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Quantitative and Qualitative Assessment of Groundwater Resources in Al-Khatim Area, UAE

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United Arab Emirates University
College of Graduate Studies

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A Thesis submitted to
College of Graduate Studies
United Arab Emirates University

By
Ahmed Khaled Othman

In partial fulfillment of the requirements for the
M.Sc Degree in Water Resources

College of Graduate Studies
United Arab Emirates University
January 2005

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Thesis Title

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Acknowledgement

After great thanks to Allah, it is my pleasure to acknowledge my thanks to my mother, wife, children, and the rest of my family who offered me help and support and provided the inspiration for me not only through the course of this study but also throughout my life. I owe them my utmost gratitude for their endurance and understanding.

My greatest appreciation goes to my advisors Prof. Mohsen Sherif, Professor of Water Resources and Coordinator of the Water Resources Master Program, College of Engineering, UAE University, and Dr. Abdel-Azim Ebraheem, Senior Researcher, Ministry of Agriculture and Fisheries, for their graciousness, expertise, generosity and help to complete this thesis in its current form.

My utmost gratitude is due to Dr. Hasan Garamoon, College of Science, for his valuable advice, patience encouragement, and continuous support throughout the study. His contribution in the analyses and discussions of the hydrogeochemical properties of the groundwater was vital.

Appreciation is due to Dr. Reyadh Almuhaideb, Vice Dean, College of Engineering and former Coordinator of Water Resources Master Program, who provided all the needed support and help. Thanks are due to Dr. Tareq AL Zabet, Dr. Ahmed EL-Bershamgy, and Dr. Mohammed Obaid for their support and help during the early stage of my study. Thanks are also due to all my teachers in the M.Sc Program whom have been very helpful.

My sincere thanks and appreciation are due to Eng. Abdulhamed Mohammed, Mahmood Moshref, Nabel Al-Samadi, and all the staff of Al-Khatim municipality for there help and support. They provide many useful information.

I am very much grateful to all the staff of Agriculture Laboratory, Abu Dhabi Municipality especially, Eng. Salem Al-Shikaly, Dr. Jalol, and Eng. Homaid Khamees for conducting chemical analysis of the water sample collected in this study.

My thanks are due to Mr. Mohammed Saqar Al-Assam, Assistant Deputy Minister, Ministry of Agriculture and Fisheries and to the technical staff of the soil and water central laboratory in Al-Ain.

Many other people contributed in some way or the other in this work. The support and help of Rashid Al-Kindi, Hamdi qandeel, Abdulmunem Al-Marshodi, Dr. Esmaeel Al-Hosani, Mohammed Saleh, CLU staff, Waleed Nasser, Ahmed Al-Hanai, Ali Abdullah, Mohammed Al-Shmsi, Mubarak Bin-Madi, Abdulmajed Al-Faqeh, Jamal Khaled, Adel Shaya, Mohammed Talab, Mohammed Hanafi, and Tyseer Al-Saidi are very much appreciated. This thesis would have not been completed in this form without their sincere support.

Abstract

The UAE has achieved remarkable progress in transformation from separated small emirates to a modern union country with a high standard of living. The country is however, considered an extreme arid region.

In spite of these harsh conditions, The UAE government has encouraged plantation in towns, villages and country side. This has led to sharp increase in the agricultural sector particularly during the last three decades. As the irrigated land kept increasing, there was a deep concern about the water demand and the impact of agriculture activities on groundwater systems. Al-Khatim area is considered one of the most important agricultural areas in Abu-Dhabi emirate with 1300 farms covering an area of 2405 ha that has been affected by the decline in groundwater levels over the last years. Additionally the groundwater salinity has increased to 33,000 µ places.

The main objective of this study is to assess the quantity and quality of groundwater in AL-Khatim area as an example of the effect of groundwater pumping and agriculture activities on the shallow aquifer. To achieve this aim, previous studies and investigations were reviewed. The required information and data about geology, hydrology, hydrogeology, and hydrochemistry were gathered and several tests have been conducted to evaluate the groundwater conditions in Al-Khatim area.

Well lithologies were drawn using Ground Water software for Windows (GWW) program from 19 newly drilled wells. From these wells several cross sections were developed. The Digital Elevation Model (DEM), developed by USGS, was used to draw elevation map for the study area. Measurements of water depth throughout the study area were conducted which were then used to draw contour maps of water level. The contour maps of water levels were presented for the years 1997, 1999, 2002, and 2003 to elaborate the drop in the water levels over the time.

The shallow unconfined aquifer in the study area was investigated by applying 2 step drawdown tests and 42 continues pumping tests. All data collected from these tests were evaluated using GWW program. The Transmisivity and Storativity of the aquifer in the study area were evaluated.

Two 2D resistivity profiles were conducted and oriented along the strike direction to intersect the maximum possible number of geologic features. The subsurface profiles were evaluated using a single channel Memory Earth Resistivity and IP Meter. Each profile consisted of 36 electrodes spaced 10 m apart which penetrate to about 60m. Wenner array was used in this survey and apparent resistivity data were collected and inverted to create a model of subsurface resistivity that approximated the true subsurface resistivity distribution and displayed as a cross section. Geophysical data interpretation was constrained with the available drilling and groundwater quality information.

Ground water-quality assessment in the study area was done by collecting 28 groundwater samples from different locations in the study area. The ground water samples were analyzed in Abu Dhabi Municipality laboratory to determine the

concentration of major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}), major anions (SO_4^{2-}, Cl^{-}, CO_3^{-}, HCO_3^{-}, NO_3^{-}), Total dissolved solids (TDS), Electrical conductivity (Ec) and pH. To follow the trend of each substance, contour maps for each element were prepared. Nitrate levels in the groundwater of Al-Khatim area were presented as it is considered the most common contaminant due to agricultural activities. In addition chemical analysis diagrams (Piper and Stiff), two hydrochemical profiles were developed. The chemical data of Al-Khatim groundwater gave an indication about the origin of the groundwater in the study area. WHO standards were used to determine the suitability of Al-Khatim groundwater for different purposes such as drinking and irrigation.

Groundwater flow model "MODFLOW" was used to simulate the groundwater conditions in Al-Khatim area. The study domain was discritized in to 129 columns and 69 rows. The modeled area was divided into two regions, the outside region with a course grid with cells of 250,000 m^2 and the region of interest with a detailed grid where each grid cell has an area 10,000 m^2. The period 1997-2002 was chosen as the calibration period until good match between the observed and simulated groundwater levels was obtained. The model was used to predict the hydraulic head and drawdown for the year 2010 assuming same groundwater extraction rates.

Utilization of the groundwater in Al-Khatim area should be rationalized to stop its deterioration. Extraction rates of the groundwater in Al-Khatim area should be reduced and controlled by the concerned authority. Increasing farmer's awareness about environmental impact of different agriculture practices on groundwater should be considered. Further development of the present numerical model might be essential to better simulate the groundwater sustainability.

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Chapter 1

INTRODUCTION

1.1 Background

The Arabian Peninsula covers an area of 3.11 million square kilometers. It represents one of the driest areas in the world. The ratio of the total renewable water resources to water consumption for domestic and agricultural purposes is less than 10%, Fig. 1.1. Rapid population growth, along with the expansion of irrigated farming, urbanization, economic activities, and high standard of living, has dramatically raised the total water demand in the Arabian Peninsula. The renewable fresh water supply per capita was 1,687 m^3/y in year 2000 and is expected to fall below the threshold of 1,000 m^3/y by year 2030. According to the definition of ESCWA, the region will be considered as a severe water stress region by the year 2030, (ESCWA, 2003). The agricultural sector is now consuming substantial volumes from non-renewable groundwater resources. If current water use practices continue, the annual water demand is expected to reach 35 billion cubic meters by the year 2010 (Al-Alwi and Abdulrazzak, 1994). Since most renewable water resources are currently fully developed, both shallow and deep fossil groundwater aquifers are being depleted at an accelerating rate to meet the increasing water demands, especially for the agriculture development. In UAE, the agriculture development depends almost entirely on groundwater resources. In the areas of Al-Ain, Dhayd, Hamaraniyah, Fujairah and Al-Khatim, groundwater of shallow aquifers is being mined and it's quality is deteriorating. Farmers are seeking a better water quality.

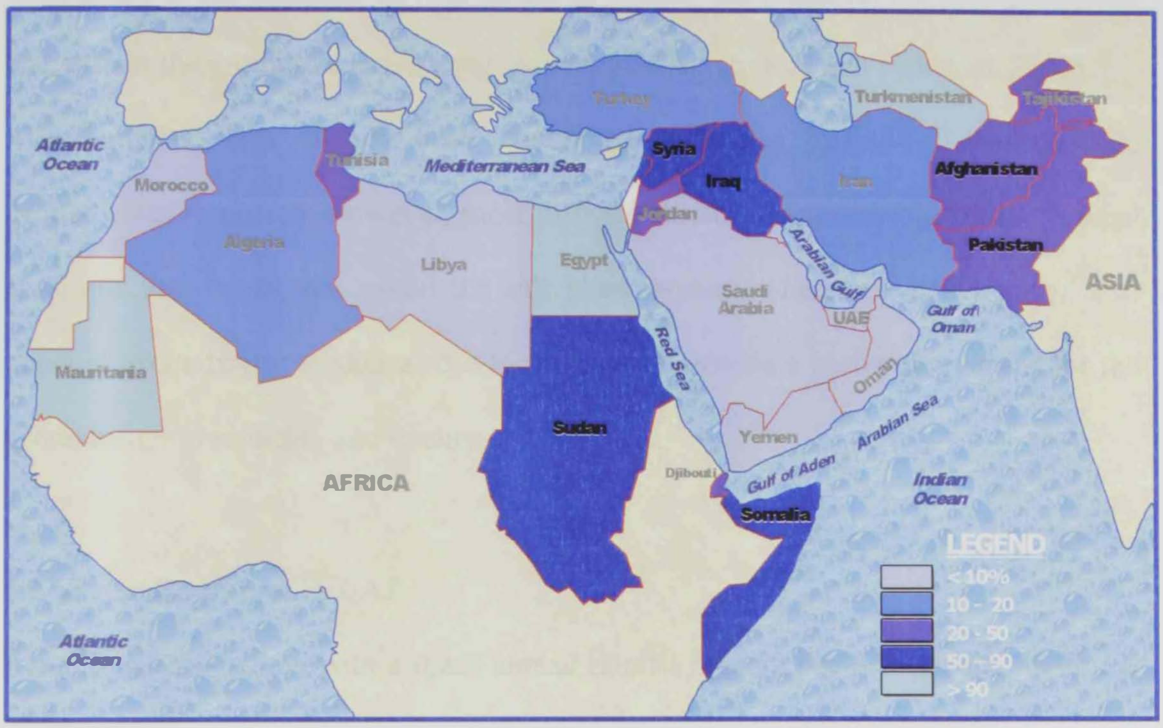


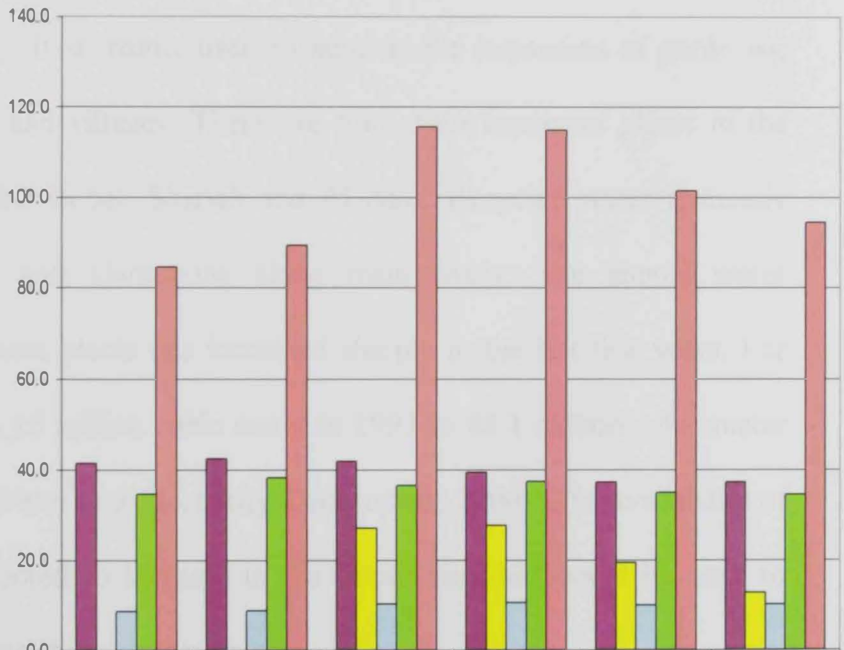
Figure 1.1. Ratio of the renewable water resources to the water consumption in the Arabian peninsula (Ebraheem, 2001).

Modern irrigation techniques such as drip and sprinkler irrigations are now used extensively in the Emirates of Abu Dhabi to reduce the irrigation water consumption and sustain the groundwater resource (Ministry of Agriculture and Fisheries, 2002). Many studies have already been conducted to assess quality of the available groundwater resources. However, most of these studies are not conducted at the local scale and are, hence, not useful for individual farmers. Therefore, it is important to conduct groundwater studies at the local scale to provide a better assessment for the groundwater potentiality and quality.

1.2 Water Resources in UAE

Rainfall in UAE is low with a mean annual rainfall ranging between 20 and 80 mm in the flat and coastal areas, and between 100 and 160 mm in the mountainous areas and the total rainfall is 836 $\times$ 10^4 m^3 per year, Fig. 1.2, (UAE National Atlas, 1993). Despite the scarcity of rainfall and the lack of the renewable water resources, the country's policy encourages plantation and development of green lands in towns, villages and country side. Desalination plants were erected in costal towns and wells were drilled elsewhere. The estimated total water demand in the UAE is approximately 2100 million cubic meter per year (Maraqa, 2001) which is satisfied through a combination of conventional resources (rainfall harvesting and groundwater exploitation mainly from shallow alluvial aquifers) and non-conventional resources (desalinated and treated wastewater), Fig. 1.3. Water demands have increased substantially during the last ten years and are expected to reach 2.45 billion cubic meter in the year 2010 (Al-Alwi and Abdulrazzak, 1994).

Figure 1.2. Mean annual rainfall map of the UAE (UAE national Atlas, 1993).



	1997	1998	1999	2000	2001	2002
FEWA: Fedral Electricity & Water Authority	41.3	42.4	41.8	39.4	37.2	37.2
ADWEA: Abu Dhabi Water & Electricity Authority			27.0	27.6	19.3	12.8
DEWA: Dubai Electricity & Water Authority	8.6	8.8	10.3	10.	10.0	10.1
SEWA: Sharjah Electricity & Water Authority	34.6	38.1	36.5	37.4	34.9	34.4
Total	84.5	89.3	115.	114.8	101.4	94.5

Figure 1.3. Evolution of groundwater usage in UAE in M m^3/year (Mangoosh, 2004).

Groundwater in the UAE consists of two types, the fossil non-renewable groundwater which was formed during two previous wet periods (6000-9000 and 25,000-30,000 years before present) and the renewable recent groundwater which is formed by percolating rainfall (Wood and Imes, 1995). Due to the high evaporation rate and surface water runoff (in the mountains area) only 10-14 % of the total precipitation is percolating to recharge the shallow groundwater aquifer which is about 200 million m^3/year (ESCWA, 2003).

The desalinated water is currently the main domestic and industrial water resource in UAE. Constituting about 92% of the water demand for domestic purposes. It expected to be the only source for drinking and domestic uses in the near future. The desalinated water in the UAE has increased from 382.4 million cubic meter per year in 1996 to 672.7 million cubic meter in the year 2002 (Mangoosh, 2004).

The treated wastewater has recently been recognized as one of the dependable resources for water supply. It is mainly used to support the expansion of gardening and landscaping in towns and villages. There are four main treatment plants in the UAE located in Abu Dhabi, Dubai, Sharjah and Al Ain. Recycled water is mostly used to irrigate gardens and plantations along main roads. The annual water production from all treatment plants has increased sharply in the last few years. For example, it increased from 16 million cubic meter in 1993 to 88.1 million cubic meter in year 1998 (Abu Dhabi Water and Electricity Department, 2000). The availability of treated wastewater is expected to increase in the future and thus could be used to relieve the stress on the groundwater resources.

1.2.1 Water consumption and irrigation efficiency

The crop Water Consumption is defined as the total amount of water which the plant losses due to evaporation and transpiration from soil surface and leaves surfaces in addition to the water consumed in building plant cells (Kramer, 1969). Plants need water in different amounts according to many conditions (weather, plant age, plant growth, plant species, etc.). However, plants need water not only to build its cells but also to evaporate from the leaves to stabilize the pressure between the internal cells of the plant and the atmospheric pressure. The problem is that the evaporative demand of the atmosphere is practically continuous where the supply of water by natural precipitation is insufficient. Irrigation is used to balance climate demand and the water supply to the plants. All farms in Al-Khatim area are irrigated by groundwater with no charges levied by government. The farmers pay for the drilling of boreholes and installation of pumping wells in their farms. Recently, the UAE has implemented new irrigation techniques, which can raise yields while avoiding waste of water and reducing contamination. The drip irrigation is the dominant irrigation system in Al-Khatim area and covers about 90% of the total irrigated area. The remaining 10% of the cultivated lands is using other methods such as sprinklers, bubbler and furrow irrigation. Larson (1986) reported that the use of drip irrigation could reduce water use about 50% compared to furrow irrigation. Despite the fact that new irrigation methods reduce the water loss, farming practices may reduce its efficiency significantly. The efficiency of water use is one of the most critical issues related to irrigation practices (Gregory, 1990). Farmers in Al-Khatim area use dribbler with a flow rate of 4 liter per hour but it can be adjusted to reach 30 liter per hour. It has been estimated that Al-Khatim farmers use 225 cubic meter per hectare every day while the normal water consumption for such farms is in the order of 100 cubic meter per hectare per day. Excessive or poorly scheduled irrigation leads to leaching of nutrients from the root zone, especially in sandy and sandy loam soil. This may seriously affect the groundwater quality in the under lying aquifers.

1.3 Groundwater Systems in UAE

Until recently groundwater has been regarded as the only freshwater resource in the Emirates. The oldest known well in the UAE is 5000 year old (Bronze age). It is located at Hili site about 5 km north Al-Ain city with a total depth of 4.0 meters (Hutchinson, 1996). The Government of Abu Dhabi Emirate has appointed a number of consultants to study the Water Resources within Abu Dhabi with special emphasis to Al Ain and Liwa regions, including:

- Harlcrow et al, (1969).
- Gibb et al, (1969).
- Hydroconsult (1978).
- Geoconsult (1985).
- USGS / NDC (1993 - Current).

The aquifer system of Abu Dhabi Emirate consists of two main units: the upper unit which is composed of shallow, unconfined alluvial and eolian sediment known as the shallow aquifer or the surficial aquifer and the lower confined which is made of fractured limestone and/or siltstone formations and known as the fractured aquifer (deep aquifer). Alluvial and eolian deposits occur in most of the Emirate areas and used to be the main source of water in Abu Dhabi emirate.

1.3.1 Unconfined aquifers

Unconfined aquifers are often called water table aquifers because they have no upper layers that restrict water movement into upper saturated or unsaturated zones from above. The water table is the upper water surface of an unconfined aquifer and it represents its upper boundary. This type of aquifers is the most dominate system in Abu Dhabi emirate including Al Ain and Liwa areas, Fig. 1.4. The most important shallow groundwater aquifer in Abu Dhabi Emirate is Al-Ain aquifer (Maddy, 1993).

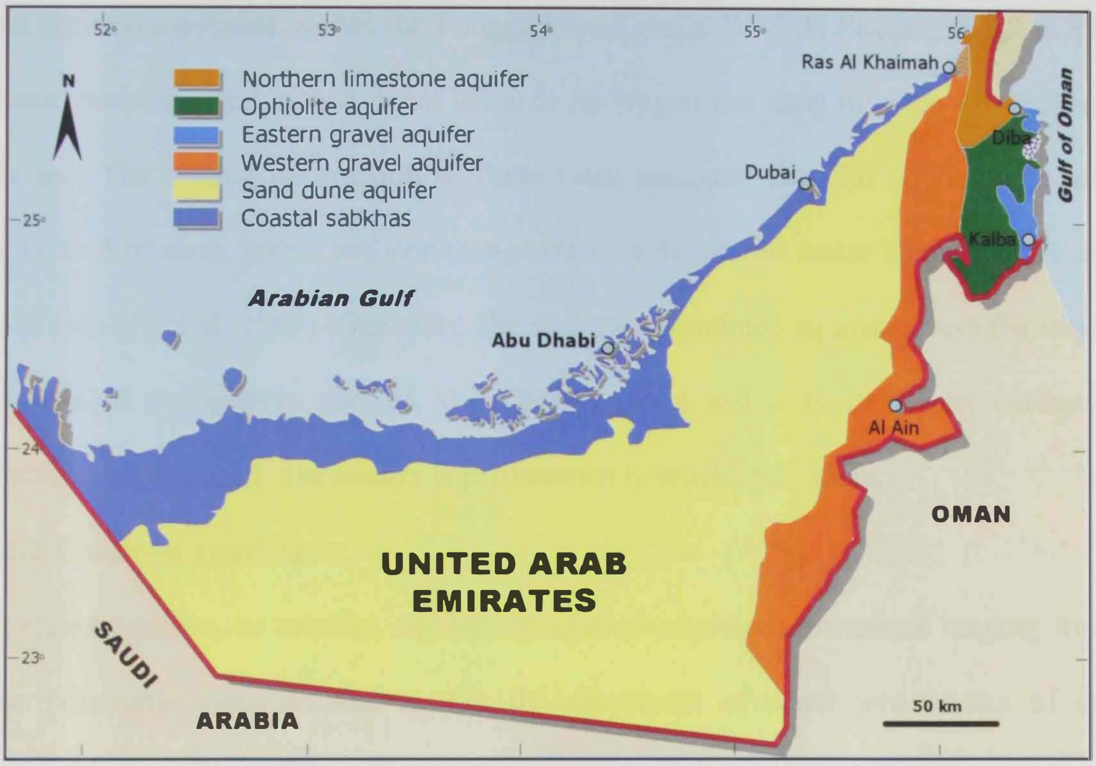


Figure 1.4. Main aquifers in the UAE (UAE national Atlas, 1993).

This shallow aquifer has been exploited due to drilling of hundreds of water wells during the last two decades and the uncontrolled pumping of groundwater. Drilling has been concentrated within the boundaries of south Tawi Al-Faaqa parallel to the Oman mountains and extend down towards Al-Wagan and west towards Al-Saad and the sea. The drilling information of these wells indicated that this aquifer is mostly composed of sand, gravel and conglomerates to a depth 150 meter below the ground level (Maddy et al, 1993). Generally, the shallow unconfined aquifer covers the major portions of the western part of Abu Dhabi emirate and is hence a very extensive aquifer. Unfortunately, the aquifer is predominantly brackish or saline.

1.3.2 Confined aquifers

Confined aquifers, or artesian aquifers consist of saturated formations ranging from low permeable materials that restrict the movement of water into or out of the saturated zone to highly permeable materials (e.g. karistified limestone). Deep aquifers in the UAE appear to be of limited aerial extent. In the area between Dhayd and Madam a moderately deep aquifer is underlying the Quaternary sediments (Juweiza aquifer). In the future, this aquifer could be used for the water supply for agricultural purposes, for example near Dhayd (IWACO,1986). In the northern part of UAE, the carbonate rocks in the mountainous areas were extensively tested (east of Ras Al-Khaima). These rocks appear to be heavily karistified and form a highly productive aquifer where significant amount of fresh water is stored. (IWACO, 1986, and Akram et al., 2004).

Deep confined aquifers are also encountered in the Al-Ain area whereas the basal confining layer altitude ranges from 250 meter to about 50 meter above the mean sea level. The basal consolidated system is dominated by slightly permeable mudstone, clay stone, and its average hydraulic conductivity is estimated to be about 2.8×10^{-4}

m/d (Maddy et al, 1993). This system usually produces small amount of water with generally poor quality. In general the thickness of this brackish water aquifer is about 100-200 meter and it contains an estimated water volume of 1.3×10^9 m^3 (Maddy et al, 1993).

1.4 Vulnerability of the Groundwater Resources

Groundwater resources in UAE are under increasing threat from the growing freshwater demands, wasteful use, and contamination. The quality of the groundwater resources is equally important to its availability. For example, a highly saline aquifer (brine) might not be of any use except for the disposal of wastes. The restoration of the groundwater quality is not only difficult, costly and requires long time but might be impossible. Useable fresh water must have specific physical, chemical, and biological characteristics. The groundwater resources, particularly the shallow groundwater systems are vulnerable to pollution, because of its exposure to the impacts of human activities including industrial and agricultural developments. Therefore, groundwater studies should address both quantitative and qualitative aspects to ensure its suitability for the intended uses

1.4.1 Sources of groundwater contamination

Since the 1970s the awareness of the vulnerable nature of the groundwater resources to various development impact has increased the concern on the quality of groundwater in aquifers. There is evidence of large-scale groundwater contamination in various parts of the world. Many researchers focused their efforts on the impacts of the anthropogenic organic and inorganic contaminants introduced by agricultural, industrial, and municipal activities. However, the ground surface materials are rich with potential sources of contaminants which if ignored or under estimated can have a major role in groundwater pollution.

The sources of groundwater contamination can vary widely and are categorized in numerous ways, including: 1- characteristics of the source of contaminant, 2- characteristics of contaminant released, and 3- characteristics of released mode of contaminant (Zoller, 1994). The Office of Technology Assessment (OTA) of the United States Congress listed more than 30 different potential sources of groundwater contamination. The OTA report (1984) divided the contamination sources into six categories.

1.5 Groundwater Contamination due to Agriculture Activities

The relation between agriculture practices and the quality of surface water and groundwater has been recognized many years ago, and has recently been regarded as an environmental and health concern. Agricultural inputs such as fertilizer, pesticides, and manure may cause groundwater contamination when improperly disposed and/or stored. Intensive agriculture in areas of high soil permeability and/or high water table levels may cause groundwater contamination from the percolation of chemicals and nutrients through the soil profile. Water pollution from agriculture can cause economic losses for farmers. The major sources of water contamination attributed to agro economical activities are discussed briefly below.

Pesticides: Pesticides, herbicides and fungicides, have been used widely in the last few years. Recently, it has been realized that some highly mobile pesticides may represent a concern because of their potential for leaching into groundwater systems. Most of pesticides are either adsorbed by the soil or degraded before they can be leached. Some pesticides are known to persist in the soil for long periods of time and have been found in groundwater. It should be noted that the longer the pesticide remains in its active form in the soil water, the greater the risk of its leaching into the groundwater. The contamination of groundwater by pesticides can also be caused by direct contact through wells and open surfaces of the shallow aquifers.

Fertilizers: Almost every farmer in the UAE uses some form of fertilizers to improve plant growth. Fertilizers can be harmful for animals and humans if they reach groundwater systems or surface water sources. Fertilizers represent a significant pollutant, particularly in areas where there are permeable sub-soils. Excess applications of chemical or organic fertilizers can percolate surface soil and reach to the groundwater. Mixing fertilizers with irrigation water can accelerate groundwater contamination.

Groundwater contamination may also occur when chemical fertilizers are stored in uncovered areas or near conduits to groundwater, such as open wells or surface depressions where water is likely to accumulate. The most common contaminants from fertilizers in groundwater worldwide is nitrate because it is highly soluble and easily to leach through soils. The most common source of Nitrates-contaminated groundwater is the heavy applications of nitrogen fertilizers specially when excess irrigation water is used in areas with permeable sandy soils. Naturally, farmers add small amounts of nitrate but the accumulation from many farms can result into high nitrate levels in groundwater. Even rotting vegetation in soil can add significant amounts of nitrates to groundwater.

Animal wastes and feedlots are also regard as potential contamination sources. Usually the wastes of livestock are collected in impoundments and these wastes may infiltrate and contaminate the groundwater. Furthermore, there is a number of livestock parasites spend part of their life cycle in water. The animal waste from feedlots or leaking manure storage tanks and pits at farms can be a source of groundwater pollution.

Agriculture requires reliable supplies of high quality water for irrigation while it returns about 30% of the water it uses to its source. The agriculture impact on groundwater can be reduced by applying sustainable management practices that reduce agricultural byproducts such as pesticides and nutrients. Also proper manure storage and handling as well as cropping practices can indirectly sustain the groundwater quality.

1.6 The Study Area

The area of Al-Khatim is located in the north western of the Abu Dhabi Emirate between Latitude 24°13' and 24°10' north and Longitude 55°00' and 55°05' East. The study area is located between UTM 293000 and 305200 Easting and 2674000 and 2680200 Northing as shown in Fig. 1.5.

When cultivation started in Al-Khatim in the early 1980's, hand dug wells were the only method available for extracting groundwater. The number of hand-dug wells at that time was about 200 with a depth not exceeding 10 meter. By the year 2000 the total number and depth of these wells were significantly increased. The number of drilled wells reached about 1500 with depths up to 25 meter. The number of farms also increased rapidly. Due to the decline of the groundwater levels rotary drilling has been implemented to drill deeper wells. Today the number of deep wells in Al-Khatim area is around 500 wells with depths ranging between 50 to 80 meter. The drilling information of 32 deep wells completed by Abu Dhabi municipality has been used in the present study. The depths of these 32 wells are in order of 40 meter.

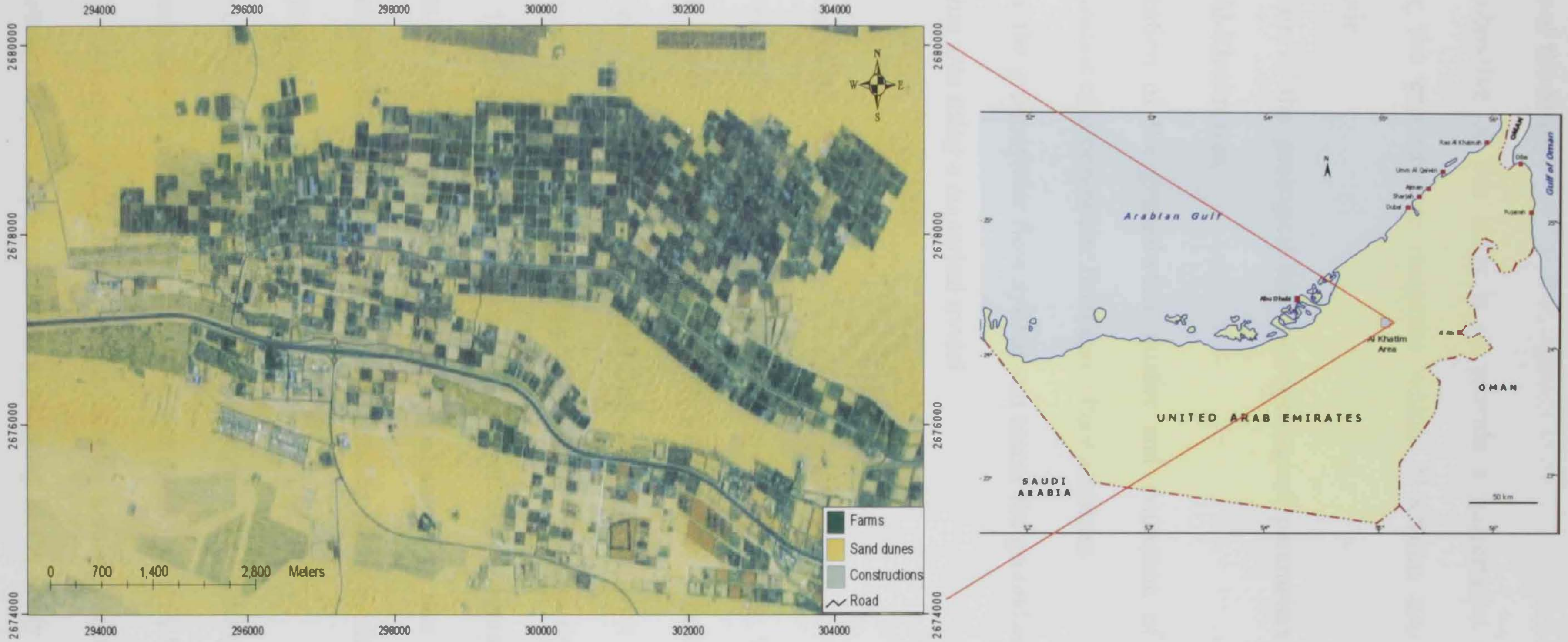


Figure 1.5.UAE map and a satellite map for the study area.

1.7 Objectives of the Study

The ultimate objective of this study is to provide a quantitative and qualitative assessment for the groundwater resources within Al-Khatim area. The specific objectives include:

- Evaluation of the geological and hydrogeological parameters of the aquifer within Al-Khatim area.
- Identification of the groundwater quality and evaluation of the degree of contamination of groundwater from agriculture activities.
- Simulate the groundwater flow system and assess the groundwater recharge in Al-Khatim area using a numerical model.

1.8 Organization of the Thesis

This thesis is composed of six chapters. Chapter one elaborates the scarcity of renewable fresh water resources in the Arabian Peninsula in general and UAE in particular. Water resources in UAE were discussed briefly with focus on the groundwater system and its classifications. The vulnerability of the groundwater resources and the impacts of development as a source of contamination were elaborated with a focus on the groundwater contamination due to agriculture activities. The objectives of the study and the organization of the thesis were included at the end of this chapter.

Chapter two presents the physical, topographic and geological settings of the study area. The climatic conditions are reviewed. The hydrogeology of Al-Khatim area is presented using subsurface geologic logs. This chapter also elaborates the relation between agriculture activities and groundwater pumping in the study area. The well pumping and step drawdown tests that have been conducted within the activities of this study are discussed.

Chapter three is devoted to the geophysical investigations in Al-Khatim area including a brief description of the main geophysical methods. The location of the two completed profiles in the study area and the site characterization are discussed. Data acquisition and processing for the geophysical profiles and the 2D profiling method used in the study area are reviewed.

Chapter four presents the hydrogeochemical settings of Al-Khatim shallow unconfined aquifer. The assessment of the effect of man-induced activities on groundwater chemistry was discussed. The measurements of major and minor chemical compositions of groundwater in the study area with emphasis on nitrate as source of groundwater contamination due to agriculture activities are discussed. The initial composition of groundwater origin was determined by three graphical diagrams. The suitability of Al-Khatim groundwater for drinking and agricultural purposes is also presented.

Chapter five is devoted to the numerical model of the groundwater flow in Al-Khatim area. The characteristics of Al-Khatim aquifer and the boundary condition in the study area are elaborated. The initial conditions and the model inputs are discussed. The model calibration and evaluation of groundwater sustainability and levels until year 2010 are presented.

Chapter six includes a summary of the completed work. The conclusions of the study are presented and several recommendations for groundwater management in Al-Khatim area are proposed.

Chapter 2

GEOLOGICAL AND HYDROGEOLOGICAL CONDITIONS

2.1 Physical Setting of Al-Khatim

Al-Khatim is located 75 km east from Abu Dhabi city between longitudes 55°00' and 55°05' East and latitudes 24°13' and 24°10' north. Bordered by Al-Khazna to the East and surrounded with sand dunes from the North and south and flat desert from the west, Fig. 1.5. The study area consists of two main parts: a- the village which is the settlement area (small village), and b- the area of farms which is considered as one of the oldest farming projects in Abu Dhabi Emirate. Groundwater is the only available resource for irrigation in Al-Khatim area Fig. 2.1.

2.2 Climatic Conditions

Meteorological data obtained from the Ministry of Agriculture and Fisheries and Abu Dhabi Airport Meteorological Station for the period 1996-2000 were used to provide an overview of the climatic conditions in the UAE and the study area. The climatic elements include: (1) solar radiation [mW h/cm^2], (2) air temperature [C°], (3) relative humidity [%], (4) wind speed [km/h], (5) pan evaporation [mm/day] and (6) rainfall [mm/month]. The following is a brief summary for each of these elements.

2.2.1 Solar radiation

The UAE receives its highest solar radiation (796 mW h/cm^2) in June and its lowest (425 mW h/cm^2) in December, with a general increase from December to June and a general decrease from July to September (Al Shamesi, 1993). The average annual hours of sunshine in Abu Dhabi is 10.1 hr per day, with a maximum of 11.9 hours in May and a minimum of 8.8 hours in December (Abu Dhabi Airport Meteorological Station).

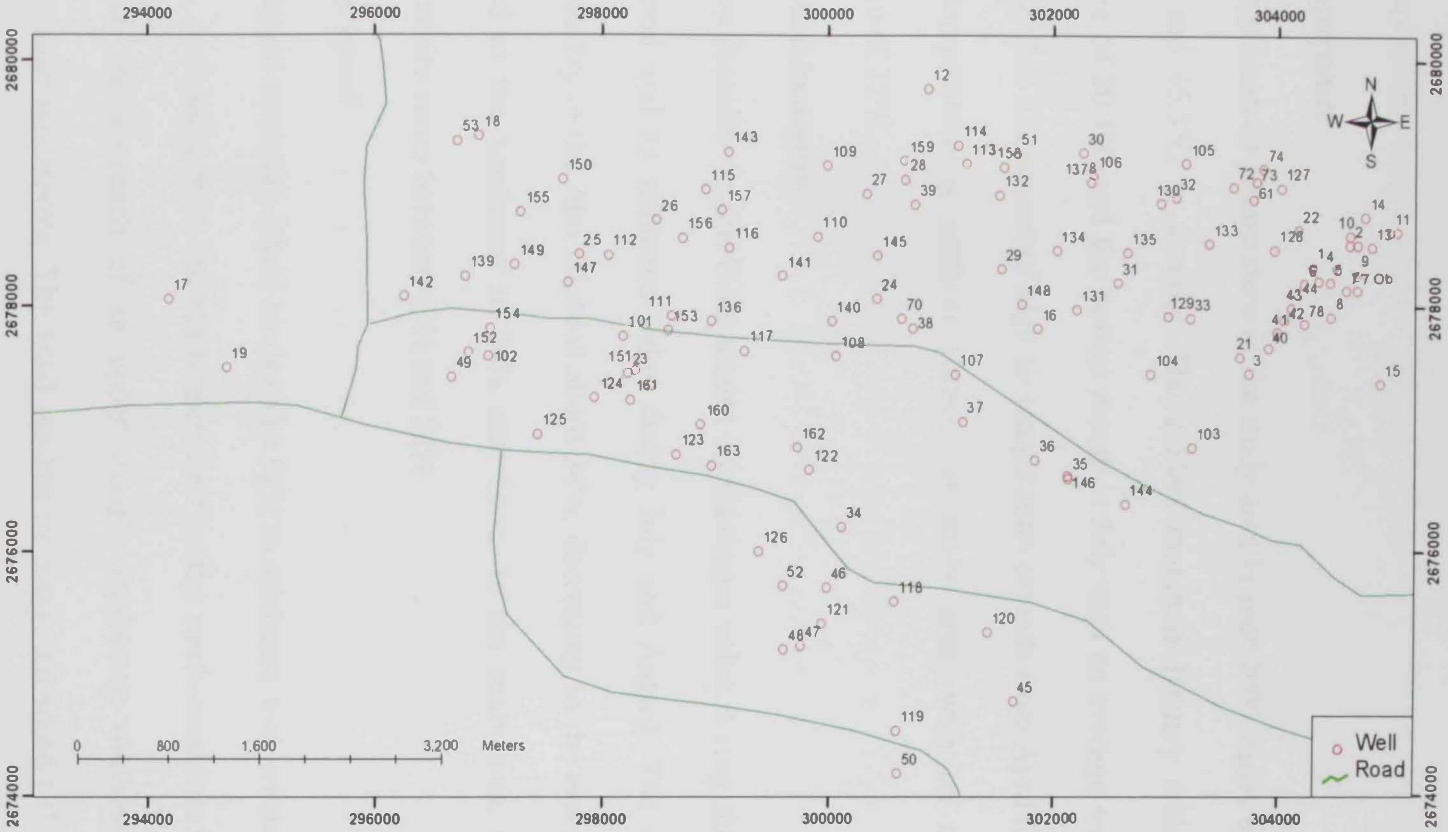


Figure 2.1. The study area and existing wells

The high intensity of solar radiation in the study area enhance the water loss through evapotranspiration.

2.2.2 Temperature

The monthly mean air temperature in the study area in year 2000 varies between 14°C in winter and 45.3°C in summer. The coldest month is January with an average temperature of 20.1°C and the hottest month is July with an average temperature of 37.4°C, Fig. 2.2. The season of high air temperature extends from April to September. The air temperature is uniform across the study area, with an annual mean temperature of 27°C.

2.2.3 Relative humidity

The relative humidity in the UAE attains its maximum value during the December-March period and its minimum value during July and August. The annual mean relative humidity in the Abu Dhabi is about 54%, decreasing to the east to 45% near Al Ain and to the Southwest to 20% near Liwa. In the study area, annual mean relative humidity varies between 45% and 54%.

2.2.4 Wind speed

The wind speed over Abu Dhabi tends to be light to moderate with an annual mean of 12.8 km/h, decreasing from the north-northwest to the south-southeast (Al Shamesi, 1993). With the approach of an upper trough, freshening south-easterly winds sometimes cause sandstorms. The wind reaches its maximum speed (41 km/h) in the summer between March and August. The fall season (September and October) has the lowest records of wind speed (2 - 6 km/h).

2.2.5 Pan evaporation

The type of evaporation pan used in the meteorological stations is a U.S. Class-A pan. The average pan coefficient determined for the Abu Dhabi airport station is 0.6. The mean evaporation for the study area over one year is 8.7 mm/day according to the nearest metrological station (MAF, 2000b).

2.2.6 Rainfall

The average annual rainfall in the UAE is 119 mm. However, in wet years, for example, 1981-1982, the annual rainfall was 282 mm, reaching more than 450 mm in some mountainous areas. The year 2000 was a dry year. The annual rainfall recorded in that year at Abu Dhabi Meteorological Station was 4.7 mm.

Based on records from eight meteorological stations for the period 1971-1992, the mean annual rainfall ranges from less than 70 mm east of the Abu Dhabi International Airport to more than 140 mm in Masfut in the northeast (Antar, 1996). The annual average rainfall in the Al Khatim area is between 90-80 mm, Fig. 1.2.

2.3 Topography

The study area of Al-Khatim is rolling desert with an altitude of 100-150 m above the mean sea level Fig. 2.3. In the south and east areas of Al-Khatim, the lands are mainly sand dunes with occasional salt flats, Fig. 1.5. The sand dunes are about 10-20 m height. Al-Khatim area consists of a village and farms. Abu Dhabi – Al-Ain highway is the main road crossing the area from west to east, Fig. 1.5.

2.4 Hydrogeological Setting

The drilling information of 19 water wells completed within the course of this study were analyzed. Fig. 2.4 represents a typical geological log in the study area, Appendix A. These logs were used to draw four subsurface geologic cross sections. The location of the sections are presented in Fig. 2.5. The cross sections are shown in Figs. 2.6 through 2.9.

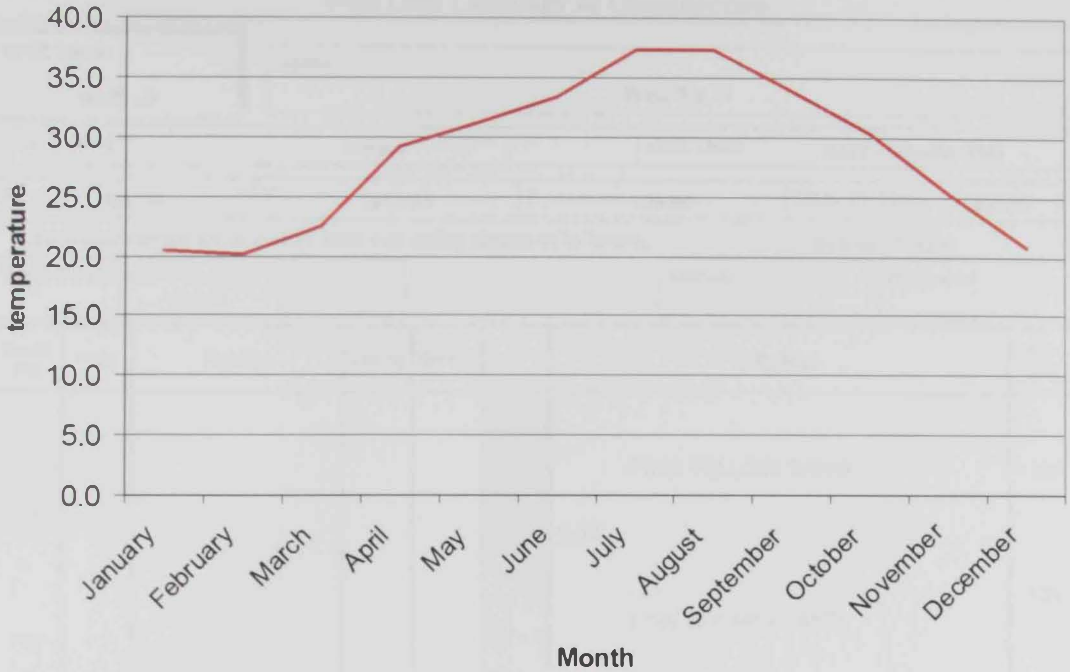


Figure 2.2 The average annual temperature in the year 2000 (MAF, 2000b)

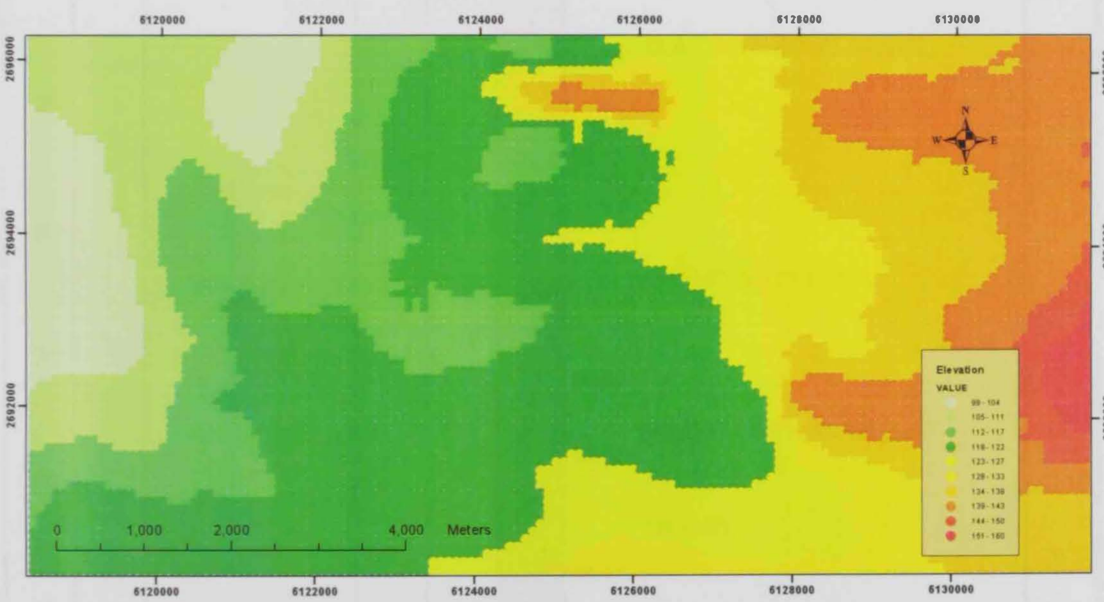


Figure 2.3. A Gradual color elevation map developed by GIS.

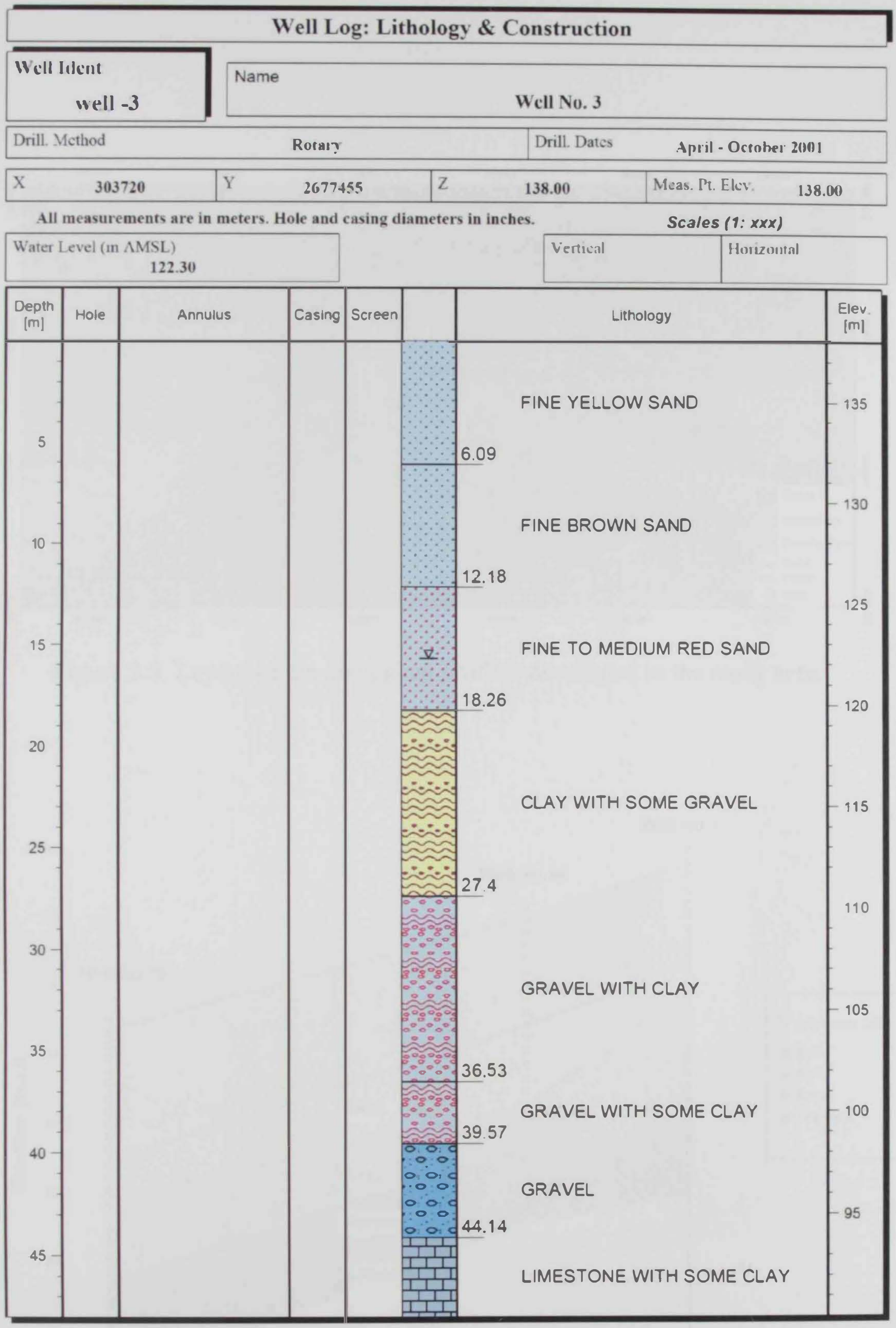


Figure 2.4. Lithologic log based on well no. 3

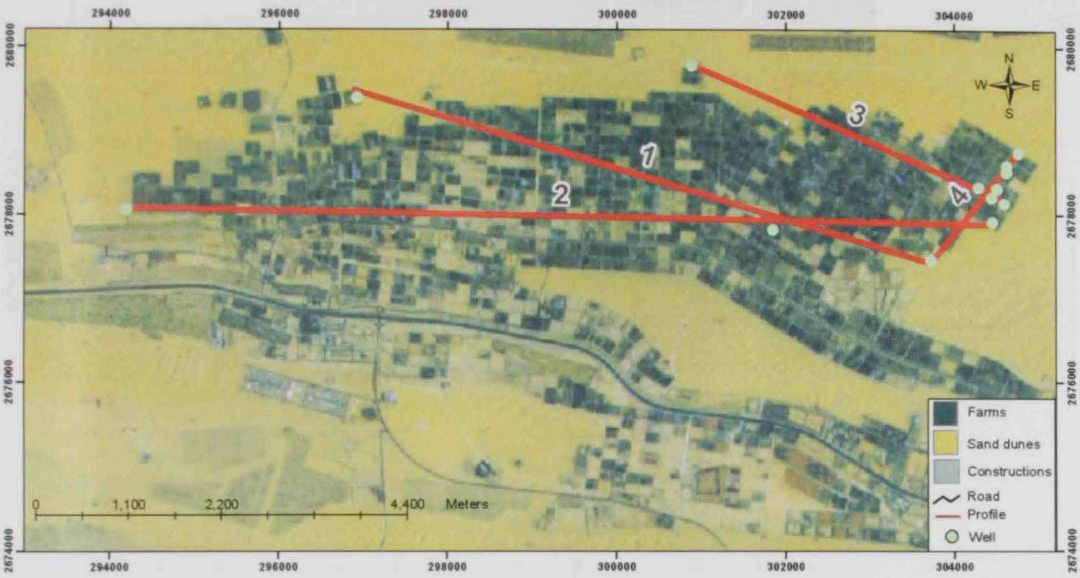


Figure 2.5. Layout of the geological profiles developed in the study area.

