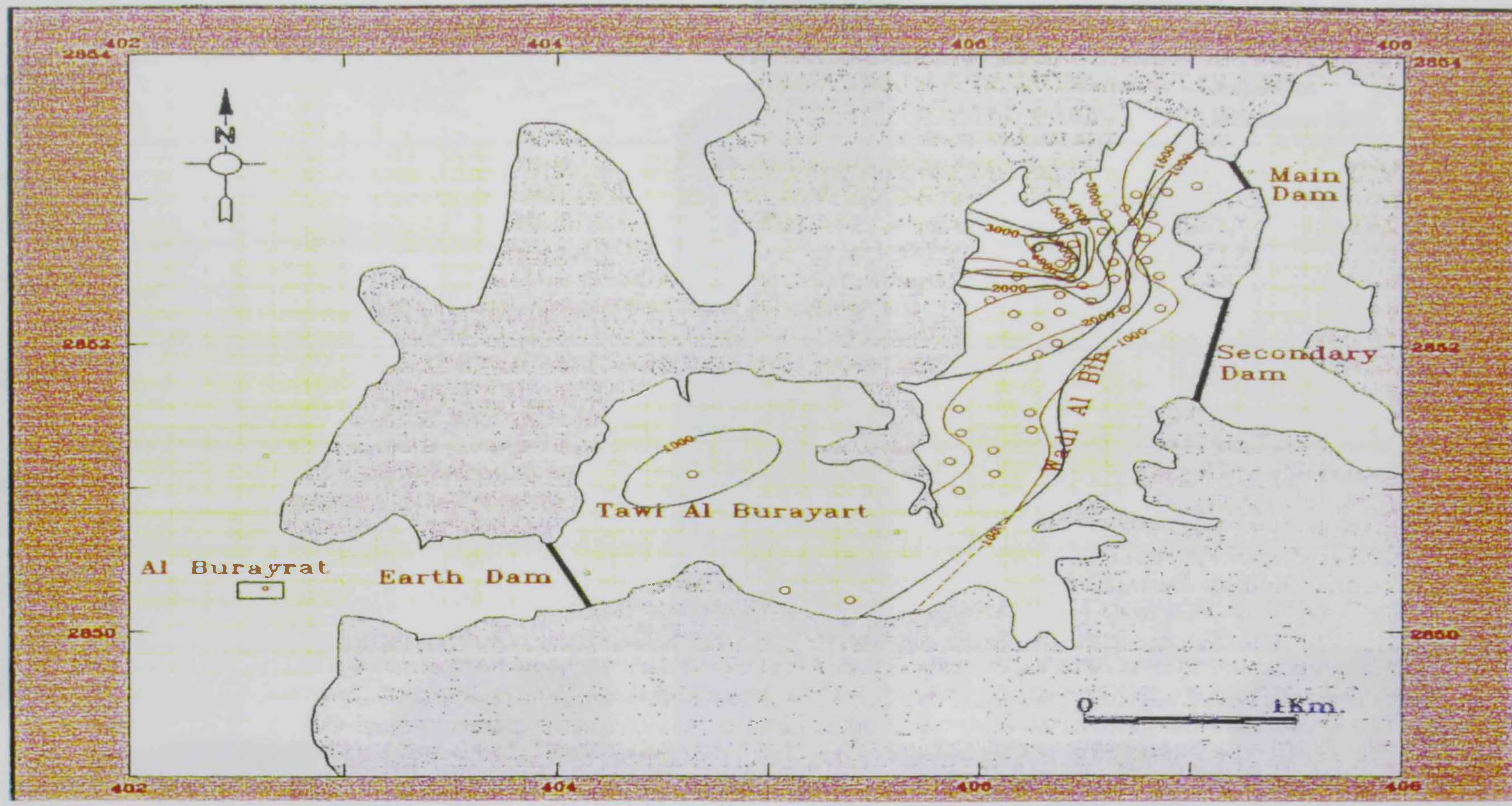

Fig. 6.2 Iso-salinity (mg/l) contour map of groundwater in Wadi Al Bih limestone aquifer in April (black lines) and September (red lines) 1996 (Al Wahedi, 1997).