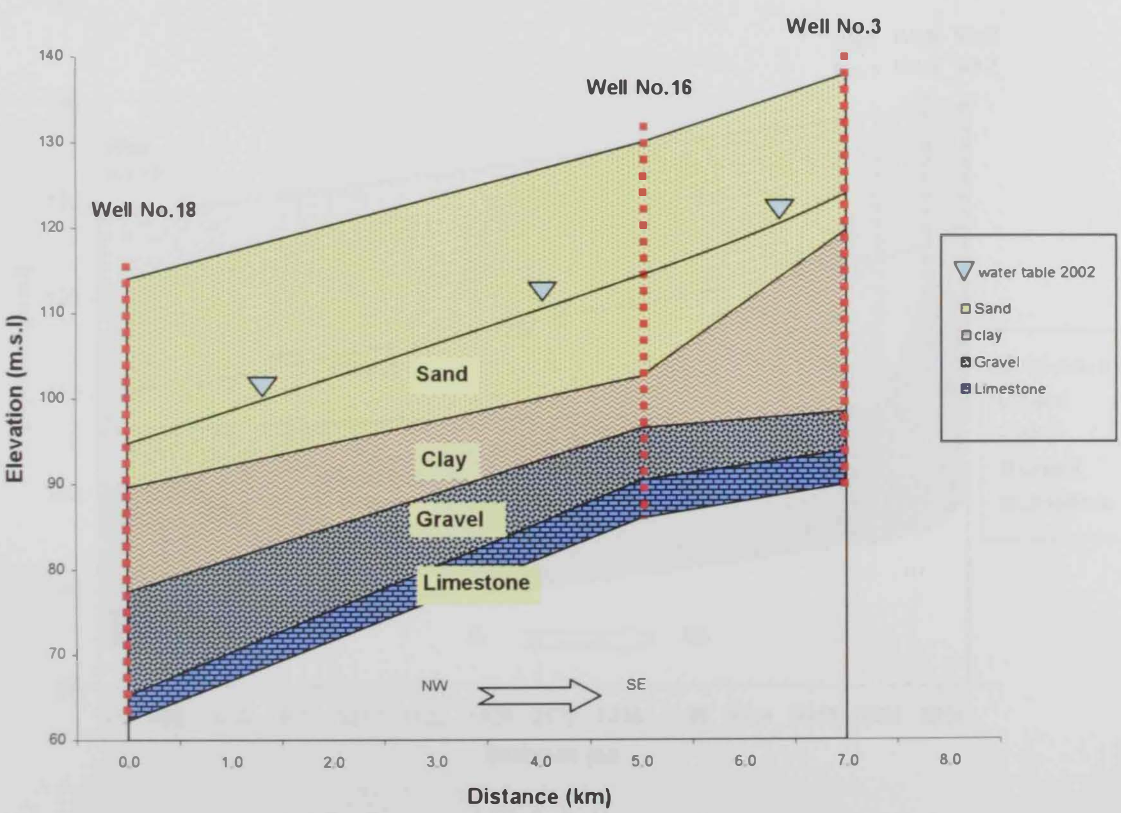


Figure 2.6. Subsurface geological cross section along profile 1.

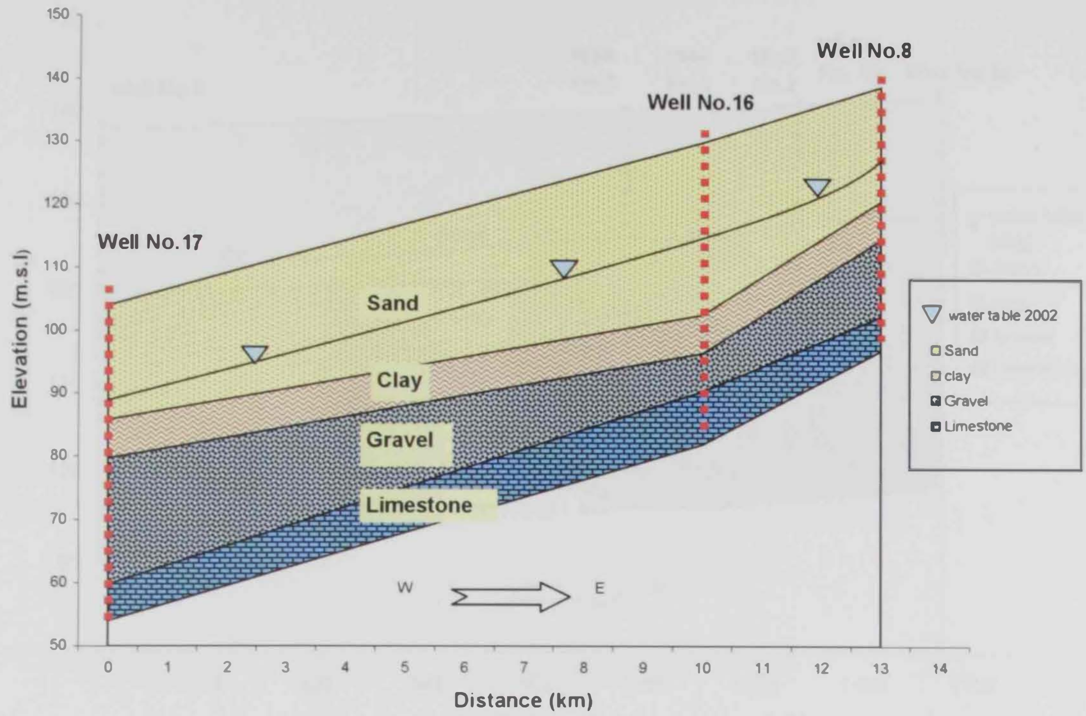


Figure 2.7. Subsurface geological cross section along profile 2.

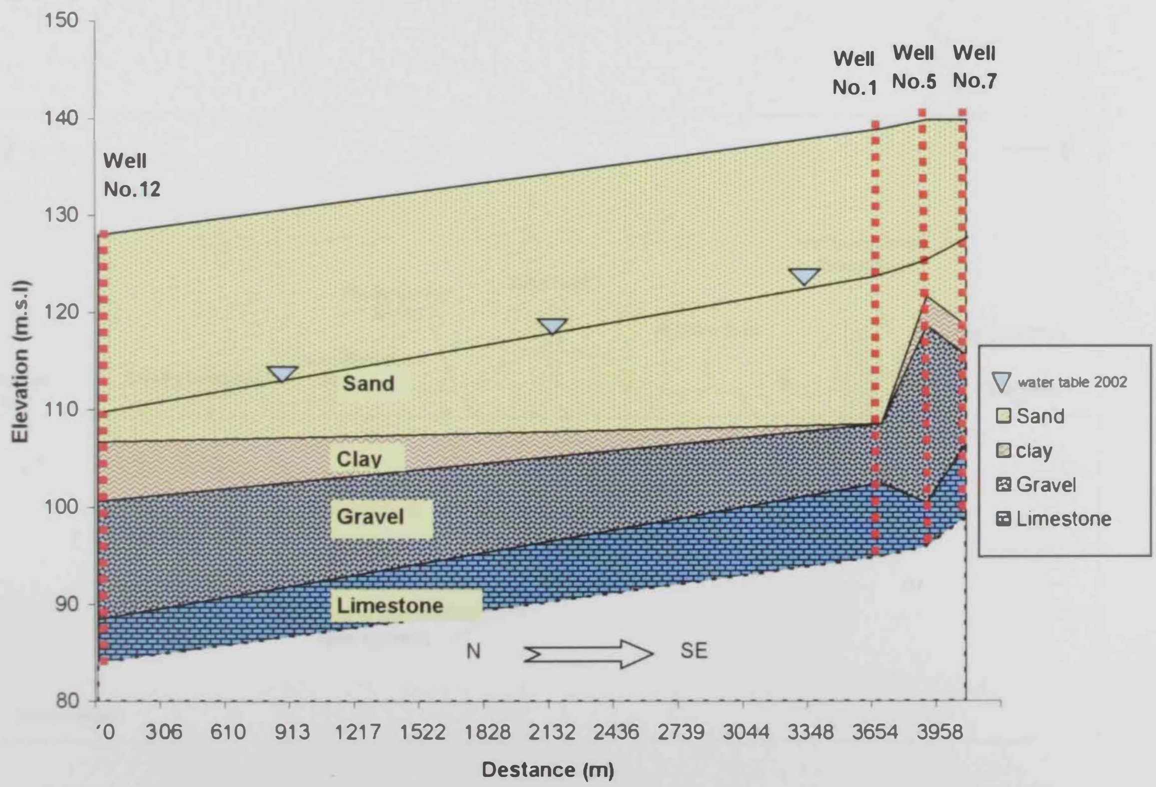


Figure 2.8. Subsurface geological cross section along profile 3.

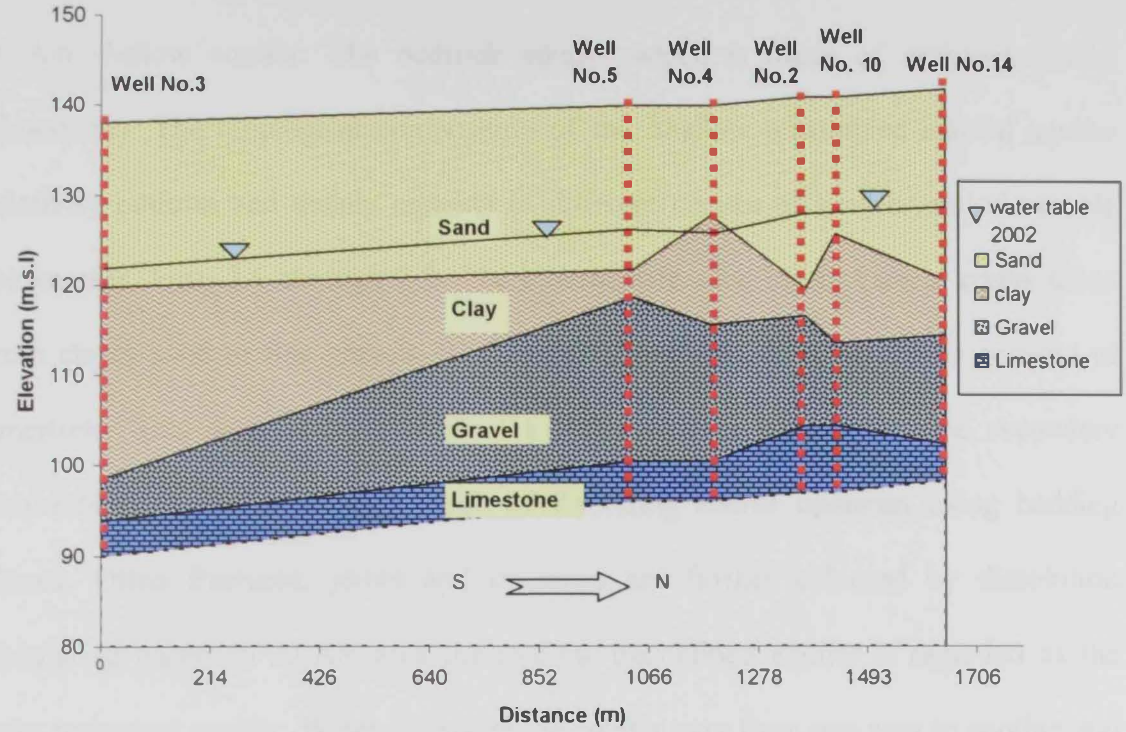


Figure 2.9. Subsurface geological cross section along profile 4.

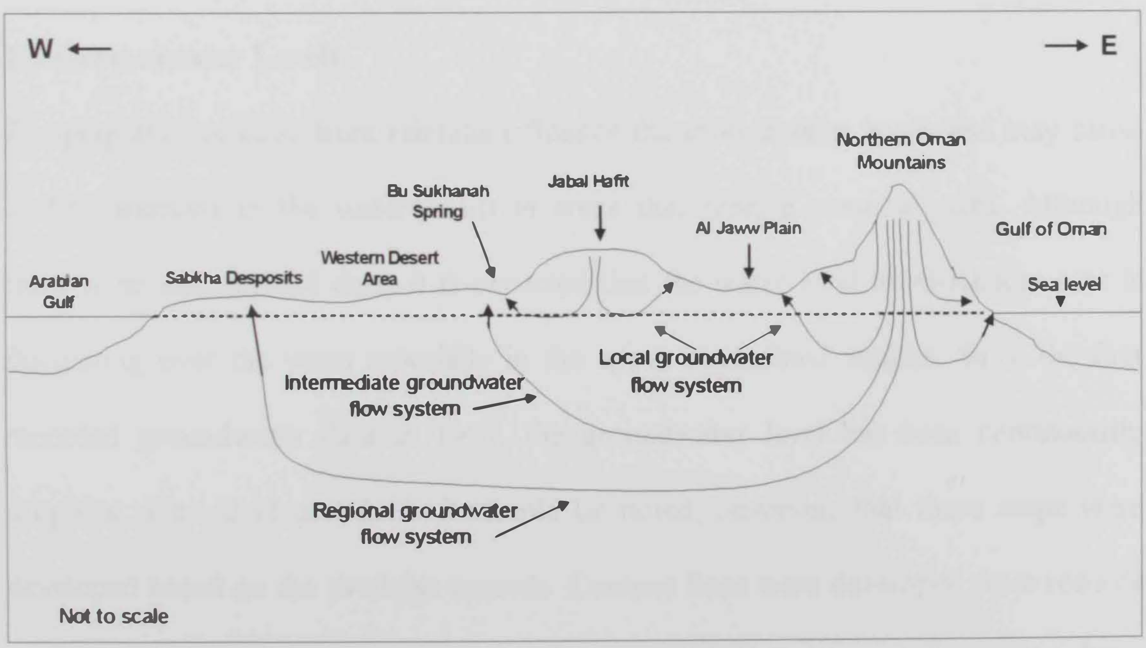


Figure 2.10. Shallow aquifer flow system (Modified after Maddy et al, 1993).

There are two groundwater aquifer systems in Al-Khatim area. The upper aquifer system which is composed of Quaternary sediments and is regarded as an extension of Al-Ain shallow aquifer. The bedrock aquifer which is made of carbonate rocks (limestone). The lithological composition of the Shallow unconfined alluvial aquifer relatively uniform and mainly consists of different classes of sand layers of variable thicknesses, Figs. 2.6 through 2.9. The intermediate sand layers vary in composition from clayey sand to fine gravels. The bedrock aquifer in Al-Khatim area consists of limestone. This layer is considered as a water bearing layer where the secondary permeability is developed as a result of fracturing and/or openings along bedding planes. Often fractures, joints and openings are further enlarged by dissolution circulating water. In Al-Ain area the shallow unconfined aquifer is regarded as the most important aquifer. Water surface in the aquifer vary from one area to another and generally dip from Al-Ain area in the east toward the sea in the west passing through the study area. The shallow aquifer flow system is presented in Fig. 2.10.

2.5 Groundwater Levels

Pumping and recharge from rainfalls influence the groundwater levels and may cause cyclic variations in the water levels in areas that receive seasonal rains. Although there is no documented data, it is expected that the water level in Al-Khatim area is fluctuating over the years especially in the upper unconfined aquifer. Since the first recorded groundwater data in 1997, the groundwater level has been continuously dropping, Figs. 2.11 and 2.12. It should be noted, however, that these maps were developed based on the available records. Contour lines were developed from records of different wells. The groundwater levels in the study area have not been comprehensively studied due to the absence of sufficient numbers of monitoring wells

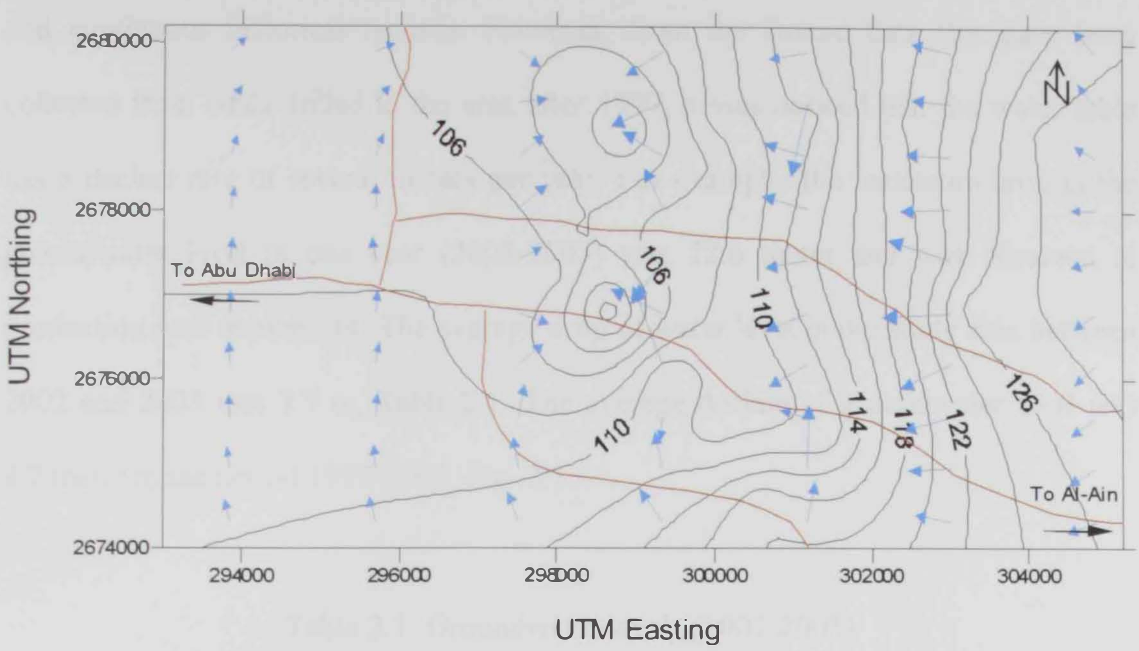


Figure 2.11. Water table contour map (m, amsl) year 1997.

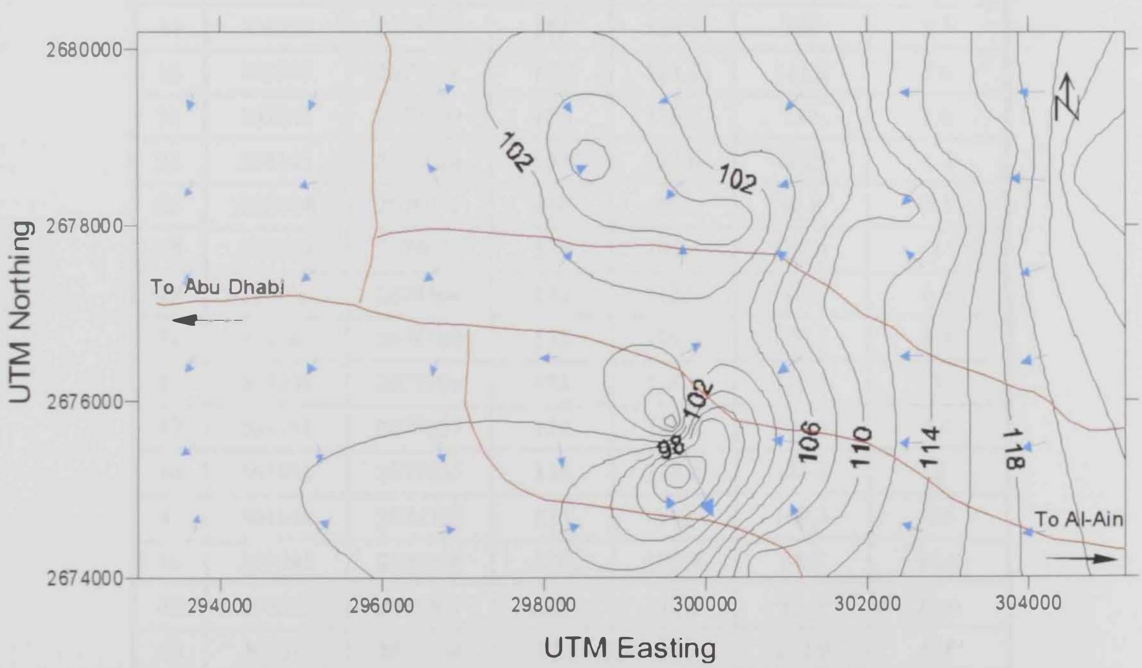


Figure 2.12. Water table contour map (m, amsl) year 2003.

and continuous historical records. However, from the limited data that have been collected from wells drilled in the area after 1997, it was noticed that the water table has a decline rate of several meters per year. For example, the maximum drop in the groundwater level in one year (2002-2003) was 22.6 meter and was observed in production well number 48. The average drop of water level in the study area between 2002 and 2003 was 3.7 m, Table 2.1. The average decline of groundwater level was 4.7 meter in the period 1997-2003, Fig. 2.13.

Table 2.1. Groundwater levels (2002-2003)

well No.	UTM Coordinates		Altitude (m)	Water level 2002(m)	Water level 2003(m)	water level change(m)
	Easting	Northing				
2	304622	2678503	141	127.7	126.7	1
7	304588	2678132	140	128.2	124.7	3.5
11	304985	2678609	142	128.7	126.7	2
14	304758	2678730	142	129.3	127	2.3
16	301847	2677818	130	115.1	111.5	3.6
21	303640	2677590	136	119.6	118	1.6
22	304163	2678624	139	122.6	120.9	1.7
26	298484	2678701	116	96.9	96.8	0.1
28	300683	2679034	124	105.4	104.4	1
29	301530	2678304	130	112.9	106	6.9
31	302561	2678190	133	109.6	109.3	0.3
33	303204	2677904	134	114.8	113.8	1
37	301191	2677057	125	111.9	109.3	2.6
40	303894	2677665	138	122.2	120.2	2
45	301640	2674783	125	110	109.5	0.5
46	299983	2675709	120	105.9	94.1	11.8
48	299608	2675207	123	112.1	89.5	22.6
50	300617	2674194	129	111	110.9	0.1
71	303761	2678869	139	123.4	117	6.4

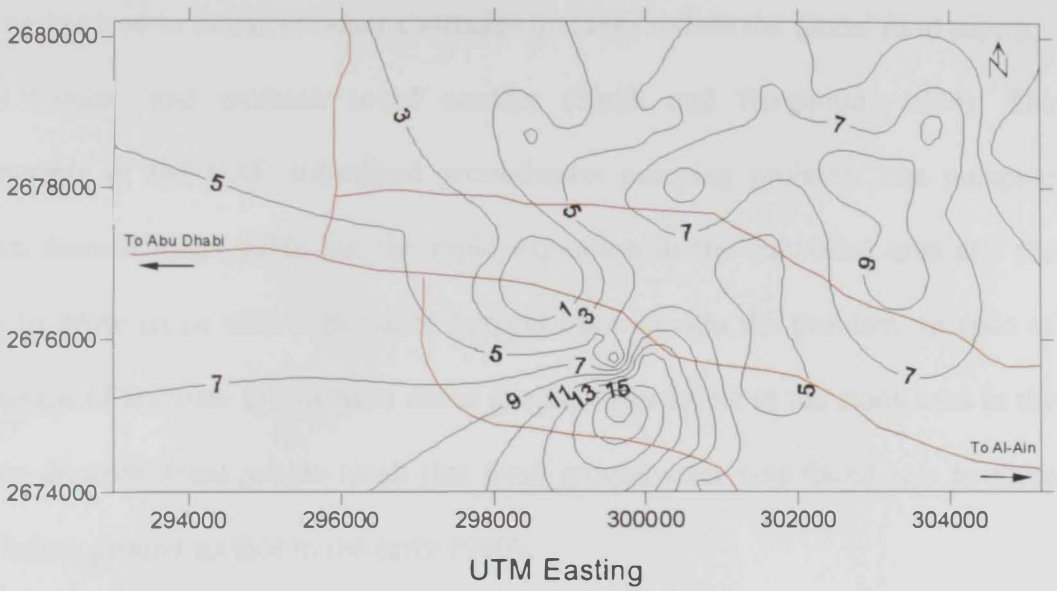


Figure 2.13. Decline in groundwater level between 1997 and 2003.

The use of modern technology and high capacity pumps to extract groundwater from deeper layers was once viewed as a boon for farmers worldwide. Now, massive pumping has lead to intensive water shortages that may reduce the global food supply, spread hunger, and increase social conflict (Sadik and Barghouti, 1994). The governments of the UAE subsidized groundwater pumping projects. The pumping problem seemed manageable but the rapid expansion in the cultivated area and the switch to grow crops with high water demand have worsen the problem. In spite of the absence of accurate information about groundwater levels in the study area in the last two decades, local people recall that fresh groundwater was found two to three meter below ground surface in the early 1980's.

2.6 Agriculture Development and Groundwater Pumping

Despite the arid climate of the United Arab Emirates, the country has been able to develop a thriving agricultural industry and reach a self-sufficient state in some vegetable crops. Small-scale individual farms (owned and developed by the private sector) form a large scale green areas in desert using modern irrigation techniques. This agriculture development is based upon groundwater availability and the generous government support in forms of subsidies, loans, services and other incentives to the farmers. The major cultivated area (84.6 % of the total farms area in UAE) has been established in the Emirate of Abu Dhabi while the remaining 15.4% of the cultivated area is distributed over the other Emirates, Fig. 2.14.

The farms are usually developed by transporting suitable soils to areas where water is available. For this reason the term "cultivable land' is somewhat relative and farms distribution may change over the time. In 1995, the total cultivated area was estimated at 74,170 ha, of which 54,970 ha were considered as cropped area and the number of

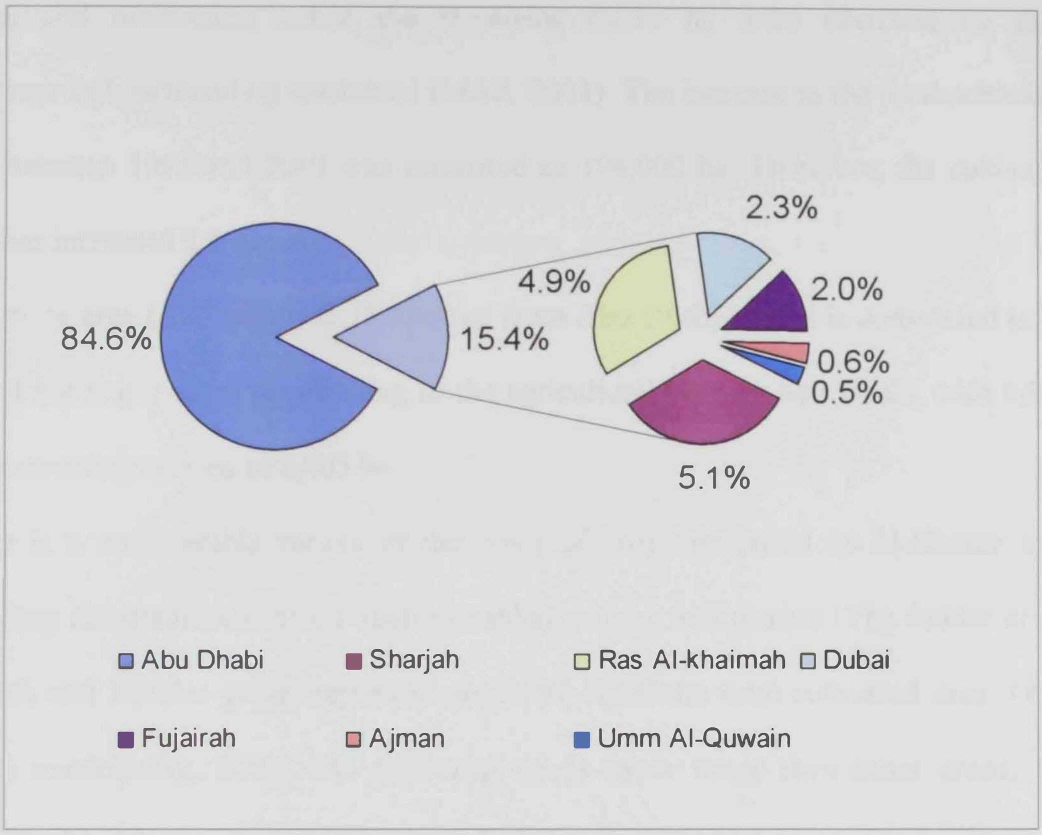


Figure 2.14. Distrbuation of cultivated areas in UAE (MAF, 2001).

farms was 21,700 (MAF, 1999). In 2001, the agricultural area was estimated at 269,060 ha including 35,384 farms, of which 262,220 ha were available for agricultural production, while the remaining 6,830 ha were occupied by farm buildings and surrounding wasteland (MAF, 2001). The increase in the total cultivated land between 1995 and 2001 was estimated as 194,900 ha. Therefore, the cultivated area has increased 2.6 times.

The study area (Al-Khatim) is 75 km east from Abu Dhabi city. It is considered to be one of the major areas contributing to the agricultural yield in Abu Dhabi, with 1,303 farms covering an area of 2,405 ha.

There is a considerable variety in the types of crops produced in Al-Khatim area including non-traditional crops such as cabbage, corn, and tomato. The fodder crops (Alfalfa and Roudes grass) represent about 97 % of the total cultivated area. (Abu Dhabi municipality, 2002). As this crop needs more water than other crops, the consumption of groundwater in area has dramatically increased.

2.7 Hydraulic Parameters

To determine the groundwater potentiality and the hydraulic parameters of Al-Khatim aquifers, two step drawdown and forty two continuous pumping tests were conducted for the newly drilled production wells during the study period. Furthermore, three pumping tests were done using available observation wells. The tests were randomly distributed in the study area. Conventional well hydraulics theory is based on the assumption that laminar flow conditions exist in the aquifer during pumping. If the flow is laminar, drawdown is directly proportional to the pumping rate. Turbulent flow occurs in some wells when they are pumped at a sufficiently high rate. Under turbulent conditions, the linear relationship between drawdown and pumping rate no longer holds, and part of the drawdown is generally related to the pumping rate raised to a power greater than 1.

When turbulent flow occurs, the well specific capacity will decline, often dramatically, as the discharge rate is increased. In this case, it is useful to have means of computing the turbulent and laminar drawdown components in order to make proper calculations concerning the optimum pumping rates and pumping-setting depth.

The step-drawdown test has been developed to examine the performance of wells having turbulent flow (Jacob, 1946). In a step-drawdown test, the well is pumped at several successively higher pumping rates and the drawdown for each rate, or step, is recorded. The entire test is usually conducted during one day, and calculations are simplified if all the pumping times are the same for each discharge rate. If time permits, the water level should be allowed to recover to the static level between each step. Usually five to eight pumping steps are used, each lasting 1 to 2 hours. The data from a step test can be used to determine the relative proportion of laminar and turbulent flow occurring at any pumping rate.

Laminar flow conditions in a perfectly efficient well drawdown in a confined aquifer can be expressed as follows:

$$s = \frac{264Q}{T}\log\left(\frac{0.3Tt}{r^2S}\right) \tag{2.1}$$

This equation can be written as:

$$s = BQ$$

Where

$$B = \frac{264}{T}\log\left(\frac{0.3Tt}{r^2S}\right) \tag{2.2}$$

s = drawdown (L), Q = discharge (L^3/t), B = constant (t/L^2), T = Transmissivity (L^2/t), t = time, r = distance between pumping and observation well (L), S = Storativity [-].

This equation is also applicable to unconfined aquifers as long as the drawdown is small as compared to aquifer thickness.

For a specific well, the value of B is time dependent. However, B changes only slightly after a reasonable pumping duration and can thus be assumed to be constant. When turbulent flow exists, Jacob suggests that the drawdown in a well can be more accurately expressed as the sum of first-order (laminar) component and a second-order (turbulent) component:

$$S = BQ + CQ^2 \qquad (2.3)$$

In this equation, Jacob called the laminar term, BQ, the aquifer loss and the turbulent term, CQ^2, the well loss (head loss attributable to inefficiency). If the drawdown measurements have been taken in the pumping well due to unavailability of nearby observation well the analyses of real wells have shown that this correlation is not correct, because the BQ term almost always includes a major portion of the well losses and the CQ^2 term occasionally includes some aquifer loss. For this reason, computing well efficiency from a step- drawdown test results in an erroneous value. The step test is still useful, however, in evaluating the magnitude of turbulent head loss for the purpose of determining optimum pumping rates.

Bierschenk (1964) used equation (2.3) to present a simple graphical method and determine B and C by dividing the equation by Q and rearranging:

$$\frac{S}{Q} = CQ + B \qquad (2.4)$$

Note that this is a linear equation in S/Q and Q. That is, if S/Q is plotted against Q, the resultant graph is a straight line with slope C and intercept B. Thus, B and C in the original equation can be calculated from this graph.

Inverting the terms in last equation shows how the specific capacity declines as the discharge increases (only with turbulent flow present):

$$\frac{Q}{S} = \frac{1}{CQ + B} \tag{2.5}$$

Observing the changes in drawdown and specific capacity while increasing the discharge useful information to select optimum pumping rates can be obtained.

A parameter often computed from a step-drawdown test is the ratio of the laminar head loss to the total head loss, expressed as a percentage:

$$L_p = \frac{BQ}{BQ + CQ^n} \times 100 \tag{2.6}$$

Thus L_p is the percentage of the total head loss that attributable to laminar flow. If the assumptions made by Jacob were correct, that is, that aquifer loss equals BQ and well loss equals CQ^n, then L_p would equal the well efficiency. However, testing of hundreds of wells has shown that these assumptions are not correct (Driscoll, 1986). Thus, when L_p is used as the efficiency value, it appears that a well which has little or no turbulent flow is judged to be efficient, when the true efficiency may be quite low (Driscoll, 1986).

The Bierschenk's method (Driscoll, 1986), was used to analyze the data collected from one of the two step- drawdown tests in the study area as shown in Table 2.2.

Table 2.2. Discharge and drawdown data from well No.3

Q		Drawdown			
m^3/day	gpm	m	ft	S / Q	L_p
432	79.2	8	26.24	0.331	43.10
492.48	90.288	10.93	35.8504	0.397	39.92
518.4	95.04	11.54	37.8512	0.398	38.70
570.24	104.544	11.61	38.0808	0.364	36.46
682.56	125.136	15.39	50.4792	0.403	32.41

Fig. 2.15 shows S/Q plotted against Q with B and C calculated as 0.225 and 0.00375, respectively, where C is the slope of the straight-line plot and B is the intercept. Table 2.2 indicates that 43% of the flow is laminar flow when the discharge is low. The flow is turning more turbulent as the pumping rate increases. When the flow is 682 m^3/day only 32.4% of the flow is laminar flow. Fig. 2.16 shows that at each pumping rate, the well loss is small if compared to the aquifer loss. Thus the well is efficient.

Pumping tests are important to determine the specific capacity of a well, and it's radius of influence. Due to the unavailability of observation wells, pumping and observations data were taken at the same well. For each pumping rate the water level was measured until the water level approaches the steady state condition. The result of these tests indicated the presence of a clayey sand layer on the top. Therefore, the alluvial aquifer was considered as semi-confined aquifer and Hantuch method was used for interpretation pumping test data.

Fig. 2.17 shows a semi-log plot of the drawdown against time for well number 1. All other results of the remaining forty two wells are presented in Appendix B. Since the wells in the study area were completed in the semi-confined alluvial deposition, the drawdown in the pumping wells would be anticipated to conform to a classic three phase of the unconfined aquifer response. In the first phase, drawdown in the pumping well is governed by Theis equation (1935) with aquifer behaving as a confined aquifer

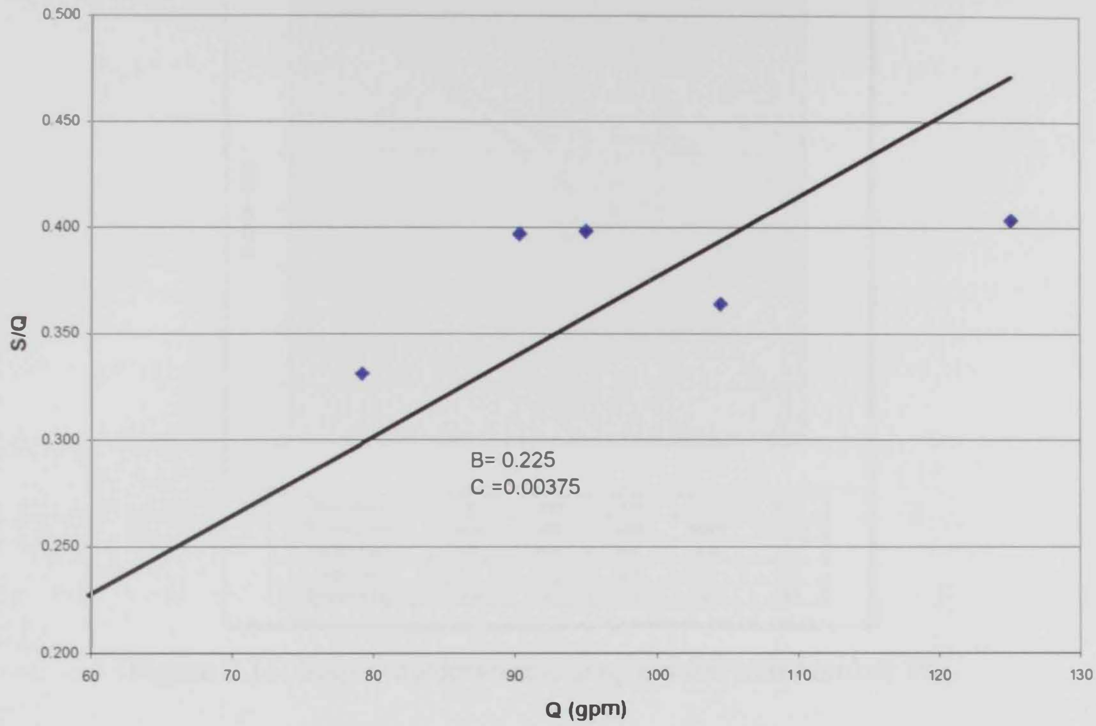


Figure 2.15. Values for B and C in the step-drawdown test for well number 3.

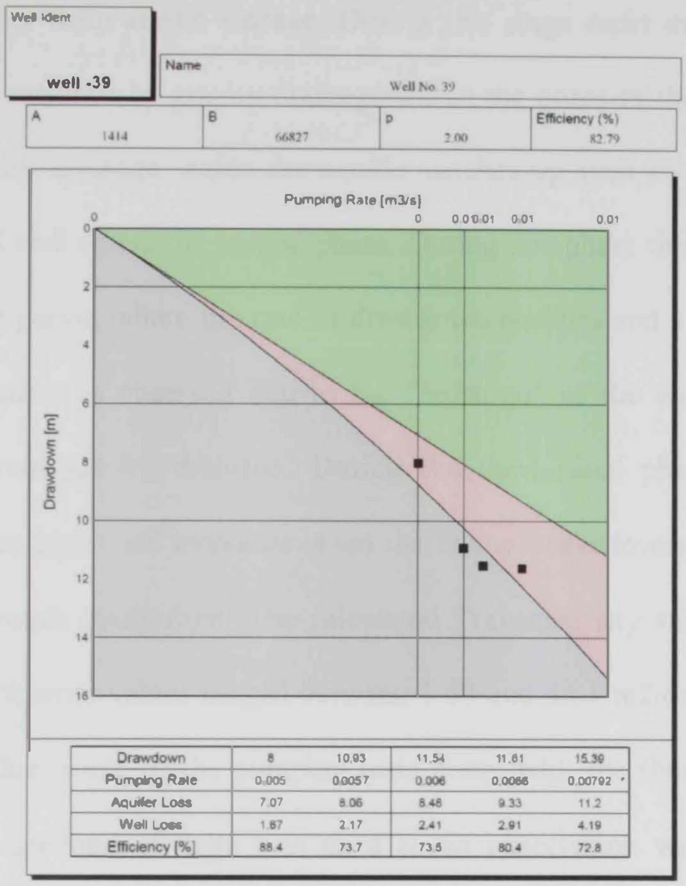


Figure 2.16. Step-drawdown test diagram for well number 39.

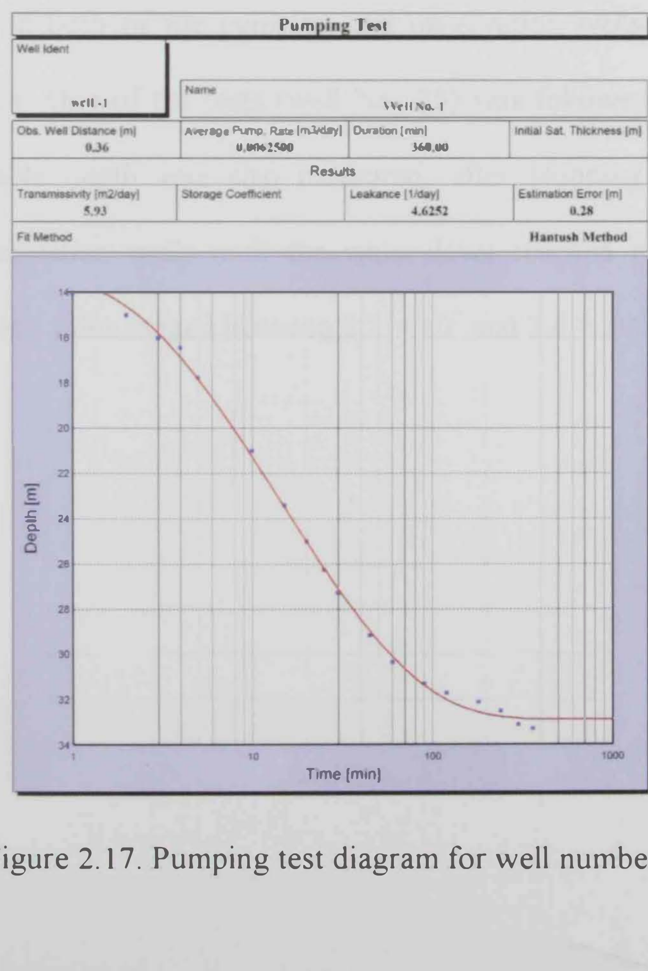


Figure 2.17. Pumping test diagram for well number 1.

and releasing water from elastic storage. During this stage rapid drop in the water levels can not be matched by gravity drainage within the pores of the aquifer. As the water under gravity drainage within the aquifer catches up with the declining water table, the pumped well enters the second phase. During this phase the drawdown goes through transition period where the rate of drawdown declines and a flattening of the drawdown–time curve is observed due to the "recharge" of the water table by the water released from gravity drainage. During the third (final phase), the rate of drawdown changes again and increases when the falling water levels and water from gravity drainage reach equilibrium. The calculated Transmissivity values are listed in Table 2.3. Transmissivity values ranged between 1.68 and 44.1 m2/day. To determine the Storativity value, some of the pumping tests done, with the shutdown of nearby production wells and one of them was used as an observation well. The distance between observation and pumping wells ranged between 80-100 meter.

The water levels in both of the pumping and observation wells were measured as shown in Table 2.4. One of the tests (well No. 25) was followed by a recovery test and the water table depth was also measured, after stopping pumping, in both pumping and observation wells until the water level reached its initial level. The calculated Storativity value ranged between 2.3×10^2 and 2.4×10^4.

Table 2.3. Transmisivity values based on the results of pumping tests.

well No.	Farm No.	region	UTM Coordinates		Transmisivity
			Easting	Northing	m^2/day
1	40	bed markhan	304287	2678326	5.93
2	56	bed markhan	304622	2678503	9.02
3	68	bed markhan	303720	2677455	5.85
4	55	bed markhan	304499	2678309	10.6
5	54	bed markhan	304445	2678199	23.6
6	41	bed markhan	304214	2678187	10
7	63	bed markhan	304588	2678132	18.3
8	64	bed markhan	304453	2677914	12.5
9	62	bed markhan	304683	2678269	8.88
10	57	bed markhan	304621	2678577	3.82
11	59	bed markhan	304985	2678609	10.9
12	649	Dahan	300885	2679768	13.9
13	60	bed markhan	304816	2678485	7.16
14	58	bed markhan	304758	2678730	6.66
15	32	bed markhan	304896	2677373	12.3
16	333	Dahan	301847	2677818	5.94
17	232	Dahan	294202	2678054	2.8
18	36	Bu deeeb	296925	2679383	25.5
19	4	Dahan	294712	2677496	10.6
34	65	alkhatem north	300118	2676202	6.84
35	470	Dahan	302124	2676601	44.1
36	468	Dahan	301827	2676749	4.48
37	463	Dahan	301191	2677057	2.88
38	193	Dahan	300749	2677816	7.53
39	390	Dahan	300772	2678828	9.42
40	46	bed markhan	303894	2677665	21.9
41	45	bed markhan	303972	2677790	3.86
42	44	bed markhan	304034	2677889	6.15
43	43	bed markhan	304095	2677988	13.5
44	42	bed markhan	304154	2678098	9.34
46	87	AL-Shobaisy	299983	2675709	3.71
47	92	AL-Shobaisy	299756	2675234	5.93
48	102	AL-Shobaisy	299608	2675207	2.43
49	66	Dahan	296681	2677420	8.52
53	21	Bu deeeb	296737	2679343	16.4
70	222	Dahan	300647	2677895	3.46
71	651	Dahan	303761	2678869	1.68
72	650	Dahan	303585	2678975	5.66
74	653	Dahan	303851	2679119	7.78
78	52	bed markhan	304213	2677859	6.97

Table 2.4. Constant-rate pumping test data for well number 11.

Time	Pumping well depth (m)	Observation well depth (m)	Water salinity in Pumping well (ds/m)
0	13.53	13.95	11440
1	15.80	14.00	-
2	16.90	14.00	-
3	17.50	14.00	-
4	18.00	14.00	-
5	18.60	14.10	11320
6	19.10	14.10	-
7	19.60	14.20	-
8	20	14.30	-
9	20.30	14.40	-
10	20.60	14.50	11230
15	21.45	14.10	11100
20	21.90	14.13	-
25	22.10	14.20	10850
30	22.25	14.25	10780
45	22.50	14.40	10650
60	22.55	14.49	10620
90	22.53	14.55	10610
120	22.53	14.59	10520
150	22.55	14.62	10520
330	22.25	14.65	10370
450	23.00	14.70	-
510	23.60	14.75	10370
750	22.60	14.90	10370

GEOPHYSICAL INVESTIGATIONS

3.1 Introduction

To meet the increasing demands for groundwater resources, the government of Abu Dhabi Emirate has made several attempts to study the shallow unconfined aquifer. Most of the studies were conducted at the regional (large) scale and did not provide a quantitative assessment at the local scale of the farms. The present study represents the first local-scale groundwater quantitative and qualitative assessment in Al-Khatim area. It integrates hydrogeological, hydrochemical, and geophysical information to provide a better understanding and assessment for the groundwater condition in Al-Khatim area.

As has been discussed in Chapter 2, the groundwater aquifers in the study area can be classified into:- 1- Upper unconfined aquifer which is composed of alluvium gravels, and 2- Lower confined aquifer which is composed of fractured and karistified limestone. The upper aquifer is directly recharged by rainfall and irrigation return water. The present study focuses on the upper shallow aquifer.

Surface geophysical profiling methods were used during the summer of 2004 at Al-Khatim area to determine the thickness of saturated zones in the shallow aquifer. 2D dc-resistivity profiling was employed to detect low resistivity zones which characterize the groundwater saturated zones.

3.2 Surface-Geophysical Methods

Surface-geophysical methods offer quick and inexpensive means to help characterize subsurface hydrogeology (Powers, et al, 1999). They provide information on subsurface properties, such as soil thickness and saturation, depth to bedrock, location and distribution of conductive fluids, location and orientation of bedrock fractures, fracture zones, and faults. Surface geophysics can also be used in conjunction with geologic, hydrologic, and borehole-geophysical investigations to optimize well siting (Jansen and Jurcek, 1997), or as a stand-alone method of fracture detection (Lieblich et al, 1991; Haeni et al, 1993). A brief description of the main geophysical methods is given hereafter.

3.2.1 Direct current resistivity method

DC resistivity methods measure the electrical resistivity distribution of the subsurface using current transmitted into the ground from DC or low-frequency sources, by two electrodes (C1 and C2), and measuring the potential difference between a second pair of electrodes (P1 and P2), Fig. 3.1. The apparent resistivity of the subsurface can be calculated by applying a geometric correction (K) to Ohm's law ($R = \Delta V/I$, where R is the resistance, ΔV is the measured potential difference, and I is the injected current), based on the specific electrode spacing and geometry. These geometrically corrected measurements are defined as apparent resistivities rather than true resistivities because a homogeneous subsurface resistivity is assumed. Measured resistivity values are controlled by material resistivity, and the presence of groundwater and its quality and quantity (Haeni et al, 1993). The resistivity of a fracture zone is controlled by the secondary porosity, and the presence of altered secondary minerals and/or precipitate. The maximum penetration depth is directly proportional to the electrode spacing and inversely proportional to the subsurface conductivity (Edwards, 1977).

3.2.2 Azimuthal square array direct current resistivity surveys

Azimuthal square-array dc-resistivity soundings measure changes in apparent resistivity with respect to azimuth and are about twice as sensitive to anisotropy as are linear arrays.

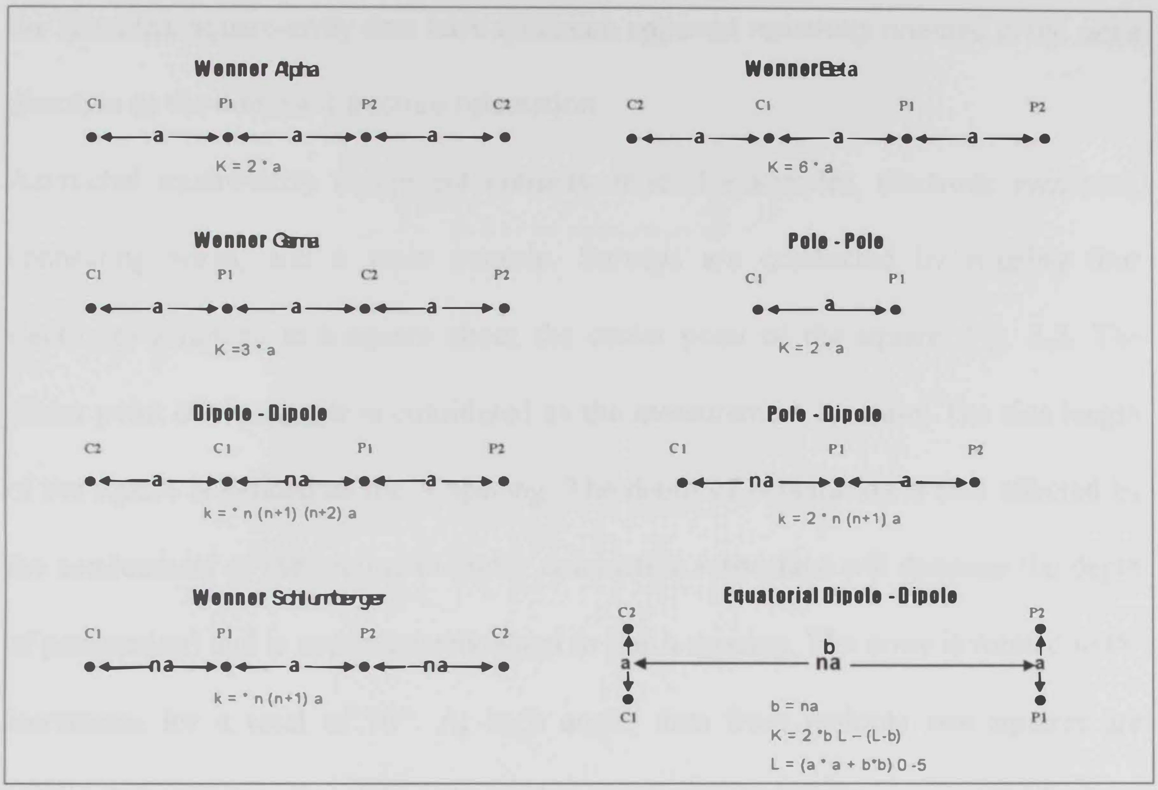


Figure 3.1. Common array used in resistivity surveys and their geometric factors.

The soundings measure changes in apparent resistivity with measurement direction and depth at a single location. For a zone of oriented, saturated, steeply dipping fractures, the azimuthal square-array data have minimum apparent resistivity oriented in the same direction as the dominant fracture orientation.

Azimuthal square-array equipment consists of steel electrodes, electrode switchers, connecting wires, and a main console. Surveys are conducted by rotating four electrodes arranged in a square about the center point of the square, Fig. 3.2. The center point of the square is considered as the measurement location. The side length of the square is defined as the A-spacing. The depth of penetration is also affected by the conductivity of the ground (a highly conductive subsurface will decrease the depth of penetration) and is approximately equal to the A-spacing. The array is rotated in 15° increments for a total of 90°. At each angle, data from multiple size squares are collected to image the different depths. Apparent resistivity is measured along perpendicular sides of each square and across the diagonals of each square. The apparent resistivity across a diagonal is used to check the precision of the measurement in a layer medium (Habberjam and Watkins, 1967).

3.2.3 Two-dimensional direct current resistivity profiling

The 2D dc-resistivity profiling method uses the same techniques and the same principles of the direct current resistivity method but conducted by making many measurements at different locations along the profile and at different offsets. The 2D dc-resistivity profiling data are inverted to create a tomogram-like model of resistivity along a section of the subsurface that can be used to detect and define individual fracture zones. The equipment used for 2D dc-resistivity profiling is the same as that used for azimuthal dc-resistivity soundings. The 2D dc-resistivity surveys are conducted with the electrodes arranged in a linear array, Fig. 3.3.

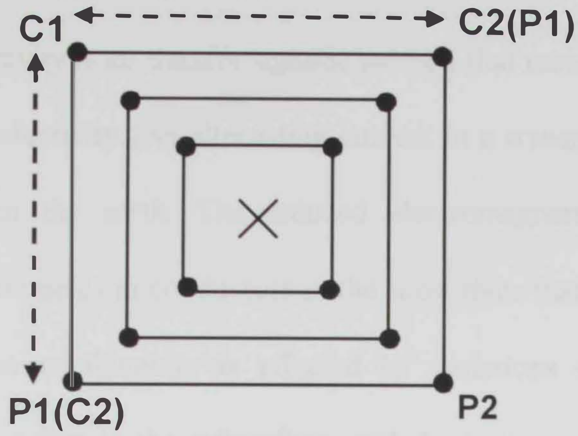


Figure 3.2. Square array.

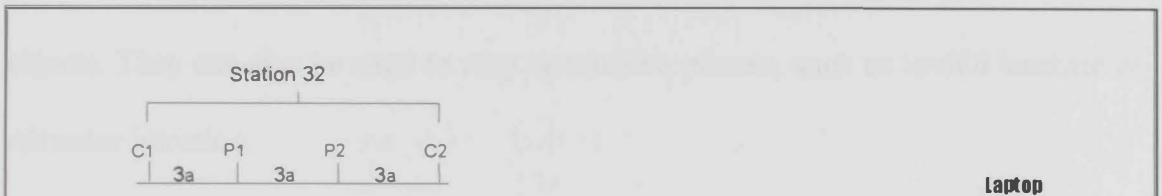


Figure 3.3. The arrangement of the electrodes for a 2-D electrical survey and the sequence of measurements used to build up a pseudo section (after Loke, 1997).

3.2.4 Inductive terrain conductivity method

Inductive terrain conductivity is an electromagnetic method that measures the apparent subsurface electrical conductivity. An alternating current in a transmitter coil induces electromagnetic fields in the earth. The induced electromagnetic fields generate secondary electromagnetic fields in conductors in the subsurface that are detected by a receiver coil. Subsurface conductivity is affected by variations in the subsurface material, the amount of water in the subsurface, and the ionic concentration of the subsurface water (McNeill, 1980). Conductive anomalies produce strong secondary electromagnetic fields. For example, inductive terrain-conductivity instruments can detect conductive features, such as fluid-filled fractures, or bodies, or buried metal objects. They can also be used to map conductive plumes, such as landfill leachate or saltwater intrusion.

Inductive terrain-conductivity equipment consists of a transmitting coil, a receiving coil, a control unit for each, and inter coil cables. The coils are held coplanar at a constant offset, and data are collected at discrete intervals along a survey line. The transmitter-receiver midpoint is considered to be the measurement location. The coils can be used in two configurations, horizontal dipole and vertical dipole. In the horizontal-dipole configuration, the coils are positioned vertically; in the vertical-dipole configuration, the coils are positioned horizontally. The electromagnetic field is induced deeper into the ground with the vertical-dipole configuration than with the horizontal-dipole configuration. Increased coil spacing and more resistive ground also increase the penetration depth of the induced electromagnetic field. An inductive terrain-conductivity measurement gives an average value for the volume approximated by the distance between the two coils and the depth of the measurement. The measurements are apparent conductivities rather than true conductivities, because a conductively homogeneous subsurface is assumed.

3.2.5 Ground penetrating radar method (GPR)

Ground penetrating radar method, GPR, systems use electromagnetic waves in the radar-frequency range (generally 10-1,000 MHz) to image the subsurface. Radar-wave propagation is affected by electromagnetic properties of subsurface materials (Daniels, 1989). When radar waves encounter contrasts in the electromagnetic properties of the subsurface, some energy is reflected and some is transmitted into deeper materials. Reflected energy is detected by a receiving antenna and recorded. Electromagnetic properties are determined by water content, lithology, and amount of conductive material, such as clays or metals, in soil. The equipment consisted of 300-MHz transmitting and receiving antennas contained in a fiberglass sled with a fixed offset of 0.5 m, a control unit, and a graphic recorder.

3.3 Site Characterization

The geophysical data presented in this study were collected between the farms near the existing borohole for which drilling information is available. The location of the 2D resitivity profiles are shown in Fig. 3.4. The 2D resistivity profiles were conducted and oriented along the strike direction to intersect the maximum possible number of geologic features and lineaments.

3.4 Data Acquisition and Processing

A single channel Memory Earth Resistivity and IP Meter instrument manufactured by Advanced Geosciences, Inc., Fig. 3.5, available in the College of Science, United Arab

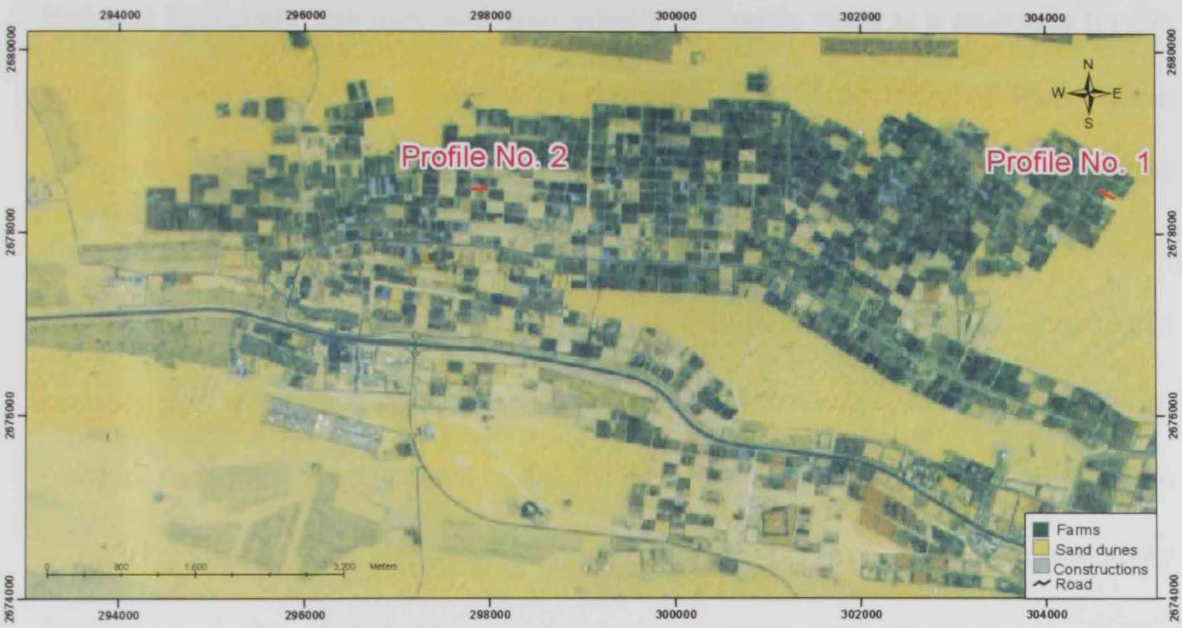


Figure 3.4. Location map of geophysical profiles.

Figure 3.5. Single Channel Memory Resistivity and IP meter.

Emirates University was used with four wheels of electric wires as a substitute for the multicore cable. Readings were taken manually. The linear array of each profile consisted of 36 electrodes spaced 10 m apart and the distancces were controlled manually by marching throug the profile forward and backward, Fig. 3.6. Wenner array Alpha was used in this survey, Fig. 3.1. By using an iterative smoothness-constrained least-squares inversion method (De Groot-Hedlin and Constable, 1990; Sasaki, 1992), apparent resistivity data collected by the 2D dc-resistivity system are inverted to create a model of subsurface resistivity that approximates the true subsurface resistivity distribution (Loke, 1997). The resistivity models were used to generate synthetic apparent resistivity data. The synthetic apparent resistivity data were inverted using Res2dinv Software and the resulting inversions were compared with the original inverted resistivity section. The resistivity models were adjusted and simplified to qualitatively match the field-data inversions. Generating resistivity models helped constrain interpretation of the field-data inversions to identify locations and orientations of anomalies.

The inverted data which are displayed as a cross section of resistivity data approximate the true subsurface resistivity distribution. Information about the subsurface along the resistivity profile is interpreted from the distribution of areas of high and low resistivity. During the inversion process, errors in the unprocessed data are amplified as depth increases. A robust solution is assured by adjusting the inversion parameters and using quality-control checks on the inverted section.

The 2D dc-resistivity field-data inversions, resistivity models and synthetic-data inversions for profiles 1 and 2 are shown in Figs. 3.7 and 3.8. The depth of penetration in both profiles is about 60 m and thus reached only the top weathered surface of the

Figure 3.6. Resistivity field work at AL-Khatim area.

limestone bedrock. The depth to the water table in the first profile is ranging from 5 to 15 meters. The resistivity of the saturated zone is varies from less than 1.5 Ωm to 50 Ωm propably reflecting different water quality with depth and/or horizontal variations in the clay content, Fig. 3.7.

The inversion of resistivity data along profile 2, Fig. 3.8, shows more or less similar pattern. Depth to water table is approximately 10 m below the ground surface along the profile.

A shallow conductive zone was detected from a depth of about 14 m to the total depth of penetration (60 m from ground surface). This zone is interpreted as a saturated sediment with brackish to saline groundwater. Based on the chemical analysis of a groundwater sample taken from a nearby well (no.25), the salinity of the groundwater in this area is 14500 mg/l. Geophysical data interpretation was constrained with the available drilling and groundwater quality information. For example, the drilling information, Fig. 2.7, indicate the unconsolidated sediments from a depth of 10-60 meter are mainly composed of sand.

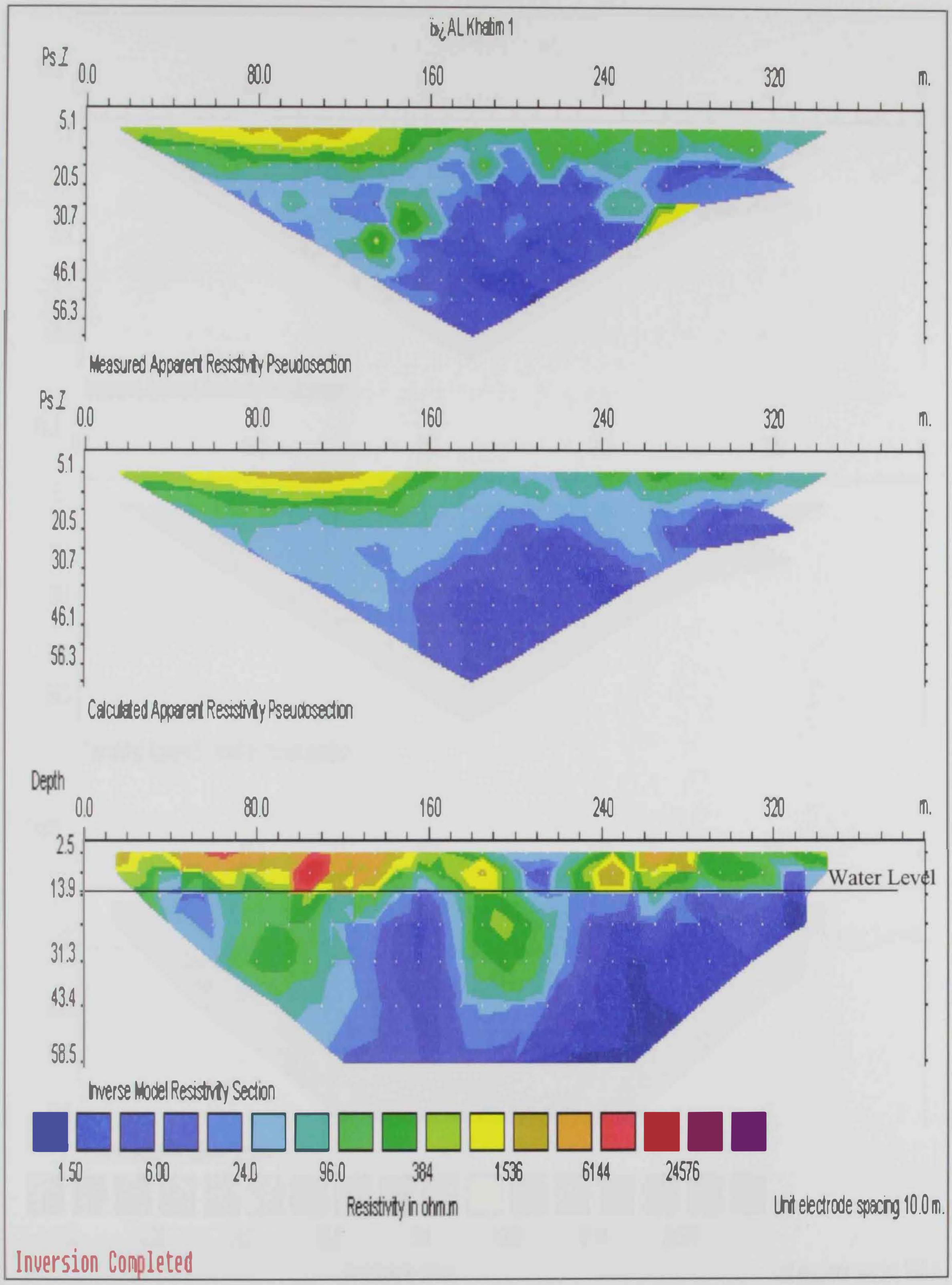


Figure 3.7. Results of geophysical measurements, profile 1.

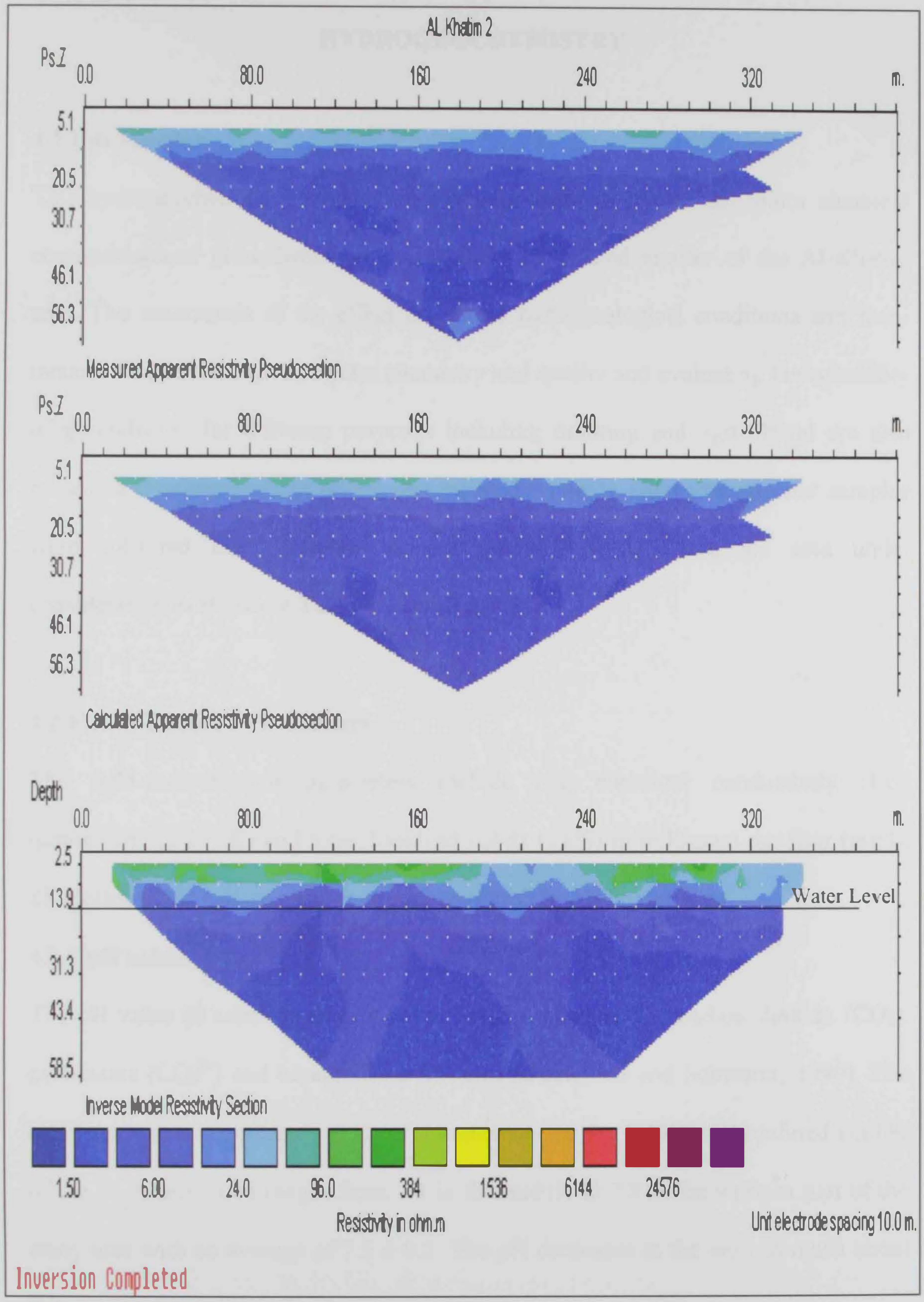


Figure 3.8. Results of geophysical measurements, profile 2.

Chapter 4

HYDROGEOCHEMISTRY

4.1 Introduction

This hydrogeochemical study includes measurement of major and minor chemical compositions of groundwater in the shallow unconfined aquifer of the Al-Khatim area. The assessment of the effect of natural hydrogeological conditions and man-induced activities on groundwater chemistry and quality and evaluating the suitability of groundwater for different purposes including drinking and agricultural are also presented. For the purpose of the present study, twenty eight groundwater samples were collected from different private pumping wells along the area under consideration as shown in Table 4.1 and Fig. 2.1.

4.2 Field-Measured Parameters

The field-measurement parameters include pH, electrical conductivity (EC) (μmohs/cm @ 25 °C) and total dissolved solids (TDS) in milligram per liter (mg/l). The following is a discussion on these parameters in Al-Khatim area.

4.2.1 pH value

The pH value of water is related to the amount of dissolved carbon dioxide (CO_2), carbonates (CO_3^{2-}) and bicarbonates (HCO_3^-) (Domenico and Schwartz, 1990). The hydrogen-ion concentrations (pH) of groundwater in the Shallow unconfined aquifer of the Al-Khatim area ranges from 7.1 in the middle to 7.8 in the western part of the study area with an average of 7.5 ± 0.2. The pH decreases to the west to reach about 7.1 at well no. 24, Fig. 4.1.

Table 4.1 Chemical analysis of 28 samples from groundwater of Al-Khatim area (mg/l)

well no.	Farm No.	Easting	Northing	Altitude	PH	Ec (µS/cm)	TDS (ppm)	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	$SO4^{2-}$	HCO_3^-	NO_3^-
2	56	304622	2678503	131	7.6	9400	6600	614	190	1313	64	2050	2250	74	76
7	63	304588	2678132	132	7.3	10900	7700	647	178	1556	67	2575	2570	116	45
11	59	304985	2678609	132	7.6	10800	7000	459	183	1610	72	2150	2450	90	37
14	58	304758	2678730	133	7.5	10200	7000	653	190	1418	71	2050	2372	86	151
16	333	301847	2677818	121	7.5	13300	8600	426	294	2007	82	3050	2590	101	60
20	53	304340	2678209	130	7.4	12500	8040	314	199	1953	78	3100	2108	105	185
21	21	303640	2677590	129	7.6	12700	8800	612	213	1835	83	3075	2680	123	145
22	27	304163	2678624	131	7.3	10300	7100	810	211	1217	78	1975	2280	148	412
23	101	298231	2677451	108	7.4	22900	15400	1006	644	3239	163	5450	3673	140	1060
24	118	300429	2678057	119	7.1	20000	12800	592	508	3038	125	5525	2827	80	57
25	250	297803	2678423	108	7.2	21200	14500	902	616	3039	144	5600	3578	88	484
26	292	298484	2678701	114	7.4	16700	11100	672	431	2323	112	4075	3094	93	347
27	392	300340	2678917	114	7.3	17700	12800	819	460	2572	114	4700	3500	115	522
28	420	300683	2679034	121	7.3	17200	11300	679	421	2580	113	4800	3441	107	175
29	493	301530	2678304	121	7.3	14700	10600	870	411	1972	105	3225	3024	137	867
30	563	302256	2679248	123	7.7	9900	6800	760	216	1190	74	1900	2260	111	337
31	581	302561	2678190	126	7.8	15400	9900	423	344	2334	93	4150	2360	96	54
32	615	303072	2678888	134	7.4	10200	7600	860	327	1257	93	2075	2071	121	760
33	634	303204	2677904	125	7.5	13100	8800	511	311	1932	81	3125	2520	96	186
37	463	301191	2677057	116	7.5	16400	11200	608	408	2516	104	3975	3436	72	96
40	46	303894	2677665	128	7.7	10300	6800	273	163	1634	62	2200	2380	104	15
45	5	301640	2674783	119	7.7	24500	15700	542	442	3800	180	5750	5457	98	142
46	87	299983	2675709	126	7.5	26900	18000	714	654	4112	203	6925	5096	36	225
48	102	299608	2675207	125	7.4	23700	16300	722	605	3811	181	5975	4745	127	126
50	1	300617	2674194	122	7.6	23800	15200	585	492	3515	141	6000	4362	96	57
51	644	301672	2679244	119	7.7	15800	10200	436	364	2416	108	4113	2660	84	14
52	42	299600	2675722	118	7.5	28200	18000	586	578	4133	211	7275	5172	89	66
71	651	303761	2678869	134	7.6	12000	7500	373	197	1888	79	2650	2230	87	12

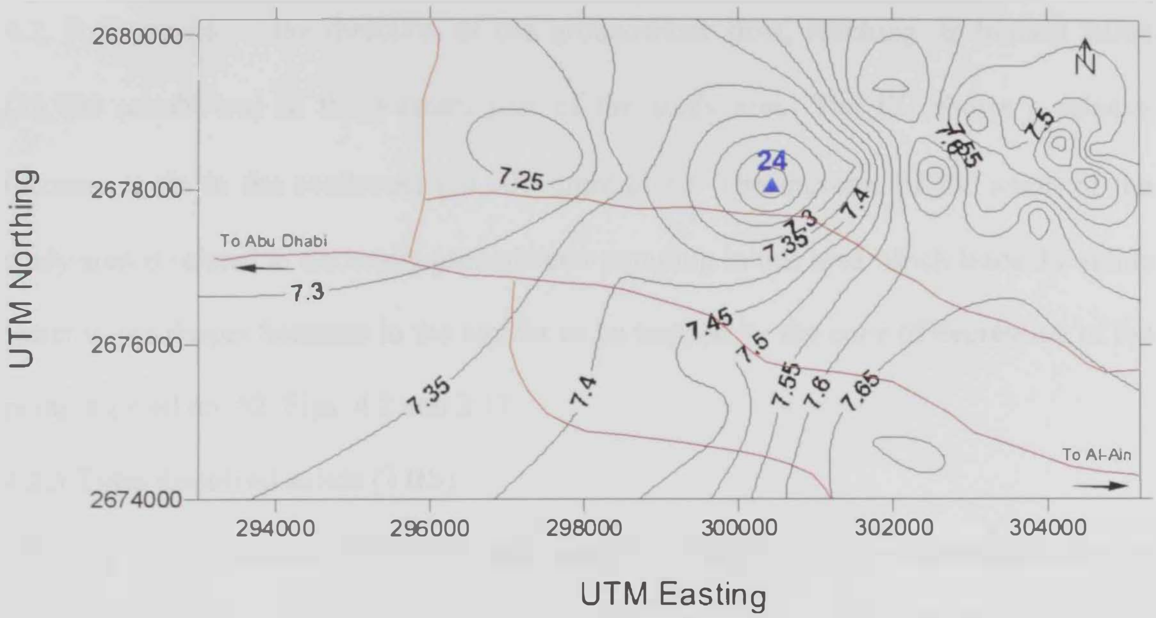


Figure 4.1. Iso-pH contour map.

4.2.2 Electrical conductance (EC)

The electrical conductance (EC) of groundwater samples collected from the unconfined shallow aquifer of the Al-Khatim area is low in the northeast (<9,500 µmohs/cm) Fig. 4.2. It increases in the direction of the groundwater flow, reaching its highest value (33,000 µmohs/cm) in the western part of the study area. The EC shows a relative increase again in the southwest (33,000 µmohs/cm). The increase of EC south of the study area is related to the heavy groundwater pumping in this area which leads the saline water in the deeper horizons in the aquifer to be trapped by the cone of depression of the pumping well no. 52, Figs. 4.2 and 2.11.

4.2.3 Total dissolved solids (TDS)

The total dissolved solids (TDS) in water samples includes all solid materials in solution whether ionized or not. It does not include suspended sediments, colloids or dissolved gases (Todd, 1980). The TDS content in groundwater is an indication of its salinity. In 2002, the TDS in the groundwater of the Shallow unconfined aquifer in the Al-Khatim area ranged from 6,511 mg/l (well no. 30) to 17,740 mg/l (well no. 46), Fig. 4.3. The iso-salinity contour map of the Shallow unconfined aquifer of the Al-Khatim area shows that the groundwater salinity increases from the northeast towards southwest, in the direction of groundwater flow. Local increase in groundwater salinity south of Al-Khatim is related to sever groundwater pumping in this area. A scatter plot and a regression analysis of the measured EC against calculated TDS from chemical analysis are given in Fig. 4.4 in which a good linear fit between these two sets of data can be recognized.

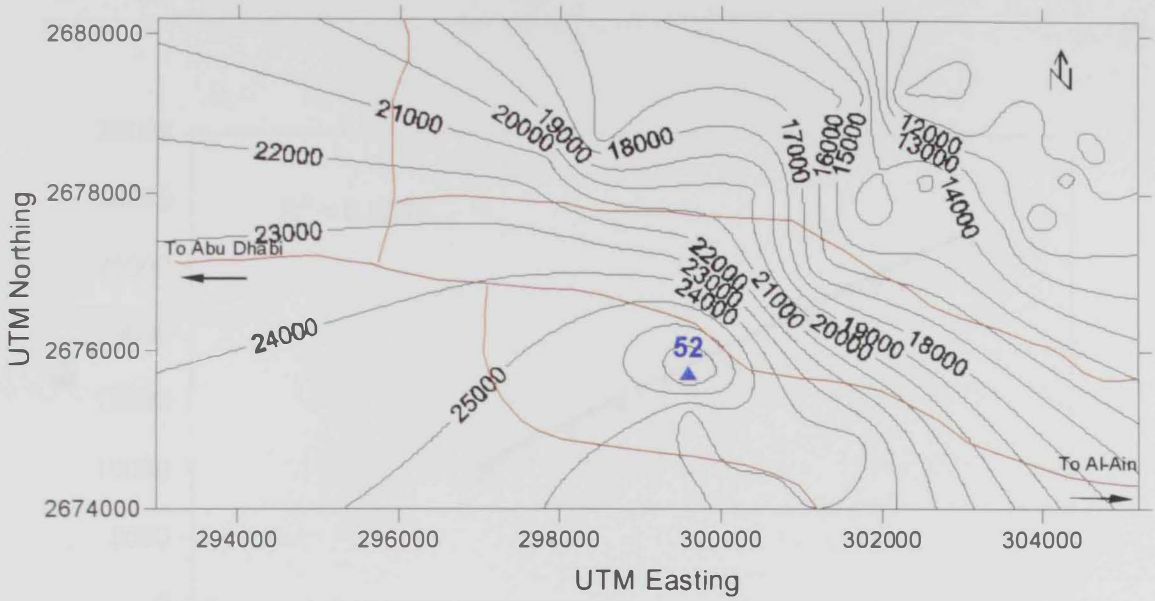


Figure 4.2. Iso-electrical conductivity (EC μmohs/cm) contour map.

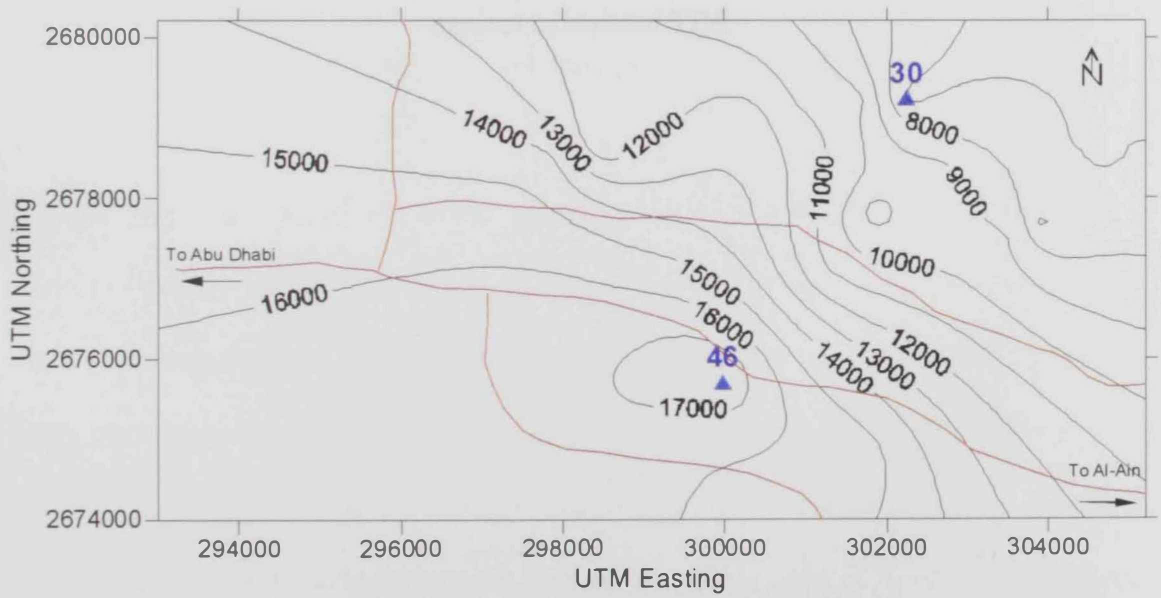


Figure 4.3. Iso-salinity TDS contour map (mg/l).

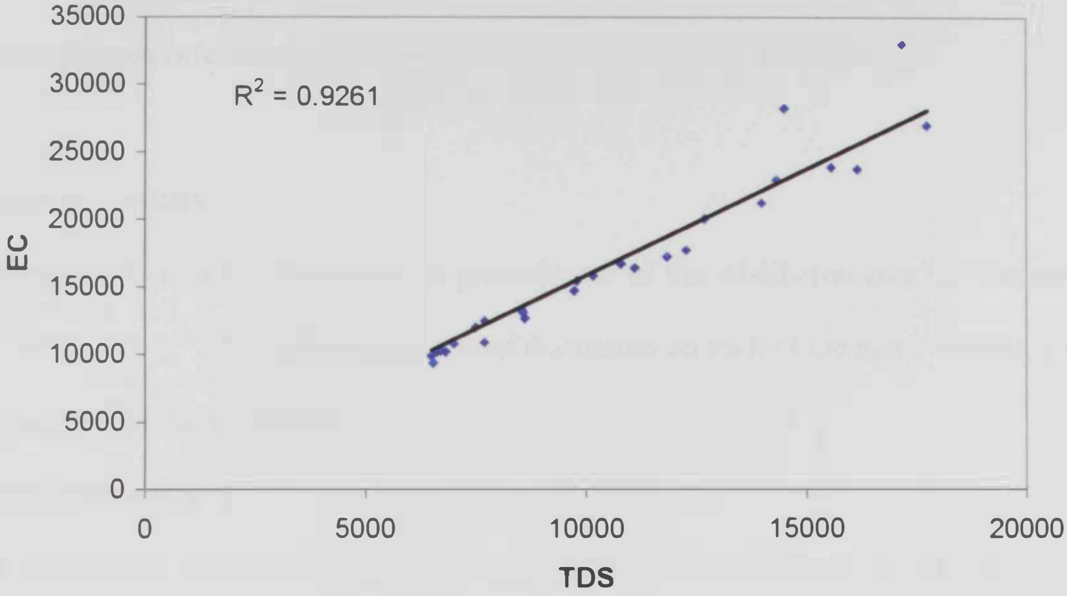


Figure 4.4. A scatter plot and a regression analysis of measured EC against calculated TDS.

4.2.4 Total hardness

The total hardness (as $CaCO_3$) can be categorized as following: Low 0-60 mg/l, Moderate 60- 180 mg/l, High > 180 mg/l. The hardness of the groundwater in the aquifer around Al-Khatim area is relatively high (total hardness as $CaCO_3$ >180 mg/l).

4.3 Major Cations

The sequence of cation dominance in groundwater of the Al-Khatim area has the order: $Na^+ > Ca^{2+} > Mg^{2+}$. The following is a brief discussion on each of the major cations in the groundwater of the study area.

4.3.1 Calcium (Ca^{2+})

The calcium-ion concentrations (Ca^{2+}) ranges from 273 mg/l (well no. 40, east of Al-Khatim) to 1,006 mg/l (well no. 23, west of Al-Khatim). The iso-concentration contour map shows a gradual increase in Ca^{2+} from the northeast towards the southwest, Fig. 4.5. The general increase in Ca^{2+} occurs in the main direction of groundwater flow.

4.3.2 Magnesium (Mg^{2+})

The magnesium ion (Mg^{2+}) concentrations in fresh water are generally less than that of calcium because of low geochemical abundance of magnesium (Mathess, 1982). Common concentrations of magnesium range from 1 to 40 mg/l and reach 100 mg/l in water circulating through magnesium-rich rocks. Magnesium-ion (Mg^{2+}) concentrations in groundwater of the shallow unconfined aquifer of the Al-Khatim area ranges from 163 mg/l (well no. 40, east of Al-Khatim) to 654 mg/l (well no. 46, in the southwestern part of the study area. Fig. 4.6 presents an iso-concentration contour map of Mg^{2+} in Al-Khatim area.

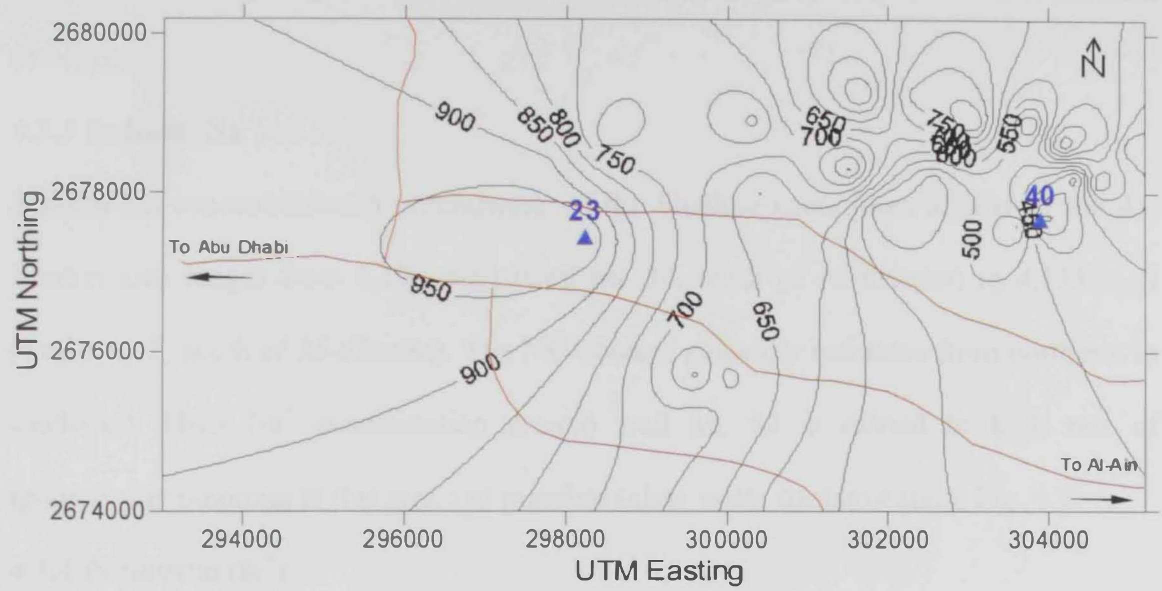


Figure 4.5. Iso-concentration (mg/l) contour map of Ca^{2+}.

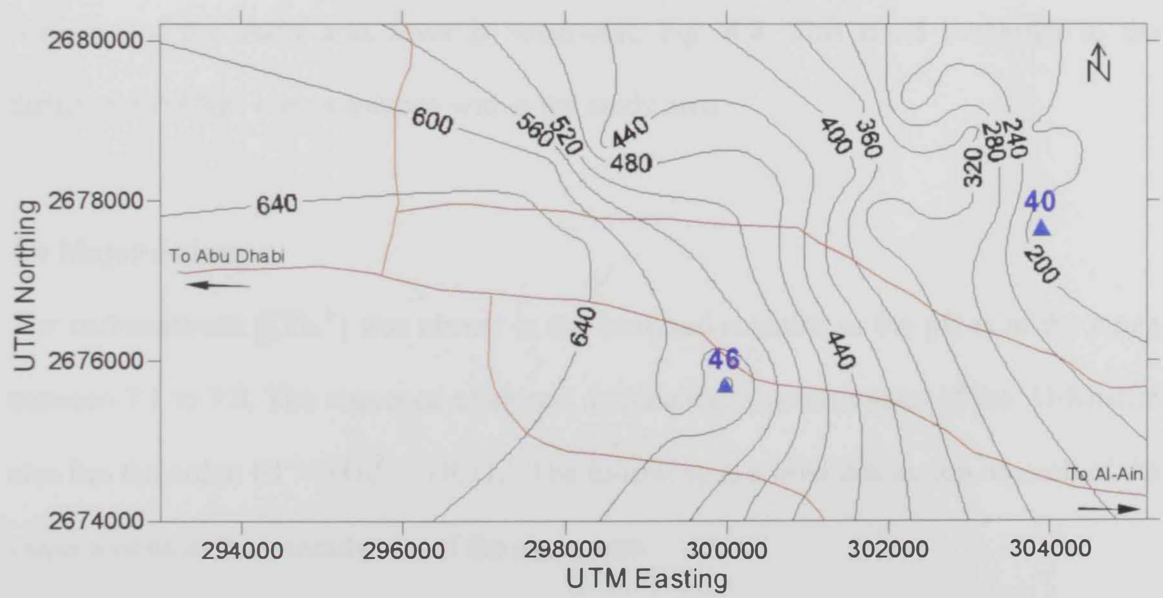


Figure 4.6. Iso-concentration (mg/l) contour map of Mg^2.

It shows high Mg^{2+} concentrations in the northeastern and southwestern portions of the study area. The high Mg^{2+} in the southwest can be explained by its enrichment in the flow direction.

4.3.3 Sodium (Na^+)

Sodium-ion concentration in groundwater of the Shallow unconfined aquifer of the Al-Khatim area ranges from 1,190 mg/l (well no. 30, north of Al-Khatim) to 4,133 mg/l (well no. 52, south of Al-Khatim). The Na^+ content generally increases from northeast to southwest. High Na^+ concentration around well no. 52 is related to high rate of groundwater pumping in this area and possible saline water contamination, Fig. 4.7.

4.3.4 Potassium (K^+)

Potassium-ion (K^+) concentration in groundwater of Shallow unconfined aquifer of the Al-Khatim area ranges from 62 mg/l (well no. 40) to 211 mg/l (well no. 52). The iso-concentration contour map shows a steady increase in K^+ concentration from the northeast of the study area towards southwest, Fig. 4.8. This trend is similar to the distribution of Na^+ concentrations within the study area.

4.4 Major Anions

The carbonate-ion (CO_3^{2-}) was absent in the analyzed samples as the pH is in the range between 7.1 to 7.8. The sequence of anions dominance in groundwater of the Al-Khatim area has the order: $Cl^- > SO_4^{2-} > HCO_3^-$. The following is a brief discussion on each of the major anions in the groundwater of the study area.

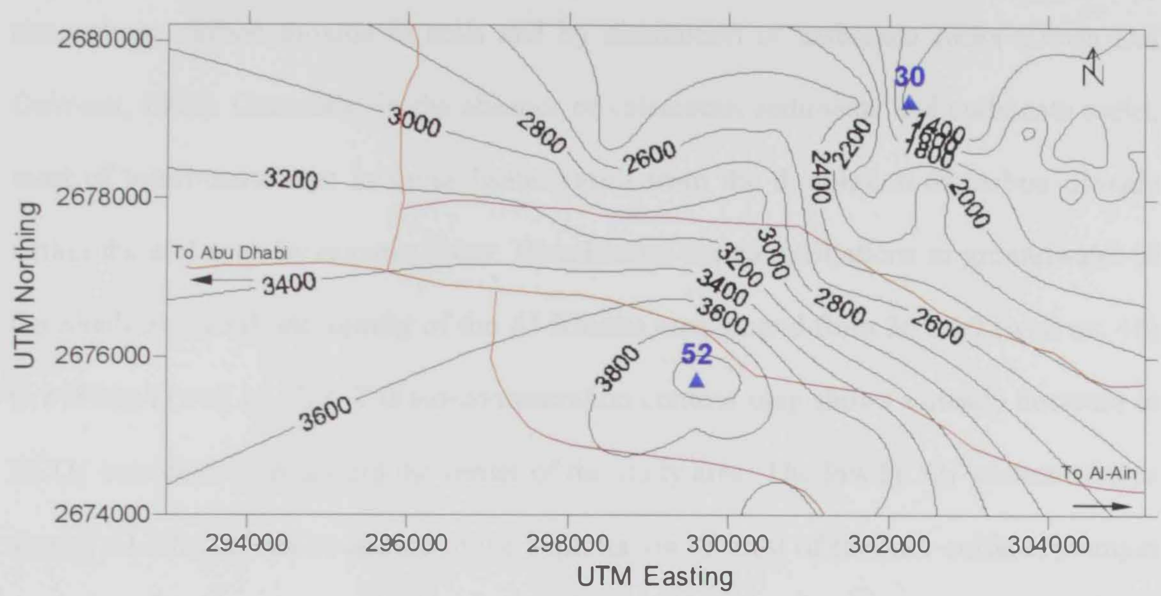


Figure 4.7. Iso-concentration (mg/l) contour map of Na^+.

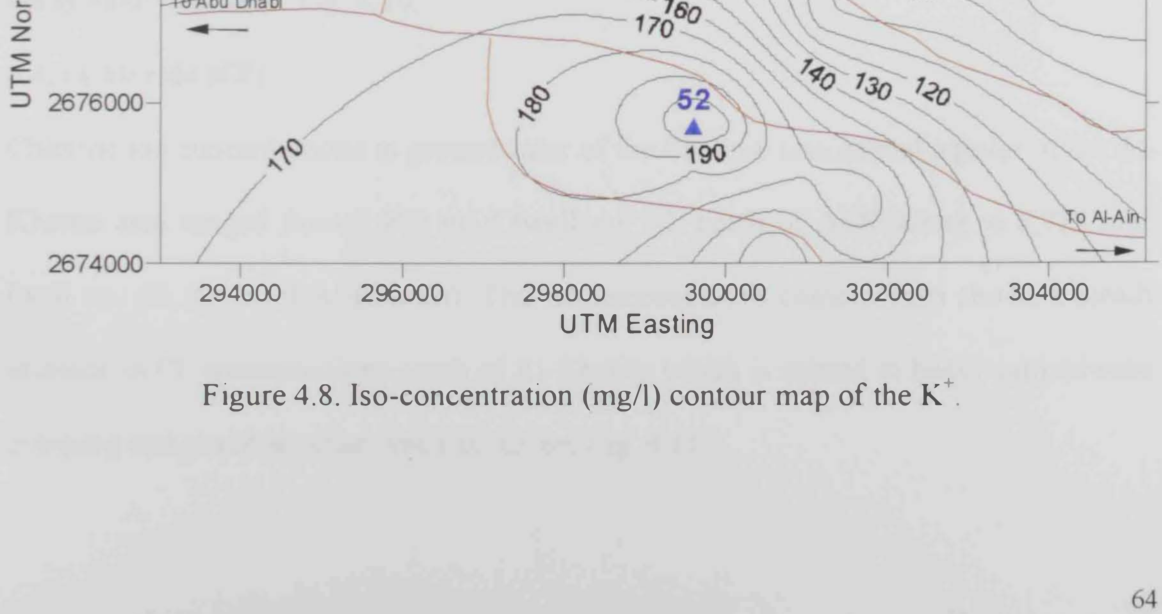


Figure 4.8. Iso-concentration (mg/l) contour map of the K^+.

4.4.1 Bicarbonate (HCO_3^-)

Most bicarbonate ions (HCO_3^-) in groundwater are derived from carbon dioxide in the atmosphere, carbon dioxide in soils and by dissolution of carbonate rocks (Davis and DeWeist, 1966). Generally, in the absence of calcareous sediments and carbonate rocks, most of bicarbonate ions in groundwater result from the dissolution of carbon dioxide within the soil zone by organic decay. Bicarbonate-ion concentrations in groundwater of the Shallow unconfined aquifer of the Al-Khatim area ranged from 36 mg/l (well no. 46) to 148 mg/l (well no. 22). The iso-concentration contour map shows a steady decrease in HCO_3^- concentrations toward the center of the study area. The low HCO_3^- concentrations around Al-Khatim can be related to the exploitation of most of the near-surface, younger water in the aquifer, Fig. 4.9.

4.4.2 Sulfate (SO_4^{2-})

Sulfate-ion concentrations in groundwater of the Shallow unconfined aquifer in Al-Khatim area in 2002 ranged from 2,071 mg/l (well no. 32, east of Al-Khatim) to 5,157 mg/l (well no. 45, south of Al-Khatim). The iso-concentration contour map shows a steady increase in SO_4^{2-} concentrations from northeast to southwest, in the direction of the groundwater flow, Fig. 4.10.

4.4.3 Chloride (Cl^-)

Chloride ion concentrations in groundwater of the Shallow unconfined aquifer of the Al-Khatim area ranged from 1,900 mg/l (well no. 30, north of Al-Khatim) to 6,925 mg/l (well no. 48, south of Al-Khatim). The iso-concentration contour map shows a steady increase in Cl^- concentrations south of Al-Khatim which is related to heavy groundwater pumping and possible saline water intrusion, Fig. 4.11.

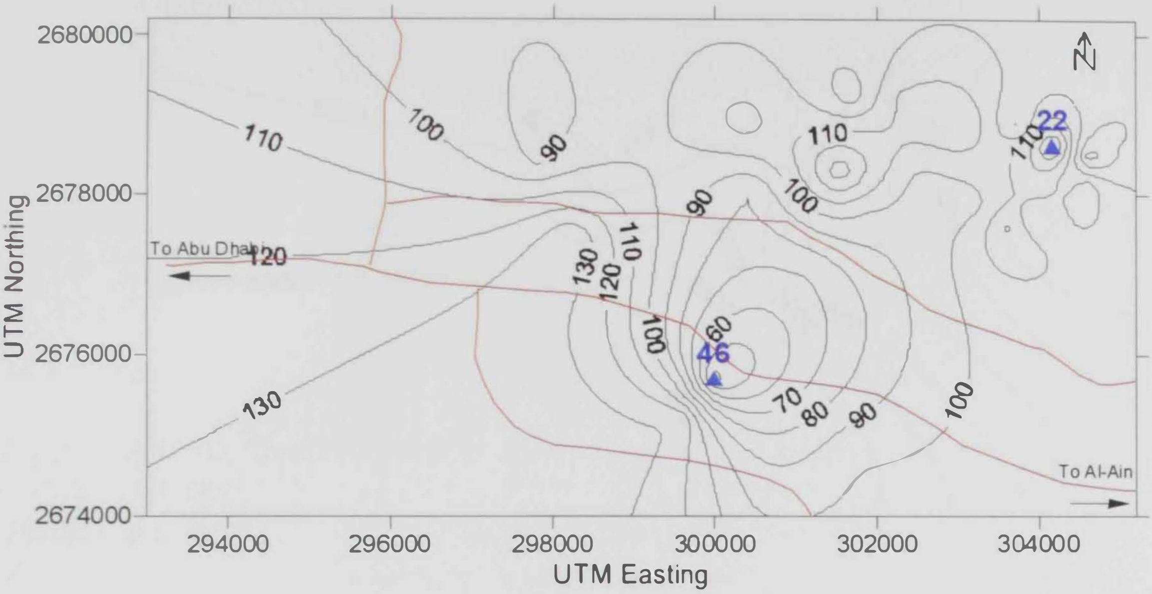


Figure 4.9. Iso-concentration (mg/l) contour map of the HCO_3^-.

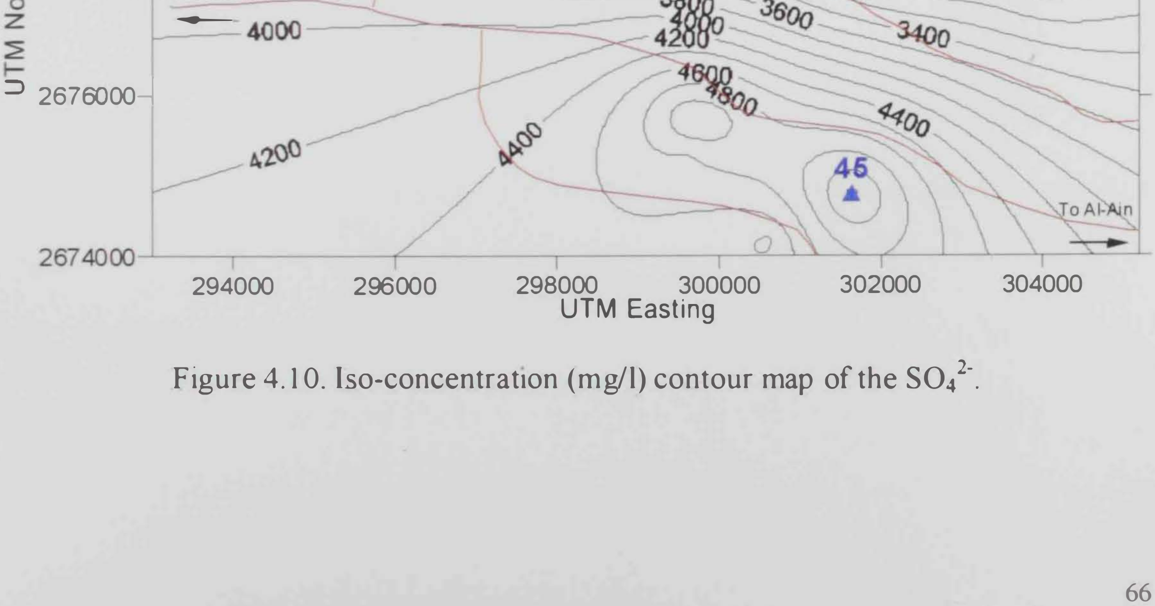


Figure 4.10. Iso-concentration (mg/l) contour map of the SO_4^{2-}.

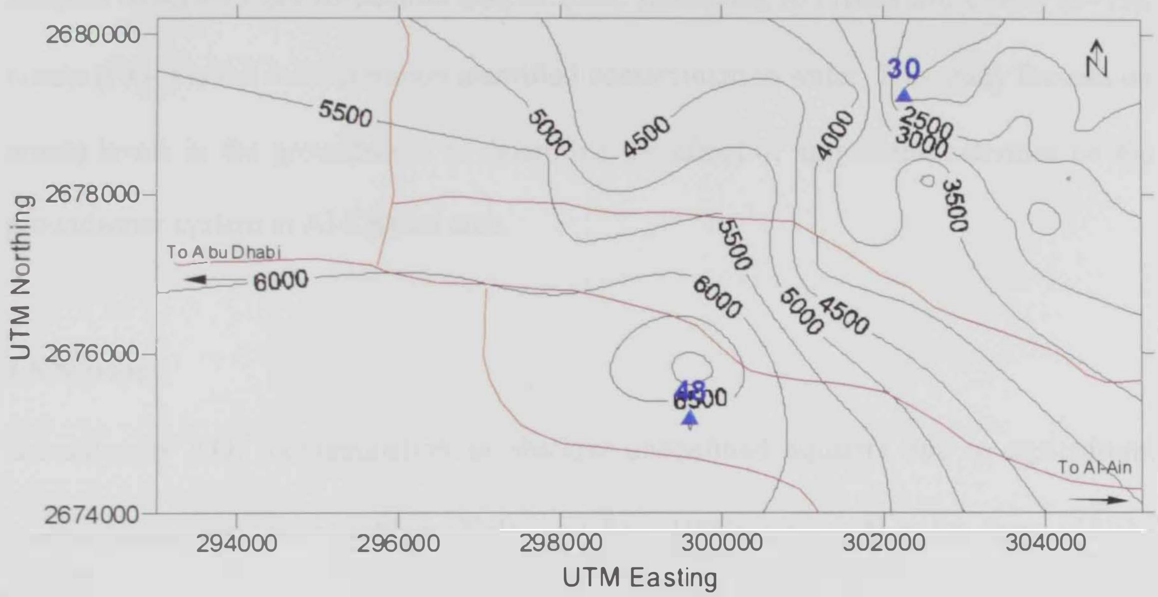


Figure 4.11. Iso-concentration (mg/l) contour map of the Cl^-.

4.5 Minor Constituents

Nitrate (NO_3^-) and Boron (B^-) ions, as well as silica (SiO_2) were measured in water samples collected from Al-Khatim area in 2002. According to Freeze and Cherry (1979), nitrate (NO_3^-) is the most common identified contaminant in water. This study focuses on nitrate levels in the groundwater to determine the effect of agriculture activities on the groundwater system in Al-Khatim area.

4.6 Nitrate

Groundwater NO_3^- contamination in shallow unconfined aquifers due to agricultural practices is a worldwide problem (Kelly and Ray. 1999). Excess N in the form of NO_3^- accumulates in the soil when land application of animal manure and inorganic, commercial fertilizers exceed the N agro-chemically required by crops. The mobile nitrate ion is easily leached to the groundwater during irrigation, especially in areas with well-drained soils and shallow water tables. Numerous studies have documented the extent of the problem and relationship between agricultural activities and NO_3^- leaching in shallow aquifers (e.g., Spalding and Exner, 1993, Stuart et al., 1994, Pukett et al., 1999, Nolan and Stoner, 2000, and Nolan, 2001).

The nitrate ion (NO_3^-) is the most water-soluble form of nitrogen as well as the form least attracted to soil particles. Therefore, its interaction with the hydrologic cycle is very important since it moves where water moves.

The extraordinary enrichment of nitrate in groundwater is a worldwide occurring phenomenon. The groundwater under about 22% of the cultivated land in the European Union has an NO_3^- concentration above 50 mg/L NO_3^- (Meinardi et al., 1995). Similarly, high concentrations in groundwater are also reported from some irrigated areas west of Mississippi in the USA (Spalding and Exner, 1993), from northern China (Zhang et al., 1996), and elsewhere.