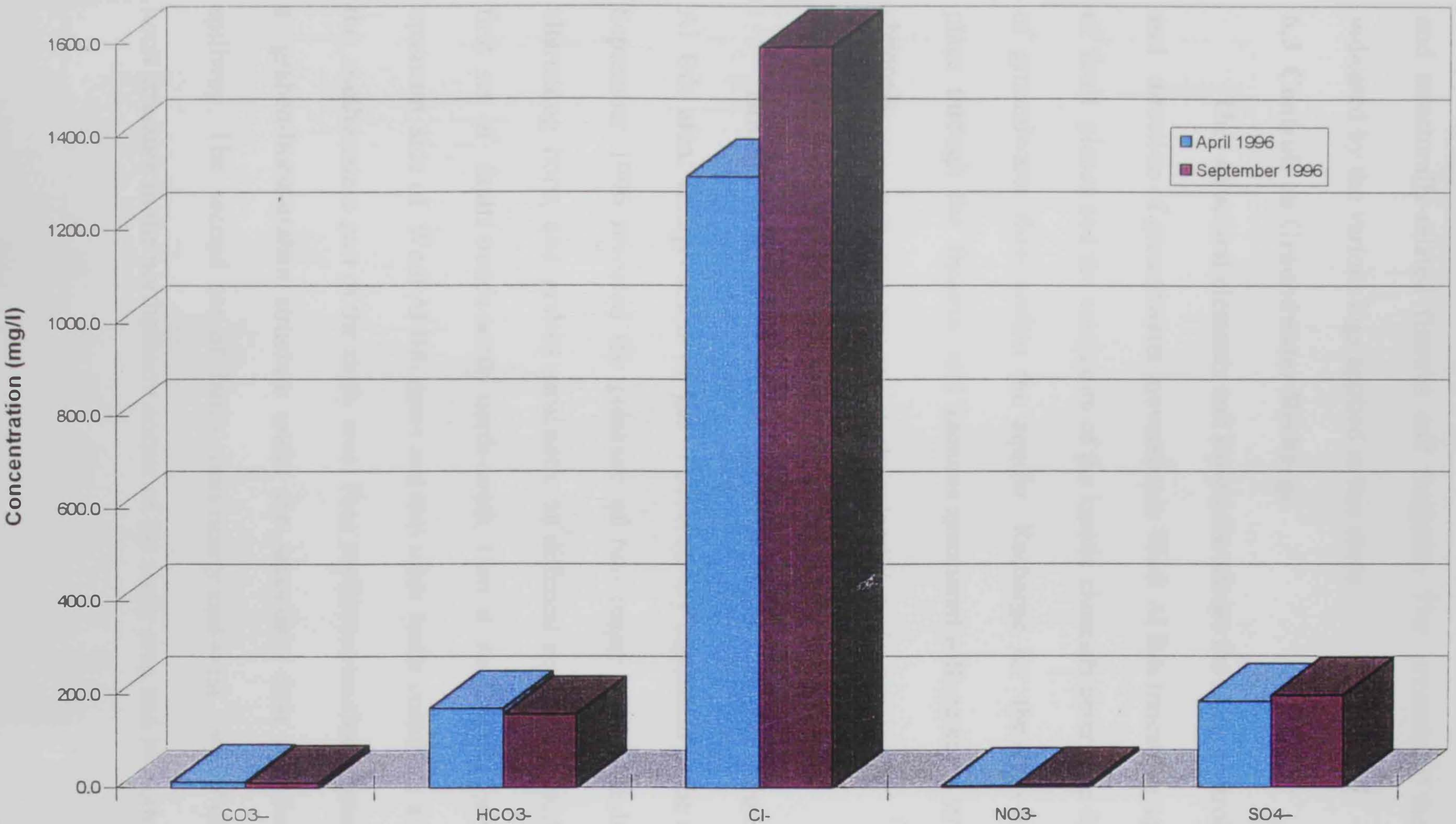

Fig. 6.3 A bar graph showing the changes in concentration of major anions in groundwater in Wadi Al Bih aquifer in April and September 1996 (Al Wahedi, 1997).

April can be related to the dilution of groundwater within the study area by lower salinity rainwater which recharges the aquifer through a complex network of karstic and structurally-related fissures and fractures. The presence of theses fractures was indicated by the various logs applied in this study.

6.3 Controls on Groundwater Recharge

The structural elements and karst network are the main controls on the capacity and direction of groundwater movement in Wadi Al Bih limestone aquifer. The nature of fault planes and the continuity of the karstic channels determine the ease and speed of groundwater flow within the aquifer. Recharge for the study area seems to take place through the fissures and fractures associated with geologic structures and karst channels.

6.3.1 Geologic Structures

Broad folding and block faulting are the main structural features affecting Wadi Al Bih area. Interpretation of the TDEM survey conducted in the study area during September 1996 revealed the presence of two major sets of faulting which form alternating horst and graben structures of different sizes and attitudes (Fig.6.4). The first set of faults trends nearly north-south. Two of these faults form a graben on the upstream side of Wadi Al Bih dams and two other faults constitute a horst structure in the southwestern part of the study area. Four northwest-southwest trending faults form a graben-horst-graben structure under the secondary dam and Southwest of the spillway. The second set of faults runs nearly east-west. Two of these faults form a horst structure in the northeastern corner of the study area and two other faults