Nitrate occurs in groundwater from variety of sources, which can be classified in two main categories, anthropogenic and non-anthropogenic sources.

4.6.1 Non-anthropogenic sources

Nitrate occurs naturally from mineral sources and animal wastes. However, it has been observed that in semi-arid areas nitrate concentrations cannot be always attributed to anthropogenic activity, as they occur in regions that are mostly uninhabited. The same results were noticed in the study area as the samples collected from desert soil contained elevated nitrate concentration, up to 91 mg/l. Understanding of nitrate enrichment, and nonanthropogenic impacts on it's dynamics, are not well investigated at the scale of the biosphere in semi-arid and arid regions.

4.6.2 Anthropogenic sources

The main sources of nitrate in soil and groundwater are dependent to some extent on human activities such as byproduct of agriculture and human wastes. Common sources of nitrate in soil and water include fertilizers, livestock waste, and septic systems. Further, agriculture is the largest contributor of nitrate pollution to groundwater. Nitrogen from excess fertilizer percolates through the soil and is detectable, as elevated nitrate concentrations. Nitrate is the most oxidized form of nitrogen in the nitrogen cycle (Thomas and David, 1995).

4.6.3 Nitrogen fertilizers

The most common source of Nitrates contaminate in groundwater systems is heavy applications of nitrogen fertilizers specially when excess irrigation water is used in areas with permeable sandy soils. Any fertilized farm field may add only small amount of nitrate but accumulation from many farms can in to high nitrate levels in groundwater. Even rotting vegetation in soil can add significant amounts of nitrates to groundwater. As the soil in the study area is considered very poor in humus and organic matter, intensive fertilizers are being supplemented to support the growth of fodders crops (Alfa-Alfa and Rhodes Grass).

4.6.4 Assessment of nitrate in Al-Khatim area

Assessment of the nitrate in groundwater system is quite complex because it depends on several factors. However, monitoring groundwater and soil quality in certain area can give an indicator of the problem. The WHO defines the nitrate level in safe drinking water must not exceed 10 mg/L as nitrate-N or 40 mg/L as Nitrate-NO_3^-. Nitrate concentrations are usually reported in units of milligrams per liter (mg/l) with the mass representing either the total mass of nitrate ion in the water (nitrate- NO_3^-), or as the mass of only the nitrogen (nitrate-N). The molecular weight of nitrate is 62 and the molecular weight of nitrogen is 14, so the ratio of a concentration measured as nitrate- NO_3^- to an equivalent concentration measured as nitrate-N is 4.43. The Maximum Contaminant Level MCL of 10 mg/l nitrate-N is equivalent to 44.3 mg/l nitrate- NO_3^-.

The high nitrate concentration has been recorded in Al-Khatim area few years ago in routine analysis of some farm wells. The iso-concentration contour map of NO_3^- indicates high concentration in the northeastern part of the study area (1060 mg/l in well no. 23), decreasing towards the west and southwest, Fig. 4.12. The high NO_3^- in the southwest can be related to leaching of nitrate from nitrogen fertilizers applied on farm land up gradient of this area. Fig. 4.13 shows that the year of the establishment for the farms has a direct relation with the amount of nitrate found in the groundwater.

4.7 Water Quality

Graphical representations of chemical analysis are useful for displaying purposes, comparing analyses and emphasizing similarities and differences. These graphs also illustrate the origin and chemical water types.

4.7.1 Piper diagrams

Piper diagrams are a combination of anion and cation triangles and a diamond shape used to plot the analysis of results. The position n of plotted analysis provides a way of expressing water type, Figs. 4.14 and 4.15.

Plotting Al-Khatim groundwater analysis from the unconfined shallow aquifer on piper diagrams, Fig. 4.16, the samples fall in the upper triangle of the diamond- shaped field. It means that the dominant groundwater types are sodium-chloride which point to the saline water. Analyzing the position of the samples shows that the groundwater in the western part of the study area is enriched in magnesium as compared to the groundwater in the eastern part indicating its precipitation as it moves down gradient.

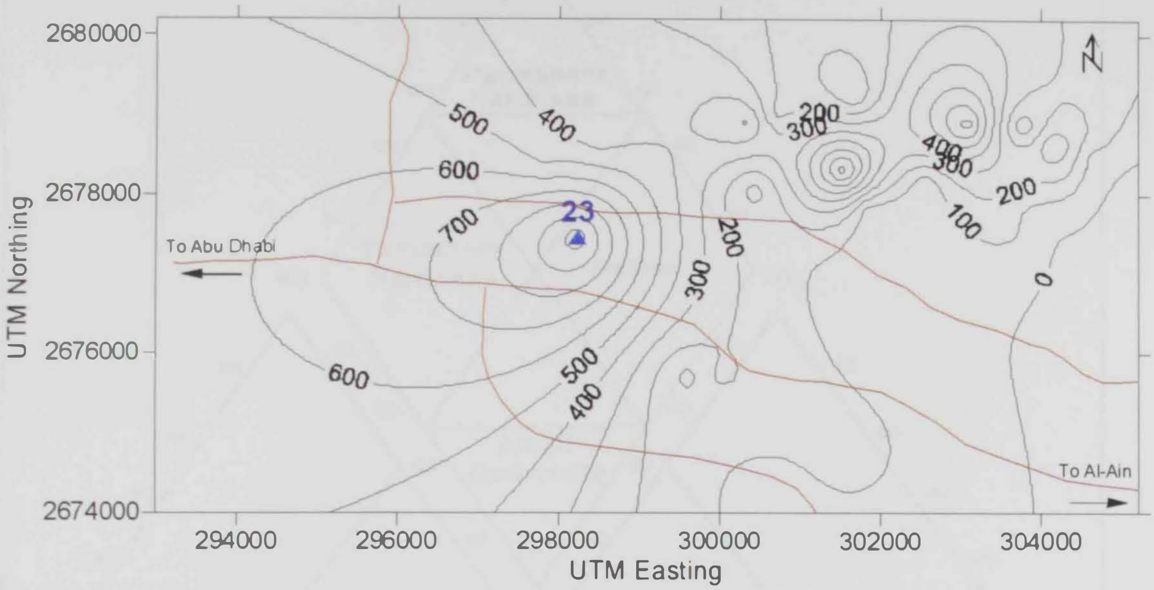


Figure 4.12. Iso-concentration (mg/l) contour map of the NO_3^-.

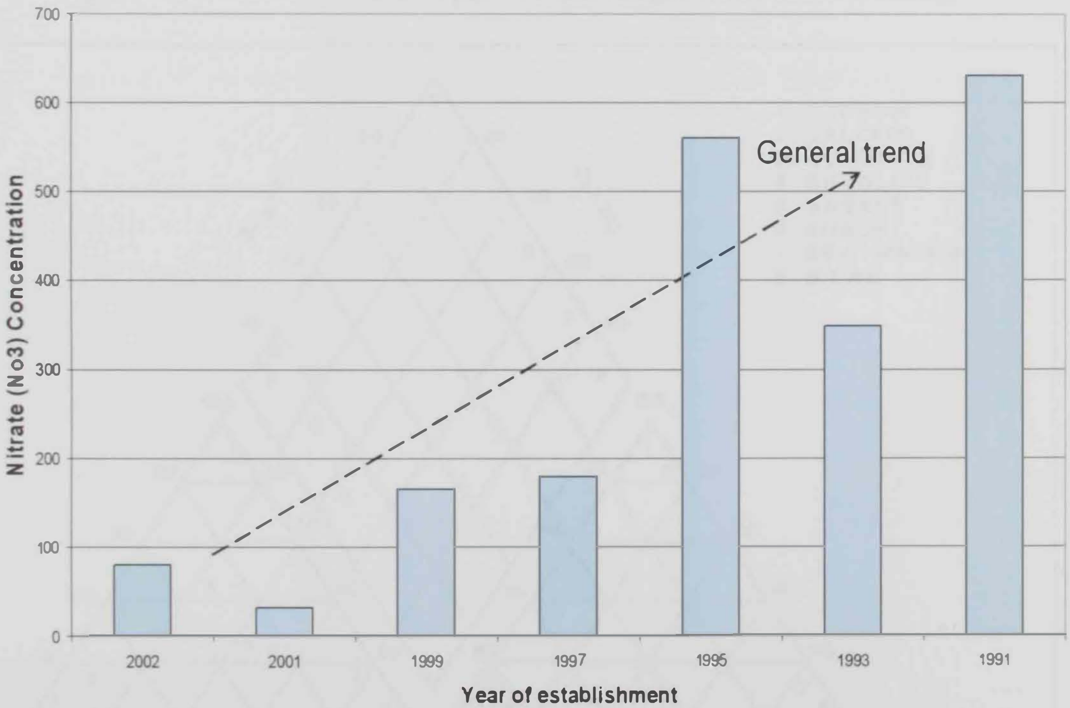


Figure 4.13. The relation between the year of establishment of farms and nitrate concentration in groundwater samples.

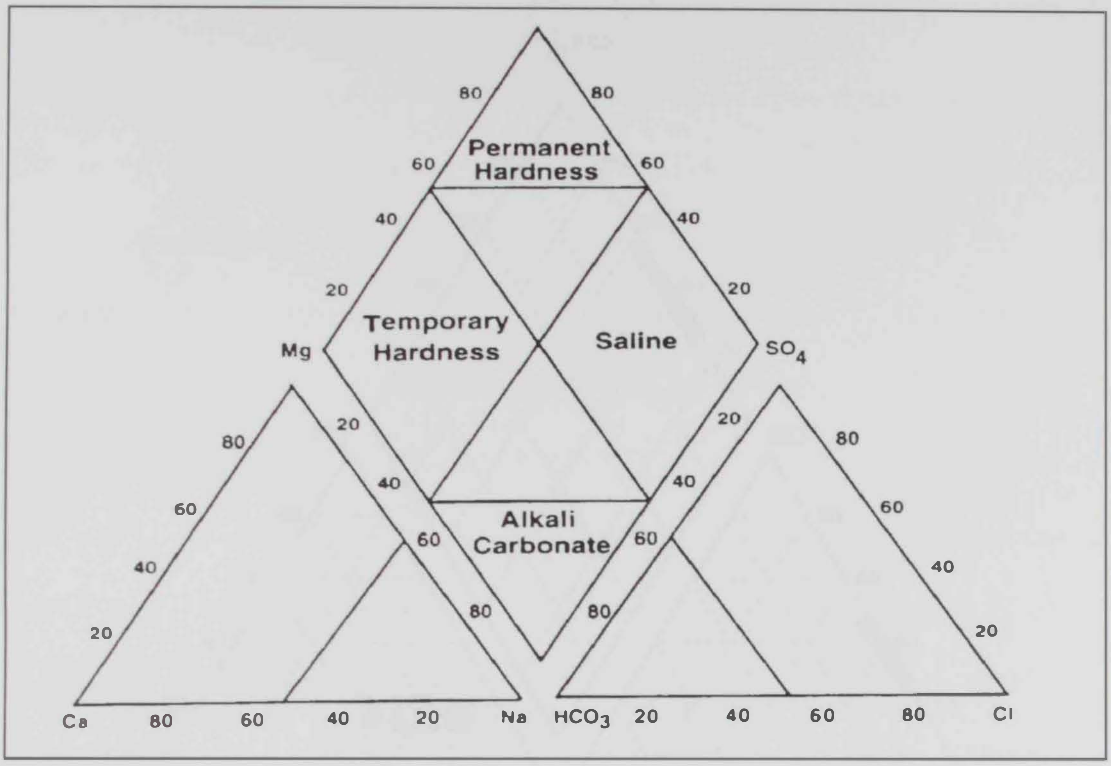


Figure 4.14. Different water types in Piper diagram (Hounsloe, 1995).

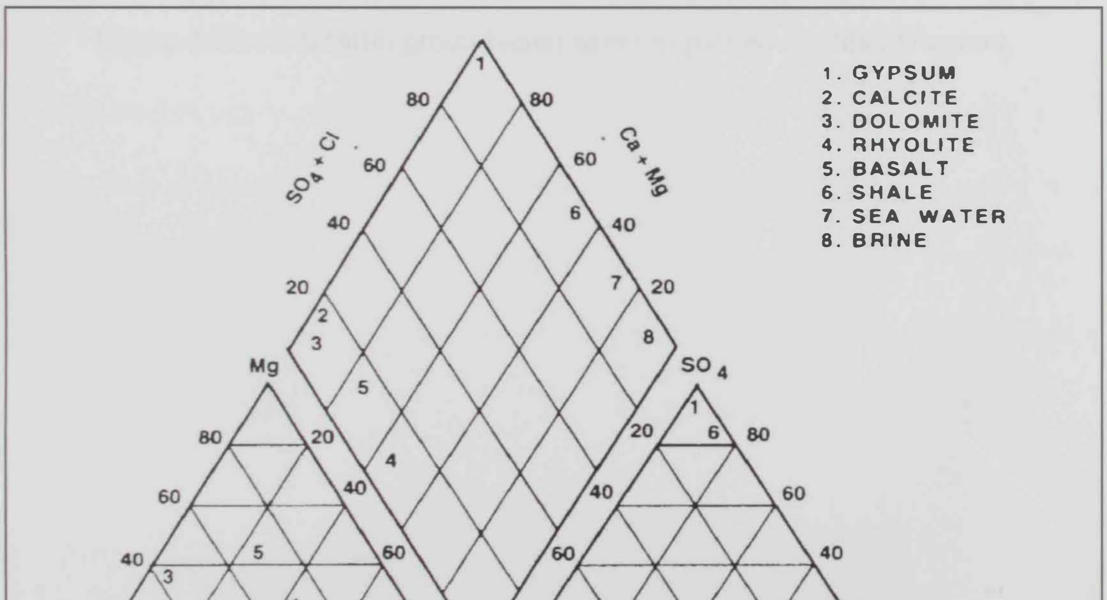


Figure 4.15. Different water origins in Piper diagram (Hounsloe, 1995).

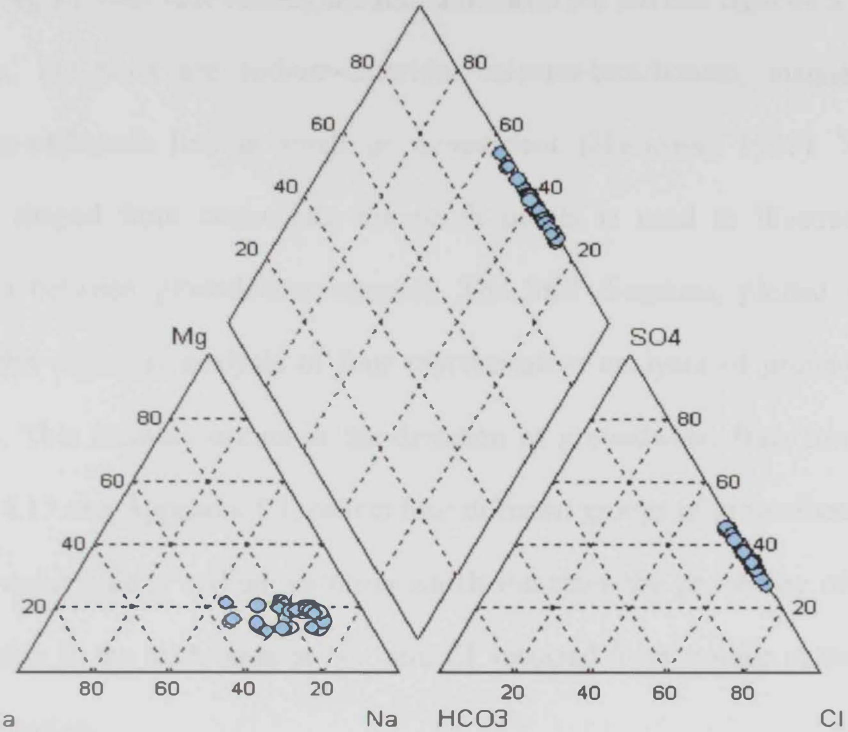


Figure 4.16. Al-Khatim groundwater samples plotted on Piper Diagram.

4.7.2 Stiff diagram

The stiff diagram uses four cations and four anions on the left and right on a vertical axes. Classically, the pairs are sodium-chloride, calcium-bicarbonate, magnesium-sulfate, while, iron-carbonate line is small or nonexistent (Hounsloe, 1995). The irregular polygonal shaped from connecting the result points is used to illustrate the solute distribution between groundwater samples. The Stiff diagrams, plotted in Fig. 4.17, represent the chemical analysis of four representative analyses of groundwater in the study area. This increase occurs in the direction of groundwater flow from east to the west. Fig. 4.17 and Appendix C1, reflect four different groups of groundwater types. The dominant water type is sodium chloride which indicates the possibility of saline water contamination in the study area or Na^+ and Cl^- released from storage in the unsaturated zone by irrigation.

4.7.3 Hydrogeochemical profiles

Two hydrochemical profiles are oriented north to south and east to west, Fig. 4.18. The two profiles are presented in, Figs. 4.19 and 4.20. The figures are developed to examine the effect of geological and hydrogeological conditions on the water quality within the study area. . These two profiles suggest the presence of saline water contamination in the direction of flow.

4.8 Origin of Groundwater

The initial concentration of solutes in rainfall water is low but during its path the solutes composition is altered by rock weathering and evaporation (Gibbs, 1970).

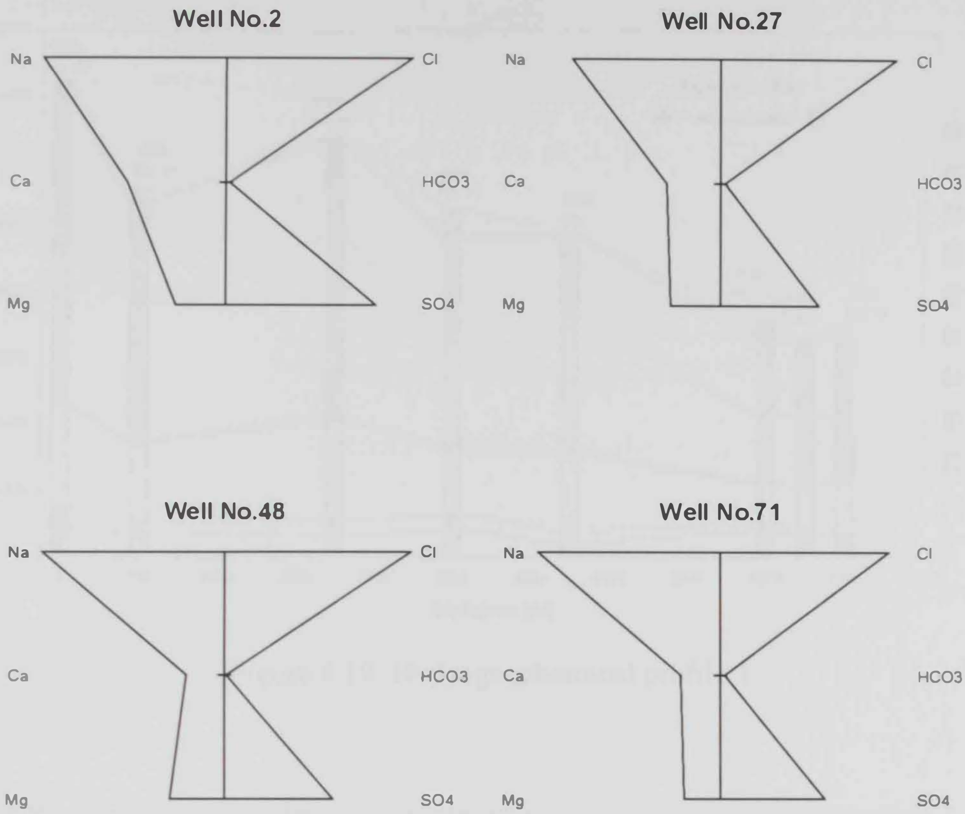


Figure 4.17. Different water types according to stiff diagram. (Appendix C1).

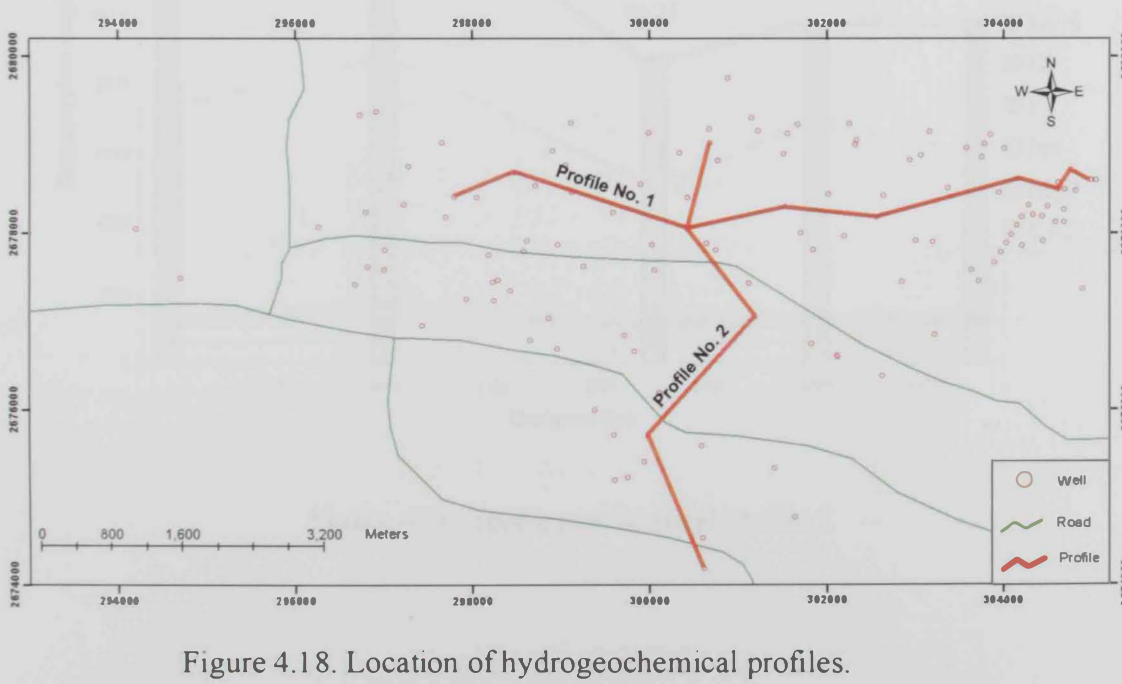


Figure 4.18. Location of hydrogeochemical profiles.

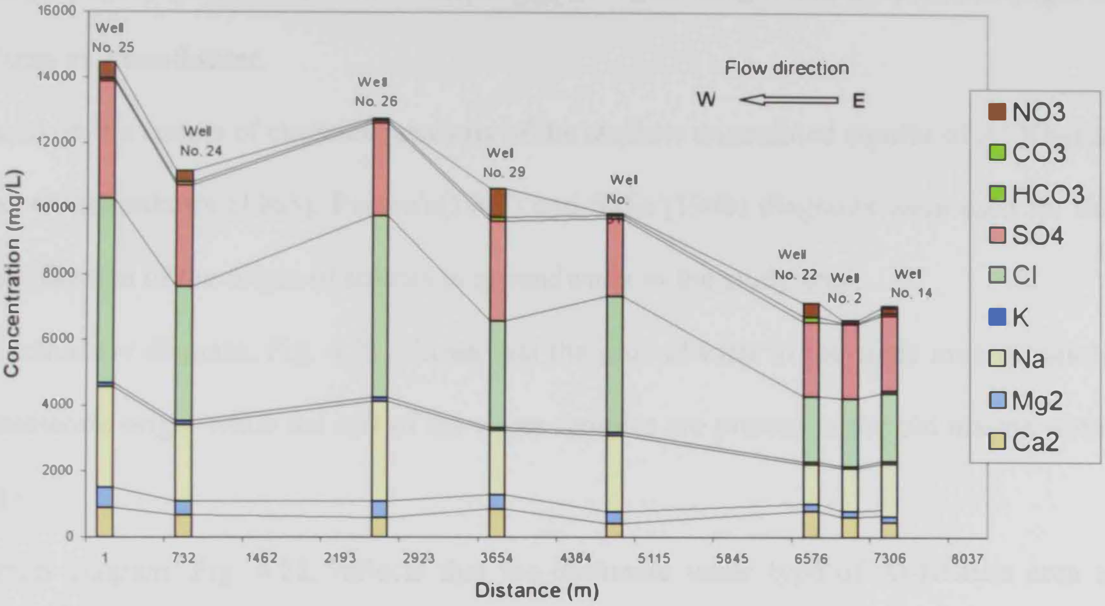


Figure 4.19. Hydrogeochemical profile 1.

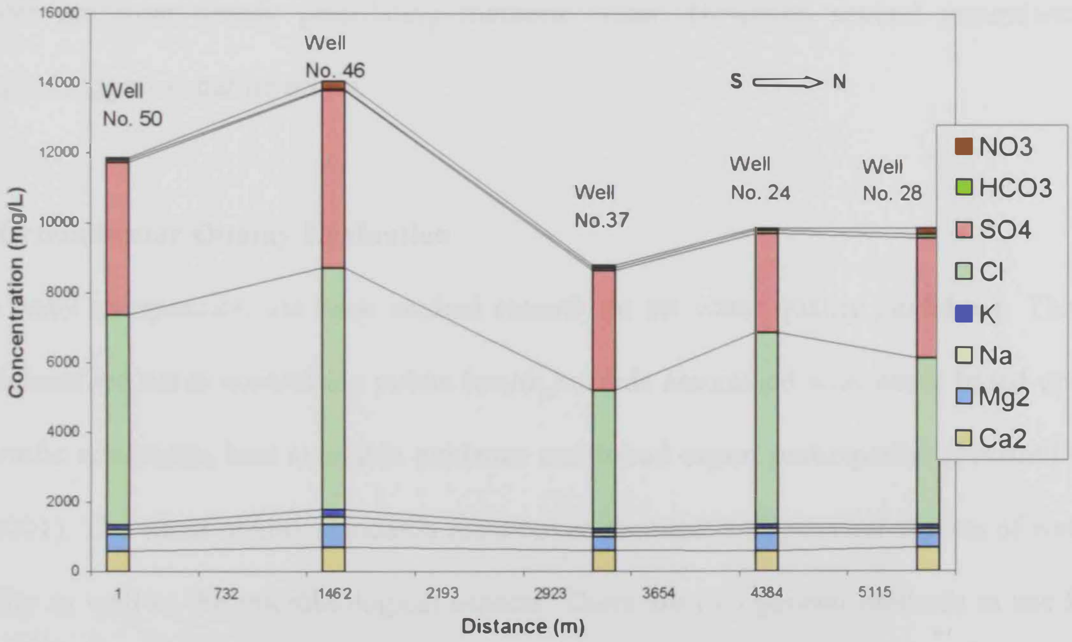


Figure 4.20. Hydrogeochemical profile 2.

The purpose of the technique described below is to gain insight into the possible origin of solutes in groundwater.

Based on the results of chemical analysis of the shallow unconfined aquifer of Al-Khatim area Ovitchinikov's (1963), Parson's(1967) and Sulin'(1948) diagrams were used for the identification of the origin of solutes in groundwater in the study area.

Ovitchinikov diagram, Fig. 4.21, shows that the groundwater in the study area is mainly of meteoric origin while the rest of the water samples are present in the old marine water field.

Parson diagram, Fig. 4.22, reflects that the dominate water type of Al-Khatim area is sodium chloride water type which represents the marine water.

Sulin graph, Fig. 4.23, suggests that most of the solutes within the shallow unconfined aquifer are from deeply percolating meteoric water. However, several groundwater samples suggest a marine origin.

4.9 Groundwater Quality Evaluation

The water composition has been studied recently to set water quality guidelines. These guidelines are set to control the public health hazards associated with water based upon scientific consensus, best available evidence and broad expert participation (Fewtrell et. al, 2001). The water quality standards must cover chemical and physical aspects of water quality as well as the microbiological aspects. There are two general methods in use for setting standards, 1- governmental stipulation, and 2- a policy of minimum degradation (Tchobanoglous and Schroeder, 1987).

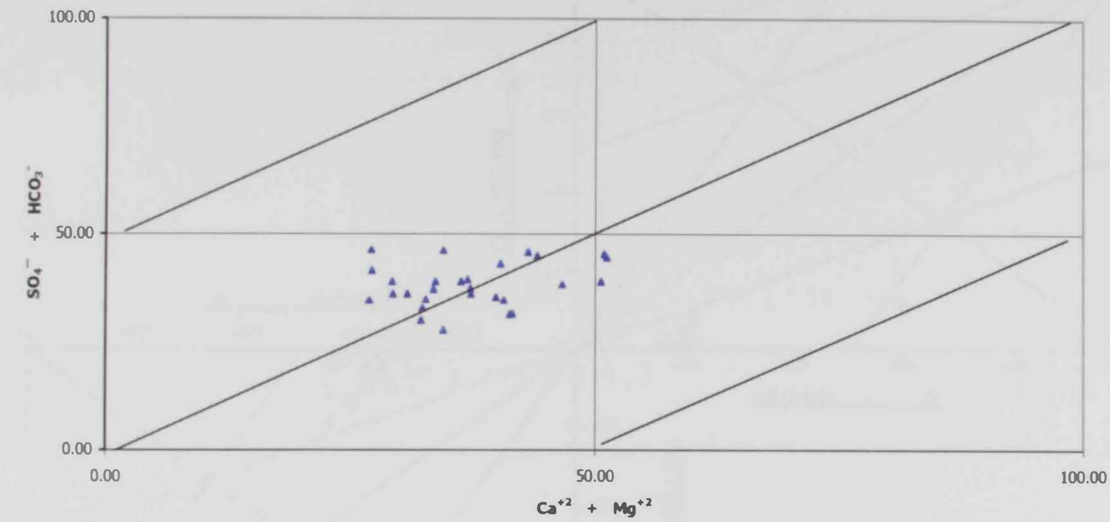


Figure 4.21. Distribution of water samples on Ovichinikov's (1963) graph.

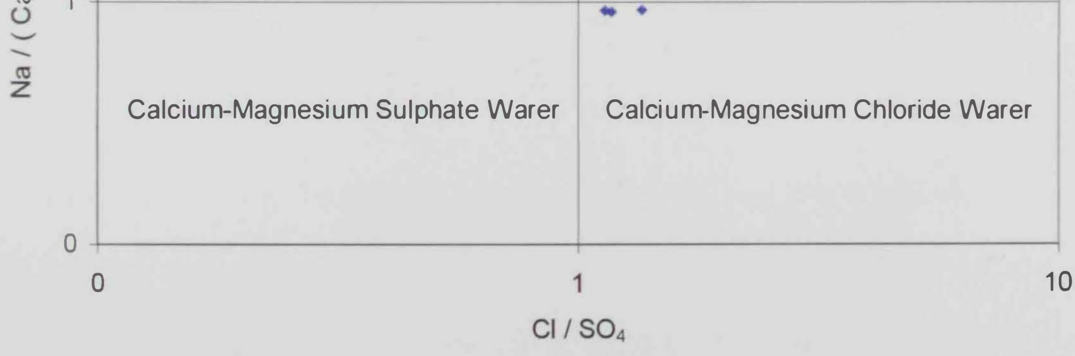


Figure 4.22. Distribution of water samples on Parson's (1967) double logarithmic graph.

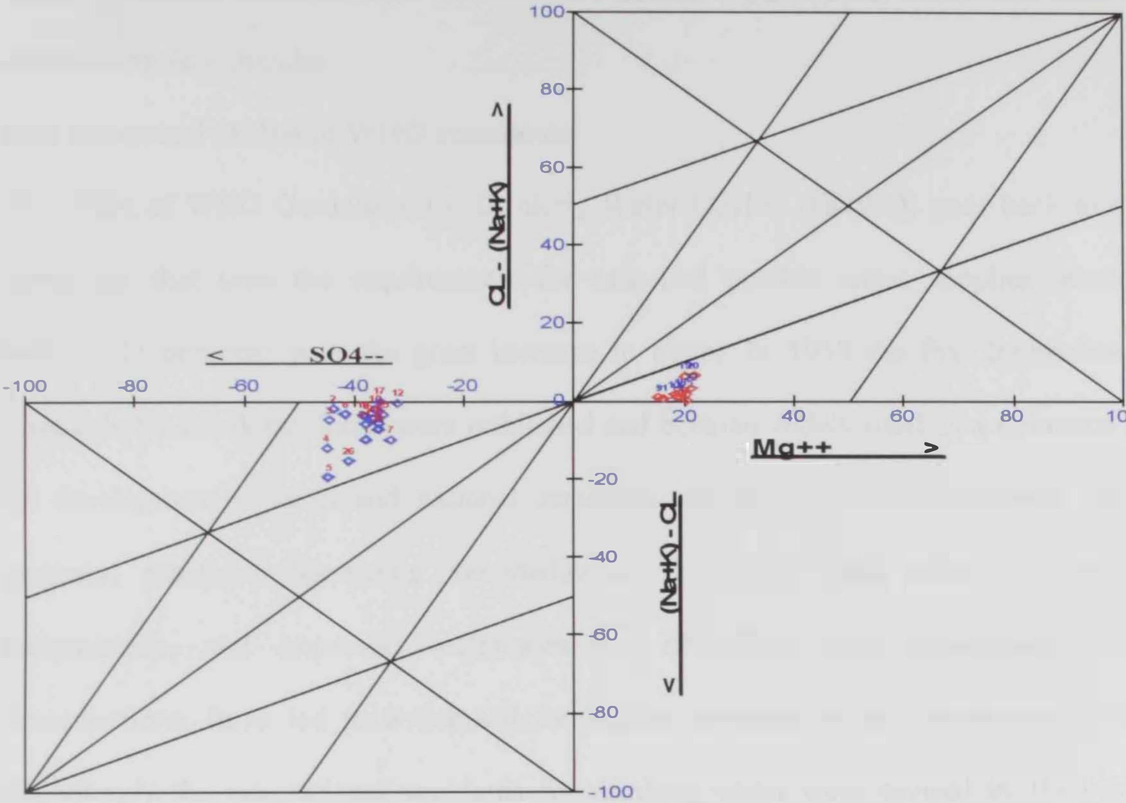


Figure 4.23. Distribution of water samples on Sulin's graph.

The International Standards (set by the World Health Organization, WHO) has been in existence for few decades.

4.9.1 Historical review of WHO standards

The origin of WHO Guidelines for Drinking-Water Quality (GDWQ) goes back to the 1950s. At that time the requirements for safe and potable water supplies became particularly pertinent with the great increase in travel. In 1958 the first International Standards for Drinking-Water were published and became widely used as a reference in the development of local and national standards and as a basis for improved water treatment practices. Increasing knowledge of the nature and effect of various contaminants, and improved techniques for identifying and determining their concentrations, have led to a demand for further revision of the recommendations. Accordingly the international standards for drinking water were revised in 1963 and 1971, (WHO 1958, 1963, 1971).

The term "standards" was used to be applied to the suggested criteria of water quality until it was superseded by the WHO Guidelines for Drinking-Water Quality (GDWQ) in 1984. The change from Standards to Guidelines meant that the guidelines were intended for use by member states as a basis for the development of national standards. In the mid-1980s the first edition of the WHO guidelines for drinking-water quality was published in three volumes.

The second edition of the GDWQ, Volume 1 was published in 1993 followed by Volume 2 in 1996 and Volume 3 in 1997. Addenda containing chemical substances and microbiological contaminant were issued in 1998 for Volumes 1 and 2 and are issued as necessary until the third edition of the GDWQ is published approximately 10 years after the second edition (WHO 1998). Some countries adopted the international standards as the official and legal standards of water quality while other countries developed national standards based in part or in whole on the international standards. The UAE government applies both of the international standards and U.S standards for drinking water quality. The following discussion intends to evaluate the suitability of groundwater in Al-Khatim area for drinking and agriculture purposes.

4.9.2 Groundwater quality for drinking purposes

The drinking water has certain standards as regard to its physical, chemical and biological properties. These standards are primarily intended to protect human health, (WHO, 1998). According to these limits the groundwater of Al-Khatim area is not suitable for drinking. To evaluate the suitability of groundwater Schoeller (1962) diagram was also plotted for the collected groundwater samples, Fig. 4.24. According to Schoeller graph Al-Khatim groundwater is ranged between temporarily potable to un-potable water. For detailed information about suitability of groundwater of Al-Khatim area reference is made to Appendix C2.

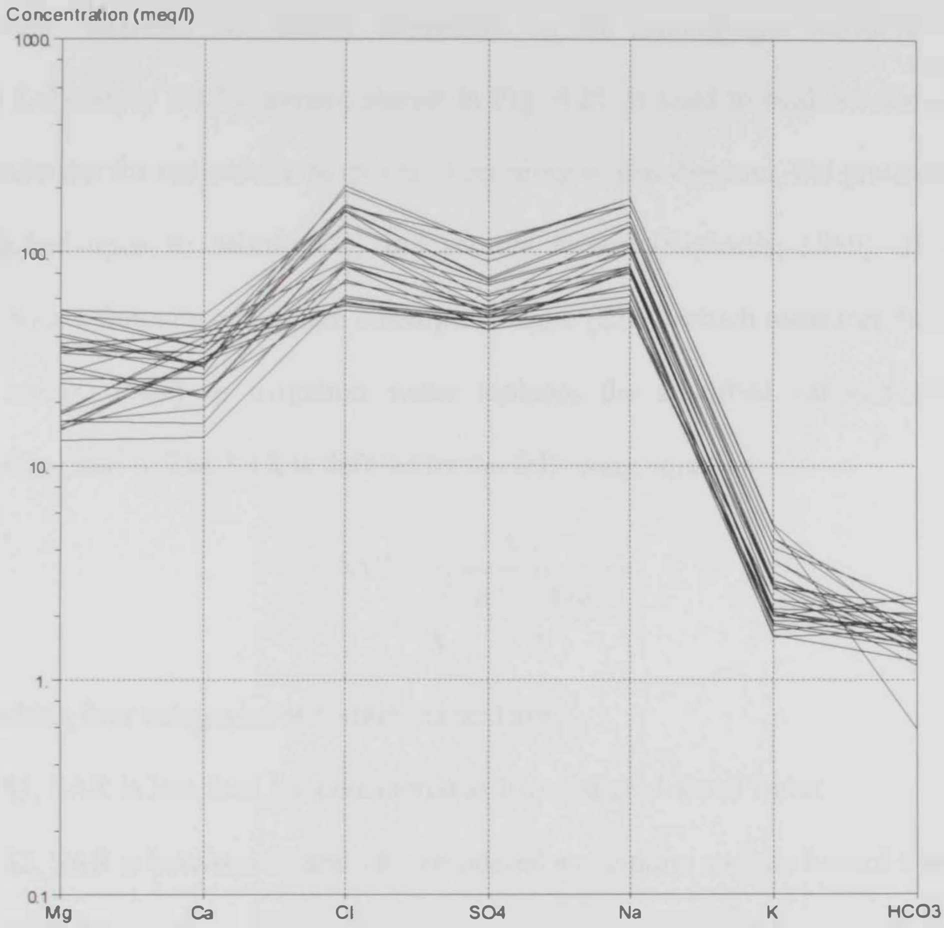


Figure 4.24. Distribution of groundwater samples on Schoeller graph.

4.9.3 Groundwater quality for irrigation purposes

The study area is considered as one of the oldest cultivated area in Abu Dhabi Emirate. Agricultural activities are mainly dependent on the groundwater resources The US Salinity Laboratory Staff diagram, shown in Fig. 4.25, is used to evaluate the suitability of groundwater for agriculture purposes. According to this diagram, the groundwater can be classified upon its salinity (C) and sodium hazard (Richards, 1969). The sodium hazard (S) is a function of Sodium Absorption Ratio (SAR) which measures the degree to which sodium (Na^+) in irrigation water replaces the adsorbed calcium (Ca^{2+}) and magnesium (Mg^{2+}). The SAR is defined by the following equation:

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

The resulting four categories of sodium hazard are:

- S1, SAR is less than 10, considered as low sodium hazard water.
- S2, SAR is between 10 and 18, considered as medium sodium hazard water.
- S3, SAR is between 18 and 26, considered as high sodium hazard water.
- S4, SAR is more 26, considered as very high sodium hazard water.

While the resulting four categories of salinity are:

- C1, salinity is less than 250 μmho, considered as low salinity water.
- C2, salinity is between 250 and 750 μmho, considered as medium salinity water
- C3, salinity is between 750 and 2250 μmho, considered as high salinity water.
- C4, salinity is more than 2250 μmho, considered as very high salinity water.

The collected groundwater samples data are out of range of the USDA graph. Therefore the samples were reported using AQUACHEM programs to identify AL-Khatim groundwater category and the results are listed in Appendix C2.

The results indicate that the groundwater of Al-Khatim area is not suitable for irrigation of traditional crops. However, it can be used to irrigate salt tolerant crops in good drainage soils.

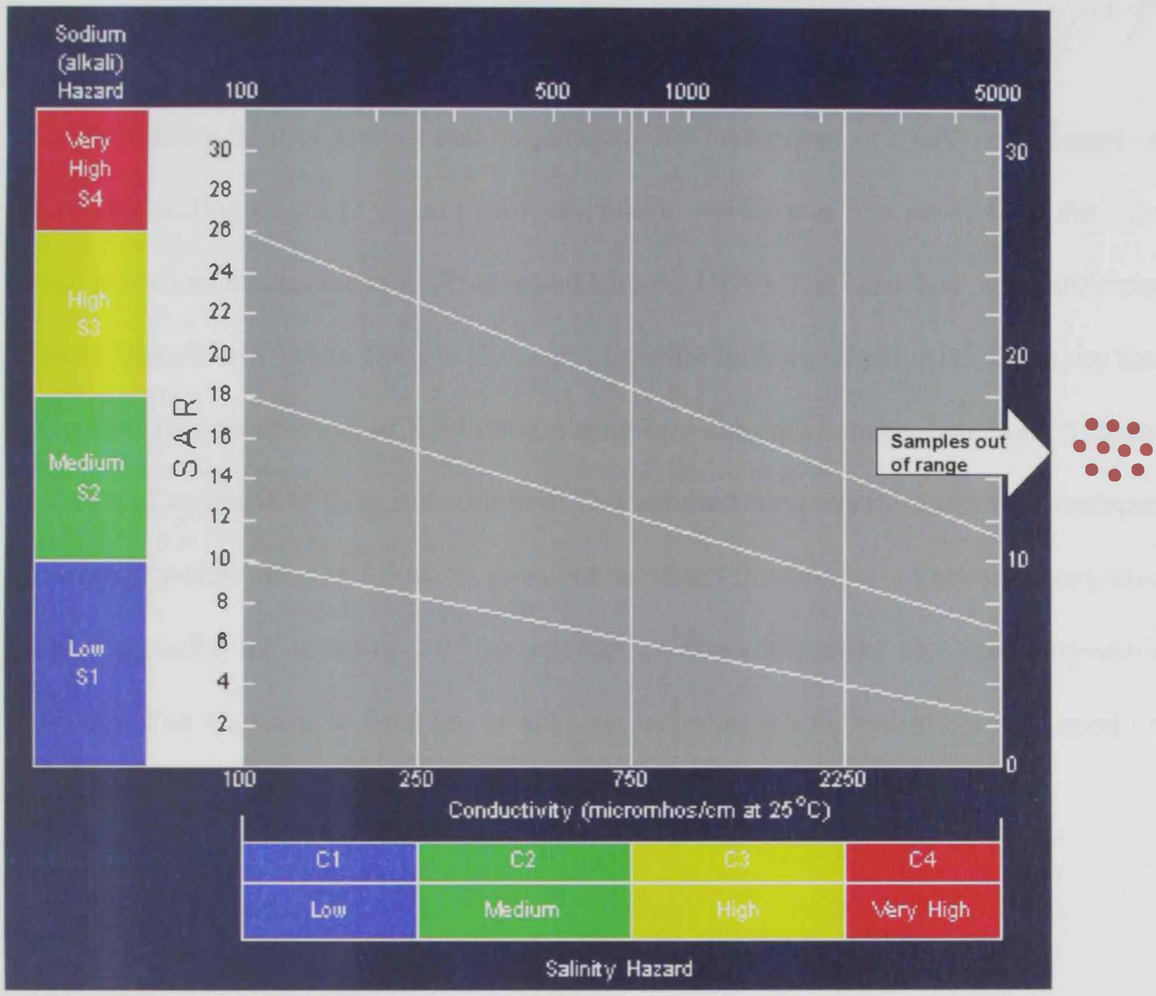


Figure 4.25 Irrigation water classifications (Richards, 1969).

Chapter 5

GROUNDWATER MODELING

5.1 Introduction

In almost every field of science and engineering the techniques of analysis are based on an understanding of the physical processes, and in most cases it is possible to describe these processes mathematically (Freeze and Cherry, 1979). The basic law of groundwater flow is Darcy's law. When Darcy's law is put together with an equation of continuity that describes the conservation of fluid mass during flow through a porous medium, a partial differential equation of flow is developed. The resulted flow equation can be developed for a- steady-state saturated flow, b- transient saturated flow, and c- transient unsaturated flow. Generally, the equation of flow appears as one component of a boundary-value problem. The standard techniques of analysis in groundwater hydrology are based on boundary-value problems that involve partial differential equations.

5.2 Numerical Local-Scale Groundwater Flow Model for Al-Khatim Area

As previously mentioned, groundwater in Al-Khatim area is currently exploited from the shallow unconfined aquifer. The present extraction rate exceeds the recharge rate. This has led to a substantial decline in the groundwater level of this aquifer with time. To determine the impact of the future extraction on the water table depth a local-scale groundwater flow model was developed for this area using the modular three-dimensional finite difference groundwater flow model software (MODFLOW, McDonald and Harbaugh, 1988).

5.2.1 Schematization of the aquifer systems

An important tool used to characterize the aquifer is the hydrogeological profiles. An example of these profiles is shown in Fig. 5.1. The aquifer can be classified into two hydrogeological layers. The magnitude and spatial distribution of the aquifer characteristics (hydraulic conductivity, K, Transmissivity, T, and storage coefficient, S) were obtained from the analysis of the samples from tests holes, pumping test data for the drilled water wells during the period 1997-2002.

5.2.2 Boundary conditions

Groundwater flow in the shallow unconfined aquifer layer is governed by the conditions at the boundaries of the regional system. These conditions are not well defined for Al-Khatim area. Therefore, in order to model the groundwater system in the Shallow unconfined aquifer of Al-Khatim area a graduate constant head was assumed for northern and southern boundaries while, a fixed constant head was assumed for the western boundary as the aquifer is extending for hundreds of kilometers in these directions without major pumping centers, Fig. 5.2. For the present study the multi layer Quaternary aquifer system has, for practical purposes, been modeled as a single layer aquifer system.

5.2.3 MODFLOW program

The MODFLOW program was used in this study to develop a local-scale groundwater flow model for Al-Khatim area. The main objective of this model is to simulate the response of the shallow unconfined aquifer based on continuation of the present groundwater development scenarios. MODFLOW was chosen in this study as this software is widely applied in hydrogeological practice for simulating groundwater flow in complicated groundwater basins. Moreover because the program: 1- is well documented

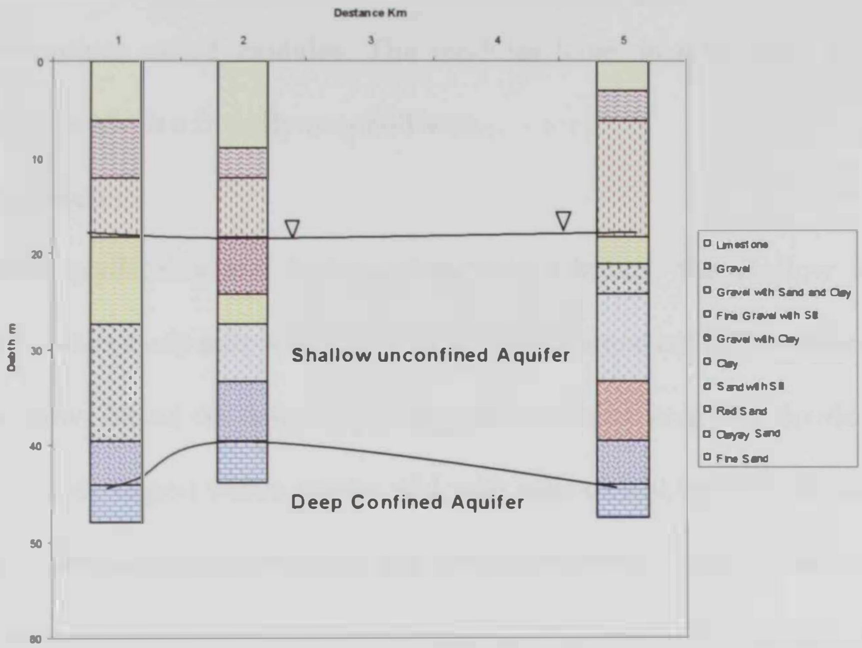


Figure 5.1. Cross section describing the two aquifers in the study area.

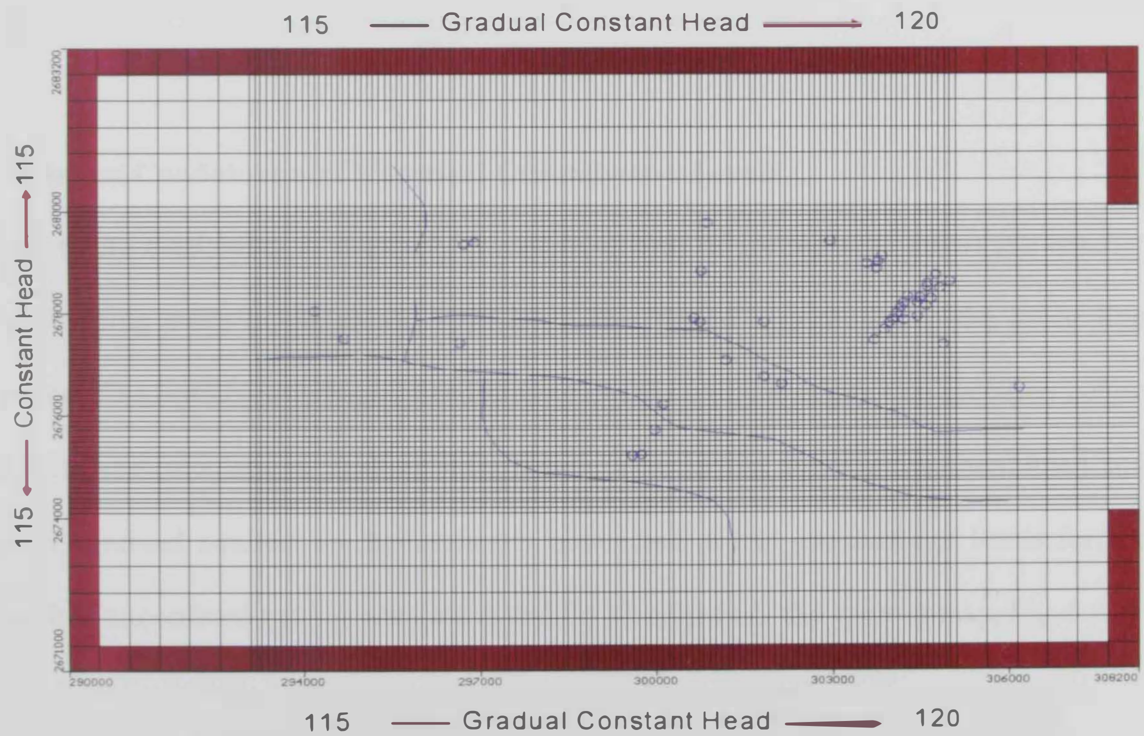


Figure 5.2 Discritization of the study area as developed by MODFLOW.

and available in public domains; and 2- has been divided into a main program and a series of subroutines called modules. The modules have, in turn, been grouped into packages, which make it a friendly-user software.

5.2.4 Discritization

Based on data availability and hydrogeological conditions, the shallow unconfined aquifer system in the study area was divided into 129 columns and 69 rows for simulating groundwater flow. Based on data availability, the modeled area was divided into two regions, the outside region with a course grid with cells of 250,000 m^2 and the region of interest with a detailed grid where each grid cell has an area 10,000 m^2 as shown in Fig. 5.2. Again based on data availability and dynamics of groundwater levels, a one month period was chosen as the period within which all hydrogeological stresses are assumed constant (stress period). Each stress period is divided into twelve time steps (Appendix D).

5.3 Initial Conditions and Historical Groundwater Levels

Due to the availability of relatively complete records of groundwater levels at a number of pumping wells in the period 1997-2002, this period was chosen as the calibration period. The initial groundwater head throughout the study area must be specified before starting the calculations. Drilling information indicate that the shallow unconfined and deep confined aquifers are hydraulically connected. Initial groundwater levels for the shallow unconfined aquifer were estimated for all cells from the contour map, Fig. 5.3.

5.4 Model Inputs

The model inputs include hydrogeological parameters (constant (K), Transmisivity, and Storativity), aerial recharge, evapotranspiration, groundwater abstraction, and boundary conditions. Each of these phenomena is simulated in MODFLOW by a separate package.

5.4.1 Hydrogeological parameters

Transmissivity, T for a confined aquifer of thickness b is defined as $T=K_x$ b, where K is the hydraulic conductivity. In the case of the unconfined aquifer, b is the saturated thickness (Karanjac and Braticevic, 1994). To calculate the transmissivity and storage coefficient, all available pumping test data for the drilled water wells in the study area within the period 1997-2002 were reinterpreted manually and automatically using GWW software as elaborated in chapter two. Outside the study area where there has been no drilling information, the values for transmissivity and storage coefficient were interpolated.

5.4.2 Evapotranspiration and aerial recharge

The climatological data collected from Al-Ain Airport Station was used to estimate the evaporation rates in the study area. Based on the soil properties and climatic conditions, an extinction depth of 5 meter was assumed. Recharge rate was approximated as 2% of the rainfall amount (Appendix D).