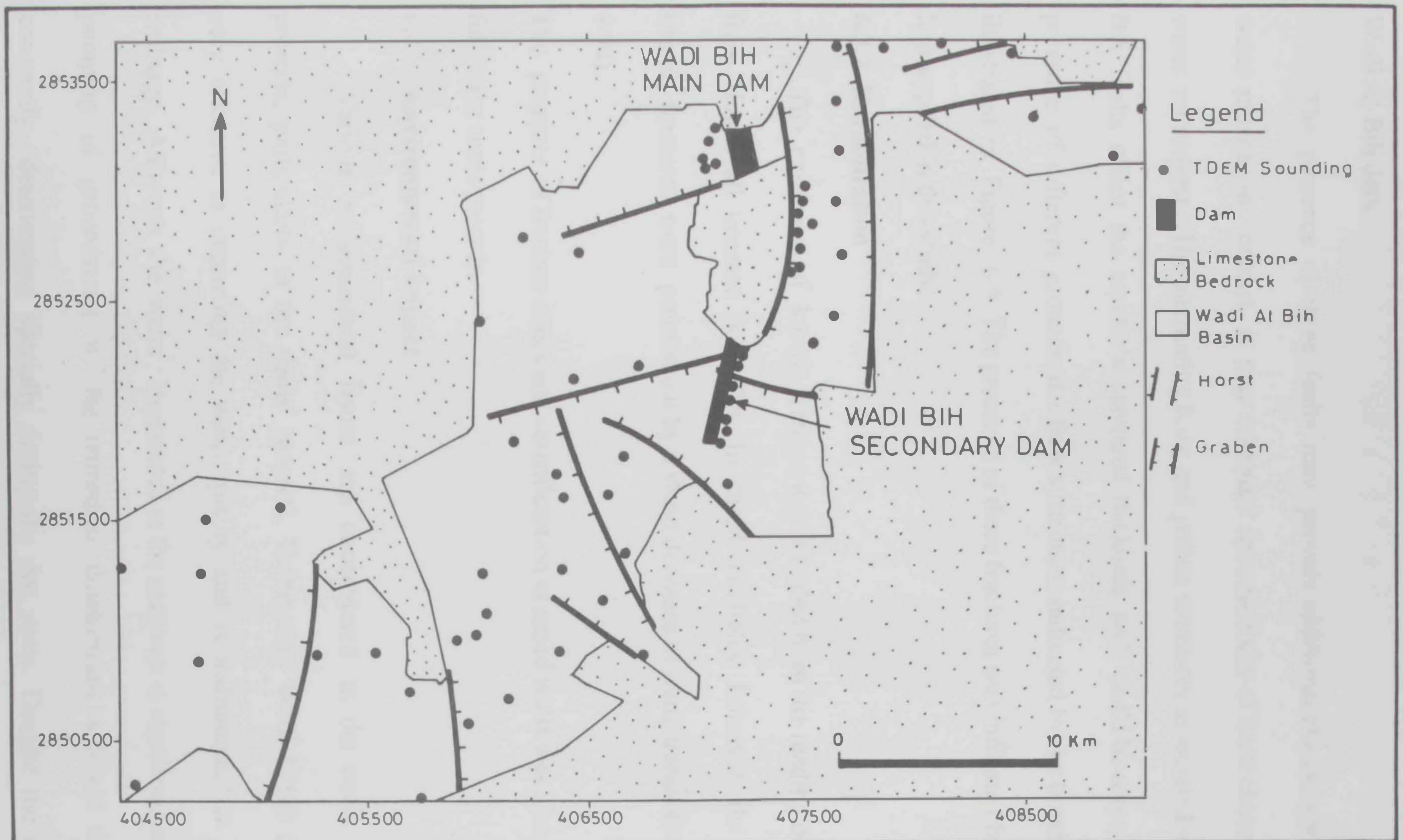

Fig. 6.4 Horst and graben structures affecting Wadi Al Bih limestone aquifer in the study area interpreted fro/m the TDEM survey.

constitute a large graben in the central part of the study area, on the western side of Wadi Al Bih dam.

The presence of these faults may provide additional channels through which water moves. In contrast, it may interrupt the continuity of karst channel and block water movement. The alternating horst and graben structures associated with Wadi Al Bih faults affect the aquifer's saturated thickness and could be responsible for the presence of different groundwater flow systems as indicated by the borehole logs and illustrated in Figure 6.5. The presence of these fractures was indicated by the various logs applied in this study.

6.3.2 Karstification

The existence of karstic features was revealed from the reading of caliper logs from almost all uncased boreholes. In cased boreholes, however, the presence of karstic fractures were pointed out by a sharp decrease in sonic transit-time (TT) (Fig. 4.9a).

The presence of fracture zones and karstificastion in cased wells was also indicated by full-wave sonic records.

6.4 Environmental Impact

Various environmental issues are encountered in the water development projects, particularly in the dams' projects. Fortunately Wadi Al Bih dam has been very effective in improving the water quality and is instrumental in groundwater recharge. Although the water impounded in the reservoir is excellent but due to over pumping of groundwater in the immediate downstream wellfield the quality is constantly deteriorating specially during the dry years. Despite the evidences of recharge presented in this study, the heavy over exploitation of the aquifer is causing a big concern. To prevent the further deterioration and to achieve a sustainable development of such aquifer, there is a need for a comprehensive study to eveluate the reservoir storage capacity and safe yield. A systematic monitoring of all the aquifer characteristics is also needed.

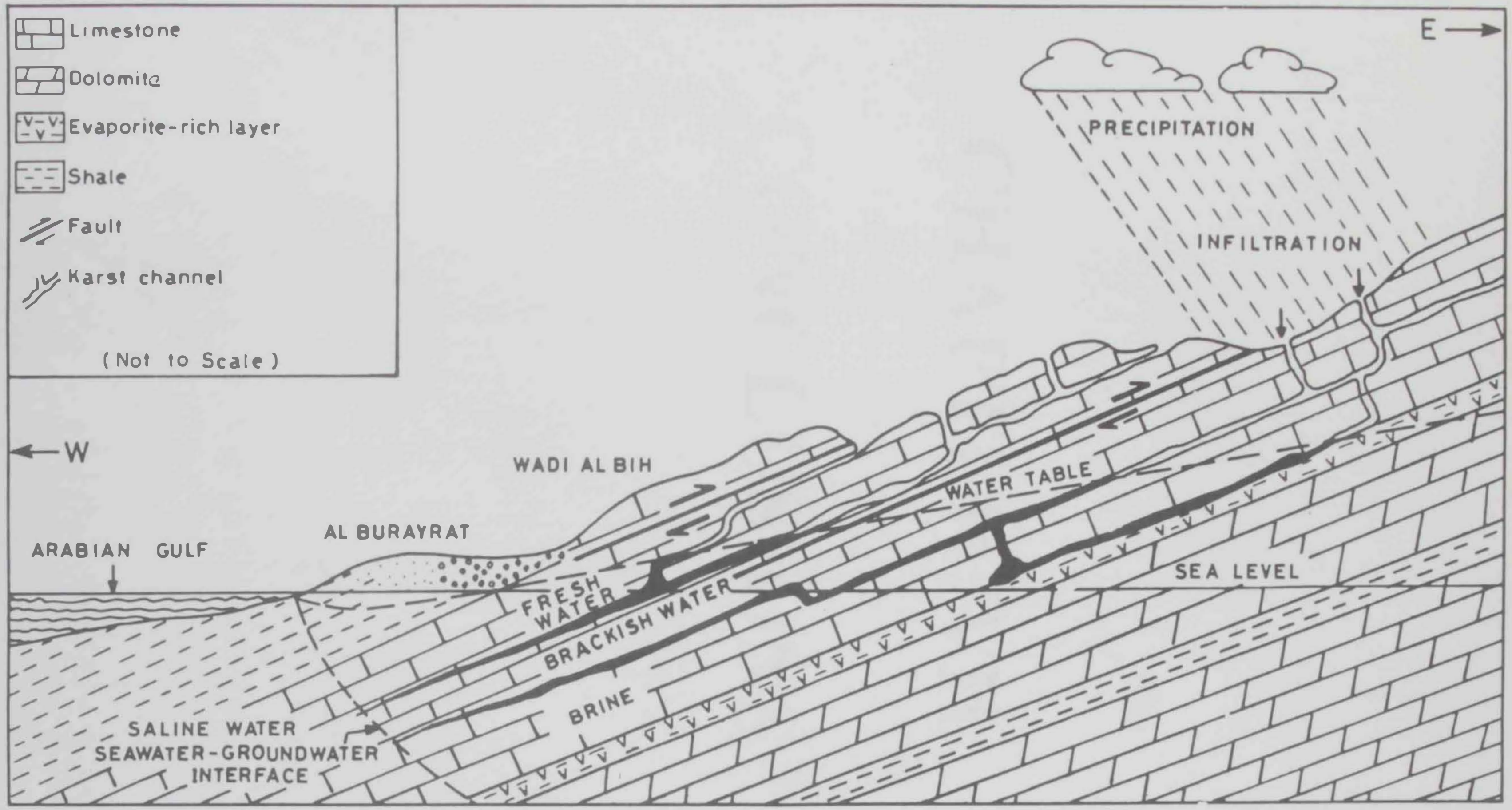

Fig. 6.5 Schematic diagram showing the hydrologic conditions of Wadi Al Bih limestone aquifer within the study area.

CHAPTER VII

CONCLUSIONS

CHAPTER VII

CONCLUSIONS

In addition to literature review, field TDEM survey, well log measurements and laboratory analysis of groundwater samples from Wadi Al Bih area in 1996, revealed the following findings:

7.1 Conclusions based on TDEM survey

a - The TDEM soundings in the Wadi Al Bih area could be interpreted by a four-layers model which, from top to bottom, are :

i - A surficial gravel of thickness varying from 4 to 72 m and averaging 16 m. The resistivity of this layer varies between 25 and 269 ohm.m and averages 104 ohm.m.

ii - Cemented gravel which is located at a depth of 53 to 134 m (average 79 m).The thickness of this layer ranges from 16 to 72 m with an average of 63 m. The resistivity of this cemented gravel is 15-475 ohm.m with an average of 225 ohm.m.

iii - Transition zone which is represented by weathered limestone. This zone occurs at a depth of 70 to 160 m. The thickness range from 2 to 101 m (average 36). The resistivities varies between 0.7 and 188 ohm.m (average 14 ohm.m). Layer 3 is the main groundwater producing horizon in Wadi Al Bih area and its thickest intervals should yield the highest amount of groundwater.

iv - The top of the Limestone bedrock layer occurs at a depth of 72 to 260 m, whereas the base was not detected. The resistivity ranges from 45 to 2411 ohm.m with an average of 925 ohm.m.

b Seven E-W, N-S, and NE-SW geoelectrical cross section constructed for the study area showed variations in thickness of different layers and the main structural elements, mainly faults, affecting these layers. These cross sections provide valuable guidance in positioning future high productive water wells.

7.2 Conclusions based on borehole logs

a -The Temperature / Conductivity log indicated the progressive increase of temperature and electrical conductivity of groundwater with depth. The log helped in the distinction of two different flow systems with different temperatures and electrical conductivity in Wadi Al Bih aquifer.

b- The three-arm caliper log indicated the presence of two major karst systems at about 100 m and 150 m deep. Waters in the shallow system (100 m) is mainly fresh whereas the water in the deep system (150) is mainly brackish.

c -Natural gamma log is an excellent indicator of the clay layers within aquifers. In Wadi Al Bih, shale intercalation were clearly identified with the gamma logs. This log can help in location of productive zone of future water wells in Wadi Al Bih area.

d - Formation density logs were used to determine the porosity of different layers. The porosity of limestone bedrock are generally low in the range of 2-10%, whereas the calculated true porosity of the transition zone (the main aquifer in Wadi Al Bih) varies between 8 and 20%.

e - Geophysical well logging revealed that the upper unit consists of limestone gravels (70%) and boulders (30%). The second layer consists of cemented gravel with about 30% clays.