5.4.3 Groundwater Abstraction

The well package is designed to simulate the inflow or outflow through recharge or pumping wells. Wells are handled in the package by specifying the location of each well and its rate (positive for recharge and negative for extraction). In Al-Khatim area, more than 1500 shallow water wells exist in the shallow unconfined aquifer. The measured

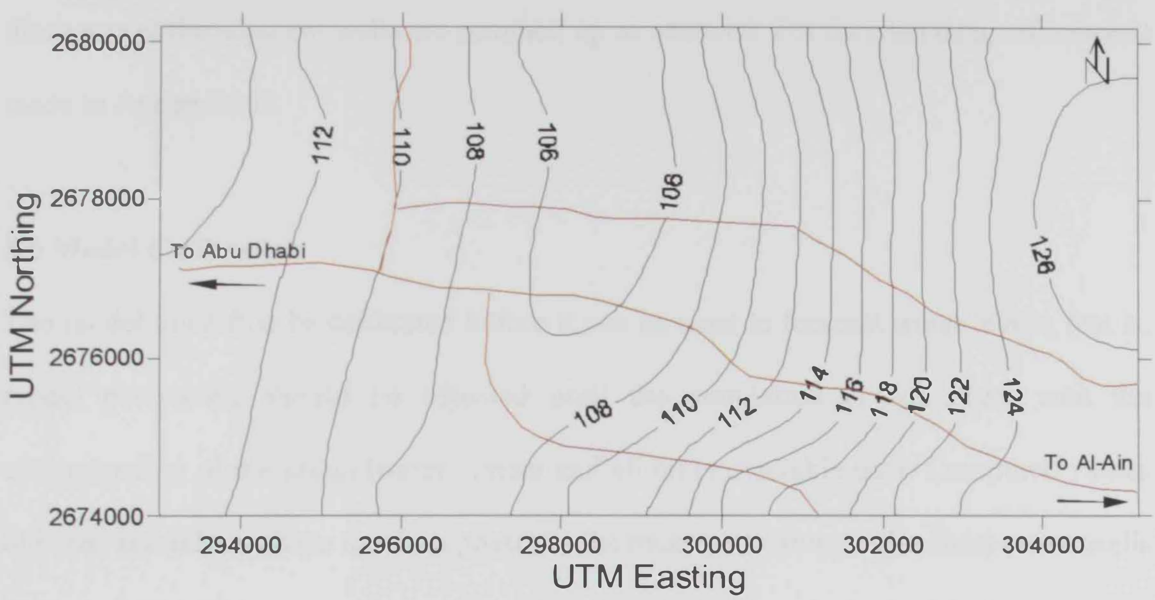


Figure 5.3. Contour map of initial groundwater levels.

records of groundwater extraction for irrigation were used to calculate the annual discharge of each individual well. In the study area, wells are close to each other and the discharge of the adjacent wells are summed up as one well. For detailed data, reference is made to Appendix D.

5.5 Model Calibration

The model must first be calibrated before it can be used to forecast water levels; that is, model parameters should be adjusted until the simulation is consistent with the understanding of the groundwater system and all other available data. Computed values of heads should match (as much as possible) the measured values at the observation wells in the aquifer. This means that a set of historical data is compared with the generated hydraulic heads developed by computer simulations. Analysis of the difference between measured and computed heads gives good indications as to where adjustments of aquifer's hydraulic and hydrogeologic parameters may be necessary in order to minimize this difference (Anderson and Woessner, 1992). In the present study, it is inappropriate to assume steady-state conditions, as the amount of annual recharge to the aquifer is very small as compared to the present annual extraction rate.

There are basically two methods of model calibration: trial and error adjustment of parameters and automated parameters optimization. The period 1997-2002 was chosen as the calibration period in this study based on the followings: 1- the initial values of the hydraulic heads before 1997 could be approximated by the steady state contours, 2- availability of relatively complete records of groundwater levels in this period, and 3- large changes in groundwater levels have occurred during this period.

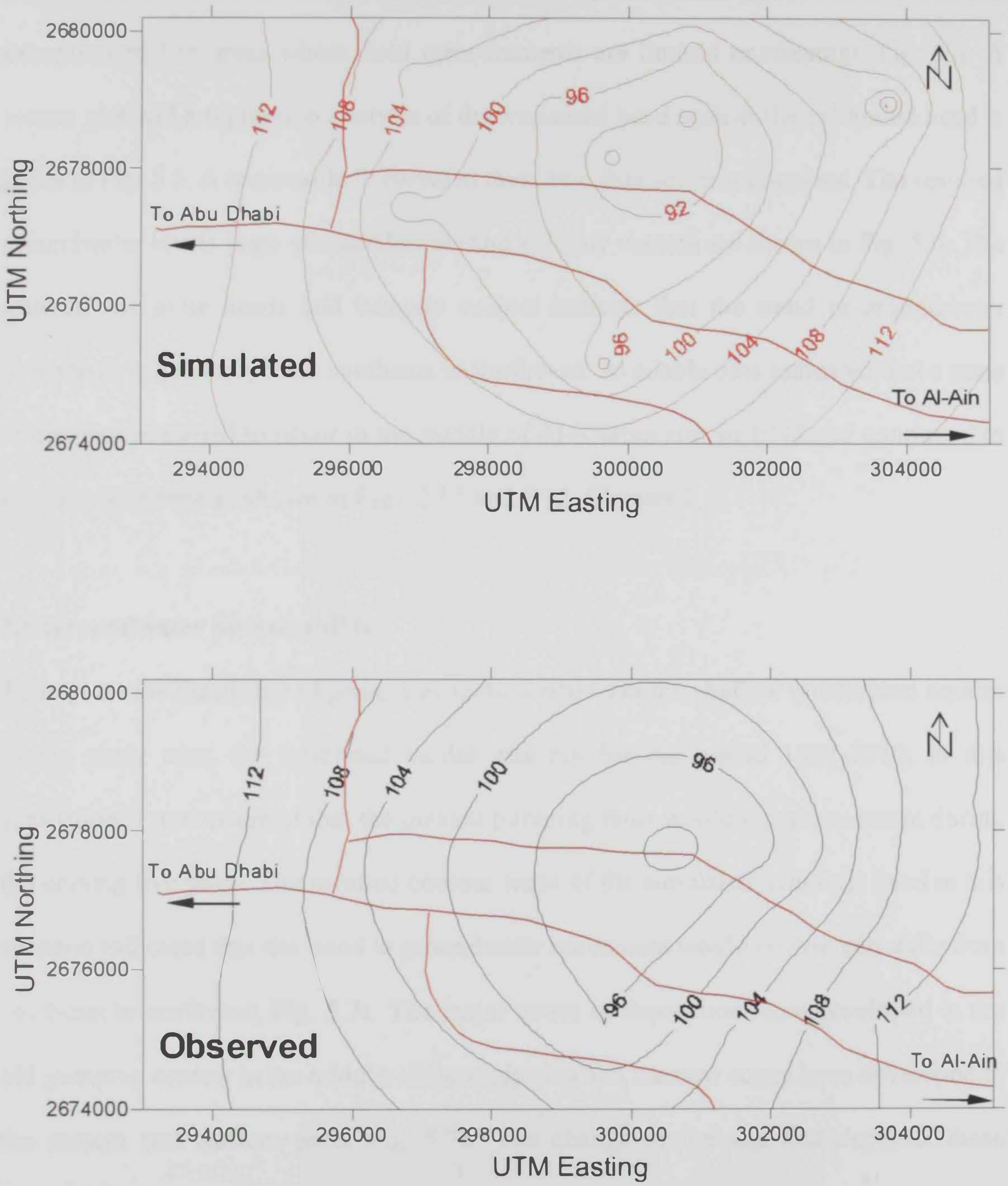


Figure 5.4. Comparison between simulated and measured hydraulic heads 2002.

Transient calibration and trial and error procedures were used. The difference between calibrated and measured values were within the acceptable limits (about 2 meters with the exception of few areas where field measurements are limited or missing), Fig. 5.4. A scatter plot and a regression analysis of the measured head against the calibrated head is given in Fig. 5.5. A reasonable fit between these two data sets is recognized. The resulted groundwater levels (equi-potential lines) and velocity vectors are shown in Fig. 5.6. The resulted hydraulic heads and velocity vectors indicate that the trend in groundwater movement is generally from southeast to northwest. Available data indicated that a cone of depression started to occur in the middle of Al-Khatim area in 1997 and continued to increase with time as shown in Figs. 2.11 and 2.12, Chapter 2.

5.6 Groundwater Sustainability

To explore the feasibility of present extraction rate from the shallow unconfined aquifer in the study area, the calibrated model was run for the period 1997-2010. In this simulation it was assumed that the present pumping rates would remain constant during the coming five years. The resulted contour maps of the simulated hydraulic head in this scenario indicated that the trend in groundwater movement would remain generally from southeast to northwest, Fig. 5.7a. The major cones of depression have developed in the old pumping centers in the middle of the study area and the new cones have developed in the eastern and western parts, Fig. 5.7b. The change in the size and depth of these depression cones is relatively small. Up to the year 2010, these cones of depression will not have observable effect on the regional groundwater movement from southeast to northwest. The depth of the groundwater in the whole area of Al-Khatim will be less than

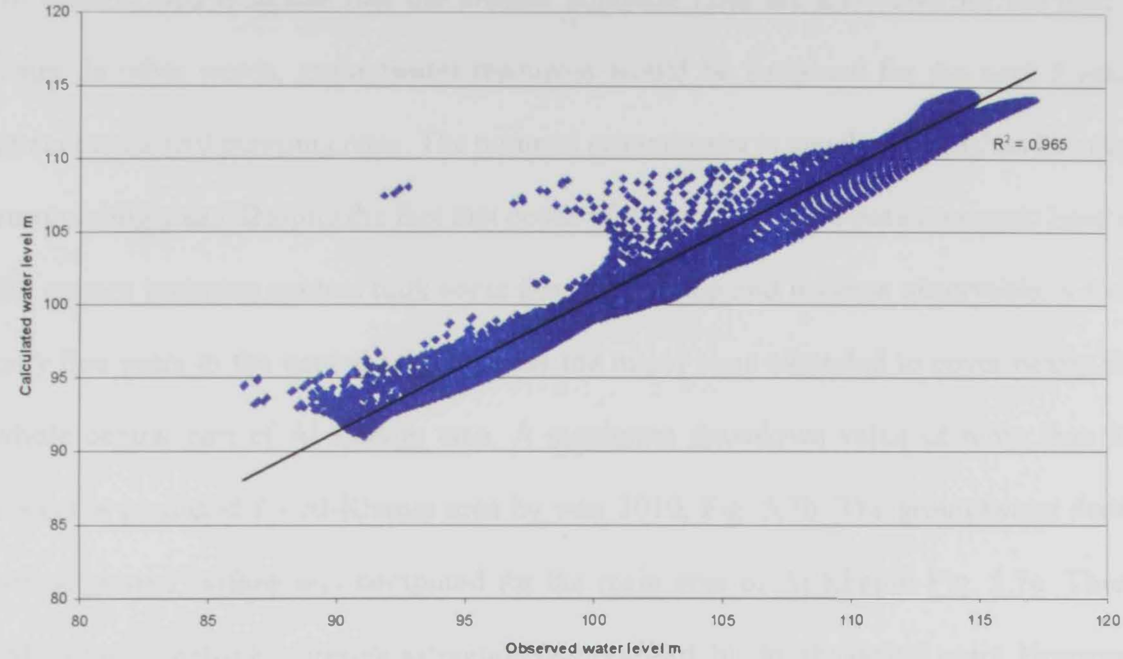


Figure 5.5. Scatter plot and linear regression analysis of calculated heads against observed heads.

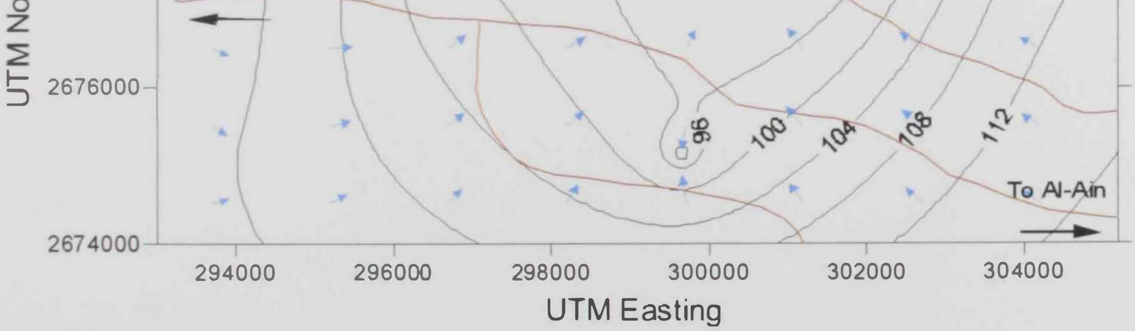


Figure 5.6. Resulted groundwater heads and velocity vectors, 2002.

30 meters. This indicates that the present pumping rates are affordable for the next 5 years. In other words, groundwater resources would be sustained for the next 5 years under the current pumping rates. The pumped groundwater is mostly replenished from the surrounding areas. Despite the fact that cones of depression of the potentiometric head in the eastern pumping centers took some time to develop and become observable, it took only five years in the central area whereas the major cone extended to cover nearly the whole central part of Al-Khatim area. A maximum drawdown value of more than 20 meters is predicted for Al-Khatim area by year 2010, Fig. 5.7b. The groundwater depth below ground surface was computed for the main area of Al-Khatim Fig. 5.7c. These values indicate that the present extraction rate is affordable for the next 5 years. However, increasing in the present extraction rates might lead to a dewatering of the shallow aquifer particularly if the present drought condition persisted for a long time.

It should be noted that the above results are based on the assumptions and boundary conditions considered in this simulation exercise. More field work and simulations are needed to verify the obtained results.

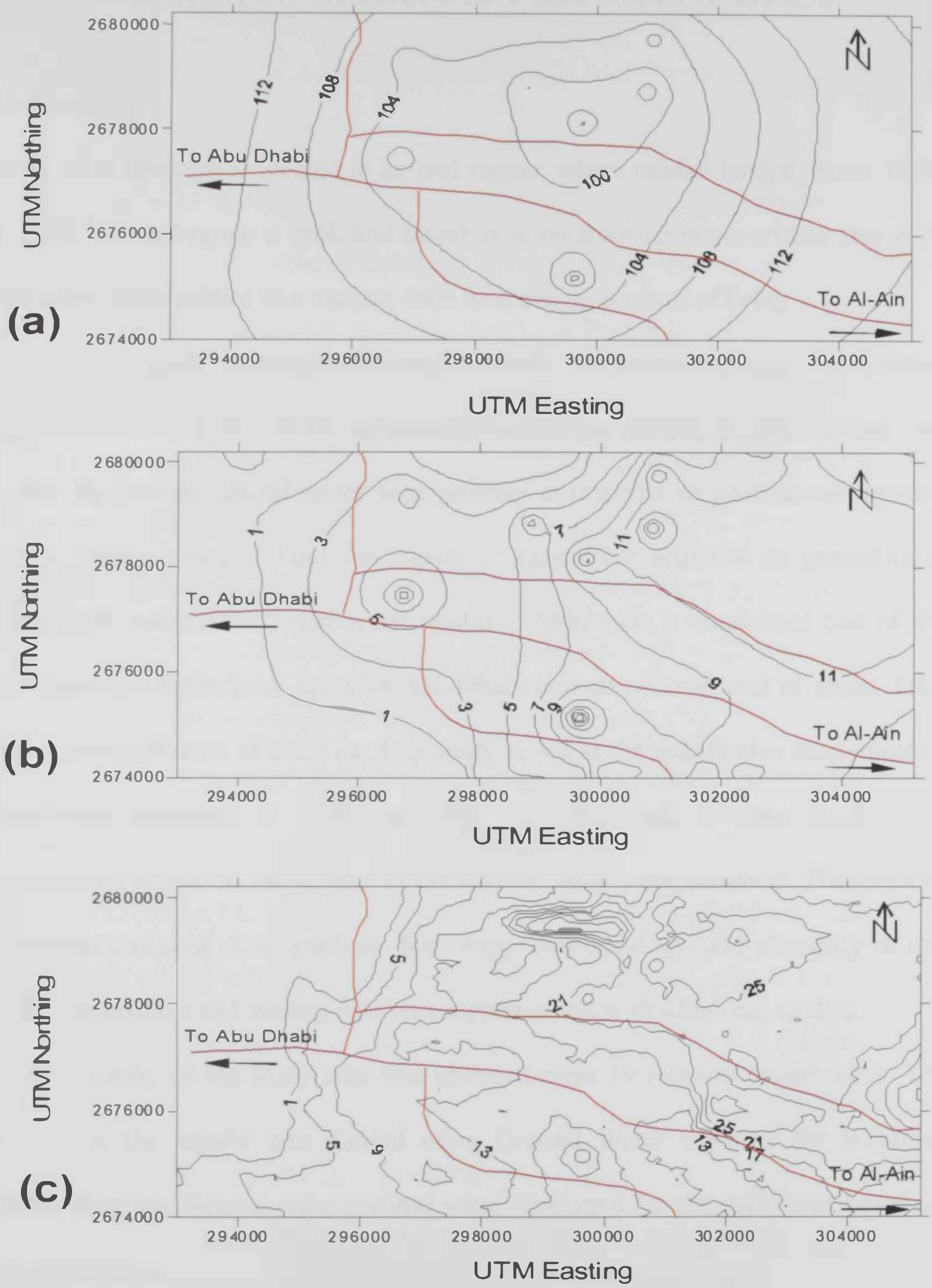


Figure 5.7. Predicted groundwater levels in the shallow aquifer for the year 2010. (a) Simulated hydraulic head (m, amsl). (b) Simulated drawdown. (c) Simulated water depth.

Chapter 6

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1. Summary

United Arab Emirates is located in an arid region, where rainfall limited. Since 1970, the UAE has undergone a profound transformation from an impoverished region of small desert principalities to a modern state with a high standard of living.

In spite of the harsh weather conditions, poor soils and water constraints, remarkable progress has been made in the agricultural sector, particularly during the last two decades As the agricultural sector kept growing in response to government support, there is a deep concern about the impact of agriculture activities on groundwater system, both quantitatively and water quality. Al-Khatim is considered one of the most important agricultural areas in Abu-Dhabi emirate with a total of about 1300 farms covering an area of 2405 ha. This study aimed at the quantitative assessment of groundwater resources in Al-Khatim area. To that end, previous studies and investigations related to the subject of the current study were reviewed. The required information and data about geology, hydrology, hydrogeology, and chemistry of this aquifer were collect and missing data was supplemented with additional studies.

The stratigraphy of the study area was obtained from 19 recently drilled wells. The lithology of the aquifer was plotted using Ground Water software for Windows (GWW) program. Several cross sections were developed for the study area based on the available logs.

Groundwater levels were collected from different authorities including Abu Dhabi municipality. Several measurements of groundwater levels were conducted during 2002 and 2003. In addition, the ground surface elevation was developed from the DEM. Contour maps for groundwater levels in 1997, and 2003 were developed.

The hydraulic parameters of the shallow unconfiened aquifer in the study area were identified by conducting step drawdown tests in two locations and 44 continuous pumping tests. All the data collected from these tests were processed and graphically presented.

Two resistivity subsurface profiles were conducted by using a single channel Memory Earth Resistivity and IP Meter instrument. Each profile consisted of 36 electrodes (point) spaced 10 m apart. Wenner array was used in this survey and the apparent resistivity data were inverted to create a model of subsurface resistivity that approximates the true subsurface resistivity distribution. The results were displayed as cross sections of resistivity.

Twenty eight groundwater samples were collected from different locations along the study area. The groundwater samples were analyzed in Abu Dhabi Municipality laboratory to determine the concentration of major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}), major anions (SO_4^{2-}, Cl^{-}, CO_3^{-}, HCO_3^{-}, NO_3^{-}), Total Dissolved Solids (TDS), Electrical conductivity (Ec) and pH. Contour maps for all the above elements were presented to identify the trend of each substance. Significant focus was devoted to Nitrate levels in the groundwater of Al-Khatim area as it is considered the most common contaminant due to agricultural activities. Piper and Stiff diagrams were developed to assess the groundwater quality in the study area. Two hydrochemical profiles were developed across the study area. To identify the origin of the groundwater, chemical data for all samples were plotted on three different graphs: Ovitchinikov, Parson and Sulin diagrams.

The suitability of Al-Khatim groundwater for different purposes including drinking and agricultural purposes was evaluated and compared with WHO standards.

Schoeller and US Salinity Staff diagrams were also used to identify the groundwater quality in the study area.

A numerical simulation for the groundwater in Al-Khatim area was performed to assess the condition of the shallow unconfined aquifer under the present pumping and recharge conditions. The flow model, "MODFLOW" (McDonald and Harbaugh, 1988) was used to simulate the groundwater levels and drawdown in the study area for the period 1997 - 2010. The model was calibrated for the period 1997 - 2002. The water levels and drawdown were predicted for the year 2010 assuming same groundwater pumping, recharge and climate conditions.

6.2. Conclusions

Based on the results of this study, several conclusions are made:

1. The groundwater systems in Al-Khatim area is composed of two main aquifers; the upper shallow unconfined aquifer and the lower confined aquifer.
2. Groundwater levels have been declining since 1997 due to the excessive pumping to meet the increasing agricultural demands.
3. The results of the pumping tests indicated that the Transmissivity of the aquifer varies between (1.68) and (44.1) m^2/d and the Storativity varies between (2.3×10^2) and (2.4×10^4). These values are based on the Hantuch method of analysis of the pumping data.
4. Two geophysical sections were developed using a Single Channel Memory Resistivity and IP meter. The total depth of penetration was 60 m and the groundwater table was found to range between 5 and 15 m below the ground surface.

5. The total dissolved solids (TDS) of the groundwater in the shallow unconfined aquifer of the Al-Khatim area varies between 6000 mg/l in the northeast and 17000 mg/l in the central area.
6. The sequence of cations dominance in groundwater of the Al-Khatim shallow unconfined aquifer is $Na^{+} > Ca^{2+} > Mg^{2+}$, whereas the sequence of anions dominance is $Cl^{-} > SO_4^{2-} > HCO_3^{-}$.
7. The electrical conductivity (EC) and concentrations of calcium, sodium, potassium, chloride and sulfate ions increase from the northeast towards southwest.
8. Based on the TDS contents, concentrations of major ions and total hardness, the groundwater in the shallow unconfined aquifer of the Al-Khatim area is not suitable for drinking and domestic purposes. However, it can be used for irrigation of salt tolerance crops cultivated in sandy soil with good drainage conditions.
9. The natural groundwater movement is generally from east to west. Major cone of depression have developed in the middle of the study area due to large groundwater withdrawal.
10. The present exploitation rate can continue for the next 5 years with out major impact on the groundwater levels.
11. By year 2010, the maximum predicted drawdown in Al-Khatim area is in order of 20 meter.

6.3. Recommendations

Groundwater is the only source of water for irrigation Al-Khatim farms. The following recommendations are made to sustain the groundwater resources in Al-Khatim area.

1. Groundwater pumping in Al-Khatim area should be reduced to meet the actual crop water requirements. This should also be associated with the use of modern irrigation techniques such as drip and sprinkler irrigation.
2. Increase of farmer's awareness on the importance of groundwater conservation through the application of modern irrigation techniques.
3. Reduce the contamination of groundwater due to agriculture activities by reducing the application of chemical fertilizers and pesticides added to the farms.
4. Focus should be devoted to the cultivation of salt tolerance and low water demand crops in Al-Khatim area.
5. Conduct comprehensive field and numerical studies in Al-Khatim area and establish a complete database about the water resources and the impact of the agriculture activities under the local conditions.
6. Develop a dynamic monitoring network in the vicinity of Al-Khatim area and other adjacent areas.
7. Study different scenarios for groundwater pumping and management using the developed model to identify the safe yield that would ensure the groundwater sustainability in Al-Khatim area on the long term.

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Appendix A
Wells Lithologic Logs

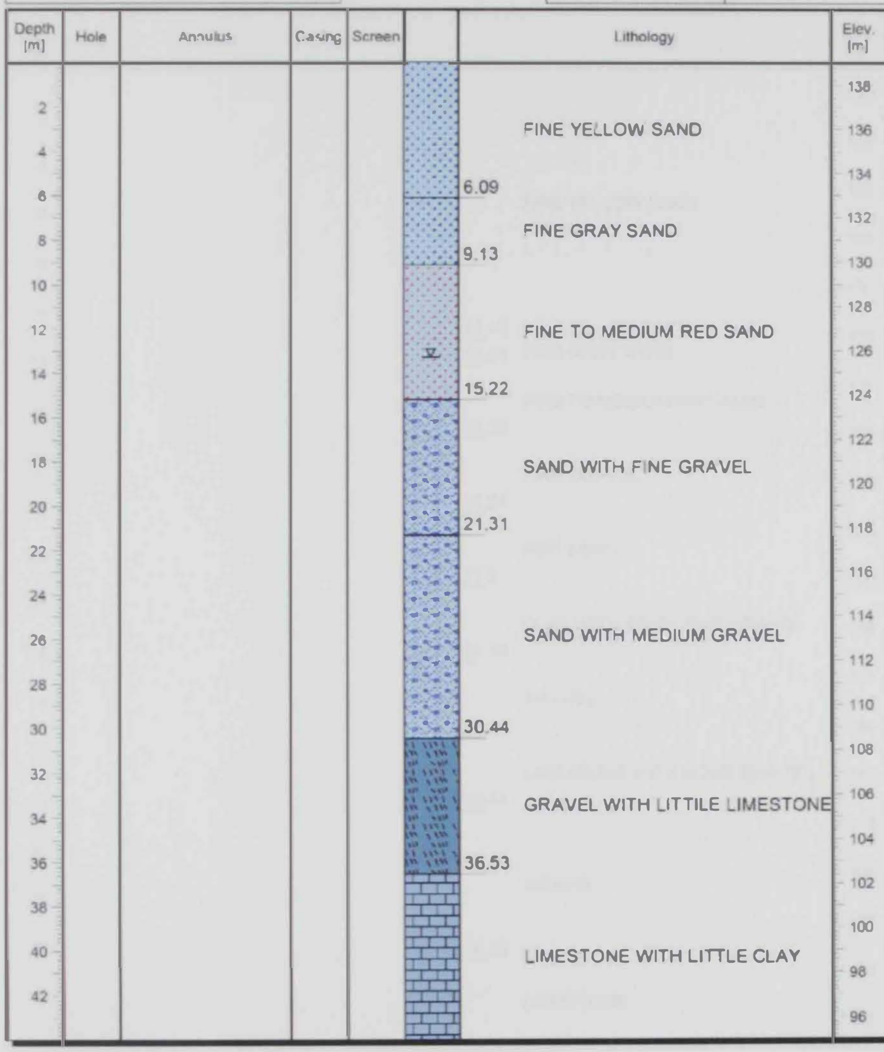
Well Log: Lithology & Construction

Well Ident	well -1	Name	Well No. 1				
Drill. Method	rotary			Drill. Dates	April - October 2001		
X	304287	Y	2678326	Z	139.00	Meas. Pt. Elev.	139.00

All measurements are in meters. Hole and casing diameters in inches.

Scales (1: xxx)

Water Level (m AMSL)	Vertical	Horizontal
125.70		



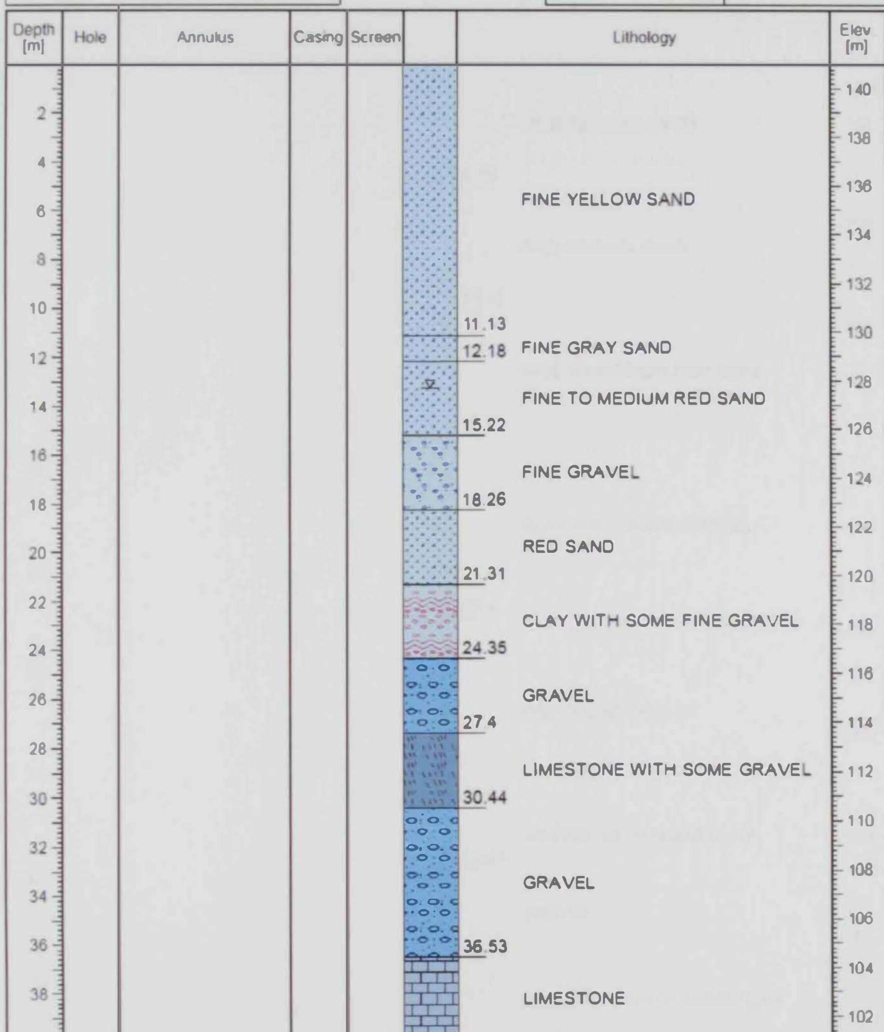
Well Log: Lithology & Construction

Well Ident	well- 2	Name	Well No. 2				
Drill Method	rotary			Drill Dates	April - October 2001		
X	304622	Y	2678503	Z	141.00	Meas. Pt. Elev.	141.00

All measurements are in meters. Hole and casing diameters in inches.

Scales (1: xxx)

Water Level (m AMSL)	127.70	Vertical	Horizontal



Well Log: Lithology & Construction

Well Ident	Name
well -3	Well No. 3

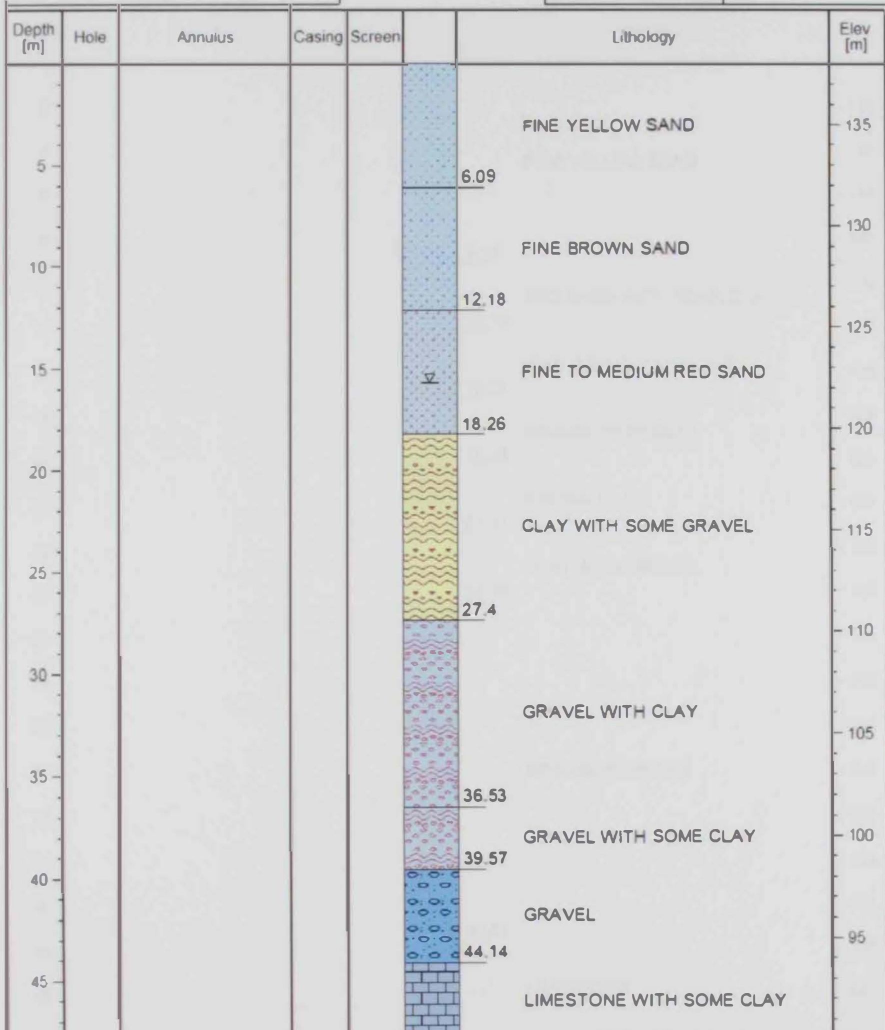
Drill. Method	Rotary	Drill. Dates	April - October 2001

X	303720	Y	2677455	Z	138.00	Meas. Pt. Elev.	138.00

All measurements are in meters. Hole and casing diameters in inches.

Scales (1: xxx)

Water Level (m AMSL)	Vertical	Horizontal
122.30		



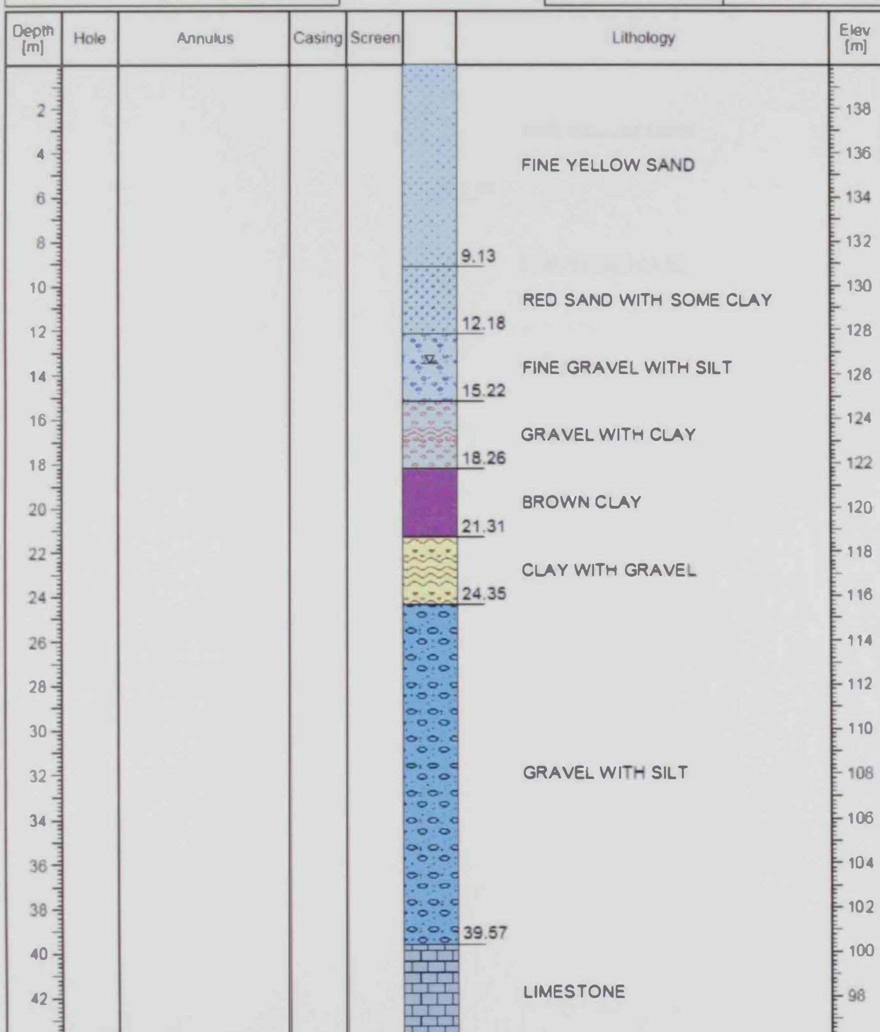
Well Log: Lithology & Construction

Well Ident	**Well -4**	Name	**Well No. 4**				
Drill Method	**Rotary**	Drill Dates	**April - October 2001**				
X	**304499**	Y	**2678309**	Z	**140.00**	Meas. Pt. Elev.	**140.00**

All measurements are in meters. Hole and casing diameters in inches.

Scales (1: xxx)

Water Level (m AMSL)	Vertical	Horizontal
126.50		



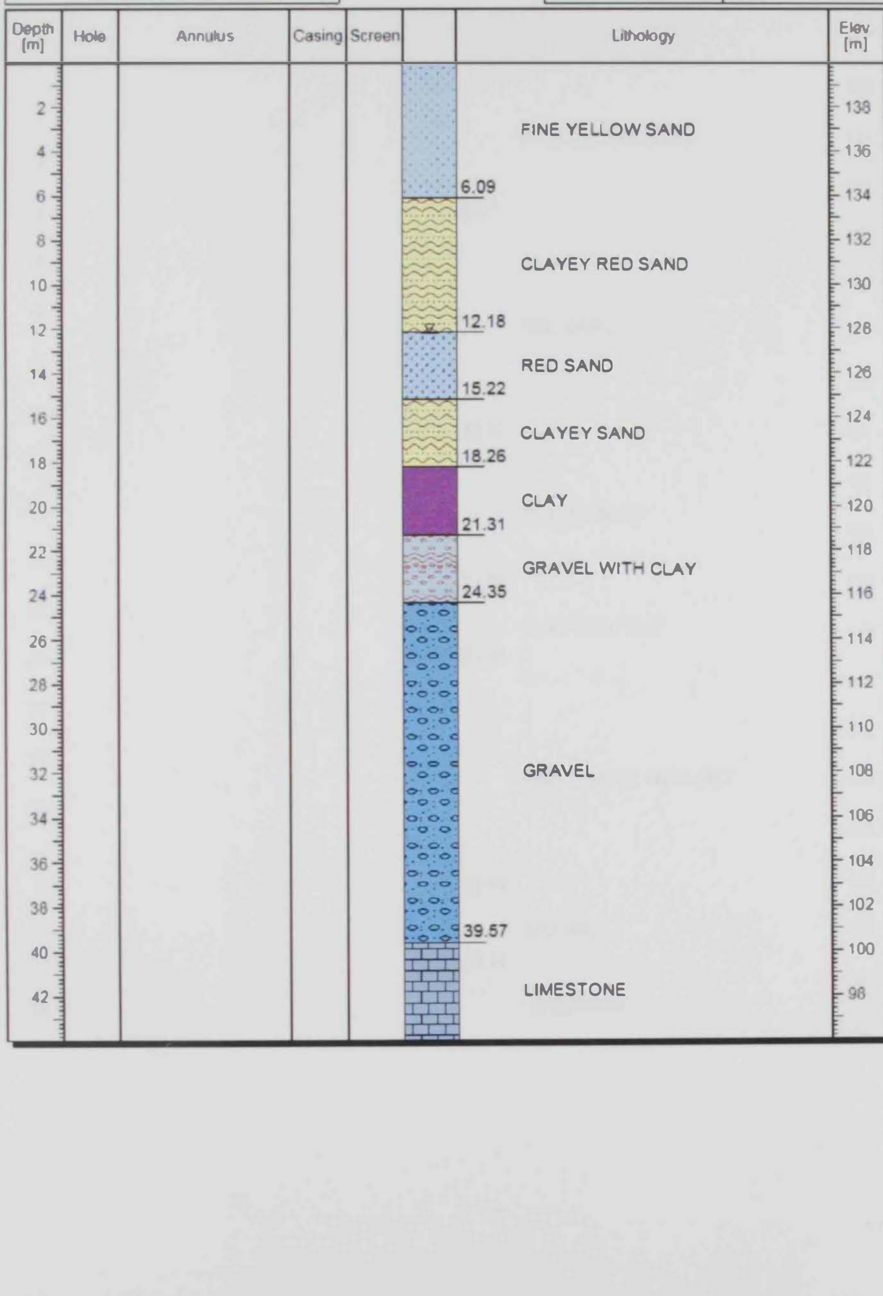
Well Log: Lithology & Construction

Well Ident	well -5	Name	Well No. 5
Drill. Method	Rotary	Drill. Dates	April - October 2001

X	304445	Y	2678199	Z	140.00	Meas. Pt. Elev.	140.00

All measurements are in meters. Hole and casing diameters in inches. ***Scales (1: xxx)***

Water Level (m AMSL)	127.80	Vertical	Horizontal



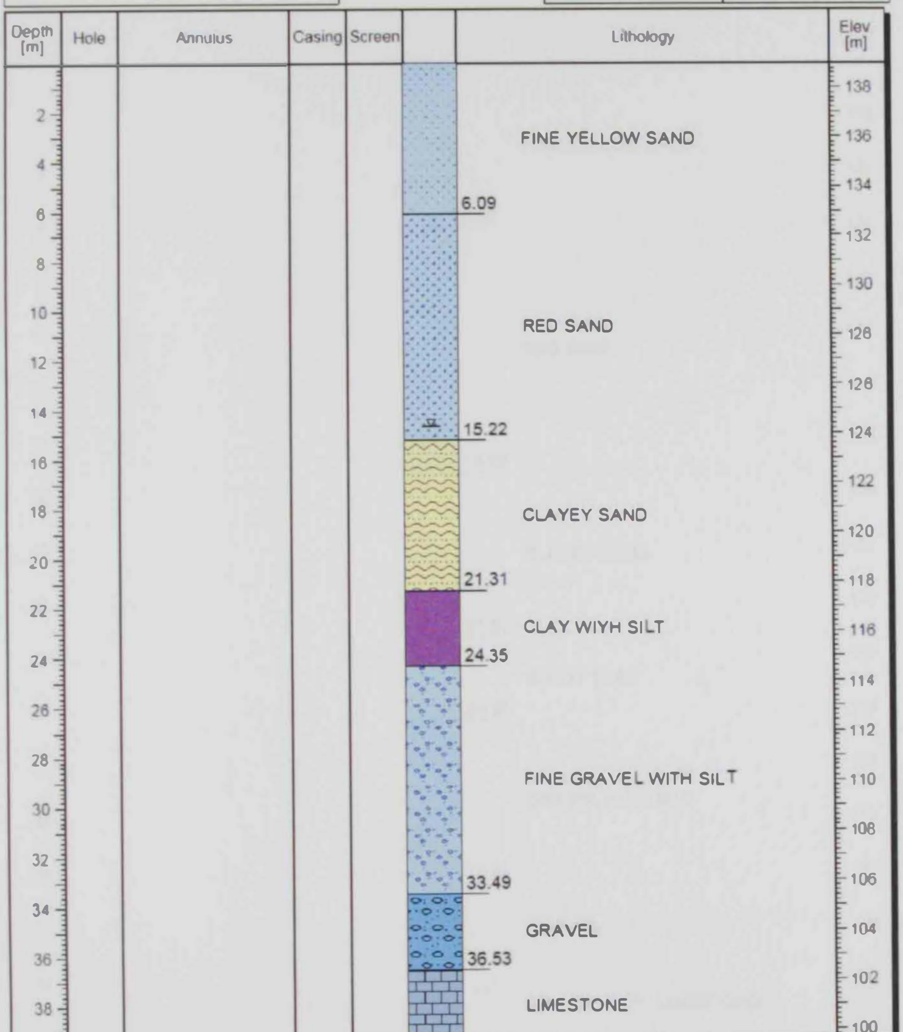
Well Log: Lithology & Construction

Well Ident	well -6	Name	Well No. 6				
Drill. Method	Rotary			Drill. Dates	April - October 2001		
X	304214	Y	2412253	Z	139.00	Meas. Pt. Elev.	139.00

All measurements are in meters. Hole and casing diameters in inches.

Scales (1: xxx)

Water Level (m AMSL)	Vertical	Horizontal
124.30		



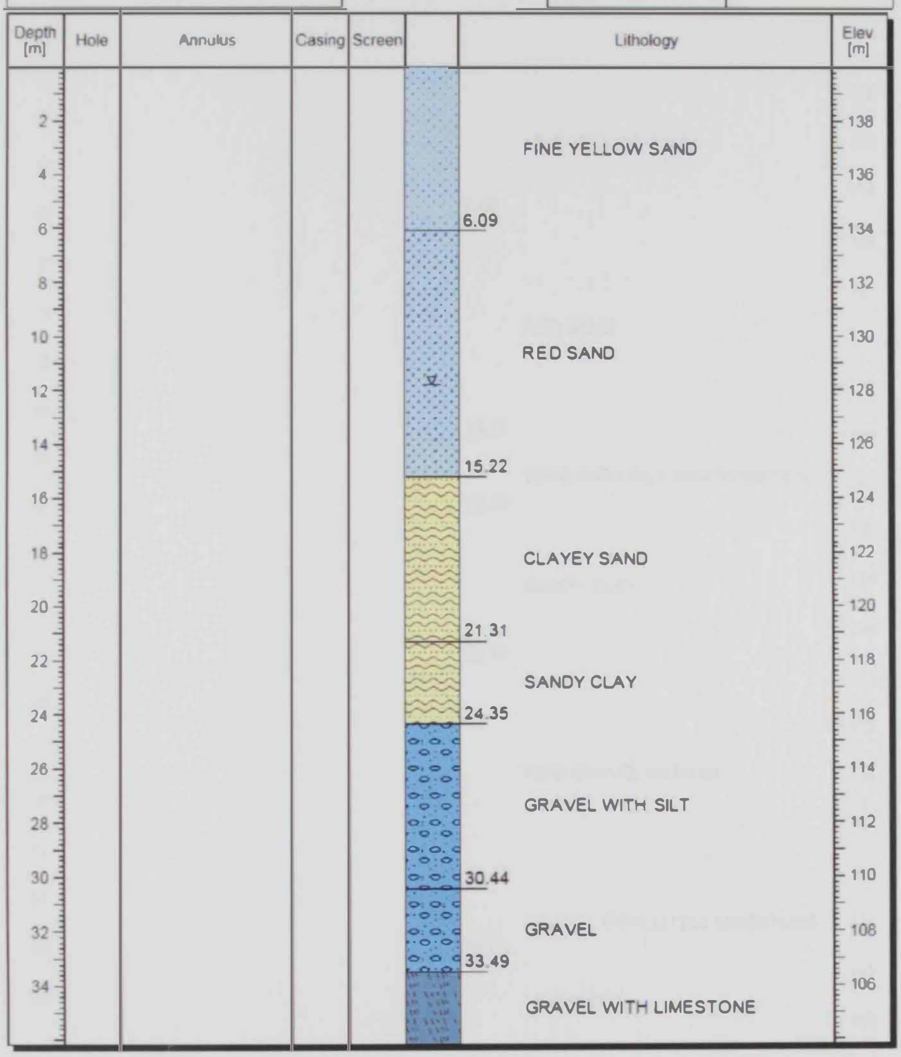
Well Log: Lithology & Construction

Well Ident	**well -7**	Name	**Well No. 7**				
Drill Method	**Rotary**			Drill Dates	**April - October 2001**		
X	**304588**	Y	**2678132**	Z	**140.00**	Meas. Pt. Elev.	**140.00**

All measurements are in meters. Hole and casing diameters in inches.

Scales (1: xxx)

Water Level (m AMSL)	Vertical	Horizontal
128.20		



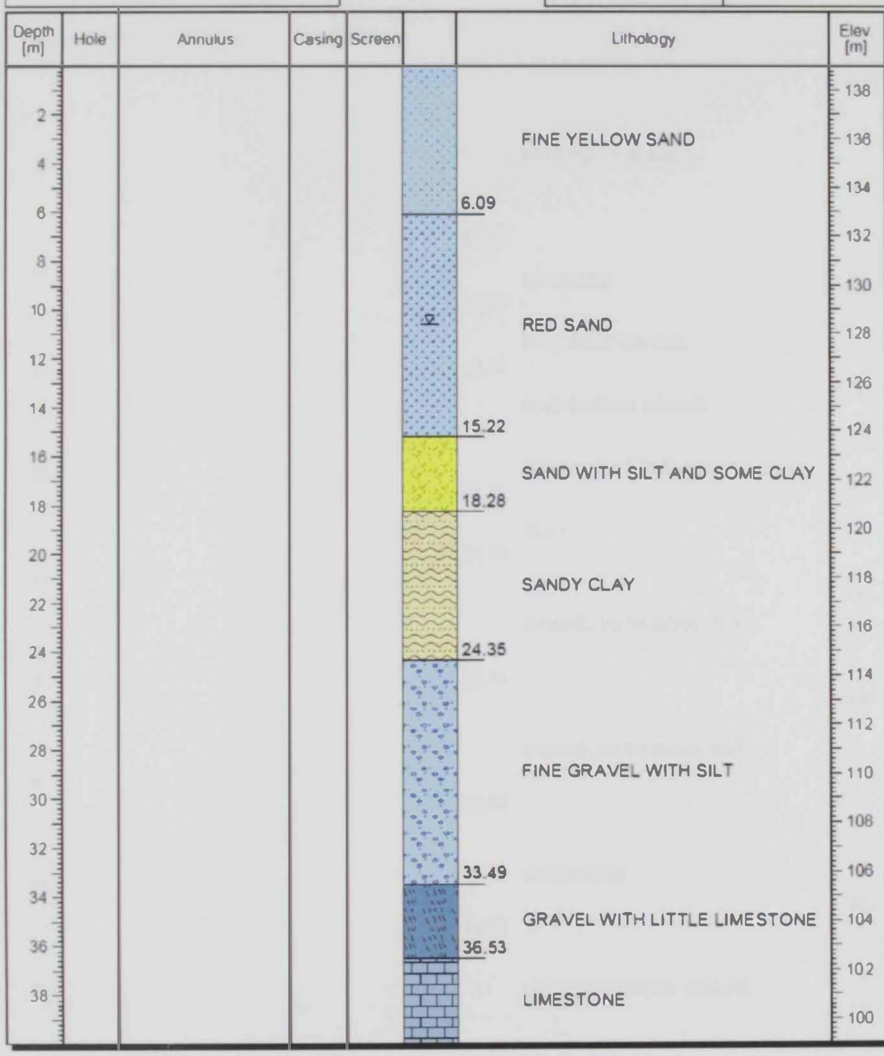
Well Log: Lithology & Construction

Well Ident	well -8	Name	Well No. 8				
Drill Method	Rotary	Drill Dates	April - October 2001				
X	304453	Y	2412107	Z	139.00	Meas. Pt. Elev.	139.00

All measurements are in meters. Hole and casing diameters in inches.

Scales (1: xxx)

Water Level (in AMSL)	Vertical	Horizontal
128.40		



Well Log: Lithology & Construction

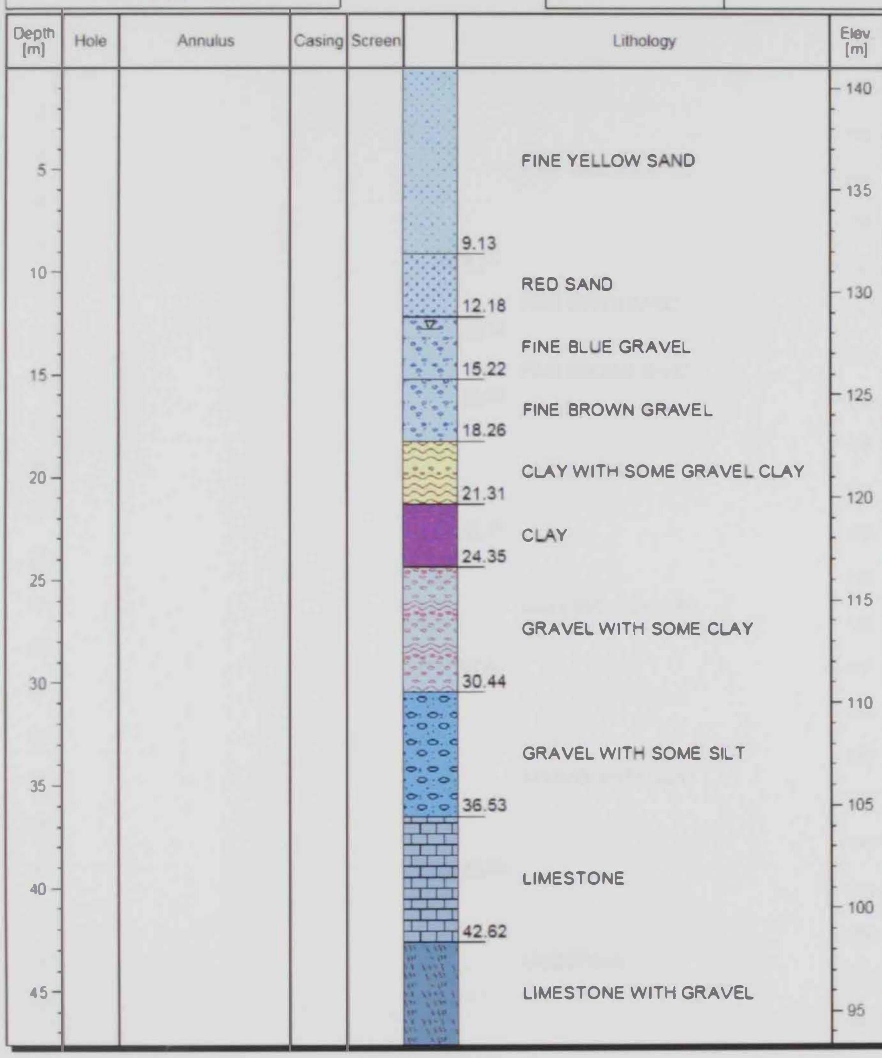
Well Ident well -9	Name: Well No. 9
Drill. Method: Rotary	Drill. Dates: April - October 2001

X	304683	Y	2678269	Z	141.00	Meas. Pt. Elev.	141.00

All measurements are in meters. Hole and casing diameters in inches.