7.3 Conclusions based on hydrochemical investigations

a - The average groundwater temperature in Wadi Al Bih aquifer in 1996 varied between 32.8°C and 38.4°C with averages of 36.1°C during winter and 36.3°C in summer. The noticeable decrease in groundwater temperatures during winter may indicate that the aquifer is recharging with low-temperature rainwaters falling on the upper reaches of the basin.

b - The hydraulic heads in Wadi Al Bih aquifer decreases from 28 metres above mean sea level in the upstream of Wadi Al Bih dams in the east to -5 m at Burayrat area in the west, indicating that the groundwater movement is taking place from Ru'us Al Jibal mountains in the east to the Arabian Gulf in the west.

c - The iso-electrical conductivity contour map of Wadi Al Bih groundwater shows a steady increase in the electrical conductivity (EC) from east to west in the direction of groundwater flow. The EC increased from <750μ S/cm in the east to > 5000 μS/cm/cm in the west. This indicated a parallel increse in groundwater salinity in the same direction.

d - The concentrations of all major ions except HCO_3^- show the same trend as EC and salinity. Concentrations of Ca^{2+}, Mg^{2+}, Na^+, K^+, SO_4^{2-}, and Cl^- increased from east to west in the direction of groundwater flow. Local increases in Na^+ and Cl^- ions are related to excessive groundwater pumping from well fields which induce high salinity brine in the deeper horizons of the aquifer to move upward " upconing" and entrapped within the cones of depressions created by well fields.

e - The concentration of trace elements Cr, Co, Zn, Mn, Cd, Ni and Sr, in the groundwater of Wadi Al Bih aquifer are below the WHO (1983) recommended limits for drinking water. In contrast, the concentrations of Fe and Pb are variable and in some areas are above the WHO limits for drinking water.

f - The calculated groundwater-dissolved salts are $Ca(HCO_3)_2$ in the eastern part of Wadi Al Bih basin $CaSO_4$ and $MgSO_4$ in the central part and $MgCl_2$ and NaCl in the western part of the basin. The presence of the HCO_3^- salts in the eastern part of the basin indicates the influence of groundwater recharge, whereas the dominance of Cl^- salts in the western part refelects the the influence of saltwater intrusion into the aquifer from the Arabian Gulf in this area.

g - The hydrochemical coefficients Cl / (CO_3+ HCO_3), NaCl, Na /(Ca+Mg),

and SO_4 /Cl were calculated for groundwater in Wadi Al Bih aquifer. The Cl / (CO_3+HCO_3) and Na / Cl indicate saline-water intrusion in most of the study area. However, the source of this saline water seems to be different in the east than in the west. The saline-water intrusion in the eastern part of the study area is related to upconing of high-salinity brine from deeper horizon in the aquifer whereas the sources of salinity in the is related to saline-water encroachment from the Arabian Gulf.

h - The calculated SAR values show that the groundwater in the eastern part of the study area has a little sodium hazard (SAR < 10) whereas the groundwater of the western part has a medium sodium hazard (SAR>10) when used for irrigation.

7.4 Conclusions Based On The Assessment Of Groundwater Recharge

a. Evidence of groundwater recharge in Wadi Al Bih aquifer were indicated by : (i) seasonal change in groundwater temperature, salinity and concentration of major and minor ions, (ii) fluid temperature logs and (iii) fluid conductivity logs.

b. The main controls on groundwater recharge for Wadi Al Bih aquifer are the geologic structures, represented by a set of horsts and grabens which influence both aquifer thickness and groundwater flow, and the presence of karstification. The karst channels represent the main conduits for fluid flow and minimize the time available for water - rock interaction, resulting in a good-quality groundwater. As indicated earlier, two karst systems were detected within the study area at depths of about 100 and 150 m below ground surface.

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APPENDIX
A

APPENDIX

A

Hydrogeochemical data of Wadi Al Bih limestone aquifer, September 1996.

TABLE A1

Results of chemical analysis of groundwater sample collected from Wadi Al Bih limestone aquifer in September 1996 (major ions)

Location	Date	Time	Sample No.	EC mmhos	pH	Cations (mg/l)				Anions (mg/l)			
						Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Cl^{-}	CO_3	HCO_3	SO_3
HAAH BH1	25-09-96	1800	1	0.891	7.50	2.6	2.2	03.7	0.10	04.6	--	03.0	01.00
AMH BH 1	26-09-96	0945	2	02.57	7.67	3.6	3.0	18.4	0.21	19.0	--	03.2	03.01
SF BH 1	25-09-96	1244	3	0.964	7.67	3.2	2.8	03.5	0.13	04.0	--	03.0	03.63
SAR BH 1	26-09-96	0900	4	02.89	7.54	4.2	3.8	21.5	0.26	20.4	--	03.0	07.36
MEW - BNOB4	26-09-96	1718	5	01.20	7.74	2.2	1.6	07.6	014.	05.6	--	03.1	04.74
MEW- BNOB3	26-09-96	1750	6	0.526	7.89	1.6	1.4	02.1	0.08	02.4	--	02.2	00.58
SSF BH 1	25-09-96	1110	7	01.28	7.75	2.4	2.2	08.3	0.13	07.0	–	02.2	03.83
SSF BH 2	25-09-96	1220	8	01.10	7.69	3.0	1.6	06.1.	0.13	06.0	--	03.0	03.83
SSF BH 3	25-09-96	1150	9	01.87	7.66	4.8	3.4	10.2	0.22	10.0	--	03.2	05.42
HAAH BH2	25-09-96	1818	10	0.713	7.79	2.0	1.6	03.3	0.10	04.6	--	02.2	00.08
RMH BH1	26-09-96	0930	11	03.16	7.52	5.0	3.0	22.4	0.26	24.0	--	03.4	03.26
SAH BH 1	25-09-96	1740	12	0.679	7.72	2.4	1.6	02.4	0.10	02.6	--	02.8	01.10
MEW BH 24	26-09-96	1620	13	01.28	7.91	3.4	2.0	06.8	0.14	07.0	--	04.1	01.24
DW1	26-09-96	1500	14	0.933	7.80	2.2	1.4	06.1	0.22	04.4	--	01.0	04.41
MEW 38	26-09-96	1005	15	03.37	7.65	5.2	3.8	24.0	0.16	24.0	--	04.2	05.06
MEW 10	26-09-96	1027	16	05.11	7.50	7.6	5.5	36.8	0.38	43.6	--	02.8	03.88
MEW BH 1	25-09-96	1720	17	0.906	7.85	2.4	1.0	05.3	0.10	05.6	--	04.0	03.20

TABLE A2

Results of chemical analysis of groundwater samples collected from Wadi Al Bih limestone aquifer, September 1996 (trace metals).

Sample # (mg/l)	Sr (mg/l)	Cr (mg/l)	Mn (mg/l)	Zn (mg/l)	Cu (mg/l)	Fe (mg/l)	Pb (mg/l)	Co (mg/l)	Ni (mg/l)	Cd (mg/l)
1	1.767	0.025	0.004	0.191	0.002	0.423	0.058	0.004	0.059	0.003
2	2.527	0.019	0.008	0.202	0.000	0.249	0.066	0.016	0.025	0.012
3	2.397	0.007	0.003	0.208	0.005	0.052	0.020	0.003	0.008	0.001
4	2.795	0.010	0.004	0.190	0.003	0.608	0.054	0.024	0.019	0.005
5	1.676	0.012	0.006	0.187	0.001	0.216	0.029	0.004	0.036	0.001
6	2.074	0.001	0.002	0.191	0.001	0.192	0.022	0.013	0.026	0.001
7	1.485	0.012	0.007	0.194	0.006	0.151	0.040	0.022	0.005	0.001
8	1.681	0.015	0.005	0.198	0.008	0.231	0.074	0.006	0.035	0.009
9	2.813	0.023	0.007	0.196	0.007	0.614	0.008	0.018	0.015	0.009
10	1.115	0.036	0.002	0.007	0.000	0.263	0.133	0.001	0.026	0.002
11	2.990	0.028	0.003	0.157	0.004	0.193	0.129	0.056	0.146	0.001
12	1.205	0.018	0.003	0.002	0.002	0.190	0.068	0.018	0.037	0.002
13	2.210	0.005	0.006	0.032	0.002	0.322	0.002	0.013	0.015	0.001
14	1.397	0.027	0.005	0.008	0.001	0.262	0.068	0.012	0.015	0.002
15	3.204	0.042	0.002	0.092	0.003	0.333	0.098	0.019	0.088	0.008
16	4.927	0.022	0.000	0.062	0.005	0.206	0.174	0.027	0.160	0.015
17	1.038	0.013	0.001	0.032	0.004	0.164	0.077	0.006	0.119	0.002

TABLE A3

Calculated hydrochemical ratios for Wadi Al Bih groundwater in September 1996.

Sample #	Ca/Mg	Na/Cl	SO_4/Cl	Cl/(CO_3+ HCO_3	Cl/SO_4	Na/(Ca + Hg)
1	1.2	0.8	0.2	1.5	4.6	0.8
2	1.2	1.0	0.2	5.9	6.3	2.8
3	1.1	0.9	0.9	1.3	1.1	0.6
4	1.1	1.1	0.4	6.8	2.8	2.7
5	1.4	1.4	0.8	1.8	1.2	2.0
6	1.1	0.9	0.2	1.1	4.1	0.7
7	1.1	1.2	0.5	3.2	1.8	1.8
8	1.9	1.0	0.6	2.0	1.6	1.3
9	1.4	1.0	0.5	3.1	1.8	1.2
10	1.3	0.8	0.2	1.8	5.0	0.9
11	1.7	0.9	0.1	7.1	7.4	2.8
12	1.5	0.9	0.4	0.9	2.4	0.6
13	1.7	1.0	0.2	1.7	5.6	1.3
14	1.6	1.4	1.0	4.4	1.0	1.7
15	1.4	1.0	0.2	5.7	4.7	2.7
16	1.4	0.8	0.1	15.6	11.2	2.8
17	2.4	0.9	0.6	1.4	1.8	1.6

TABLE A4

Calculated groundwater-dissolved salts of Wadi Al Bih aquifer in September 1996.