Scales (1: xxx)

Water Level (m AMSL)	Vertical	Horizontal
128.20		



Well Log: Lithology & Construction

Well Ident	Name
well -10	Well No. 10

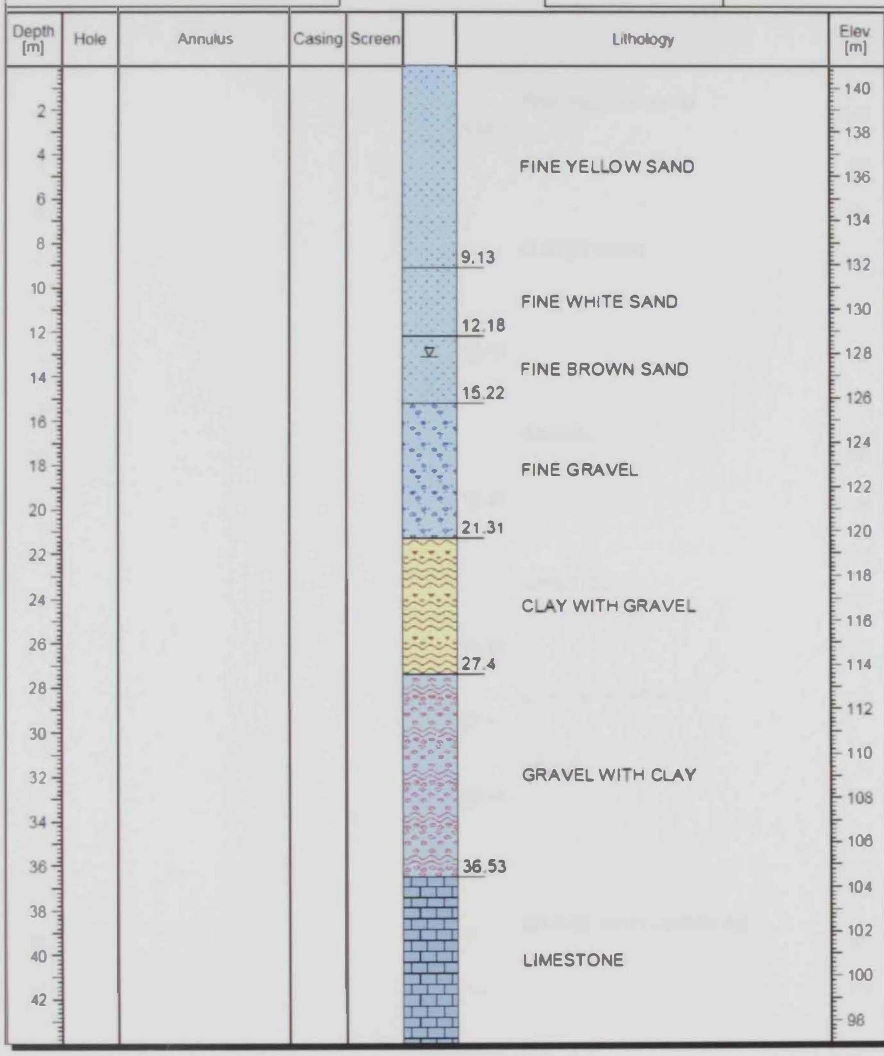
Drill. Method		Drill. Dates	
	Rotary		April - October 2001

X		Y		Z		Meas. Pt. Elev.	
	304621		2678577		141.00		141.00

All measurements are in meters. Hole and casing diameters in inches.

Scales (1: xxx)

Water Level (m AMSL)	Vertical	Horizontal
127.88		



Well Log: Lithology & Construction

Well Ident	Name
well - 11	Well No. 11

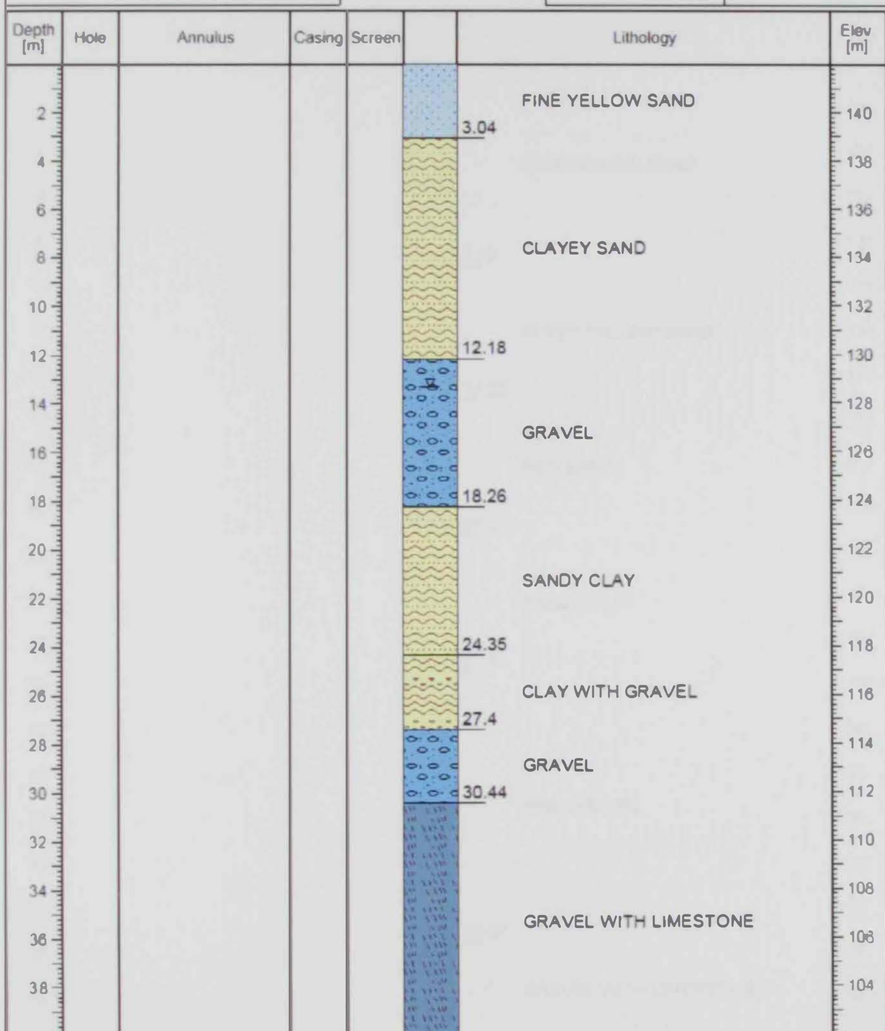
Drill. Method	Rotary	Drill. Dates	April - October 2001

X	304985	Y	2678609	Z	142.00	Meas. Pt. Elev.	142.00

All measurements are in meters. Hole and casing diameters in inches.

Scales (1: xxx)

Water Level (m AMSL)	Vertical	Horizontal
128.67		



Well Log: Lithology & Construction

Well Ident: well -12

Name: Well No. 12

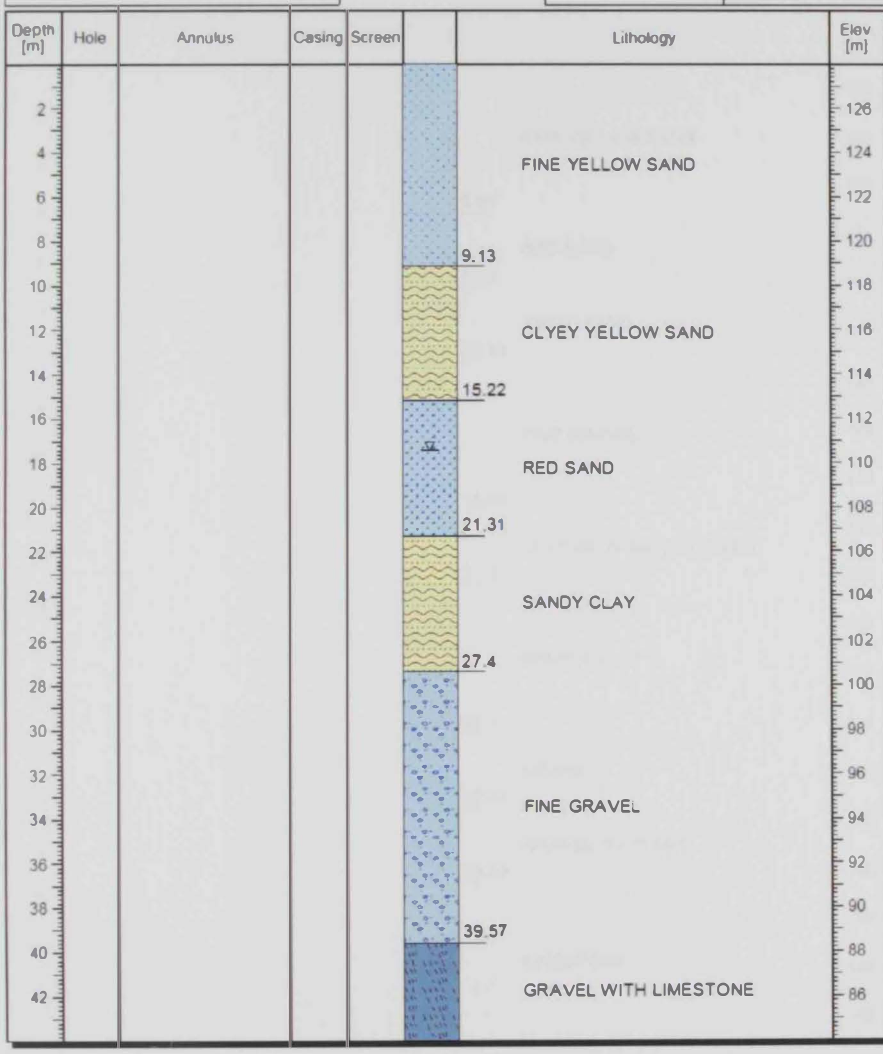
Drill Method: Rotary | Drill Dates: April - October 2001

X	Y	Z	Meas. Pt. Elev.
300885	2679768	128.00	128.00

All measurements are in meters. Hole and casing diameters in inches. ***Scales (1: xxx)***

Water Level (m AMSL): 110.55

Vertical | Horizontal



Well Log: Lithology & Construction

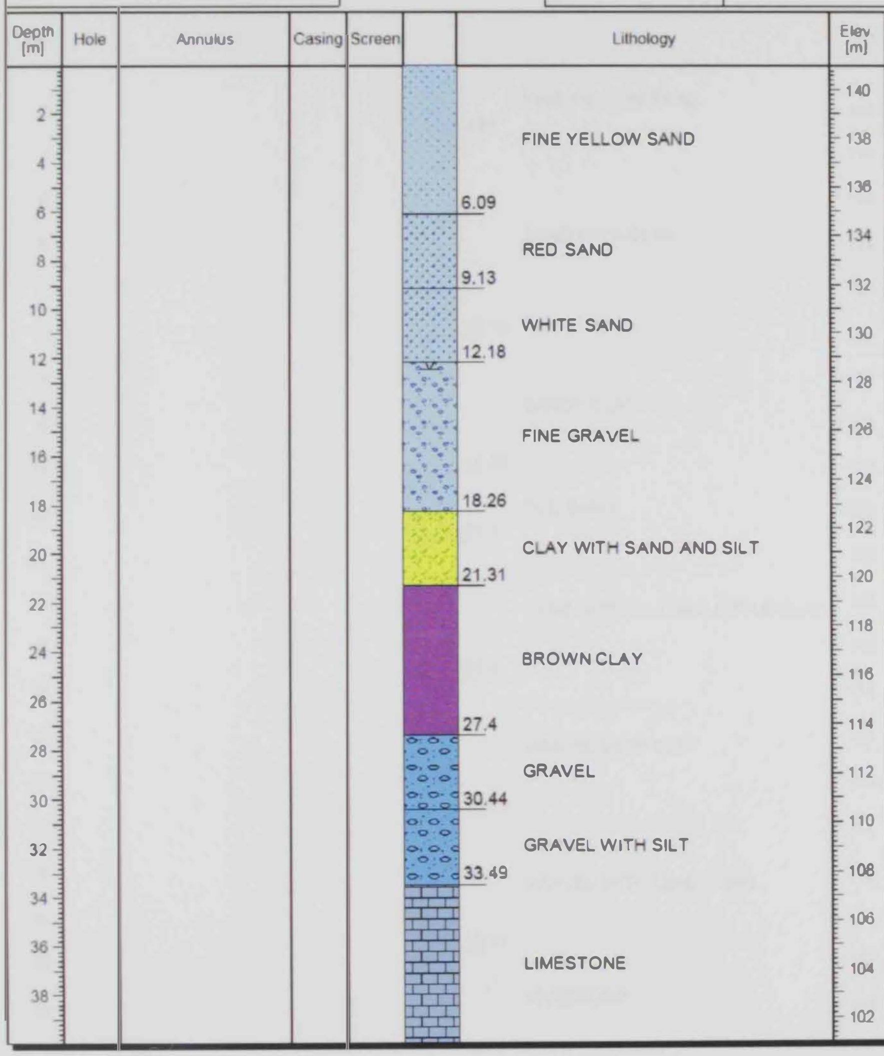
Well Ident	well -13	Name	Well No. 13
Drill. Method	Rotary	Drill. Dates	April - October 2001

X	304816	Y	2678485	Z	141.00	Meas. Pt. Elev.	141.00

All measurements are in meters. Hole and casing diameters in inches.

Scales (1: xxx)

Water Level (m AMSL)	128.50	Vertical	Horizontal



Well Log: Lithology & Construction

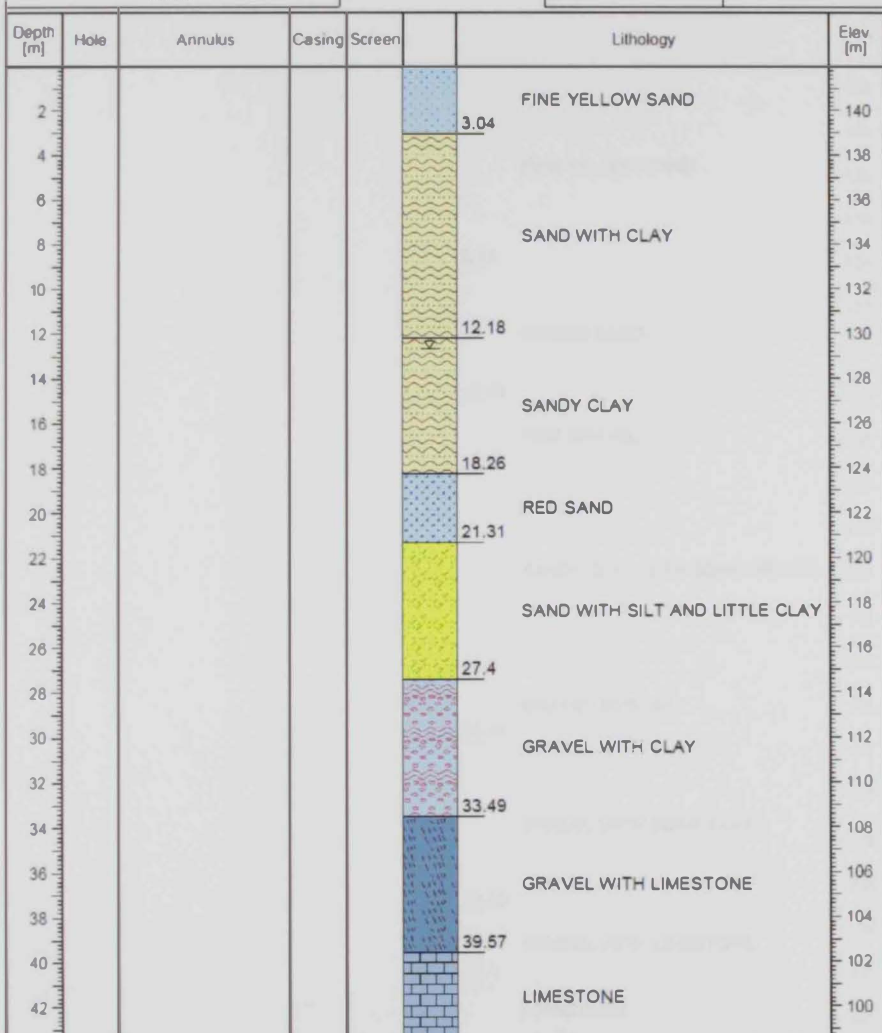
Well Ident well -14	Name: **Well No. 14**
Drill Method: **Rotary**	Drill Dates: **April - October 2001**

X	Y	Z	Meas. Pt. Elev.
304758	2678730	142.00	142.00

All measurements are in meters. Hole and casing diameters in inches.

Scales (1: xxx)

Water Level (m AMSL)	Vertical	Horizontal
129.30		



Well Log: Lithology & Construction

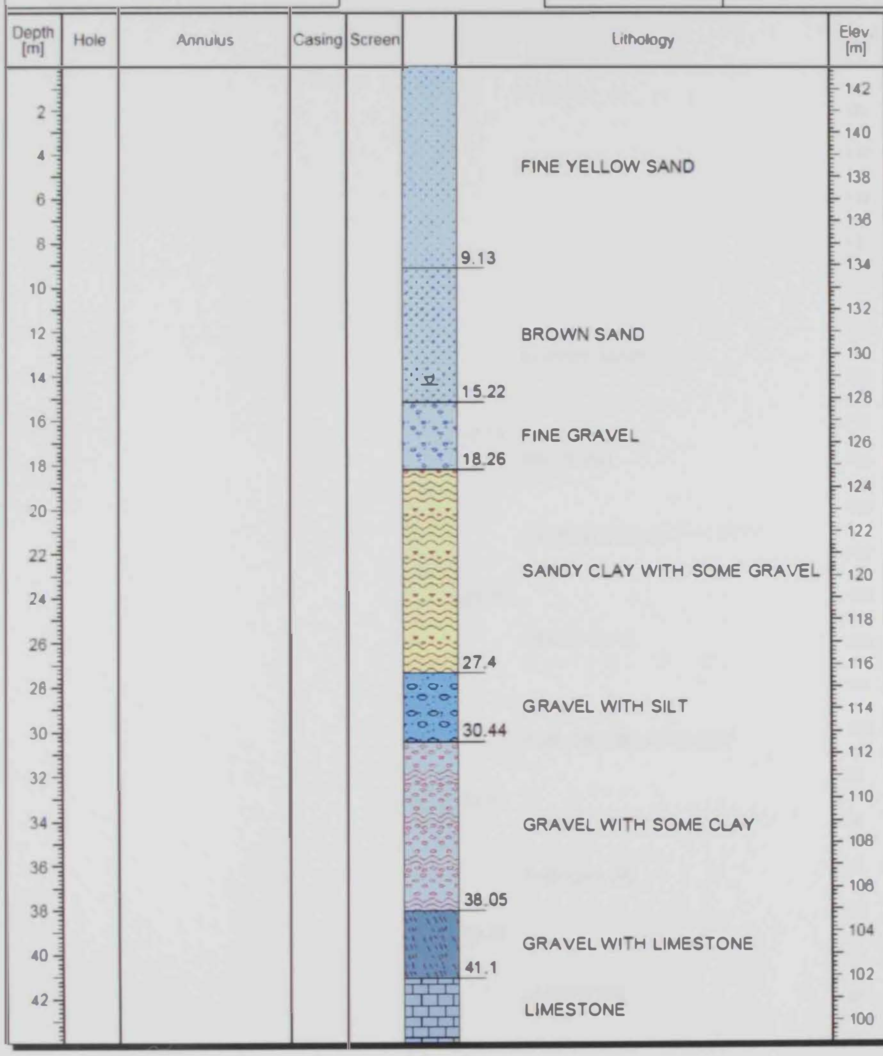
Well Ident	Name
well -15	Well No. 15

Drill. Method	Rotary	Drill. Dates	April - October 2001

X	304896	Y	2677373	Z	143.00	Meas. Pt. Elev.	143.00

All measurements are in meters. Hole and casing diameters in inches. ***Scales (1: xxx)***

Water Level (m AMSL)	Vertical	Horizontal
128.60		



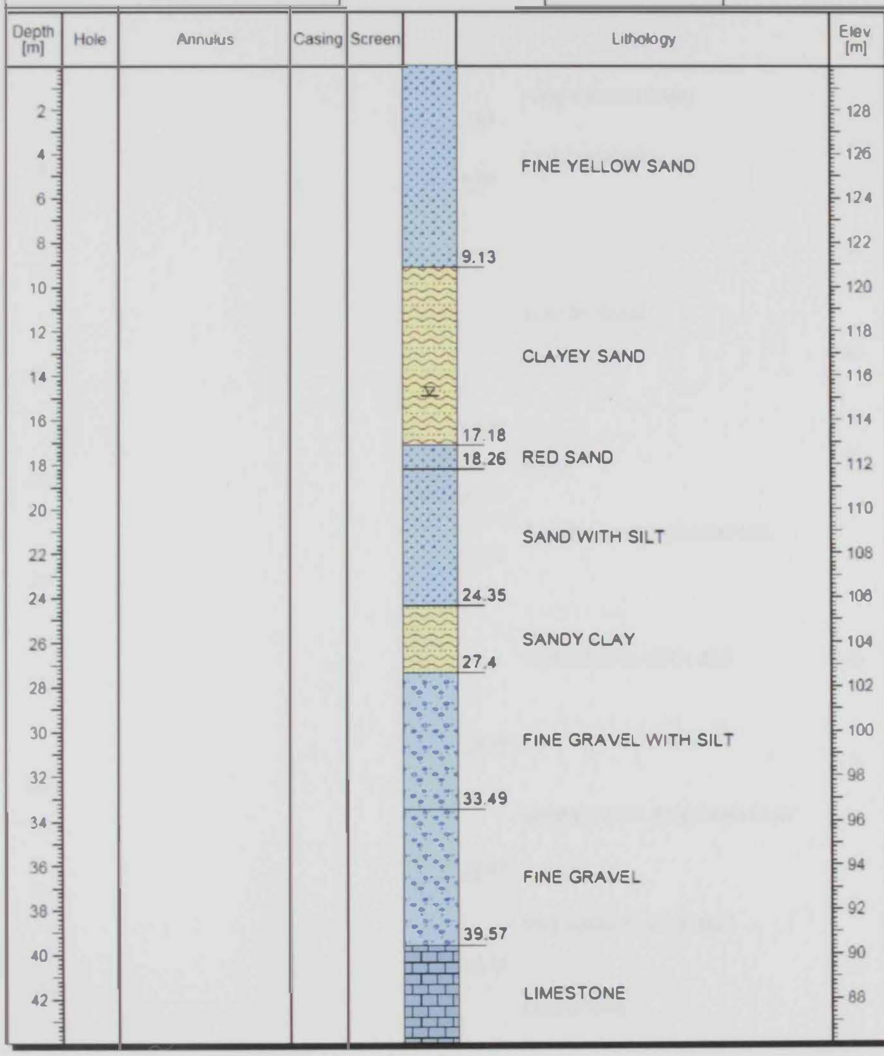
Well Log: Lithology & Construction

Well Ident: **well -16**	Name: **Well No. 16**		
Drill. Method: **Rotary**	Drill. Dates: **April - October 2001**		
X: 301847	Y: 2677818	Z: 130.00	Meas. Pt. Elev.: 130.00

All measurements are in meters. Hole and casing diameters in inches.

Scales (1: xxx)

Water Level (m AMSL)	Vertical	Horizontal
115.07		



Well Log: Lithology & Construction

Well Ident	Name
well -17	Well No. 17

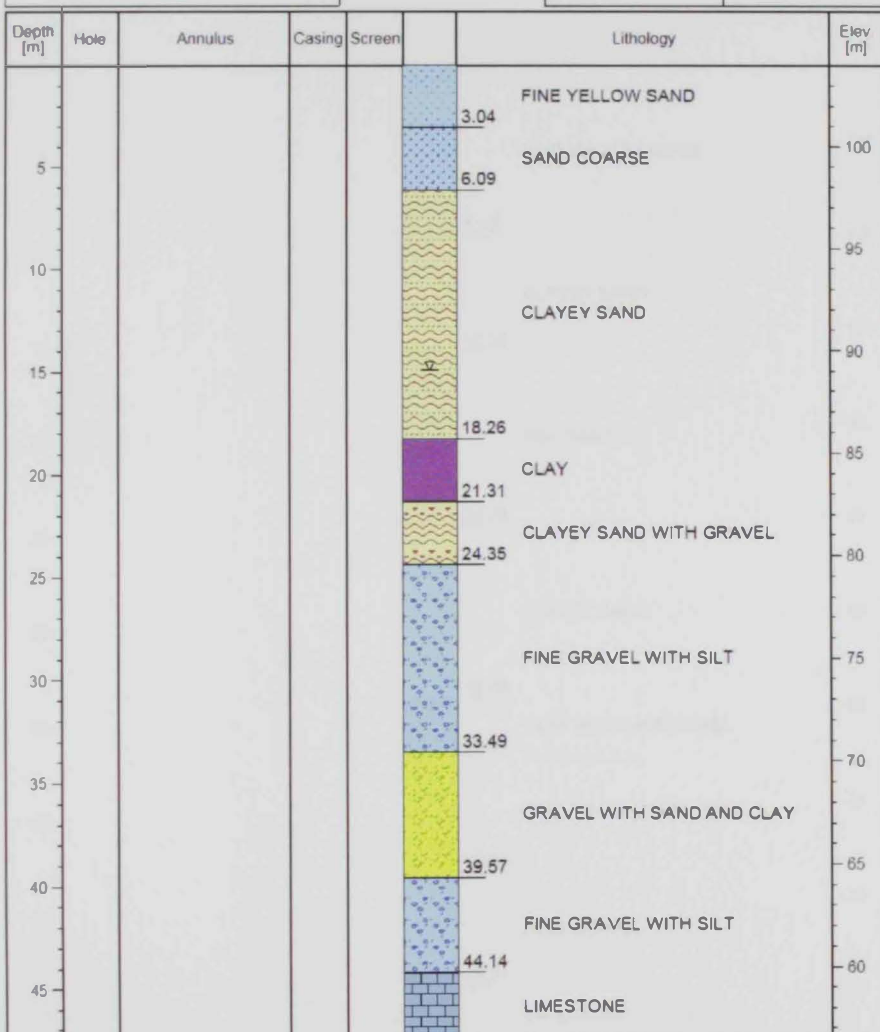
Drill. Method		Drill. Dates	
Rotary		April - October 2001	

X		Y		Z		Meas. Pt. Elev.	
294202		2678054		104.00		104.00	

All measurements are in meters. Hole and casing diameters in inches.

Scales (1: xxx)

Water Level (m AMSL)	Vertical	Horizontal
89.08		



Well Log: Lithology & Construction

Well Ident	Name
well -18	Well No. 18

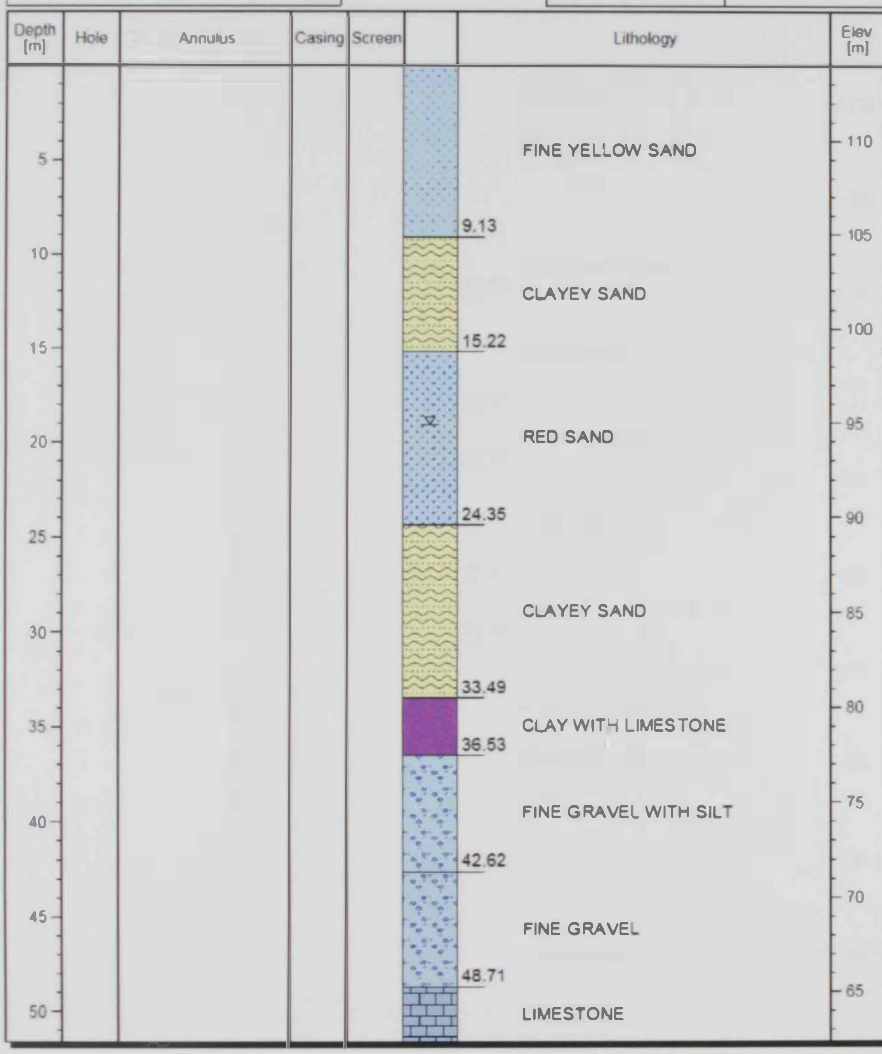
Drill Method		Drill Dates	
Rotary		April - October 2001	

X	Y	Z	Meas. Pt. Elev.
296925	2679383	114.00	114.00

All measurements are in meters. Hole and casing diameters in inches.

Scales (1: xxx)

Water Level (m AMSL)	Vertical	Horizontal
94.90		



Well Log: Lithology & Construction

Well Ident	Name
well -19	Well No. 19

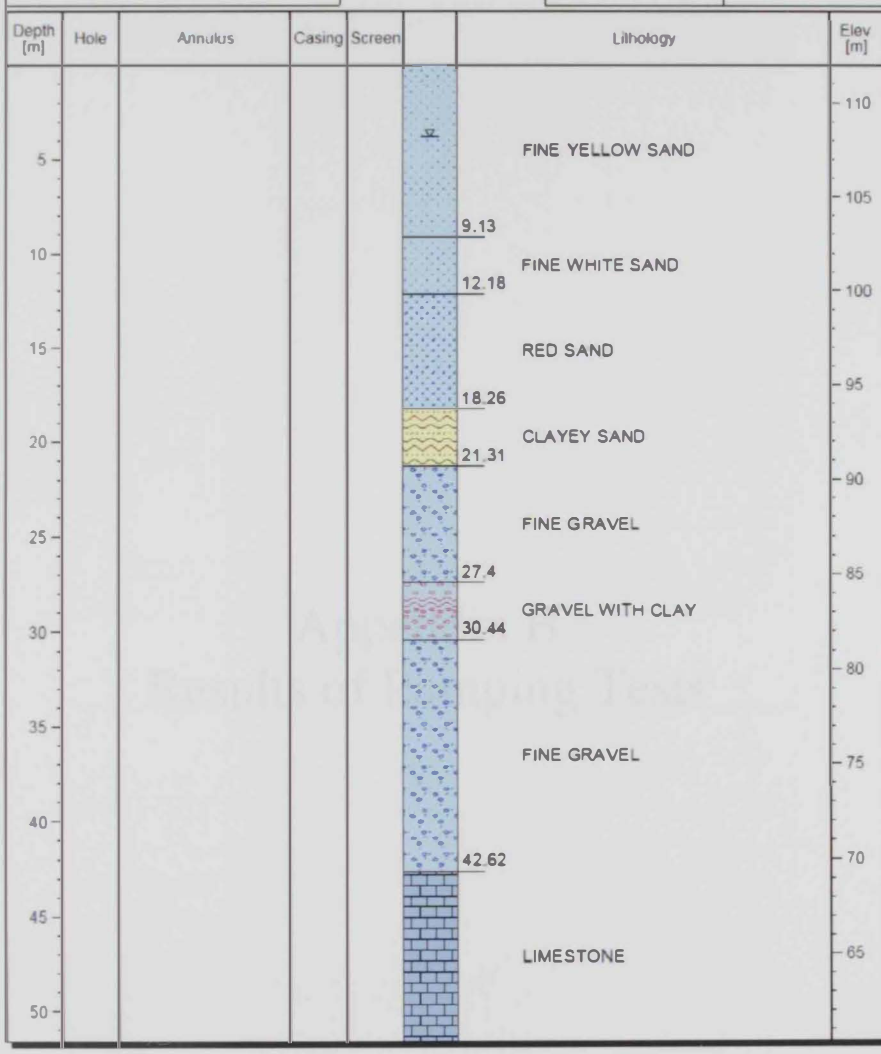
Drill. Method		Drill. Dates	
	Rotary		April - October 2001

X		Y		Z		Meas. Pt. Elev.	
	294712		2677496		112.00		112.00

All measurements are in meters. Hole and casing diameters in inches.

Scales (1: xxx)

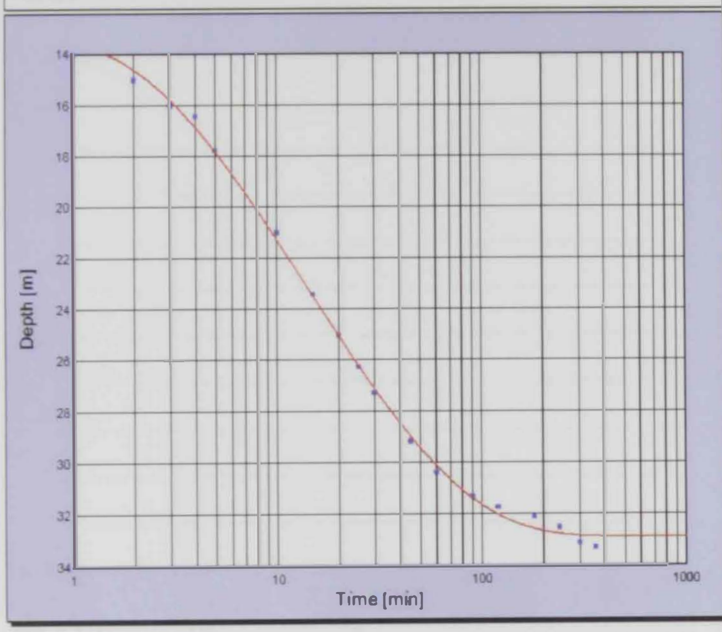
Water Level (m AMSL)	Vertical	Horizontal
108.17		



Appendix B
Results of Pumping Tests

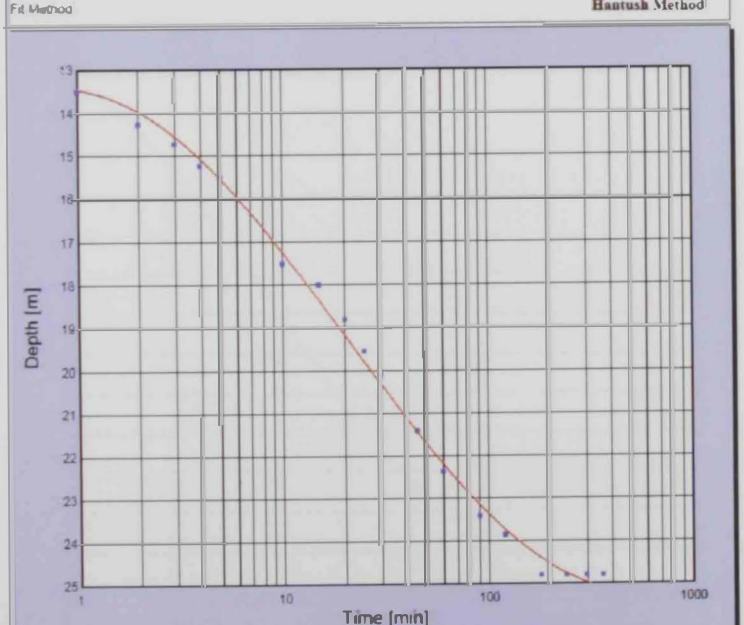
Pumping Test

Well Ident	Name		
well -1	Well No. 1		
Obs. Well Distance [m]	**Average Pump. Rate [m3/day]**	**Duration [min]**	**Initial Sat. Thickness [m]**
0.36	0.0062500	360.00	
Results			
Transmissivity [m2/day]	**Storage Coefficient**	**Leakance [1/day]**	**Estimation Error [m]**
5.93		4.6252	0.28
Fit Method			Hantush Method



Pumping Test

Well Ident	Name		
well- 2	Well No. 2		
Obs. Well Distance [m]	**Average Pump. Rate [m3/day]**	**Duration [min]**	**Initial Sat. Thickness [m]**
0.36	0.0044000	360.00	
Results			
Transmissivity [m2/day]	**Storage Coefficient**	**Leakance [1/day]**	**Estimation Error [m]**
9.02		2.8166	0.23
Fit Method			Hantush Method

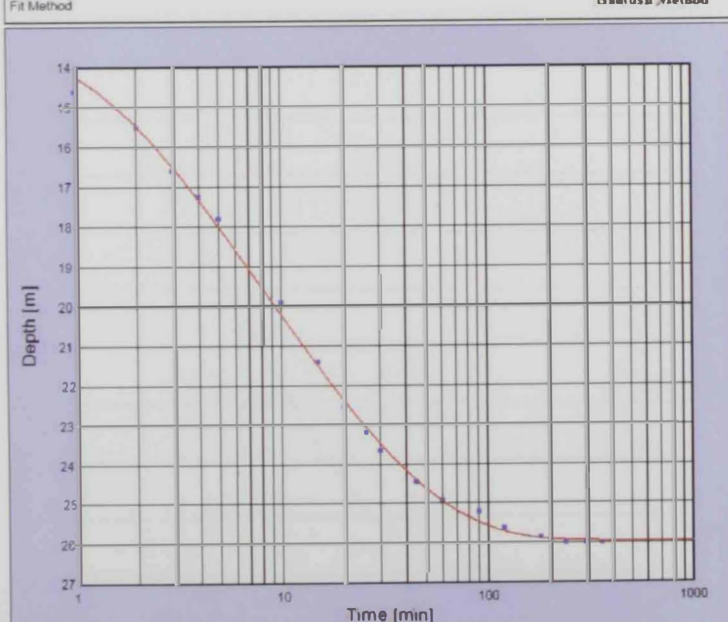


Pumping Test

Well Ident	Name		
well -3	Well No. 3		
Obs. Well Distance [m]	**Average Pump. Rate [m3/day]**	**Duration [min]**	**Initial Sat. Thickness [m]**
0.36	0.0062500	360.00	
Results			
Transmissivity [m2/day]	**Storage Coefficient**	**Leakance [1/day]**	**Estimation Error [m]**
5.85		3.9665	0.58
Fit Method			Hantush Method

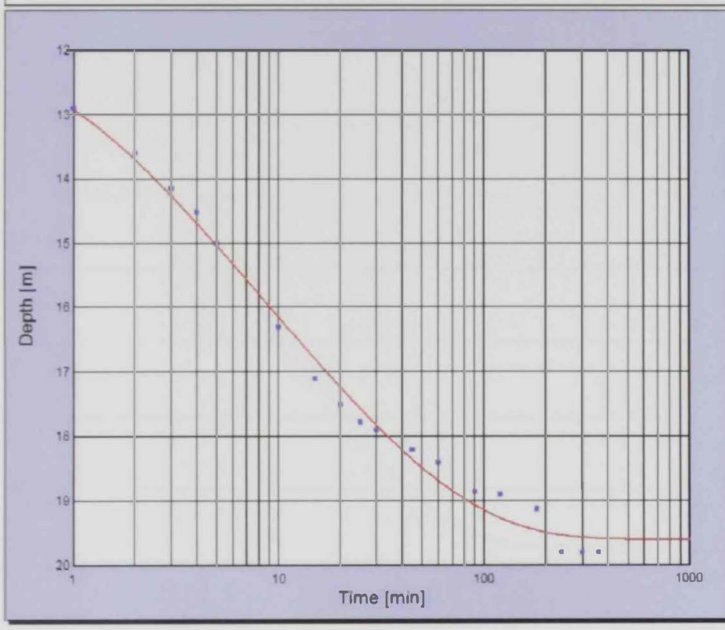
Pumping Test

Well Ident	Name		
Well -4	Well No. 4		
Obs. Well Distance [m]	**Average Pump. Rate [m3/day]**	**Duration [min]**	**Initial Sat. Thickness [m]**
0.36	0.0062500	360.00	
Results			
Transmissivity [m2/day]	**Storage Coefficient**	**Leakance [1/day]**	**Estimation Error [m]**
10.6		5.5955	0.17
Fit Method			Hantush Method



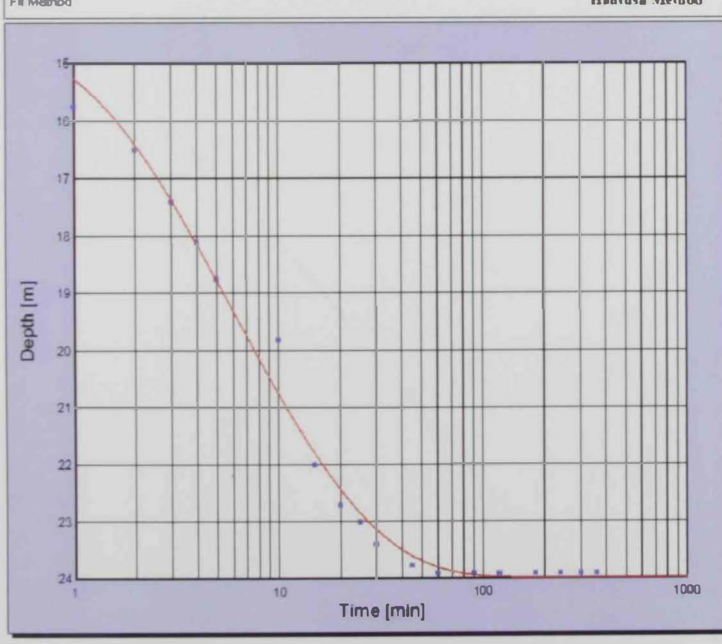
Pumping Test

Well Ident	Name		
well -5	Well No. 5		
Obs. Well Distance [m]	**Average Pump. Rate [m3/day]**	**Duration [min]**	**Initial Sat. Thickness [m]**
0.36	0.0062500	360.00	
Results			
Transmissivity [m2/day]	**Storage Coefficient**	**Leakance [1/day]**	**Estimation Error [m]**
23.6		4.6430	0.22
Fit Method			Hantush Method



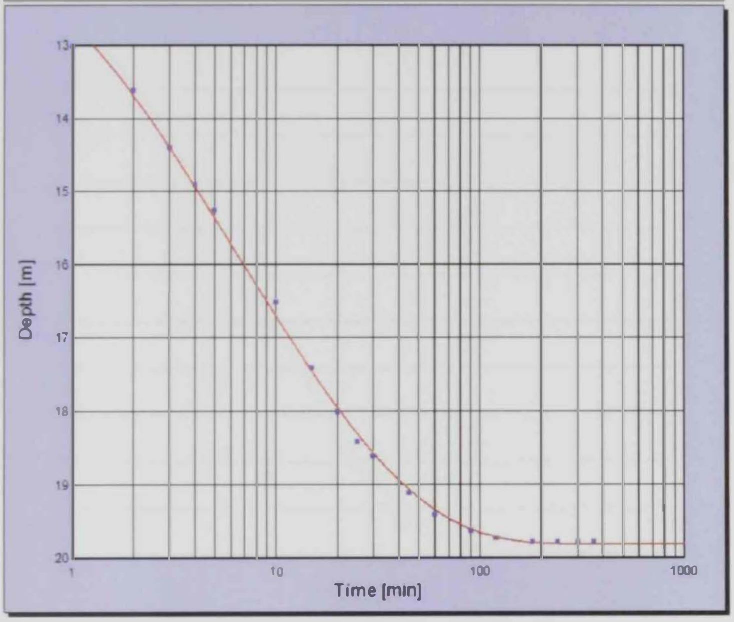
Pumping Test

Well Ident	Name		
well -6	Well No. 6		
Obs. Well Distance[m]	**Average Pump. Rate [m3/day]**	**Duration [min]**	**Initial Sat. Thickness [m]**
0.36	0.0062500	360.00	
Results			
Transmissivity [m2/day]	**Storage Coefficient**	**Leakance [1/day]**	**Estimation Error [m]**
10.00		14.088	0.28
Fit Method			Hantush Method



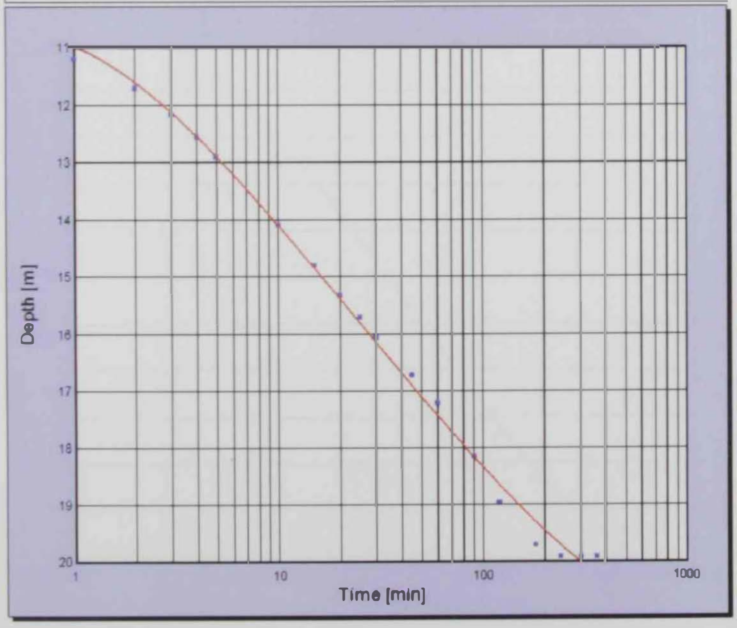
Pumping Test

Well Ident	Name		
well -7	Well No. 7		
Obs. Well Distance [m]	**Average Pump. Rate [m3/day]**	**Duration [min]**	**Initial Sat. Thickness [m]**
0.36	0.0062500	360.00	
Results			
Transmissivity [m2/day]	**Storage Coefficient**	**Leakance [1/day]**	**Estimation Error [m]**
18.3		6.8141	0.10
Fit Method			Hantush Method



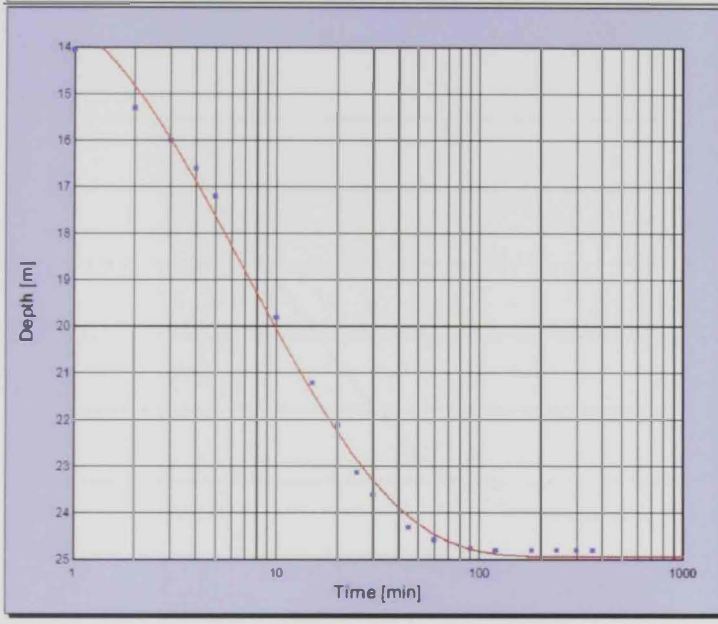
Pumping Test

Well Ident	Name		
well -8	Well No. 8		
Obs. Well Distance [m]	**Average Pump. Rate [m3/day]**	**Duration [min]**	**Initial Sat. Thickness [m]**
0.36	0.0036000	360.00	
Results			
Transmissivity [m2/day]	**Storage Coefficient**	**Leakance [1/day]**	**Estimation Error [m]**
12.5		0.69619	0.18
Fit Method			Hantush Method



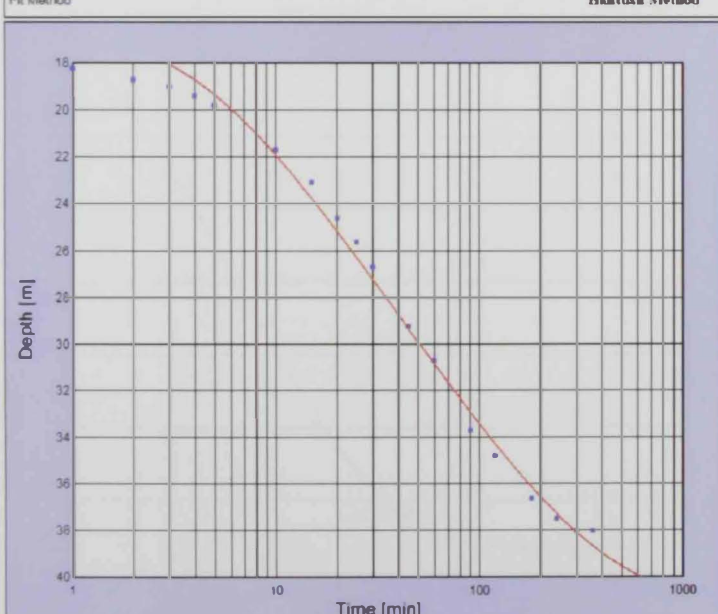
Pumping Test

Well Ident	Name		
well -9	Well No. 9		
Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
0.36	0.0062500	360.00	
Results			
Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
8.88		8.5395	0.26
Fit Method			Hantush Method



Pumping Test

Well Ident	Name		
well -10	Well No. 10		
Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness[m]
0.36	0.0033000	360.00	
Results			
Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
3.82		0.76519	0.65
Fit Method			Hantush Method

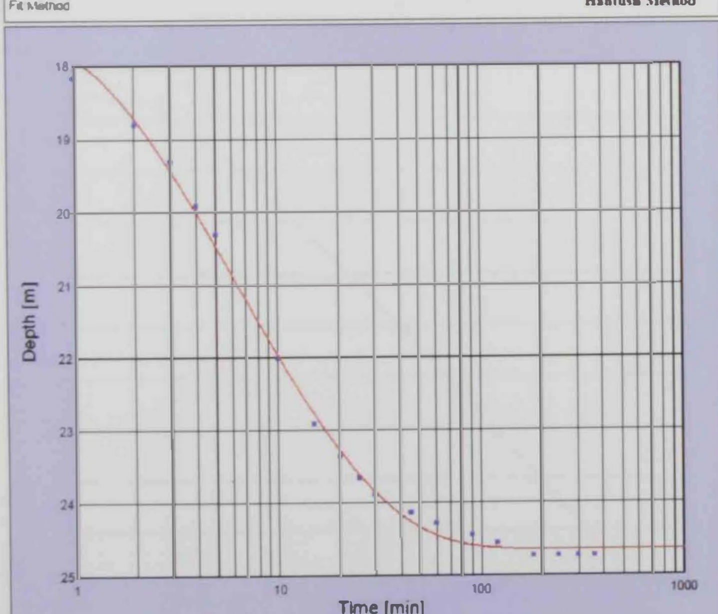


Pumping Test

Well Ident	Name		
well -11	Well No. 11		
Obs. Well Distance [m]	**Average Pump. Rate [m3/day]**	**Duration [min]**	**Initial Sat. Thickness [m]**
0.36	0.0062500	360.00	
Results			
Transmissivity [m2/day]	**Storage Coefficient**	**Leakance [1/day]**	**Estimation Error [m]**
10.9		3.8552	0.25
Fit Method			Hantush Method

Pumping Test

Well Ident	Name		
well -12	Well No. 12		
Obs. Well Distance [m]	**Average Pump. Rate [m3/day]**	**Duration [min]**	**Initial Sat. Thickness [m]**
0.36	0.0062500	360.00	
Results			
Transmissivity [m2/day]	**Storage Coefficient**	**Leakance [1/day]**	**Estimation Error [m]**
13.9		16.380	0.12
Fit Method			Hantush Method



Pumping Test

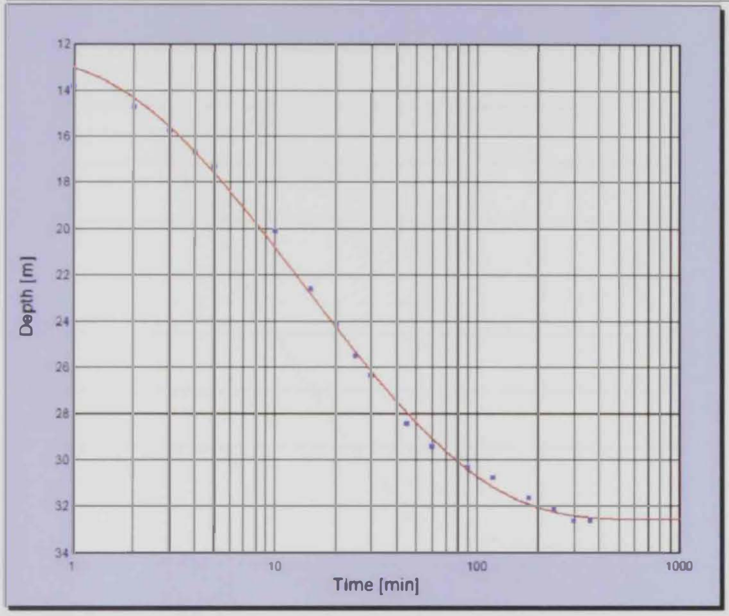
Well Ident	Name
well -13	Well No. 13

Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
0.36	0.0062500	360.00	

Results

Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
7.16		2.8778	0.35

Fit Method	
	Hantush Method



Pumping Test

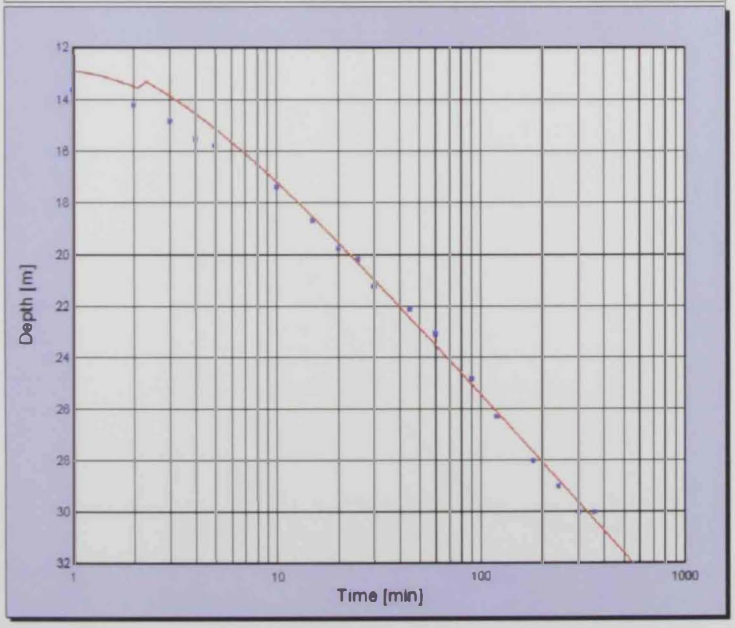
Well Ident	Name
well -14	Well No. 14

Obs. Well Distance[m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
0.36	0.0036000	360.00	

Results

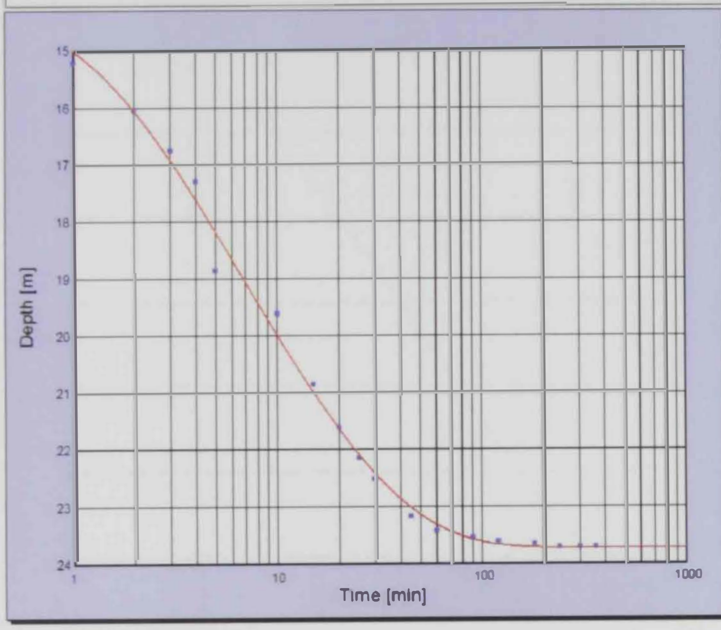
Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
6.66		1.9751E-13	0.50

Fit Method	
	Hantush Method



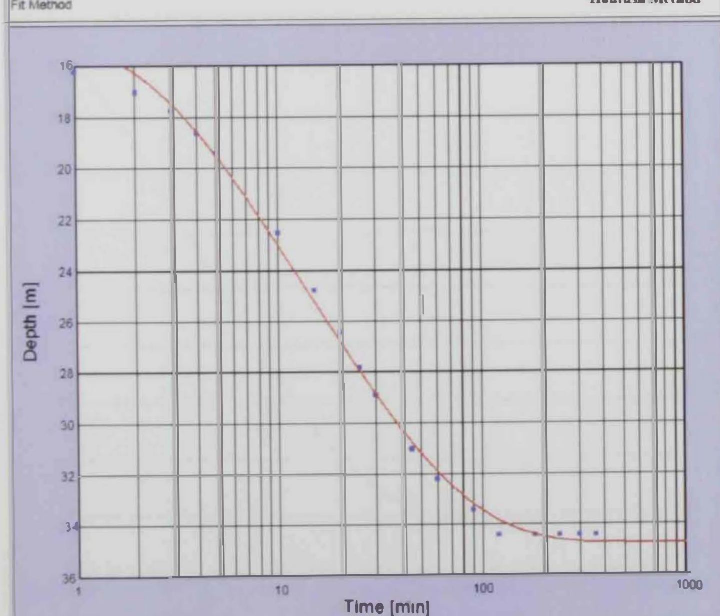
Pumping Test

Well Ident	Name		
well -15	Well No. 15		
Obs. Well Distance [m]	**Average Pump. Rate [m3/day]**	**Duration [min]**	**Initial Sat. Thickness [m]**
0.36	0.0062500	360.00	
Results			
Transmissivity [m2/day]	**Storage Coefficient**	**Leakance [1/day]**	**Estimation Error [m]**
12.3		10.048	0.22
Fit Method			Hantush Method



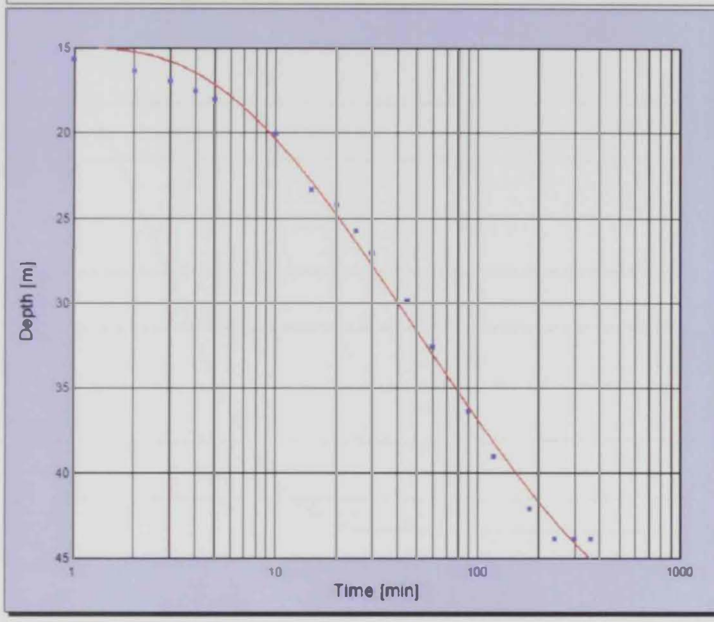
Pumping Test

Well Ident	Name		
well -16	Well No. 16		
Obs. Well Distance [m]	**Average Pump. Rate [m3/day]**	**Duration [min]**	**Initial Sat. Thickness [m]**
0.36	0.0062500	360.00	
Results			
Transmissivity [m2/day]	**Storage Coefficient**	**Leakance [1/day]**	**Estimation Error [m]**
5.94		4.4689	0.41
Fit Method			Hantush Method



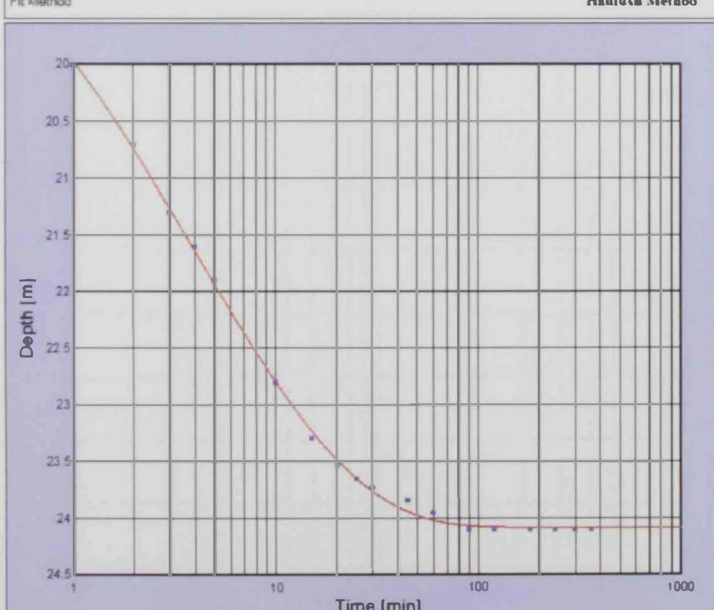
Pumping Test

Well Ident	Name		
well -17	Well No. 17		
Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
0.36	0.0036000	360.00	
Results			
Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
2.80		0.65739	0.82
Fit Method			Hantush Method



Pumping Test

Well Ident	Name		
well -18	Well No. 18		
Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
0.36	0.0062500	360.00	
Results			
Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
25.5		15.189	0.04
Fit Method			Hantush Method



Pumping Test

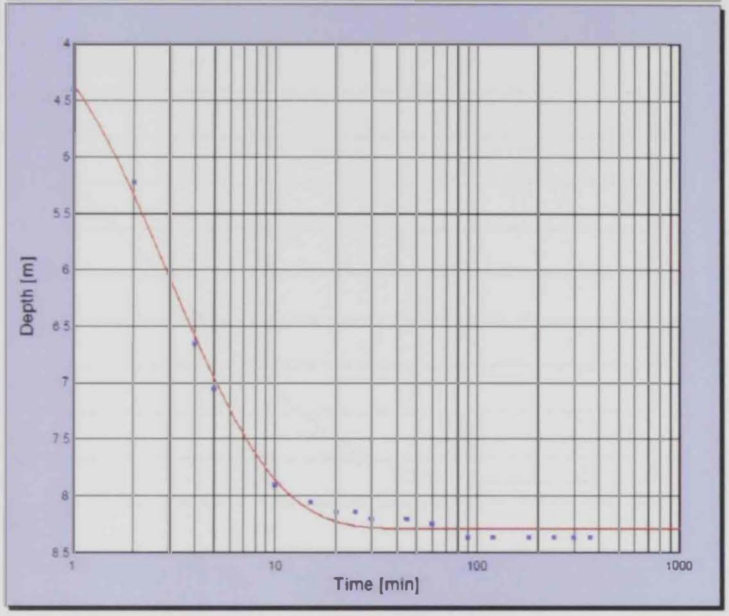
Well Ident	Name
well -19	Well No. 19

Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
0.36	0.0062500	360.00	

Results

Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
10.6		56.022	0.08

Fit Method: **Hantush Method**



Pumping Test

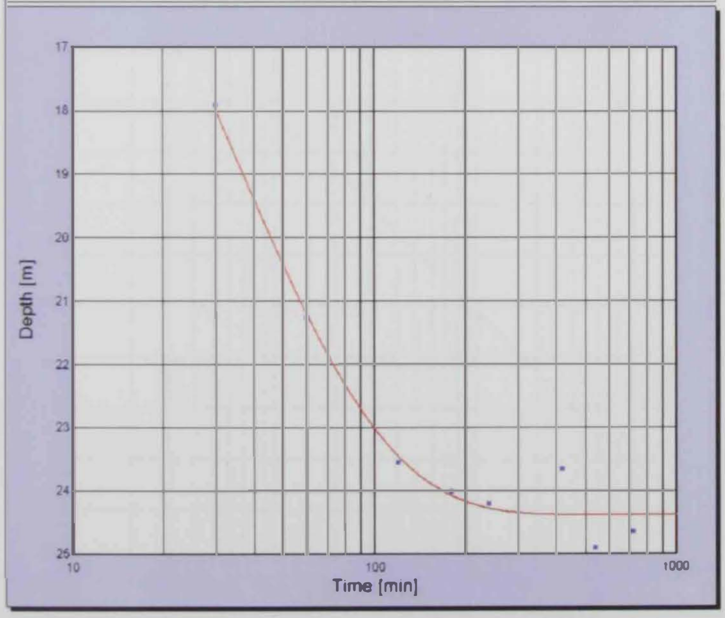
Well Ident	Name
well -20	Well No. 20

Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
0.36	0.0062500	720.00	

Results

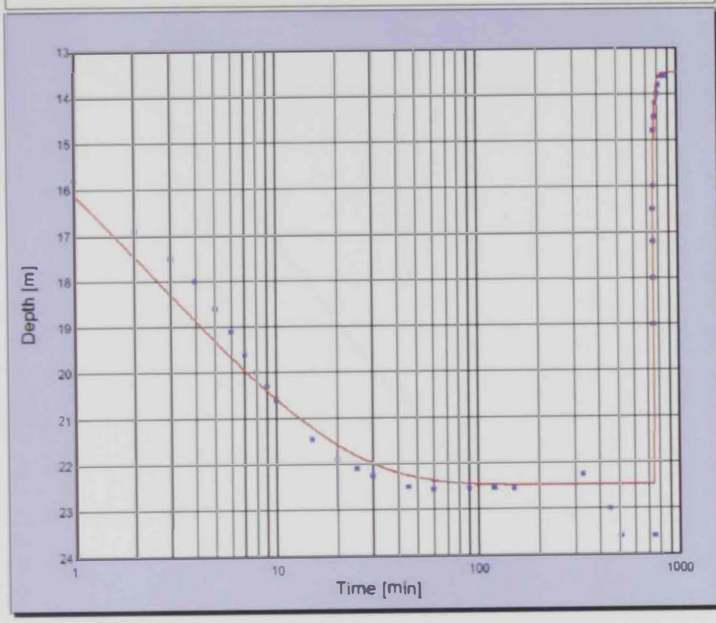
Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
3.54		24.555	0.34

Fit Method: **Hantush Method**



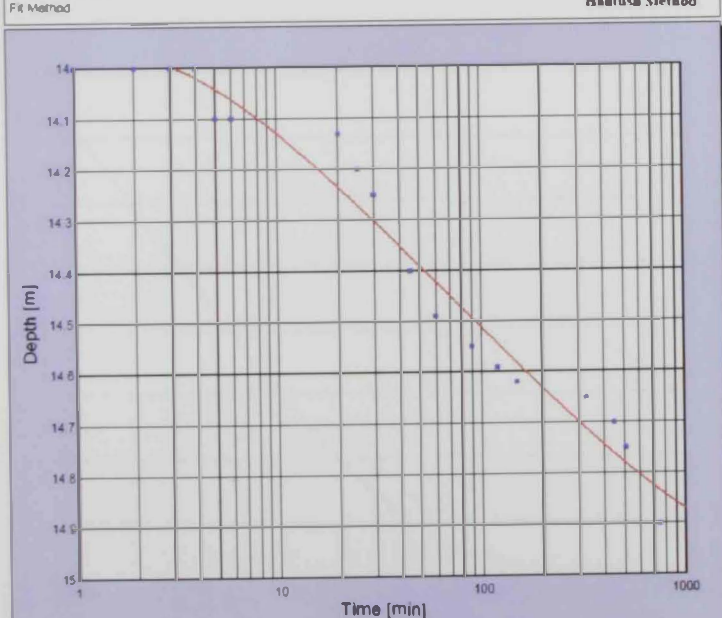
Pumping Test

Well Ident	Name		
WELL -25			
Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
0.15	0.0080000	870.00	
Results			
Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
23.4		33.828	0.50
Fit Method			Hantush Method



Pumping Test

Well Ident	Name		
WELL -26			
Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
96.80	0.0080000	750.00	
Results			
Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
302	0.00024558	0.00017113	0.05
Fit Method			Hantush Method



Pumping Test

Well Ident	Name		
well -34	Well No. 34		
Obs. Well Distance [m]	**Average Pump Rate [m3/day]**	**Duration [min]**	**Initial Sat. Thickness [m]**
0.36	0.0062500	360.00	

Results

Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
6.84		3.0994	0.44

Fit Method: **Hantush Method**

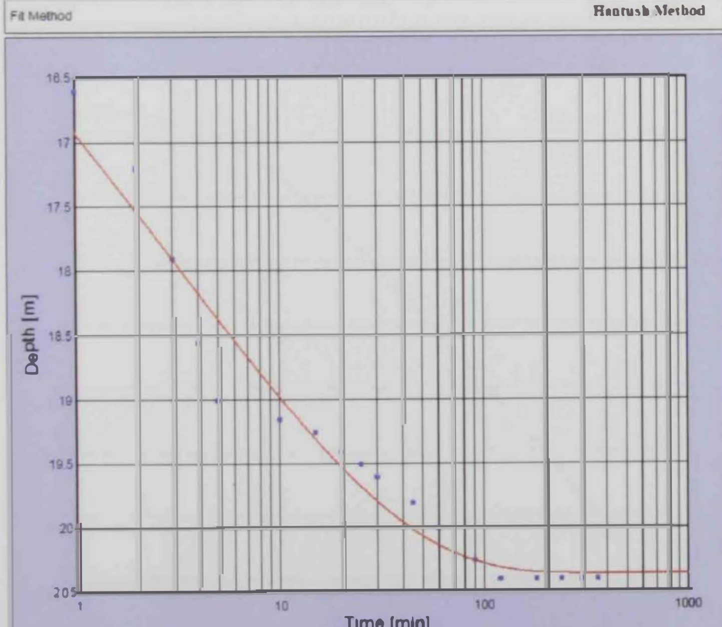
Pumping Test

Well Ident	Name		
well -35	Well No. 35		
Obs. Well Distance [m]	**Average Pump Rate [m3/day]**	**Duration [min]**	**Initial Sat. Thickness [m]**
0.36	0.0062500	360.00	

Results

Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
44.1		3.4309	0.23

Fit Method: **Hantush Method**



Pumping Test

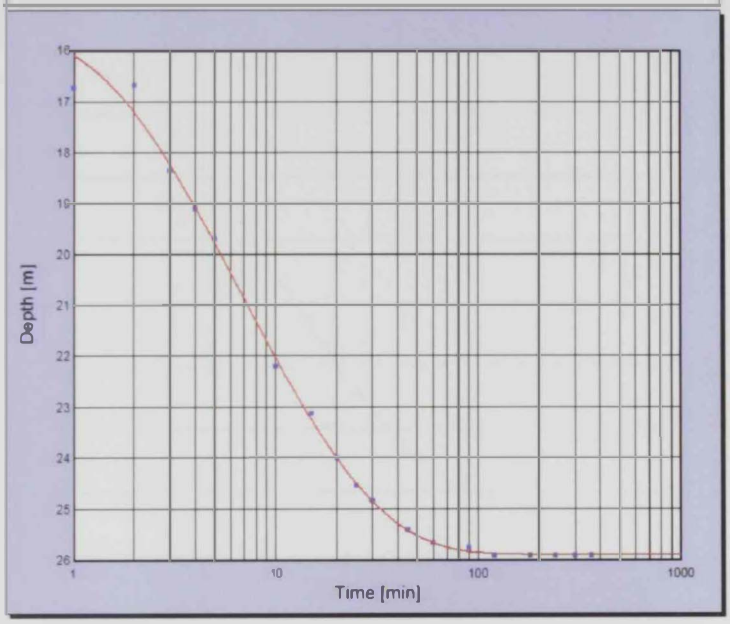
Well Ident	Name
well -36	Well No. 36

Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
0.36	0.0033000	360.00	

Results

Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
4.48		7.3904	0.21

Fit Method: **Hantush Method**



Pumping Test

Well Ident	Name
well-37	Well No. 37

Obs. Well Distanee [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
0.36	0.0033000	360.00	

Results

Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
2.88		5.7507E-13	0.51

Fit Method: **Hantush Method**

Pumping Test

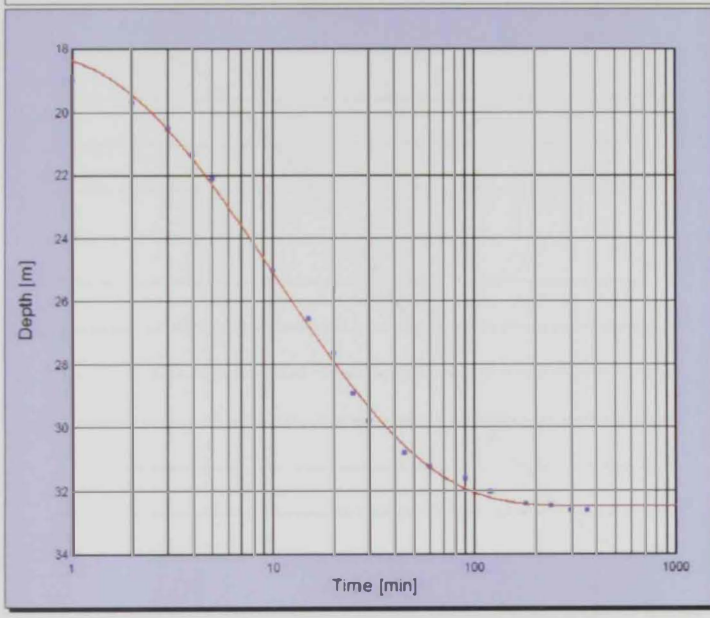
Well Ident	Name
well -38	Well No. 38

Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
0.36	0.0062500	360.00	

Results

Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
7.53		7.0020	0.25

Fit Method: **Hantush Method**



Pumping Test

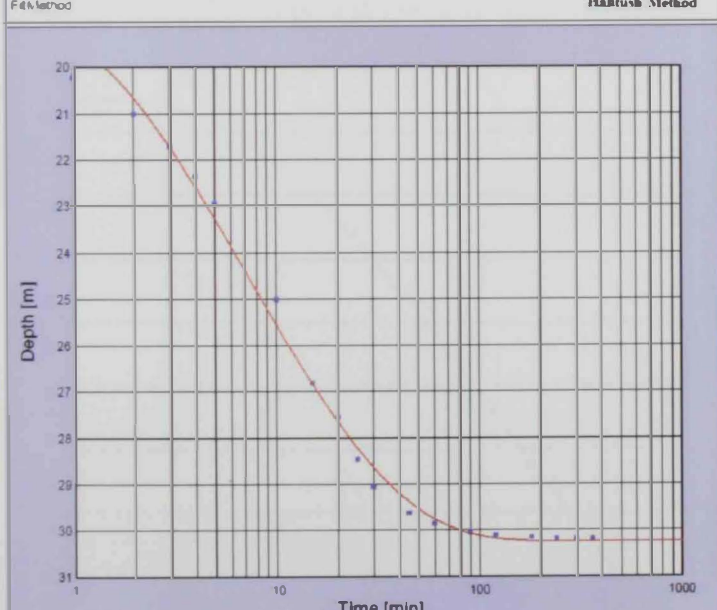
Well Ident	Name
well -39	Well No. 39

Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
0.36	0.0062500	360.00	

Results

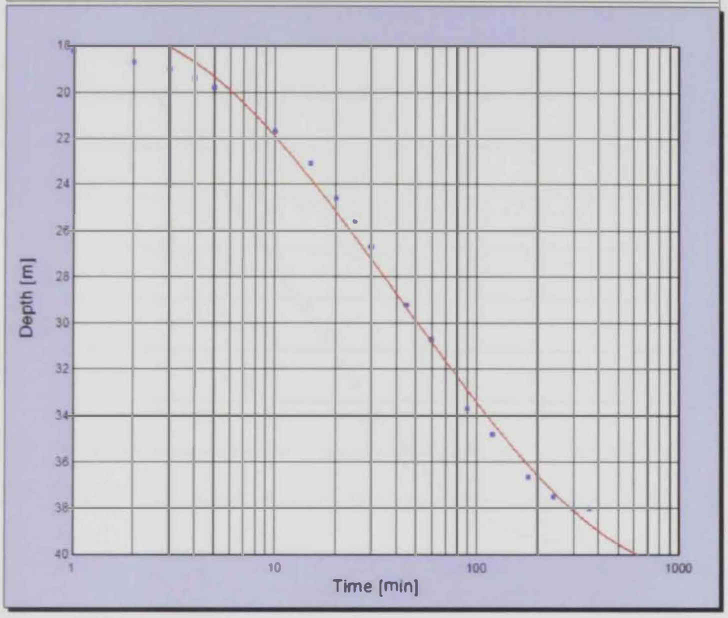
Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
9.42		9.0618	0.29

Fit Method: **Hantush Method**



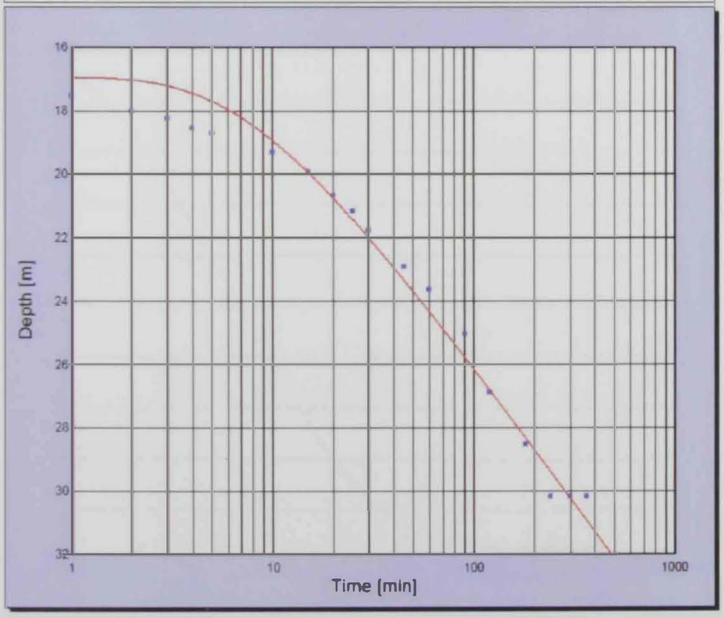
Pumping Test

Well Ident	Name		
well -41	Well No. 41		
Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
0.36	0.0033300	360.00	
Results			
Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
3.86		0.77214	0.65
Fit Method			Hantush Method



Pumping Test

Well Ident	Name		
well -42	Well No. 42		
Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
0.36	0.0033000	360.00	
Results			
Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
6.15		0.00000070073	0.63
Fit Method			Hantush Method



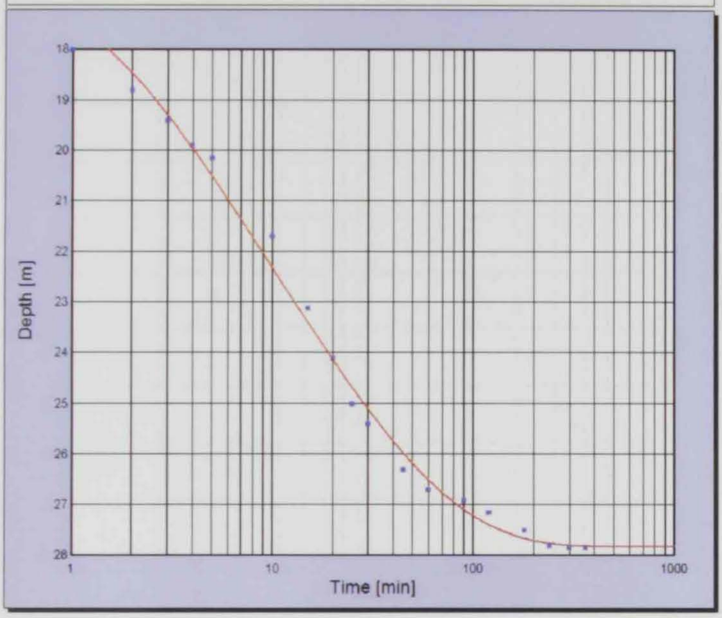
Pumping Test

Well Ident	Name		
well -43	Well No. 43		
Obs. Well Distance [m]	**Average Pump Rate [m3/day]**	**Duration [min]**	**Initial Sat. Thickness [m]**
0.36	0.0062500	360.00	

Results

Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
13.5		4.8929	0.29

Fit Method: Hantush Method



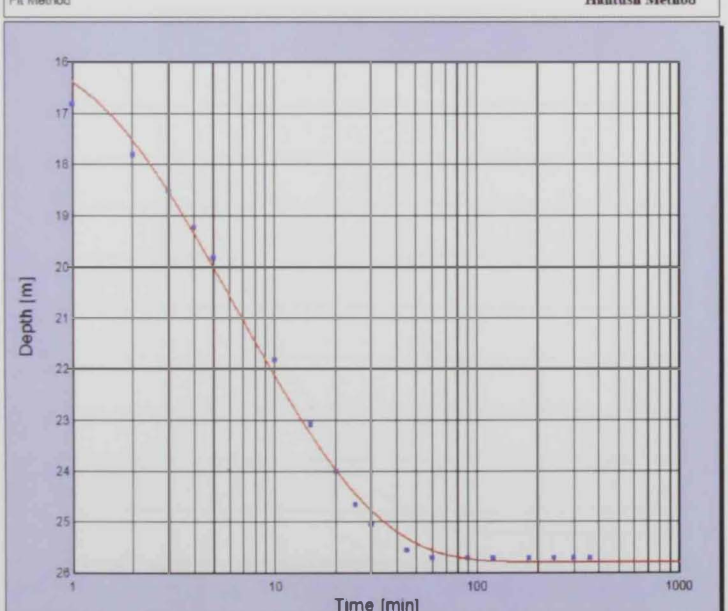
Pumping Test

Well Ident	Name		
well -44	Well No. 44		
Obs. Well Distance [m]	**Average Pump Rate [m3/day]**	**Duration [min]**	**Initial Sat. Thickness [m]**
0.36	0.0062500	360.00	

Results

Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
9.34		13.173	0.19

Fit Method: Hantush Method



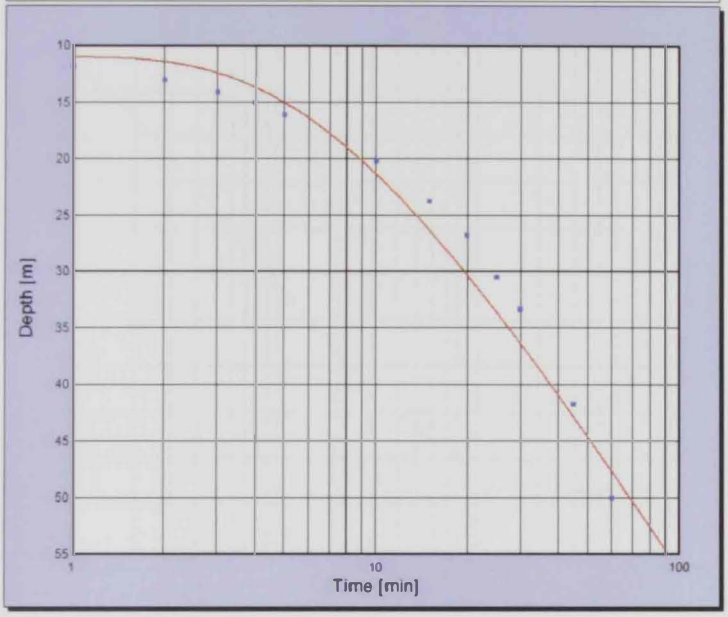
Pumping Test

Well Ident	Name		
well -48	Well No. 48		
Obs. Well Distance [m]	**Average Pump. Rate [m3/day]**	**Duration [min]**	**Initial Sat. Thickness [m]**
0.36	0.0062500	60.000	

Results

Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
2.43		2.7331E-13	2.13

Fit Method: **Hantush Method**



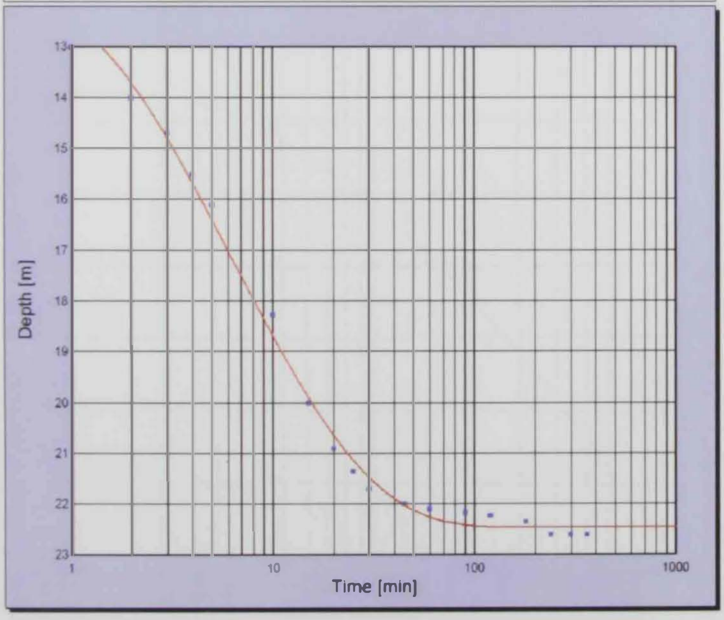
Pumping Test

Well Ident	Name		
well -49	Well No. 49		
Obs. Well Distance [m]	**Average Pump. Rate [m3/day]**	**Duration [min]**	**Initial Sat. Thickness [m]**
0.36	0.0062500	360.00	

Results

Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
8.52		12.937	0.24

Fit Method: **Hantush Method**



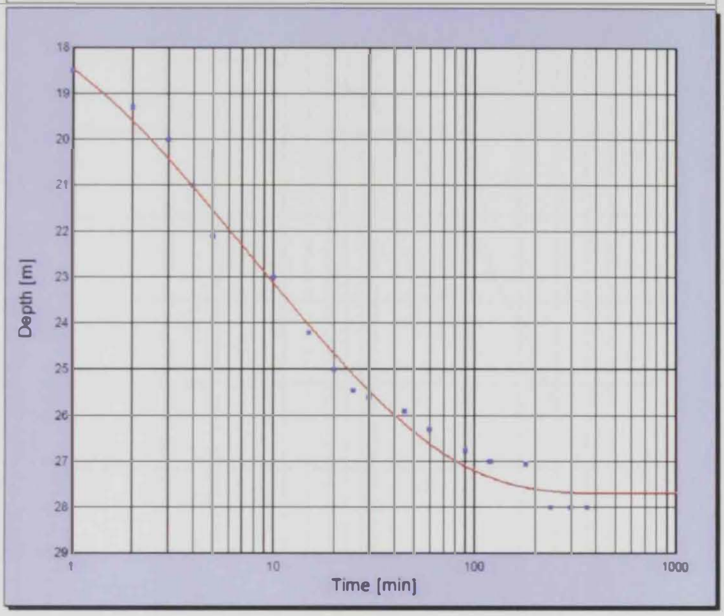
Pumping Test

Well Ident	Name		
well -53	Well No. 53		
Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
0.36	0.0062500	360.00	

Results

Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
16.4		3.6236	0.33

Fit Method: Hantush Method



Pumping Test

Well Ident	Name		
well -70	Well No. 70		
Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
0.36	0.0062500	90.000	

Results

Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
3.46		2.1848E-14	0.66

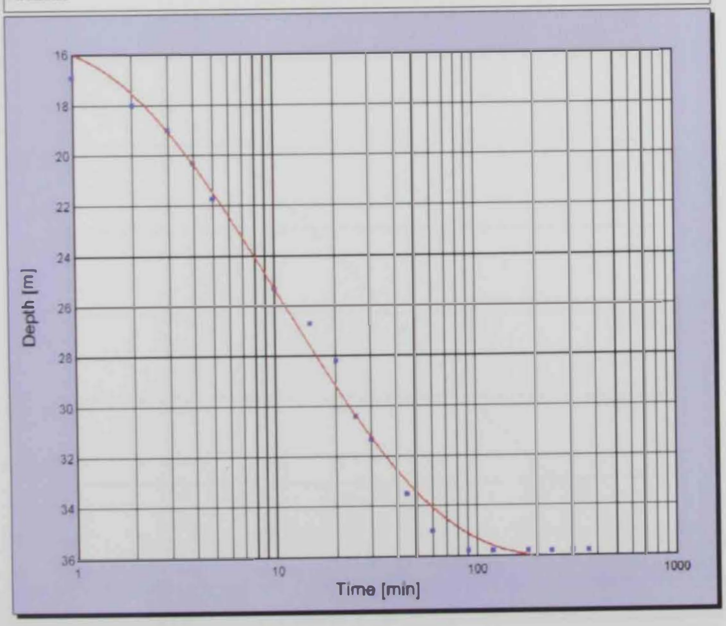
Fit Method: Hantush Method

Pumping Test

Well Ident	Name		
well -71	Well No. 71		
Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
0.36	0.0062500	60.000	
Results			
Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
1.68		3.3959E-13	3.23
Fit Method			Hantush Method

Pumping Test

Well Ident	Name		
well -72	Well No. 72		
Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
0.36	0.0062500	360.00	
Results			
Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
5.66		4.2818	0.52
Fit Method			Hantush Method



Pumping Test

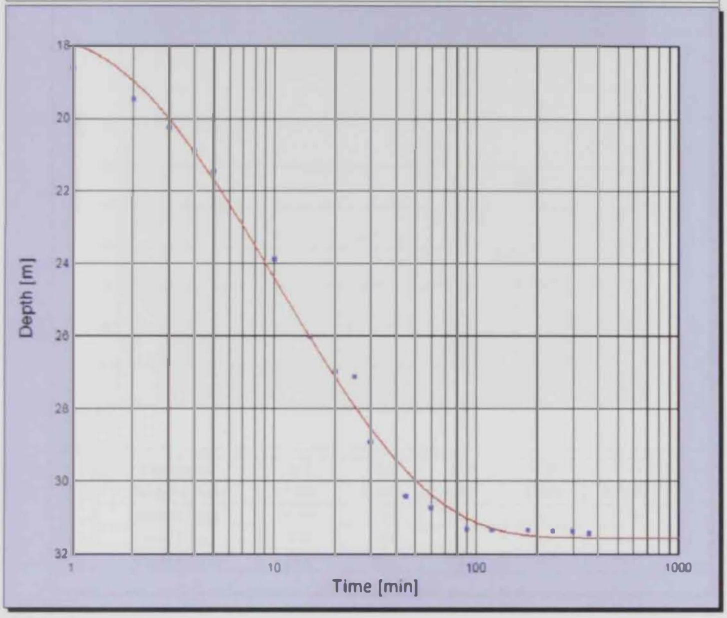
Well Ident	Name
well -74	Well No. 74

Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
0.36	0.0062500	360.00	

Results

Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
7.78		7.3460	0.39

Fit Method	
	Hantush Method



Pumping Test

Well Ident	Name
well -78	Well No. 78

Obs. Well Distance [m]	Average Pump. Rate [m3/day]	Duration [min]	Initial Sat. Thickness [m]
0.36	0.0062500	360.00	

Results

Transmissivity [m2/day]	Storage Coefficient	Leakance [1/day]	Estimation Error [m]
6.97		0.70849	0.94

Fit Method	
	Hantush Method

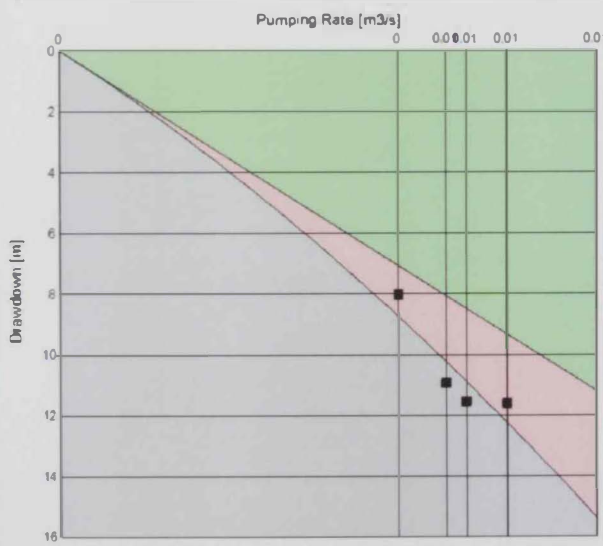
Well Ident	Name
well -3	Well No. 3

A	B	p	Efficiency (%)
2202	94068	2.00	84.18

Drawdown	12.5	16.25	17.6	17.82	23.34
Pumping Rate	0.005	0.0057	0.006	0.0066	0.00792 *
Aquifer Loss	11.01	12.55	13.21	14.53	17.44
Well Loss	2.35	3.06	3.39	4.1	5.9
Efficiency [%]	88.1	77.2	75.1	81.6	74.7

Well Ident	Name
well -39	Well No 39

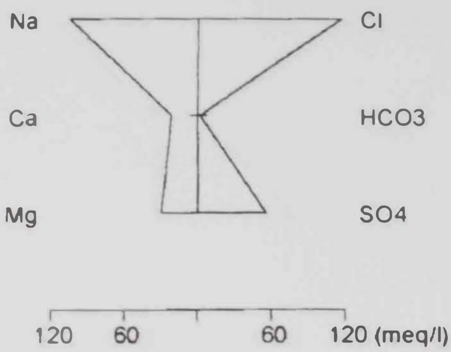
A	B	p	Efficiency (%)
1414	66827	2.00	82.79



Drawdown	8	10.93	11.54	11.61	15.39
Pumping Rate	0.005	0.0057	0.006	0.0066	0.00792 *
Aquifer Loss	7.07	8.08	8.48	9.33	11.2
Well Loss	1.67	2.17	2.41	2.91	4.19
Efficiency [%]	88.4	73.7	73.5	80.4	72.8

Appendix C1
Stiff Diagrams

12



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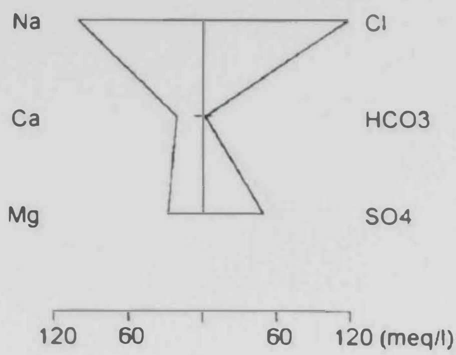

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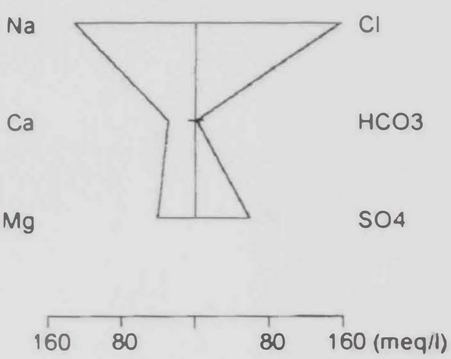

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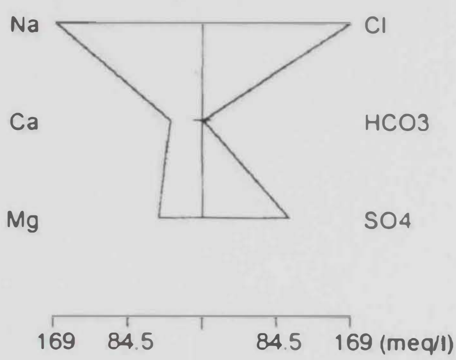

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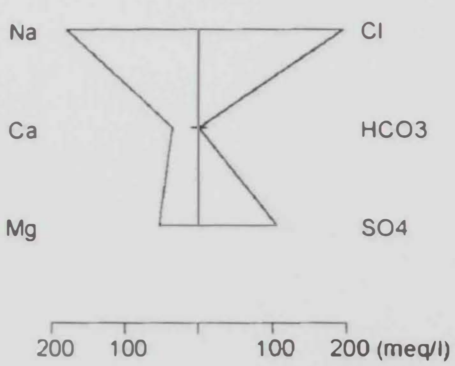

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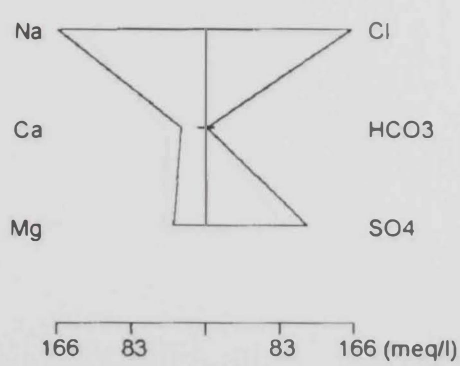

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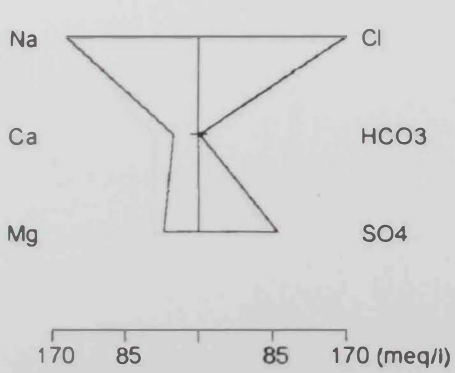

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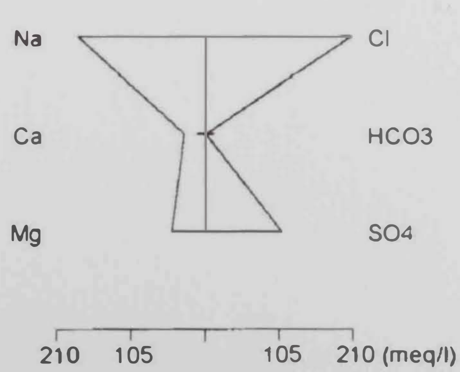

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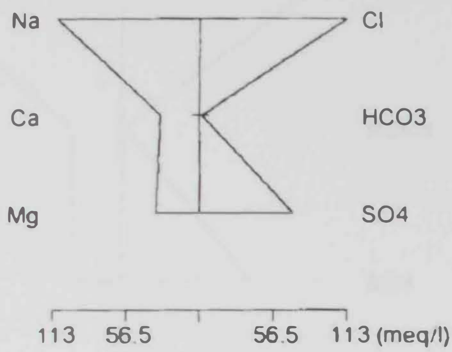

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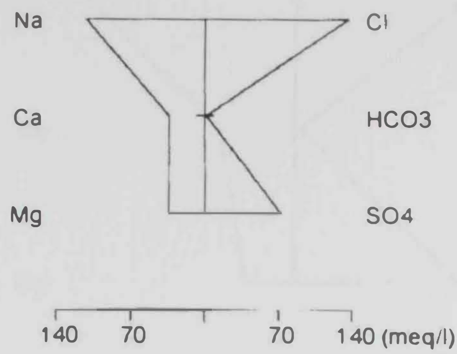

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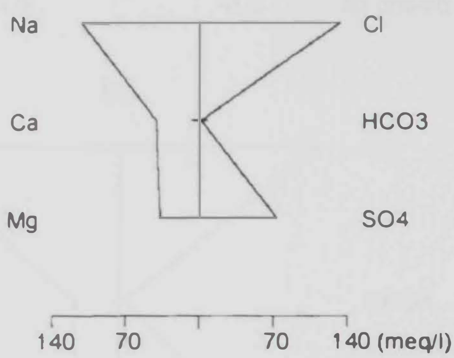

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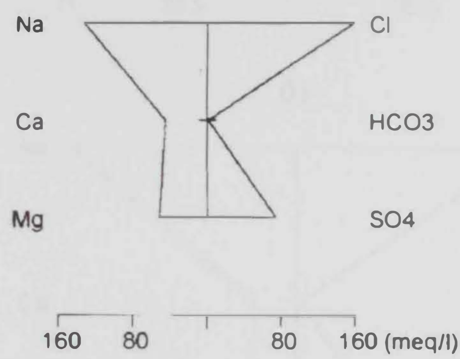

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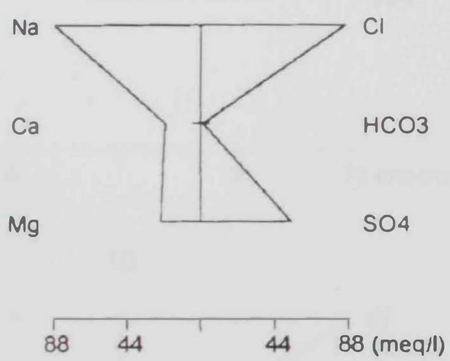

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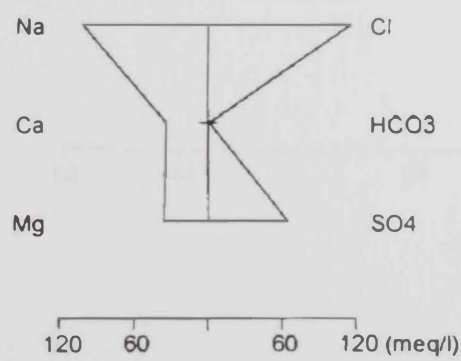

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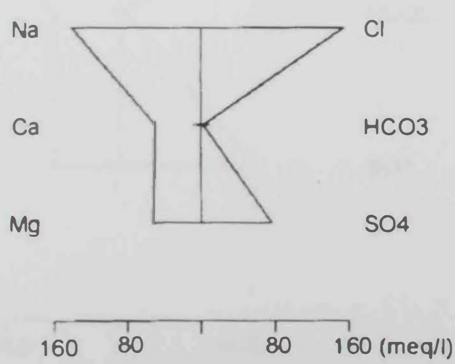

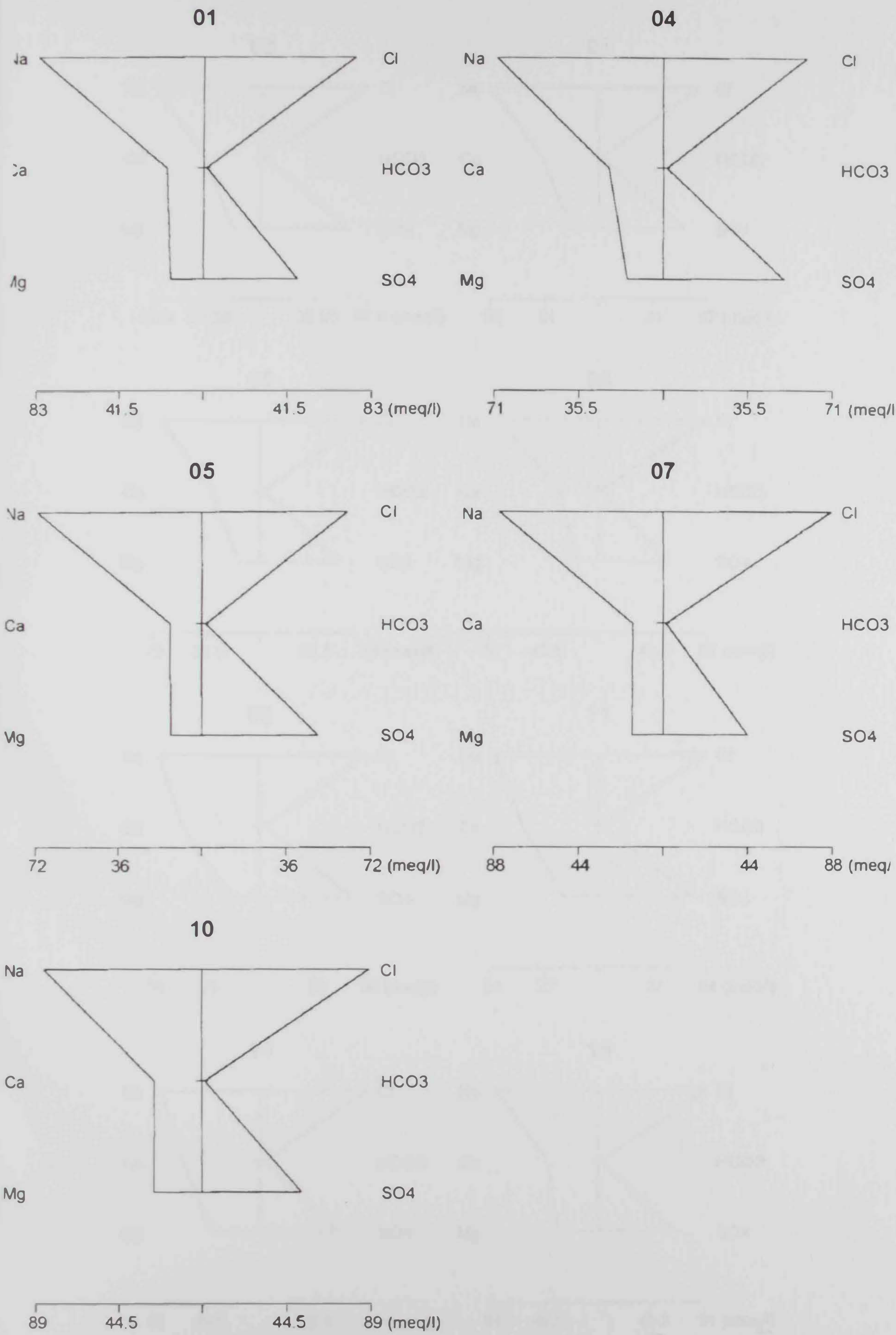
01
Na
Ca
Mg
Cl
HCO3
SO4
83
41.5
41.5
83 (meq/l)
04
Na
Ca
Mg
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HCO3
SO4
71
35.5
35.5
71 (meq/l
05
Na
Ca
Mg
Cl
HCO3
SO4
72
36
36
72 (meq/l)
07
Na
Ca
Mg
Cl
HCO3
SO4
88
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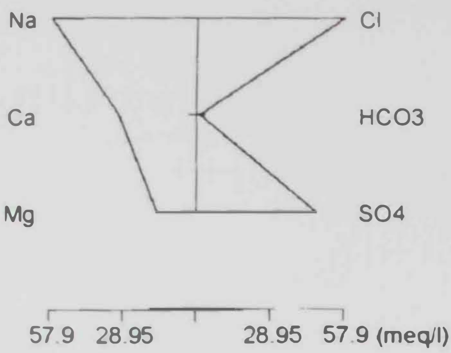
Cl
HCO3
SO4
89
44.5
44.5
89 (meq/l)