Sample #	KCl	NaCl	$MgCl_2$	$CaCl_2$	K_2SO_4	Na_2SO_4	$MgSO_4$	$CaSO_4$	$Ca(HCO_3)_2$
1	0.5	34	31	0.	0.	0.	8	3	24.6
2	0.4	65	17	0.	0.	0.	3	7	8.1
3	0.6	28	19	0.	0.	0.	23	9	20.7
4	0.5	64	10	0.	0.	0.	12	8	6.3
5	0.6	51	0	0.	0.	7	23	3	16.5
6	0.7	32	26	0.	0.	0.	10	0	27.6
7	0.5	54	8	0.	0.	0.	19	7	11.5
8	0.6	48	8	0.	0.	0.	16	11	16.4
9	0.6	46	17	0.	0.	0.	12	13	11.7
10	0.7	38	29	0.	0.	0.	6	5	21.8
11	0.5	66	17	17	0.	0.	0	0	0.0
12	0.7	29	22	0.	0.	0.	15	1	32.2
13	0.6	47	21	0.	0.	0.	5	4	23.1
14	1.1	52	0	0.	0.	1	23	15	7.0
15	0.4	64	15	0.	0.	0.	5	8	8.1
16	0.4	66	19	16	0.	0.	0	0	0.0
17	0.6	53	1	0.	0.	0.	18	5	22.6

TABLE A5

Calculated sodium adsorption ratio (SAR) for groundwater samples collected from Wadi Al Bih limestone aquifer in September 1996.

Sample #	SAR	Ajusted SAR
1	2.4	4.7
2	10.1	20.8
3	2.0	4.2
4	10.8	22.6
5	5.5	10.4
6	1.7	3.0
7	5.5	9.9
8	4.0	7.9
9	5.0	10.9
10	2.5	4.3
11	11.2	23.9
12	1.7	3.3
13	4.1	8.9
14	4.5	6.2
15	11.3	25.5
16	14.4	31.4
17	4.1	7.9

ARABIC SUMMARY

عن تلك المعدلات . وتعتبر الأملاح الذائبة السائدة في إتجاه المنبع هي بيكربونات الكالسيوم وفي المنطقة الوسطى من الوادي تسود أملاح كبريتات الكالسيوم والمغنيوم بينما في منطقة المصب يسود كلوريد الصوديوم ، مما يؤكد التأثير الإيجابي لإعادة شحن الخزان بالمياه في أتجاه الشرق وتأثير تداخل المياه المالحة في الخزان نحو الغرب . وتؤكد نسبة أيون الكلور / أيون الصوديوم وجود تداخل للمياه المالحة العميقة على هيئة مخروط مقلوب تحت حقل آبار وزارة الكهرباء والمياه وكذا تداخل مياه البحر في أتجاه الغرب عند المصب على أن القيم المحسوبة لمعامل إدمتصاص الصوديوم الـ ý(SAR) تدل على خطورة منخفضة لأيون الصوديوم بمياه الجزء الشرقي من الوادي ، مما يعني صلاحية المياه للري ، ترتفع الى خطورة متوسطة في الجزء الغربي .

هذا وقد استدل على فاعليه السد في تغذية الخزان من واقع التغير الفصلي لحرارة المياه الجوفية والملوحة التي أظهرهما التحاليل الكيميائية للمياه الجوفية بالإضافة إلى التسجيلات البئرية لحرارة الموائع ودرجة توصيلها . كما أوضحت نتائج الدراسة أن التراكيب الجيولوجية وفجوات الإذابة تحت السطحية في الصخور الجيرية المكونة للخزان الجوفي في منطقة وادي البيح يمثلان أهم العوامل التي تحكم حركة وإعادة تغذية المياه الجوفية .

وتعتبر الطبقة الثالثة أهم مصدر للمياه الجوفية في منطقة وادي البيح حيث توجد أكبر كميات من المياه خصوصا في المناطق التي يزيد فيها سمك هذه الطبقة .

أما الطبقة الرابعة فقيم المقاومة فيها عالية حيث تزيد في عمومها عن (٥٠٠ أوم . متر) وتضاهي هذه القيم مقاومات الحجر الجيري الصلد .

هذا وقد أجريت تسجيلات بئرية من أنواع مختلفة بغية الوصول إلى مفاهيم مفصلة عن الطبيعة الصخرية للطبقات ومساميتها وما بها من فواصل وشقوق تسهل سريان المياه وكذا معلومات عن طبيعة المياه الجوفية ومساراتها . وقد تلخصت نتائج السجلات البئرية لكل من مقياس إتساع فوهة البئر والمقاومة النوعية العميقة والمقياس الصوتي والنيوترون والكثافة والتدرج الحراري وكذا درجة توصيل الموانع والمجل الجامي في النقاط التالية :-

١- بالنسبة للطبقة السطحية فإنها تتكون من رسوبيات من خليط من الجلاميد بنسبة ٣٠% ورواسب حصوية مفككة بنسبة ٧٠% . ويظهر مقياس اتساع فوهة البئر أمام هذه الطبقة تغييرات متواتره دلالة على الطبيعة المفككة لهذا التكوين الصخري .

٢- أما بالنسبة للطبقة الثانية فهي تتكون من نفس الرواسب التي تلتصق حبيباتها بمواد طينية بواقع ٣٠% بالحجم حيث أستدل على ذلك من السجل الجامي .

٣- يلي ذلك نطاق ترتفع فيه المقاومة نسبيا وتحتوى هذه الطبقة على حصى مشتق من صخور الأفيوليت والحجر الجيري ويطلق عليها النطاق الأنتقالي . هذا وقد قدرت مسامية هذا النطاق المشبع فوجد أنها تقع ما بين ٨% ، ٢٥% .

٤- من واقع بيانات سجل إتساع فوهة البئر تم التعرف على نطاقات تحوي شقوق وفجوات في الصخور على أعماق ١٠٠ متر ، ١٥٠ متر تقريبا، حيث تسري المياه الجوفية المختلفة الخواص والملوحة فيما بين نطاقات التكسير هذه وهو ما تأكد من نتائج سجل التدرج الحراري وسجل درجة توصيل الموانع أمام تلك الشقوق والفجوات .