02



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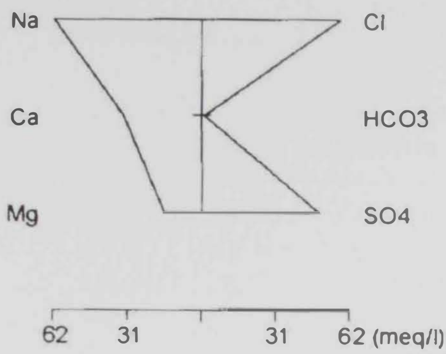

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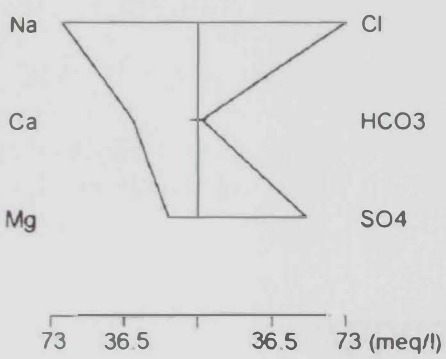

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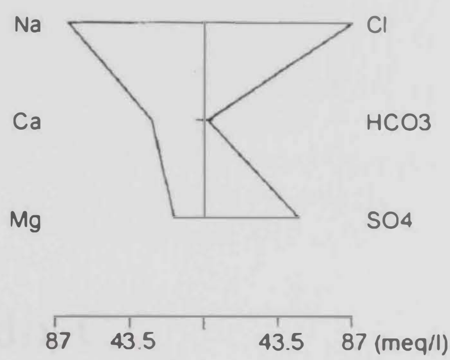

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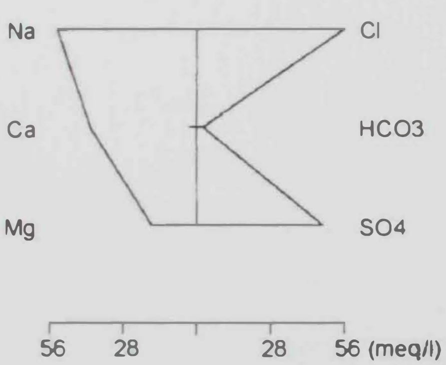

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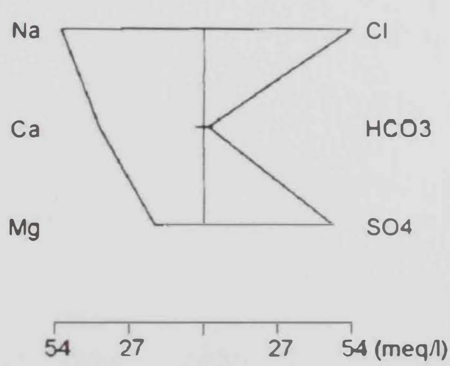

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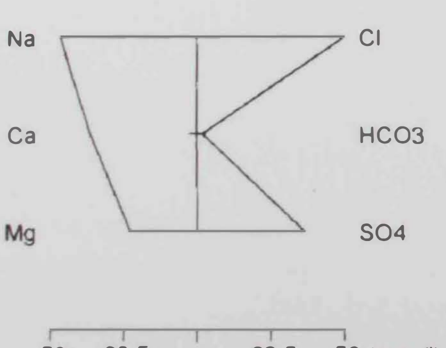

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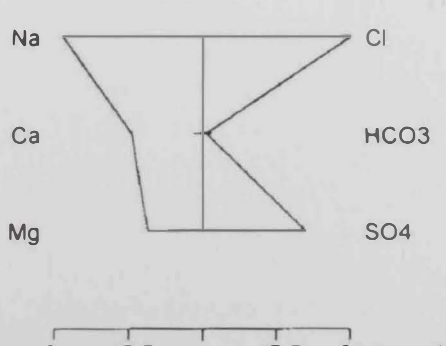

Appendix C2
Water Suitability Reports

ample ID : **Well No. 2**
ocation : markhan
ite : 56
ampling Date : 1/5/2002

rinking Water Quality Regulations:

lement	Measured	Recommended	Maximum
ond	9400	< 400	< 1250
Ca	614	< 100	
Mg	190	< 30	< 50
Na	1313	< 20	
K	64	12- 10	
Cl	2050	< 20	< 200
SO4	2250	10- 50	< 200
NO3	76	< 25	< 50

rrigation water:
onductivity = 9400 uS (group C4: Very igh salinity water)
odium Adsorption Ratio (SAR) : 11.87
xchangeable sodium ratio (ESR) : 1.23
lagnesium hazard (MH) : 33.78

ample ID : **Well No. 7**
ocation : markhan
ite : 63
ampling Date : 1/5/2002

Drinking Water Quality Regulations:

lement	Measured	Recommended	Maximum
ond	10900	< 400	< 1250
Ca	647	< 100	
Mg	178	< 30	< 50
Na	1556	< 20	
K	67	12- 10	
Cl	2575	< 20	< 200
O4	2570	10- 50	< 200
O3	45	< 25	< 50

rrigation water:
onductivity = 10900 uS (group C4: Very igh salinity water)
odium Adsorption Ratio (SAR) : 13.97
xchangeable sodium ratio (ESR) : 1.44
lagnesium hazard (MH) : 31.20

Sample ID : **Well No. 11**
Location : markhan
Site : 59
Sampling Date : 1/5/2002

Drinking Water Quality Regulations:

Element	Measured	Recommended	Maximum
Cond	10800	< 400	< 1250
Ca	459	< 100	
Mg	183	< 30	< 50
Na	1610	< 20	
K	72	12- 10	
Cl	2150	< 20	< 200
SO4	2450	10- 50	< 200
NO3	37	< 25	< 50

Irrigation water:
Conductivity = 10800 uS (group C4: Very high salinity water)
Sodium Adsorption Ratio (SAR) : 16.07
Exchangeable sodium ratio (ESR) : 1.84
Magnesium hazard (MH) : 39.66

Sample ID : **Well No. 14**
Location : markhan
Site : 58
Sampling Date : 1/5/2002

Drinking Water Quality Regulations:

Element	Measured	Recommended	Maximum
Cond	10200	< 400	< 1250
Ca	653	< 100	
Mg	190	< 30	< 50
Na	1418	< 20	
K	71	12- 10	
Cl	2050	< 20	< 200
SO4	2372	10- 50	< 200
NO3	151	< 25	< 50

Irrigation water:
Conductivity = 10200 uS (group C4: Very high salinity water)
Sodium Adsorption Ratio (SAR) : 12.56
Exchangeable sodium ratio (ESR) : 1.28
Magnesium hazard (MH) : 32.42

Sample ID : **Well No. 16**
Location : Dahan
Site : 333
Sampling Date : 1/5/2002

Drinking Water Quality Regulations:

Element	Measured	Recommended	Maximum
Cond	13300	< 400	< 1250
Ca	426	< 100	
Mg	294	< 30	< 50
Na	2007	< 20	
K	82	12- 10	
Cl	3050	< 20	< 200
SO4	2590	10- 50	< 200
NO3	60	< 25	< 50

Irrigation water:
Conductivity = 13300 uS (group C4: Very high salinity water)
Sodium Adsorption Ratio (SAR) : 18.31
Exchangeable sodium ratio (ESR) : 1.92
Magnesium hazard (MH) : 53.22

Sample ID : **Well No. 21**
Location : Markhan
Site : 21
Sampling Date : 1/5/2002

Drinking Water Quality Regulations:

Element	Measured	Recommended	Maximum
Cond	12700	< 400	< 1250
Ca	612	< 100	
Mg	213	< 30	< 50
Na	1835	< 20	
K	83	12- 10	
Cl	3075	< 20	< 200
SO4	2680	10- 50	< 200
NO3	145	< 25	< 50

Irrigation water:
Conductivity = 12700 uS (group C4: Very high salinity water)
Sodium Adsorption Ratio (SAR) : 16.28
Exchangeable sodium ratio (ESR) : 1.66
Magnesium hazard (MH) : 36.46

Sample ID : **Well No. 20**
Location : Markhan
Site : 53
Sampling Date : 1/5/2002

Drinking Water Quality Regulations:

Element	Measured	Recommended	Maximum
Cond	12500	< 400	< 1250
Ca	314	< 100	
Mg	199	< 30	< 50
Na	1953	< 20	
K	78	12- 10	
Cl	3100	< 20	< 200
SO4	2108	10- 50	< 200
NO3	185	< 25	< 50

Irrigation water:
Conductivity = 12500 uS (group C4: Very high salinity water)
Sodium Adsorption Ratio (SAR) : 21.22
Exchangeable sodium ratio (ESR) : 2.65
Magnesium hazard (MH) : 51.10

Sample ID : **Well No. 22**
Location : Markhan
Site : 27
Sampling Date : 1/5/2002

Drinking Water Quality Regulations:

Element	Measured	Recommended	Maximum
Cond	10300	< 400	< 1250
Ca	810	< 100	
Mg	211	< 30	< 50
Na	1217	< 20	
K	78	12- 10	
Cl	1975	< 20	< 200
SO4	2280	10- 50	< 200
NO3	412	< 25	< 50

Irrigation water:
Conductivity = 10300 uS (group C4: Very high salinity water)
Sodium Adsorption Ratio (SAR) : 9.85
Exchangeable sodium ratio (ESR) : 0.92
Magnesium hazard (MH) : 30.04

Sample ID : **Well No. 23**
Location : Dahan
Site : 101
Sampling Date : 1/5/2002

Drinking Water Quality Regulations:

Element	Measured	Recommended	Maximum
Cond	22900	< 400	< 1250
Ca	1006	< 100	
Mg	644	< 30	< 50
Na	3239	< 20	
K	163	12- 10	
Cl	5450	< 20	< 200
SO4	3673	10- 50	< 200
NO3	1060	< 25	< 50

Irrigation water:
Conductivity = 22900 uS (group C4: Very high salinity water)
Sodium Adsorption Ratio (SAR) : 19.61
Exchangeable sodium ratio (ESR) : 1.37
Magnesium hazard (MH) : 51.35

Sample ID : **Well No. 24**
Location : Dahan
Site : 118
Sampling Date : 1/5/2002

Drinking Water Quality Regulations:

Element	Measured	Recommended	Maximum
Cond	20000	< 400	< 1250
Ca	592	< 100	
Mg	508	< 30	< 50
Na	3038	< 20	
K	125	12- 10	
Cl	5525	< 20	< 200
SO4	2827	10- 50	< 200
NO3	57	< 25	< 50

Irrigation water:
Conductivity = 20000 uS (group C4: Very high salinity water)
Sodium Adsorption Ratio (SAR) : 22.13
Exchangeable sodium ratio (ESR) : 1.85
Magnesium hazard (MH) : 58.59

Sample ID : **Well No. 25**
Location : Dahan
Site : 250
Sampling Date : 1/5/2002

Drinking Water Quality Regulations:

Element	Measured	Recommended	Maximum
Cond	21200	< 400	< 1250
Ca	902	< 100	
Mg	616	< 30	< 50
Na	3039	< 20	
K	144	12- 10	
Cl	5600	< 20	< 200
SO4	3578	10- 50	< 200
NO3	484	< 25	< 50

Irrigation water:
Conductivity = 21200 uS (group C4: Very high salinity water)
Sodium Adsorption Ratio (SAR) : 19.11
Exchangeable sodium ratio (ESR) : 1.38
Magnesium hazard (MH) : 52.96

Sample ID : **Well No. 26**
Location : Dahan
Site : 292
Sampling Date : 1/5/2002

Drinking Water Quality Regulations:

Element	Measured	Recommended	Maximum
Cond	16700	< 400	< 1250
Ca	672	< 100	
Mg	431	< 30	< 50
Na	2323	< 20	
K	112	12- 10	
Cl	4075	< 20	< 200
SO4	3094	10- 50	< 200
NO3	347	< 25	< 50

Irrigation water:
Conductivity = 16700 uS (group C4: Very high salinity water)
Sodium Adsorption Ratio (SAR) : 17.20
Exchangeable sodium ratio (ESR) : 1.46
Magnesium hazard (MH) : 51.40

Sample ID : **Well No. 27**
Location : Dahan
Site : 392
Sampling Date : 1/5/2002

Drinking Water Quality Regulations:

Element	Measured	Recommended	Maximum
Cond	17700	< 400	< 1250
Ca	819	< 100	
Mg	460	< 30	< 50
Na	2572	< 20	
K	114	12- 10	
Cl	4700	< 20	< 200
SO4	3500	10- 50	< 200
NO3	522	< 25	< 50

Irrigation water:
Conductivity = 17700 uS (group C4: Very high salinity water)
Sodium Adsorption Ratio (SAR) : 17.83
Exchangeable sodium ratio (ESR) : 1.42
Magnesium hazard (MH) : 48.08

Sample ID : **Well No. 29**
Location : Dahan
Site : 493
Sampling Date : 1/5/2002

Drinking Water Quality Regulations:

Element	Measured	Recommended	Maximum
Cond	14700	< 400	< 1250
Ca	870	< 100	
Mg	411	< 30	< 50
Na	1972	< 20	
K	105	12- 10	
Cl	3225	< 20	< 200
SO4	3024	10- 50	< 200
NO3	867	< 25	< 50

Irrigation water:
Conductivity = 14700 uS (group C4: Very high salinity water)
Sodium Adsorption Ratio (SAR) : 13.80
Exchangeable sodium ratio (ESR) : 1.11
Magnesium hazard (MH) : 43.78

Sample ID : **Well No. 28**
Location : Dahan
Site : 420
Sampling Date : 1/5/2002

Drinking Water Quality Regulations:

Element	Measured	Recommended	Maximum
Cond	17200	< 400	< 1250
Ca	679	< 100	
Mg	421	< 30	< 50
Na	2580	< 20	
K	113	12- 10	
Cl	4800	< 20	< 200
SO4	3441	10- 50	< 200
NO3	175	< 25	< 50

Irrigation water:
Conductivity = 17200 uS (group C4: Very high salinity water)
Sodium Adsorption Ratio (SAR) : 19.17
Exchangeable sodium ratio (ESR) : 1.64
Magnesium hazard (MH) : 50.55

Sample ID : **Well No. 30**
Location : Dahan
Site : 493
Sampling Date : 1/5/2002

Drinking Water Quality Regulations:

Element	Measured	Recommended	Maximum
Cond	9900	< 400	< 1250
Ca	760	< 100	
Mg	216	< 30	< 50
Na	1190	< 20	
K	74	12- 10	
Cl	1900	< 20	< 200
SO4	2260	10- 50	< 200
NO3	337	< 25	< 50

Irrigation water:
Conductivity = 9900 uS (group C4: Very high salinity water)
Sodium Adsorption Ratio (SAR) : 9.81
Exchangeable sodium ratio (ESR) : 0.93
Magnesium hazard (MH) : 31.91

Sample ID : **Well No. 31**
Location : Dahan
Site : 581
Sampling Date : 1/5/2002

Drinking Water Quality Regulations:

Element	Measured	Recommended	Maximum
Cond	15400	< 400	< 1250
Ca	423	< 100	
Mg	344	< 30	< 50
Na	2334	< 20	
K	93	12- 10	
Cl	4150	< 20	< 200
SO4	2360	10- 50	< 200
NO3	54	< 25	< 50

Irrigation water:
Conductivity = 15400 uS (group C4: Very high salinity water)
Sodium Adsorption Ratio (SAR) : 20.43
Exchangeable sodium ratio (ESR) : 2.05
Magnesium hazard (MH) : 57.28

Sample ID : **Well No. 33**
Location : Dahan
Site : 634
Sampling Date : 1/5/2002

Drinking Water Quality Regulations:

Element	Measured	Recommended	Maximum
Cond	13100	< 400	< 1250
Ca	511	< 100	
Mg	311	< 30	< 50
Na	1932	< 20	
K	81	12- 10	
Cl	3125	< 20	< 200
SO4	2520	10- 50	< 200
NO3	186	< 25	< 50

Irrigation water:
Conductivity = 13100 uS (group C4: Very high salinity water)
Sodium Adsorption Ratio (SAR) : 16.63
Exchangeable sodium ratio (ESR) : 1.65
Magnesium hazard (MH) : 50.09

Sample ID : **Well No. 32**
Location : Dahan
Site : 615
Sampling Date : 1/5/2002

Drinking Water Quality Regulations:

Element	Measured	Recommended	Maximum
Cond	5700	< 400	< 1250
Ca	860	< 100	
Mg	327	< 30	< 50
Na	1257	< 20	
K	93	12- 10	
Cl	2075	< 20	< 200
SO4	2071	10- 50	< 200
NO3	760	< 25	< 50

Irrigation water:
Conductivity = 5700 uS (group C4: Very high salinity water)
Sodium Adsorption Ratio (SAR) : 9.25
Exchangeable sodium ratio (ESR) : 0.78
Magnesium hazard (MH) : 38.53

Sample ID : **Well No. 37**
Location : Dahan
Site : 463
Sampling Date : 1/5/2002

Drinking Water Quality Regulations:

Element	Measured	Recommended	Maximum
Cond	16400	< 400	< 1250
Ca	608	< 100	
Mg	408	< 30	< 50
Na	2516	< 20	
K	104	12- 10	
Cl	3975	< 20	< 200
SO4	3436	10- 50	< 200
NO3	96	< 25	< 50

Irrigation water:
Conductivity = 16400 uS (group C4: Very high salinity water)
Sodium Adsorption Ratio (SAR) : 19.36
Exchangeable sodium ratio (ESR) : 1.71
Magnesium hazard (MH) : 52.52

Sample ID : **Well No. 40**
Location : Markhan
Site : 46
Sampling Date : 1/5/2002

Drinking Water Quality Regulations:

Element	Measured	Recommended	Maximum
Cond	10300	< 400	< 1250
Ca	273	< 100	
Mg	163	< 30	< 50
Na	1634	< 20	
K	62	12- 10	
Cl	2200	< 20	< 200
SO4	2380	10- 50	< 200

Irrigation water:
Conductivity = 10300 uS (group C4: Very high salinity water)
Sodium Adsorption Ratio (SAR) : 19.33
Exchangeable sodium ratio (ESR) : 2.63
Magnesium hazard (MH) : 49.61

Sample ID : **Well No. 46**
Location : Shobasy
Site : 87
Sampling Date : 1/5/2002

Drinking Water Quality Regulations:

Element	Measured	Recommended	Maximum
Cond	26900	< 400	< 1250
Ca	714	< 100	
Mg	654	< 30	< 50
Na	4112	< 20	
K	203	12- 10	
Cl	6925	< 20	< 20
SO4	5096	10- 50	< 200
NO3	225	< 25	< 50

Irrigation water:
Conductivity = 26900 uS (group C4: Very high salinity water)
Sodium Adsorption Ratio (SAR) : 26.75
Exchangeable sodium ratio (ESR) : 2.00
Magnesium hazard (MH) : 60.16

Sample ID : **Well No. 45**
Location : Shobasy
Site : 5
Sampling Date : 1/5/2002

Drinking Water Quality Regulations:

Element	Measured	Recommended	Maximum
Cond	24500	< 400	< 1250
Ca	542	< 100	
Mg	442	< 30	< 50
Na	3800	< 20	
K	180	12- 10	
Cl	5750	< 20	< 200
SO4	5457	10- 50	< 200
NO3	142	< 25	< 50

Irrigation water:
Conductivity = 24500 uS (group C4: Very high salinity water)
Sodium Adsorption Ratio (SAR) : 29.36
Exchangeable sodium ratio (ESR) : 2.61
Magnesium hazard (MH) : 57.35

Sample ID : **Well No. 48**
Location : Shobasy
Site : 102
Sampling Date : 1/5/2002

Drinking Water Quality Regulations:

Element	Measured	Recommended	Maximum
Cond	23700	< 400	< 1250
Ca	722	< 100	
Mg	605	< 30	< 50
Na	3811	< 20	
K	181	12- 10	
Cl	5975	< 20	< 200
SO4	4745	10- 50	< 200
NO3	126	< 25	< 50

Irrigation water:
Conductivity = 23700 uS (group C4: Very high salinity water)
Sodium Adsorption Ratio (SAR) : 25.31
Exchangeable sodium ratio (ESR) : 1.93
Magnesium hazard (MH) : 58.01

Sample ID : **Well No. 50**
Location : Shobasy
Site : 1
Sampling Date : 1/5/2002

Drinking Water Quality Regulations:

Element	Measured	Recommended	Maximum
Cond	23800	< 400	< 1250
Ca	585	< 100	
Mg	492	< 30	< 50
Na	3515	< 20	
K	141	12- 10	
Cl	6000	< 20	< 200
SO4	4362	10- 50	< 200
NO3	57	< 25	< 50

Irrigation water:
Conductivity = 23800 uS (group C4: Very high salinity water)
Sodium Adsorption Ratio (SAR) : 25.90
Exchangeable sodium ratio (ESR) : 2.19
Magnesium hazard (MH) : 58.10

Sample ID : **Well No. 52**
Location : Ksouth
Site : 43
Sampling Date : 1/5/2002

Drinking Water Quality Regulations:

Element	Measured	Recommended	Maximum
Cond	28200	< 400	< 1250
Ca	585.9999	< 100	
Mg	578	< 30	< 50
Na	4133	< 20	
K	211	12- 10	
Cl	7274.998	< 20	< 200
SO4	5172.001	10- 50	< 200
NO3	66	< 25	< 50

Irrigation water:
Conductivity = 28200 uS (group C4: Very high salinity water)
Sodium Adsorption Ratio (SAR) : 29.01
Exchangeable sodium ratio (ESR) : 2.34
Magnesium hazard (MH) : 61.92

Sample ID : **Well No. 51**
Location : Dahan
Site : 644
Sampling Date : 1/5/2002

Drinking Water Quality Regulations:

Element	Measured	Recommended	Maximum
Cond	15800	< 400	< 1250
Ca	436	< 100	
Mg	364	< 30	< 50
Na	2416	< 20	
K	108	12- 10	
Cl	4113	< 20	< 200
SO4	2660	10- 50	< 200

Irrigation water:
Conductivity = 15800 uS (group C4: Very high salinity water)
Sodium Adsorption Ratio (SAR) : 20.67
Exchangeable sodium ratio (ESR) : 2.03
Magnesium hazard (MH) : 57.92

Sample ID : **Well No. 71**
Location : Dahan
Site : 651
Sampling Date : 1/5/2002

Drinking Water Quality Regulations:

Element	Measured	Recommended	Maximum
Cond	12000	< 400	< 1250
Ca	373	< 100	
Mg	197	< 30	< 50
Na	1888	< 20	
K	79	12- 10	
Cl	2650	< 20	< 200
SO4	2230	10- 50	< 200

Irrigation water:
Conductivity = 12000 uS (group C4: Very high salinity water)
Sodium Adsorption Ratio (SAR) : 19.68
Exchangeable sodium ratio (ESR) : 2.36
Magnesium hazard (MH) : 46.55

Appendix D
Stress Periods for MODFLOW

S	From	To	Days	Dischrge (m^3/day)	Recharge (mm/day)	Evaporation (mm/day)
1	01/01/1997	19/01/1997	18	-6000	0	0.0055
2	19/01/1997	21/01/1997	2	-6000	22	0
3	21/01/1997	24/01/1997	3	-6000	93	0
4	24/01/1997	30/01/1997	6	-6000	0	0.0055
5	30/01/1997	27/02/1997	28	-6000	0	0.0088
6	27/02/1997	06/03/1997	7	-6000	0	0.0085
7	06/03/1997	08/03/1997	2	-6000	2	0
8	08/03/1997	10/03/1997	2	-6000	0	0.0085
9	10/03/1997	13/03/1997	3	-6000	23	0
10	13/03/1997	15/03/1997	2	-6000	28	0
11	15/03/1997	17/03/1997	2	-6000	2	0
12	17/03/1997	21/03/1997	4	-6000	0	0.0085
13	21/03/1997	23/03/1997	2	-6000	8	0
14	23/03/1997	26/03/1997	3	-6000	0	0.0085
15	26/03/1997	29/03/1997	3	-6000	37	0
16	29/03/1997	20/04/1997	22	-6000	0	0.0129
17	20/04/1997	22/04/1997	2	-6000	5	0
18	22/04/1997	28/04/1997	6	-6000	0	0.0129
19	28/04/1997	29/05/1997	31	-6000	0	0.0204
20	29/05/1997	28/06/1997	30	-6000	0	0.0213
21	28/06/1997	29/07/1997	31	-4000	0	0.018
22	29/07/1997	29/08/1997	31	-2000	0	0.0181
23	29/08/1997	28/09/1997	30	-2000	0	0.0172
24	28/09/1997	21/10/1997	23	-2000	0	0.0136
25	21/10/1997	23/10/1997	2	-4000	0	0
26	23/10/1997	27/10/1997	4	-4000	0	0.0136
27	27/10/1997	29/10/1997	2	-4000	20	0
28	29/10/1997	09/11/1997	11	-4000	0	0.0076
29	09/11/1997	11/11/1997	2	-6000	3	0
30	11/11/1997	13/11/1997	2	-6000	0	0.0076
31	13/11/1997	17/11/1997	4	-6000	8	0
32	17/11/1997	19/11/1997	2	-6000	0	0.0076
33	19/11/1997	23/11/1997	4	-6000	16	0
34	23/11/1997	28/11/1997	5	-6000	16	0
35	28/11/1997	02/12/1997	4	-6000	0	0.0059
36	02/12/1997	04/12/1997	2	-6000	52	0
37	04/12/1997	29/12/1997	25	-6000	0	0.0059
38	29/12/1997	01/01/1998	3	-6000	39	0
39	01/01/1998	03/01/1998	2	-6000	0	0.0053
40	03/01/1998	05/01/1998	2	-6000	1	0
41	05/01/1998	09/01/1998	4	-6000	5	0
42	09/01/1998	11/01/1998	2	-6000	8	0
43	11/01/1998	22/01/1998	11	-6000	0	0.0053
44	22/01/1998	27/01/1998	5	-6000	69	0
45	27/01/1998	29/01/1998	2	-6000	0	0.0053
46	29/01/1998	09/02/1998	11	-6000	0	0.0078
47	09/02/1998	12/02/1998	3	-6000	9	0
48	12/02/1998	17/02/1998	5	-6000	0	0.0078
49	17/02/1998	20/02/1998	3	-6000	101	0
50	20/02/1998	24/02/1998	4	-6000	0	0.0078
51	24/02/1998	26/02/1998	2	-6000	1	0
52	26/02/1998	28/02/1998	2	-6000	0	0
53	28/02/1998	04/03/1998	4	-6000	0	0.0128

S	From	To	Days	Dischrge (m³/day)	Recharge (mm/day)	Evaporation (mm/day)
54	04/03/1998	06/03/1998	2	-6000	9	0
55	06/03/1998	29/03/1998	23	-6000	0	0.0128
56	29/03/1998	28/04/1998	30	-6000	0	0.017
57	28/04/1998	29/05/1998	31	-6000	0	0.0204
58	29/05/1998	28/06/1998	30	-6000	0	0.021
59	28/06/1998	29/07/1998	31	-4000	0	0.0219
60	29/07/1998	29/08/1998	31	-2000	0	0.0204
61	29/08/1998	28/09/1998	30	-2000	0	0.0177
62	28/09/1998	29/10/1998	31	-2000	0	0.014
63	29/10/1998	28/11/1998	30	-4000	0	0.0086
64	28/11/1998	15/12/1998	17	-6000	0	0.0071
65	15/12/1998	18/12/1998	3	-6000	8	0
66	18/12/1998	29/12/1998	11	-6000	0	0.0071
67	29/12/1998	29/01/1999	31	-6000	0	0.0064
68	29/01/1999	11/02/1999	13	-6000	0	0.0088
69	11/02/1999	13/02/1999	2	-6000	16	0
70	13/02/1999	26/02/1999	13	-6000	0	0.0088
71	26/02/1999	28/02/1999	2	-6000	31	0
72	28/02/1999	11/03/1999	11	-6000	0	0.0118
73	11/03/1999	13/03/1999	2	-6000	1	0
74	13/03/1999	29/03/1999	16	-6000	0	0.0118
75	29/03/1999	28/04/1999	30	-6000	0	0.0171
76	28/04/1999	29/05/1999	31	-6000	0	0.0194
77	29/05/1999	28/06/1999	30	-6000	0	0.022
78	28/06/1999	29/07/1999	31	-4000	0	0.0197
79	29/07/1999	23/08/1999	25	-2000	0	0.0211
80	23/08/1999	25/08/1999	2	-2000	0	0
81	25/08/1999	29/08/1999	4	-2000	0	0.0211
82	29/08/1999	28/09/1999	30	-2000	0	0.0169
83	28/09/1999	29/10/1999	31	-2000	0	0.013
84	29/10/1999	28/11/1999	30	-4000	0	0.0089
85	28/11/1999	29/12/1999	31	-6000	0	0.0069
86	29/12/1999	29/01/2000	31	-6000	0	0.0067
87	29/01/2000	27/02/2000	29	-6000	0	0.0081
88	27/02/2000	30/03/2000	32	-6000	0	0.012
89	30/03/2000	29/04/2000	30	-6000	0	0.017
90	29/04/2000	30/05/2000	31	-6000	0	0.0191
91	30/05/2000	29/06/2000	30	-6000	0	0.0196
92	29/06/2000	30/07/2000	31	-4000	0	0.0204
93	30/07/2000	30/08/2000	31	-2000	0	0.0193
94	30/08/2000	29/09/2000	30	-2000	0	0.015
95	29/09/2000	30/10/2000	31	-2000	0	0.0135
96	30/10/2000	29/11/2000	30	-4000	0	0.0085
97	29/11/2000	12/12/2000	13	-6000	0	0.006
98	12/12/2000	14/12/2000	2	-6000	17	0
99	14/12/2000	30/12/2000	16	-6000	0	0.006
100	30/12/2000	30/01/2001	31	-6000	0	0.0058
101	30/01/2001	27/02/2001	28	-6000	0	0.0081
102	27/02/2001	15/03/2001	16	-6000	0	0.0102
103	15/03/2001	17/03/2001	2	-6000	3	0
104	17/03/2001	29/03/2001	12	-6000	0	0.0102
105	29/03/2001	28/04/2001	30	-6000	0	0.0156
106	28/04/2001	29/05/2001	31	-6000	0	0.0183

S	From	To	Days	Dischrge (m^3/day)	Recharge (mm/day)	Evaporation (mm/day)
107	29/05/2001	28/06/2001	30	-6000	0	0.0203
108	28/06/2001	27/07/2001	29	-4000	0	0.0185
109	27/07/2001	29/07/2001	2	-4000	7	0
110	29/07/2001	29/08/2001	31	-4000	0	0.0189
111	29/08/2001	28/09/2001	30	-4000	0	0.0164
112	28/09/2001	29/10/2001	31	-4000	0	0.0129
113	29/10/2001	28/11/2001	30	-4000	0	0.0085
114	28/11/2001	29/12/2001	31	-6000	0	0.0063
115	29/12/2001	29/01/2002	31	-6000	0	0.0058
116	29/01/2002	15/02/2002	17	-6000	0	0.0081
117	15/02/2002	17/02/2002	2	-6000	1	0
118	17/02/2002	26/02/2002	9	-6000	0	0.0081
119	26/02/2002	05/03/2002	7	-6000	0	0.0102
120	05/03/2002	07/03/2002	2	-6000	9	0
121	07/03/2002	14/03/2002	7	-6000	0	0.0102
122	14/03/2002	16/03/2002	2	-6000	77	0
123	16/03/2002	19/03/2002	3	-6000	0	0.0102
124	19/03/2002	21/03/2002	2	-6000	0	0
125	21/03/2002	29/03/2002	8	-6000	0	0.0102
126	29/03/2002	09/04/2002	11	-6000	0	0.0156
127	09/04/2002	11/04/2002	2	-4000	6	0
128	11/04/2002	28/04/2002	17	-4000	0	0.0156
129	28/04/2002	07/05/2002	9	-4000	0	0.0183
130	07/05/2002	09/05/2002	2	-4000	18	0
131	09/05/2002	29/05/2002	20	-4000	0	0.0183
132	29/05/2002	28/06/2002	30	-4000	0	0.0203
133	28/06/2002	29/07/2002	31	-4000	0	0.0185
134	29/07/2002	29/08/2002	31	-4000	0	0.0189
135	29/08/2002	28/09/2002	30	-4000	0	0.0164
136	28/09/2002	29/10/2002	31	-4000	0	0.0129
137	29/10/2002	28/11/2002	30	-4000	0	0.0085
138	28/11/2002	15/12/2002	17	-4000	0	0.0063
139	15/12/2002	17/12/2002	2	-4000	0	0
140	17/12/2002	29/12/2002	12	-4000	0	0.0063
141	29/12/2002	17/01/2003	19	-6000	0	0.0055
142	17/01/2003	19/01/2003	2	-6000	22	0
143	19/01/2003	22/01/2003	3	-6000	93	0
144	22/01/2003	28/01/2003	6	-6000	0	0.0055
145	28/01/2003	25/02/2003	28	-6000	0	0.0088
146	25/02/2003	05/03/2003	8	-6000	0	0.0085
147	05/03/2003	07/03/2003	2	-6000	2	0
148	07/03/2003	09/03/2003	2	-6000	0	0.0085
149	09/03/2003	12/03/2003	3	-6000	23	0
150	12/03/2003	14/03/2003	2	-6000	28	0
151	14/03/2003	16/03/2003	2	-6000	2	0
152	16/03/2003	20/03/2003	4	-6000	0	0.0085
153	20/03/2003	22/03/2003	2	-6000	8	0
154	22/03/2003	25/03/2003	3	-6000	0	0.0085
155	25/03/2003	28/03/2003	3	-6000	37	0
156	28/03/2003	19/04/2003	22	-6000	0	0.0129
157	19/04/2003	21/04/2003	2	-6000	5	0
158	21/04/2003	27/04/2003	6	-6000	0	0.0129
159	27/04/2003	28/05/2003	31	-6000	0	0.0204

S	From	To	Days	Dischrge (m^3/day)	Recharge (mm/day)	Evaporation (mm/day)
160	28/05/2003	27/06/2003	30	-6000	0	0.0213
161	27/06/2003	28/07/2003	31	-4000	0	0.018
162	28/07/2003	28/08/2003	31	-2000	0	0.0181
163	28/08/2003	27/09/2003	30	-2000	0	0.0172
164	27/09/2003	20/10/2003	23	-2000	0	0.0136
165	20/10/2003	22/10/2003	2	-4000	0	0
166	22/10/2003	26/10/2003	4	-4000	0	0.0136
167	26/10/2003	28/10/2003	2	-4000	20	0
168	28/10/2003	08/11/2003	11	-4000	0	0.0076
169	08/11/2003	10/11/2003	2	-6000	3	0
170	10/11/2003	12/11/2003	2	-6000	0	0.0076
171	12/11/2003	16/11/2003	4	-6000	8	0
172	16/11/2003	18/11/2003	2	-6000	0	0.0076
173	18/11/2003	22/11/2003	4	-6000	16	0
174	22/11/2003	27/11/2003	5	-6000	16	0
175	27/11/2003	01/12/2003	4	-6000	0	0.0059
176	01/12/2003	03/12/2003	2	-6000	52	0
177	03/12/2003	28/12/2003	25	-6000	0	0.0059
178	28/12/2003	31/12/2003	3	-6000	39	0
179	31/12/2003	02/01/2004	2	-6000	0	0.0053
180	02/01/2004	04/01/2004	2	-6000	1	0
181	04/01/2004	08/01/2004	4	-6000	5	0
182	08/01/2004	10/01/2004	2	-6000	8	0
183	10/01/2004	21/01/2004	11	-6000	0	0.0053
184	21/01/2004	26/01/2004	5	-6000	69	0
185	26/01/2004	28/01/2004	2	-6000	0	0.0053
186	28/01/2004	08/02/2004	11	-6000	0	0.0078
187	08/02/2004	11/02/2004	3	-6000	9	0
188	11/02/2004	16/02/2004	5	-6000	0	0.0078
189	16/02/2004	19/02/2004	3	-6000	101	0
190	19/02/2004	23/02/2004	4	-6000	0	0.0078
191	23/02/2004	25/02/2004	2	-6000	1	0
192	25/02/2004	27/02/2004	2	-6000	0	0
193	27/02/2004	03/03/2004	5	-6000	0	0.0128
194	03/03/2004	05/03/2004	2	-6000	9	0
195	05/03/2004	28/03/2004	23	-6000	0	0.0128
196	28/03/2004	27/04/2004	30	-6000	0	0.017
197	27/04/2004	28/05/2004	31	-6000	0	0.0204
198	28/05/2004	27/06/2004	30	-6000	0	0.021
199	27/06/2004	28/07/2004	31	-4000	0	0.0219
200	28/07/2004	28/08/2004	31	-2000	0	0.0204
201	28/08/2004	27/09/2004	30	-2000	0	0.0177
202	27/09/2004	28/10/2004	31	-2000	0	0.014
203	28/10/2004	27/11/2004	30	-4000	0	0.0086
204	27/11/2004	14/12/2004	17	-6000	0	0.0071
205	14/12/2004	17/12/2004	3	-6000	8	0
206	17/12/2004	28/12/2004	11	-6000	0	0.0071
207	28/12/2004	28/01/2005	31	-6000	0	0.0064
208	28/01/2005	10/02/2005	13	-6000	0	0.0088
209	10/02/2005	12/02/2005	2	-6000	16	0
210	12/02/2005	25/02/2005	13	-6000	0	0.0088
211	25/02/2005	27/02/2005	2	-6000	31	0
212	27/02/2005	09/03/2005	10	-6000	0	0.0118

S	From	To	Days	Dischrge (m^3/day)	Recharge (mm/day)	Evaporation (mm/day)
213	09/03/2005	11/03/2005	2	-6000	1	0
214	11/03/2005	27/03/2005	16	-6000	0	0.0118
215	27/03/2005	26/04/2005	30	-6000	0	0.0171
216	26/04/2005	27/05/2005	31	-6000	0	0.0194
217	27/05/2005	26/06/2005	30	-6000	0	0.022
218	26/06/2005	27/07/2005	31	-4000	0	0.0197
219	27/07/2005	21/08/2005	25	-2000	0	0.0211
220	21/08/2005	23/08/2005	2	-2000	0	0
221	23/08/2005	27/08/2005	4	-2000	0	0.0211
222	27/08/2005	26/09/2005	30	-2000	0	0.0169
223	26/09/2005	27/10/2005	31	-2000	0	0.013
224	27/10/2005	26/11/2005	30	-4000	0	0.0089
225	26/11/2005	27/12/2005	31	-6000	0	0.0069
226	27/12/2005	27/01/2006	31	-6000	0	0.0067
227	27/01/2006	25/02/2006	29	-6000	0	0.0081
228	25/02/2006	28/03/2006	31	-6000	0	0.012
229	28/03/2006	27/04/2006	30	-6000	0	0.017
230	27/04/2006	28/05/2006	31	-6000	0	0.0191
231	28/05/2006	27/06/2006	30	-6000	0	0.0196
232	27/06/2006	28/07/2006	31	-4000	0	0.0204
233	28/07/2006	28/08/2006	31	-2000	0	0.0193
234	28/08/2006	27/09/2006	30	-2000	0	0.015
235	27/09/2006	28/10/2006	31	-2000	0	0.0135
236	28/10/2006	27/11/2006	30	-4000	0	0.0085
237	27/11/2006	10/12/2006	13	-6000	0	0.006
238	10/12/2006	12/12/2006	2	-6000	17	0
239	12/12/2006	28/12/2006	16	-6000	0	0.006
240	28/12/2006	28/01/2007	31	-6000	0	0.0058
241	28/01/2007	25/02/2007	28	-6000	0	0.0081
242	25/02/2007	14/03/2007	17	-6000	0	0.0102
243	14/03/2007	16/03/2007	2	-6000	3	0
244	16/03/2007	28/03/2007	12	-6000	0	0.0102
245	28/03/2007	27/04/2007	30	-6000	0	0.0156
246	27/04/2007	28/05/2007	31	-6000	0	0.0183
247	28/05/2007	27/06/2007	30	-6000	0	0.0203
248	27/06/2007	26/07/2007	29	-4000	0	0.0185
249	26/07/2007	28/07/2007	2	-4000	7	0
250	28/07/2007	28/08/2007	31	-4000	0	0.0189
251	28/08/2007	27/09/2007	30	-4000	0	0.0164
252	27/09/2007	28/10/2007	31	-4000	0	0.0129
253	28/10/2007	27/11/2007	30	-4000	0	0.0085
254	27/11/2007	28/12/2007	31	-6000	0	0.0063
255	28/12/2007	28/01/2008	31	-6000	0	0.0058
256	28/01/2008	14/02/2008	17	-6000	0	0.0081
257	14/02/2008	16/02/2008	2	-6000	1	0
258	16/02/2008	25/02/2008	9	-6000	0	0.0081
259	25/02/2008	04/03/2008	8	-6000	0	0.0102
260	04/03/2008	06/03/2008	2	-6000	9	0
261	06/03/2008	13/03/2008	7	-6000	0	0.0102
262	13/03/2008	15/03/2008	2	-6000	77	0
263	15/03/2008	18/03/2008	3	-6000	0	0.0102
264	18/03/2008	20/03/2008	2	-6000	0	0
265	20/03/2008	28/03/2008	8	-6000	0	0.0102

S	From	To	Days	Dischrge (m^3/day)	Recharge (mm/day)	Evaporation (mm/day)
266	28/03/2008	08/04/2008	11	-6000	0	0.0156
267	08/04/2008	10/04/2008	2	-4000	6	0
268	10/04/2008	27/04/2008	17	-4000	0	0.0156
269	27/04/2008	06/05/2008	9	-4000	0	0.0183
270	06/05/2008	08/05/2008	2	-4000	18	0
271	08/05/2008	28/05/2008	20	-4000	0	0.0183
272	28/05/2008	27/06/2008	30	-4000	0	0.0203
273	27/06/2008	28/07/2008	31	-4000	0	0.0185
274	28/07/2008	28/08/2008	31	-4000	0	0.0189
275	28/08/2008	27/09/2008	30	-4000	0	0.0164
276	27/09/2008	28/10/2008	31	-4000	0	0.0129
277	28/10/2008	27/11/2008	30	-4000	0	0.0085
278	27/11/2008	14/12/2008	17	-4000	0	0.0063
279	14/12/2008	16/12/2008	2	-4000	0	0
280	16/12/2008	28/12/2008	12	-4000	0	0.0063
281	28/12/2008	16/01/2009	19	-6000	0	0.0055
282	16/01/2009	18/01/2009	2	-6000	22	0
283	18/01/2009	21/01/2009	3	-6000	93	0
284	21/01/2009	27/01/2009	6	-6000	0	0.0055
285	27/01/2009	24/02/2009	28	-6000	0	0.0088
286	24/02/2009	03/03/2009	7	-6000	0	0.0085
287	03/03/2009	05/03/2009	2	-6000	2	0
288	05/03/2009	07/03/2009	2	-6000	0	0.0085
289	07/03/2009	10/03/2009	3	-6000	23	0
290	10/03/2009	12/03/2009	2	-6000	28	0
291	12/03/2009	14/03/2009	2	-6000	2	0
292	14/03/2009	18/03/2009	4	-6000	0	0.0085
293	18/03/2009	20/03/2009	2	-6000	8	0
294	20/03/2009	23/03/2009	3	-6000	0	0.0085
295	23/03/2009	26/03/2009	3	-6000	37	0
296	26/03/2009	17/04/2009	22	-6000	0	0.0129
297	17/04/2009	19/04/2009	2	-6000	5	0
298	19/04/2009	25/04/2009	6	-6000	0	0.0129
299	25/04/2009	26/05/2009	31	-6000	0	0.0204
300	26/05/2009	25/06/2009	30	-6000	0	0.0213
301	25/06/2009	26/07/2009	31	-4000	0	0.018
302	26/07/2009	26/08/2009	31	-2000	0	0.0181
303	26/08/2009	25/09/2009	30	-2000	0	0.0172
304	25/09/2009	18/10/2009	23	-2000	0	0.0136
305	18/10/2009	20/10/2009	2	-4000	0	0
306	20/10/2009	24/10/2009	4	-4000	0	0.0136
307	24/10/2009	26/10/2009	2	-4000	20	0
308	26/10/2009	06/11/2009	11	-4000	0	0.0076
309	06/11/2009	08/11/2009	2	-6000	3	0
310	08/11/2009	10/11/2009	2	-6000	0	0.0076
311	10/11/2009	14/11/2009	4	-6000	8	0
312	14/11/2009	16/11/2009	2	-6000	0	0.0076
313	16/11/2009	20/11/2009	4	-6000	16	0
314	20/11/2009	25/11/2009	5	-6000	16	0
315	25/11/2009	29/11/2009	4	-6000	0	0.0059
316	29/11/2009	01/12/2009	2	-6000	52	0
317	01/12/2009	26/12/2009	25	-6000	0	0.0059
318	26/12/2009	29/12/2009	3	-6000	39	0

S	From	To	Days	Dischrge (m^3/day)	Recharge (mm/day)	Evaporation (mm/day)
319	29/12/2009	31/12/2009	2	-6000	0	0.0053
320	31/12/2009	02/01/2010	2	-6000	1	0
321	02/01/2010	06/01/2010	4	-6000	5	0
322	06/01/2010	08/01/2010	2	-6000	8	0
323	08/01/2010	19/01/2010	11	-6000	0	0.0053
324	19/01/2010	24/01/2010	5	-6000	69	0
325	24/01/2010	26/01/2010	2	-6000	0	0.0053
326	26/01/2010	06/02/2010	11	-6000	0	0.0078
327	06/02/2010	09/02/2010	3	-6000	9	0
328	09/02/2010	14/02/2010	5	-6000	0	0.0078
329	14/02/2010	17/02/2010	3	-6000	101	0
330	17/02/2010	21/02/2010	4	-6000	0	0.0078
331	21/02/2010	23/02/2010	2	-6000	1	0
332	23/02/2010	25/02/2010	2	-6000	0	0
333	25/02/2010	01/03/2010	4	-6000	0	0.0128
334	01/03/2010	03/03/2010	2	-6000	9	0
335	03/03/2010	26/03/2010	23	-6000	0	0.0128
336	26/03/2010	25/04/2010	30	-6000	0	0.017
337	25/04/2010	26/05/2010	31	-6000	0	0.0204
338	26/05/2010	25/06/2010	30	-6000	0	0.021
339	25/06/2010	26/07/2010	31	-4000	0	0.0219
340	26/07/2010	26/08/2010	31	-2000	0	0.0204
341	26/08/2010	25/09/2010	30	-2000	0	0.0177
342	25/09/2010	26/10/2010	31	-2000	0	0.014
343	26/10/2010	25/11/2010	30	-4000	0	0.0086
344	25/11/2010	12/12/2010	17	-6000	0	0.0071
345	12/12/2010	15/12/2010	3	-6000	8	0
346	15/12/2010	26/12/2010	11	-6000	0	0.0071
347	26/12/2010	26/01/2011	31	-6000	0	0.0064

الأملاح الكلية الذائبة وتم رسم خرائط كنتورية لجميع العناصر السابقة توضح مواقع تركيز كل عنصر. كما تم التركيز على تقدير النترات في المياه الجوفية لأنها تعتبر أكثر ملوث للمياه عن طريق النشاط الزراعي. ومن هذه التحاليل تم مناقشة مصدر المياه الجوفية في المنطقة ومدى صلاحيتها للاستخدام سواء للزراعة أو الشرب وذلك بعد مقارنة النتائج بالمستويات القياسية الموضوعة من قبل منظمة الصحة العالمية.

كما تضمنت الدراسة استخدام نموذج رياضي ثنائي الأبعاد لدراسة حركة المياه الجوفية ومستوى المياه الجوفية المتوقعة خلال الفترة القادمة حيث قسمت المنطقة إلى 7794 خلية مساحة كل خلية 100 متر مربع واستخدمت الفترة من 1997 إلى 2002 كفترة معايرة للنموذج الرياضي حتى أعطى نتائج مقاربة للبيانات المتوفرة خلال هذه الفترة ثم استخدم هذا النموذج لعمل توقعات عن مستوى المياه الجوفية ومقدار الهبوط في هذا المستوى حتى عام 2010.

بناء على نتائج هذه الدراسة فقد تم طرح بعض التوصيات للدراسات المستقبلية ووقف تدهور المياه الجوفية في منطقة الختم منها: ترشيد استهلاك المياه الجوفية في المنطقة وزيادة الوعي لدى المزارعين بضرورة المحافظة على المياه الجوفية كذلك توصي هذه الدراسة بأن استخدام المياه الجوفية يجب أن يخضع لسلطة عليا تمتلك الصلاحيات والقدرة على التحديد المقننات المائية لكل مزرعة. كما أن تطوير النموذج الرياضي الحالي سيساهم في إعطاء رؤية مستقبلية للوضع المائي في المنطقة

ملخص الرسالة

لقد شهدت دولة الإمارات العربية المتحدة في العقود الثلاثة الماضية تطوراً اقتصاديا كبيراً مما انعكس على زيادة ملحوظة في عدد السكان وازدهار كبير للصناعة والزراعة وقد تطلب ذلك البحث عن مصادر دائمة وكافية من المياه العذبة في ظل ضعف المصادر الطبيعية للمياه الجوفية فضلا عن الجفاف الذي يستمر على امتداد فصول السنة لقلة وعدم انتظام تساقط الأمطار.

إن الظروف المناخية الصعبة التي تعيشها الدولة لم تثني حكومة الإمارات من التوسع في القطاع الزراعي لما لهذا القطاع من أهمية اقتصادية وإستراتيجية. وتعتبر الزيادة الملحوظة في المساحات الخضراء سواء في المدن أو القرى أهم ما يميز الدولة. لقد شكل هذا التوسع الكبير قلقا في توفير الاحتياجات المائية لهذا القطاع كما ظهرت تساؤلات عن تأثير النشاط الزراعي على المياه الجوفية خاصة في المناطق التي تعتمد على هذه المياه كمصدر وحيد في ظل ندرة مياه الأمطار.

كما تعتبر منطقة الختم واحدة من أهم المناطق الزراعية في إمارة أبو ظبي حيث تحتوي على 1300 مزرعة تعتمد على المياه الجوفية حيث تحتل مساحة إجمالية تقدر بـ 2405.1 هكتار تقوم بزراعة المحاصيل المختلفة وخاصة محاصيل الأعلاف والتي تعتمد كلياً على المياه الجوفية على مدى العام. و تشهد منطقة الختم حاليا تدهورا خطيرا في مستوى ونوعية المياه الجوفية حيث هبط مستوى المياه عدة أمتار ووصلت ملوحة المياه في بعض الآبار إلى 33000 مايكرو موز وهو ولا شك مؤشر خطير يدعم التساؤل الذي افترضته الدراسة عن تأثيرا لنشاط الزراعي على المياه الجوفية .

تعتني الدراسة الحالية بتقييم كمي ونوعي للمياه الجوفية في منطقة الختم كمثال للمناطق الزراعية المشابه لها في الدولة كما تعطي لمحة عن تأثير الزراعة على المياه الجوفية تحت الظروف المحلية.

من أجل تحقيق هذا الهدف تم استعراض الدراسات السابقة عن المياه الجوفية وتم جمع البيانات الجيولوجية والمائية والكيميائية كما تم عمل مجموعة من الاختبارات والتحاليل للمياه الجوفية في المنطقة.

واستخدم برنامج GWW لعمل 19 قطاع لطبقات التربة المختلفة بعمق 45 متر كما استخدمت هذه البيانات لعمل مقاطع عرضية في عدة اتجاهات. وقد تم أجراء قياسات لمستوى المياه الجوفية في عدة مناطق بما يمثل تغطية كاملة لمستوى المياه في منطقة الدراسة وتمت الاستعانة ببعض البيانات القديمة المتوفرة عن عمق المياه الجوفية في المنطقة لرسم خرائط كنتورية لمستوى المياه الجوفية للأعوام 1997 و1999 و2002 و 2003 كما تمت المقارنة بين مستويات المياه الجوفية المختلفة في الأعوام المذكورة لإظهار نسبة الانخفاض في مستوى المياه عبر السنوات.

ومن خلال هذه الدراسة تم عمل عدد 2 اختبار ضخ متعدد المراحل و42 اختبار ضخ مستمر وذلك لدراسة خزان المياه الجوفية في المنطقة ومدى فاعليته كما استخدمت البيانات المستخرجة من هذه الاختبارات بمساعدة البرامج المتخصصة لحساب معامل فدرة التربة على نقل المياه وكمية المياه التي يستطيع أن يعطيها هذا الخزان.

كما تم عمل قطاعات جيوفيزيائية ثنائية الأبعاد في منطقتين لجمع البيانات المتعلقة بالخواص الجيولوجية للمنطقة. ولقد تم عمل هذه القطاعات بطول 360 متراً باستخدام 36 قطب كهربائي تفصلهم مسافة 10 أمتار مما يشكل اختراق قدره 60 مترا تقريباً. واستخدمت البيانات المستخرجة لرسم قطاعات تحت سطحية لمنطقة الدراسة وتم تدعيم هذه النتائج بالبيانات المتحصل عليها من الاختبارات الأخرى.

لتقييم نوعية المياه الجوفية في منطقة الختم تم أخذ 28 عينة مياه وتحليلها في مختبر قسم الزراعة التابع لبلدية أبوظبي وذلك لتحديد تركيز العناصر الأساسية وتشمل الكالسيوم والمغنيسيوم والصوديوم والبوتاسيوم والكبريتات والكربونات والبيكربونات بالإضافة إلى النترات. كما تم تقدير درجة الحموضة و ملوحة المياه بدرجة التوصيل الكهربائي وكمية

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رسالة ماجستير مقدمة إلى

عمادة الدراسات العليا

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لاستكمال متطلبات الحصول على درجة الماجستير في العلوم
في موارد المياه

إعداد

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