وفيما يتعلق بمنسوب المياه الجوفية أثناء سبتمبر ١٩٩٦م في خزان وادي البيح فانه يتفاوت ما بين ٢٧ متر فوق مستوى سطح البحر في الجانب الشرقي من السد و١٩ متر فوق مستوى سطح البحر في حقل الآبار التابع لوزارة الكهرباء والماء والواقع غرب السد بسبب الضخ الكثير من الحقل . وتظهر التحاليل الدورية لعينات المياه زيادة مضطردة في تركيز الأيونات (أي في الملوحة) ما عدا أيون البيكربونات وذلك من الشرق إلى الغرب في اتجاه سريان المياه . هذا ويعتبر تركيز الكروم والكوبالت والزنك والمنجنيز والكادميوم والنيكل والإسترانشيوم في عينات المياه التي تم تحليلها تحت معدلات منظمة الصحة العالمية ودول مجلس التعاون والخاصة بمياه الشرب - ومن ناحية أخرى فإن تركيز كل من الحديد والرصاص تزيد قليلا

الخلاصة

تشكل المياه الجوفية في منطقة وادي البيح المصدر الرئيسي لمياه الري والشرب والإستخدامات المنزلية في إمارة رأس الخيمة بدولة الأمارات العربية المتحدة . وبسبب النمو السكاني المضطرد في هذه الإمارة تطلب الأمر زيادة الضخ من المياه الجوفية في تلك المنطقة ، الأمر الذي أدى إلى إختلال التوازن المائي ما بين الكمية المطلوبة للإستهلاك السنوي لسكان المنطقة ومعدل إعادة الشحن الطبيعي لهذا الخزان الجوفي . وكمحاولة لاعادة التوازن المائي وتحسين نوعية المياه الجوفية في ذلك الوادي تم تنفيذ سد وادي البيح في بداية الثمانينات .

وتهدف الدراسة الحالية إلى فحص وإستقصاء صفات الخزان الجوفي الجيري لوادي البيح وتقييم خواصه الهيدروكيميائية من جهة ثم تقدير مدى تأثير سد وادي البيح في إعادة شحن الخزان الجوفي من جهه أخرى . وقد استخدمت لتحقيق هذا الغرض تقنيات جيوفيزيائية مثل المجال الكهرومغناطيسي وتسجيلات الآبار و تقنيات هيدروكيميائية وهيدروجيولوجية .

وقد أوضحت نتائج دراسة المجال الكهرومغناطيسي في مواقع الجسات المختلفة عن وجود أربعة طبقات تحت سطحية لذلك الخزان . تتميز الطبقة السطحية الأولى بمقاومة كهربية أعلى من (٤٠ أوم . متر) وسمك يتراوح بين (١٥-٢٠ متراً) على أمتداد منطقة الدراسة حيث تمثل هذه الخواص خزاناً جيداً بيد أن هذه الطبقة تقع فوق المستوى العام للماء الجوفي وهي بالتالي غير مشبعة بالمياه . أما السبب في إنخفاض مقاومتها الكهربية فيعود للنسبة العالية للطفلة التي توجد على هيئة طبقات رقيقة تمنع تسرب المياه إلى أسفل . وتدل قيم المقاومة أيضاً على أن هذه الطبقة تتكون من رسوبيات حصوية مفككة . أما الطبقة الثانية فتتميز بإختلافات كبيرة في مقاومتها الكهربائية حيث تتراوح قيم المقاومة ما بين (١٥-٤٧٠ أوم . متر) وتفسر هذه المقاومات بأنها نتاج طبقة مكونة من رسوبيات حصوية ملتصقة ومتماسكة حيث تمثل الأجزاء المنخفضة المقاومة إزدياداً في نسبة المواد الطينية أو الطفلية فيها وهذه الطبقة أكبرسمكاً من الأولى حيث يصل سمكها الى ٦٣ متراً تقريباً في المتوسط. هذا ويقع الجزء السفلى لهذا الطبقة تحت مستوى سطح الماء الجوفي .

وتعمل المناطق التي بها نسبة عالية من الطفلة وكذا المناطق التي تتماسك فيها الرسوبيات الحصوية بدرجة عالية على إعاقة تسرب وتخلل مياه الفيضانات في هذه المناطق إلى أسفل لتصل إلى الخزان الجوفي . أما الطبقة الثالثة فيتراوح سمكها ما بين٥ إلى٩٥ متراً ويأخذ سطح الطبقة السفلى نفس طوبوغرافية سطح الطبقة التي تليها إلى أسفل وهي متأثرة بها إلىحدكبير .وتبلغ المقاومة النوعية في هذه الطبقة ما بين (٥-٢٠ أوم.متر) حيث تمثل نطاقاً إنتقالياً بين رواسب الوديان والحجر الجيري في الطبقة الرابعة والمكون لصخر الأساس لهذا الوادي .

تطبيق التقنيات الجيوفيزيائية والهيدروكيميائية لتقييم تغذية المياه الجوفية بواسطة سدود وادي البيح ، رأس الخيمة ، الإمارات العربية المتحدة

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(١٩٨١)

رسالة مقدمة الى

كلية العلوم – جامعة الإمارات العربية المتحدة

لأستكمال متطلبات الحصول على درجة الماجستير

في علوم البيئة

كلية العلوم

جامعة الإمارات العربية المتحدة

ديسمبر ١٩٩٧م