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Development of a GIS Database for Water Resources Management in Ajman Emirate, UAE.

Mohammad Rehan Yusuf

United Arab Emirates University
College of Graduate Studies

Development of a GIS Database for Water Resources Management in Ajman Emirate, UAE

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By

Mohammad Rehan Yusuf

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Author's Name

Mohammad Rehan Yousuf

Supervisor

Prof. Mohsen Sherif

Chairman and Professor of Water Resources
Civil and Environmental Engineering Department
College of Engineering
United Arab Emirates University

Co Supervisor

Dr. AlaEldin Mohamed Elhassan Idris

Planning Coordinator
General Directorate of Water
Sharjah Electricity and Water Authority (SEWA)

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Examination Committee	**Signature**
Prof. Mohsen Sherif, Chair Civil and Environmental Engineering Department College of Engineering, UAE University Al Ain, UAE	....
Dr. Assefa Mekonnen Melesse, External Examiner Associate Professor Department of Environmental Studies Florida International University Miami, Florida USA	
Prof. Abdel Mohsen Onsy Mohamed, Internal Examiner Civil and Environmental Engineering Department College of Engineering, UAE University Al Ain, UAE	....

Approval:
Dean of Graduate Studies: Prof. Ben Bennani ....

United Arab Emirates University
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Abstract

The lack of freshwater resources represents a major constraint against the sustainable development in arid and semi-arid regions. Because of the scarcity and randomness nature of rainfall in arid regions, surface water resources are almost absent. Groundwater resources are always under stress and in many cases do not suffice the water demands for different sectors. Desalination plants are widely constructed to substitute for the water shortage. The UAE, including Ajman emirate, is witnessing a rapid development in the industrial, commercial, construction and agricultural fields which has led to a tremendous increase in water demands.

Proper management of the limited water resources in UAE requires a comprehensive knowledge on water resources availability and potentials. Data related to water resources are numerous and diverse and are generally not preserved in a digital form. Therefore, retrieval of data may require excessive effort and time in such a way that hinders the decision makers to take the proper actions. No effort has been made, so far, to review, assess and analyze the available data related to water resources in Ajman emirate.

Efficient and integrated management of the available water resources in Ajman require availability of huge data. Such data include, among others, water demand and water supply patterns in the emirate, distribution of water demands among various consumption sectors, geometric, hydrological and hydrogeological characteristics of the aquifer systems, groundwater levels and quality, pumping rates, location of pumping and observation wells, and others. Such diverse data and information can only be managed and analyzed through Geographical Information Systems (GIS) databases.

The thesis demonstrates the development of the GIS database of Ajman emirate. Well fields, groundwater levels and quality, geological and hydrogeological information, aquifer parameters, rainfall records, groundwater quality data, pipelines, and other related data were mapped to recent remote sensing images. The obtained GIS maps provide a good support to decision makers in the area of water resources management and sustainability in Ajman emirate.

The ultimate aim, which can be fully achieved in future studies, is to integrate the Ajman water resources GIS database into other related databases in the country. The results of the current study can serve as a model for the development of water resources databases in the other emirates.

The importance of water resources in the sustainable development in Ajman emirate and UAE can not be over emphasized. The results of the study are expected to have a direct and significant impact on the water resources management in Ajman. These results will help professionals and researchers to conduct advanced research to assess, develop, protect and sustain the available water resources in Ajman. The GIS database will provide the needed support for decision making process. The developed GIS database of water resources in Ajman might be regarded as a model to GIS databases in the other emirates. Water resources databases in the different emirates can then be integrated to develop a national database.

Key Words: Ajman emirate, water resources, management, GIS, database, groundwater

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Chapter 1. Introduction and Literature Review

1.1. Water Resources in West Asia

The 4-million-square-kilometre west Asia region can be divided geographically and ecologically into two sub-regions, the Mashriq and the Arabian Peninsula. The region comprises 12 states with a total population of 85.6 million in 1995. The Mashriq, with a 1995 population of 45.1 million, includes Lebanon, Syria, Jordan, Iraq and the territories of the National Palestinian Authority (NPA). The Arabian Peninsula, with a 1995 population of 40.5 million, includes Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, the United Arab Emirates (UAE) and Yemen.

The great majority of the region (over 72 per cent) has an annual rainfall of less than 100 millimeters; about 18 per cent receives between 100 and 300 millimeters; less than 10 per cent receives between 300 and 1300 millimeters (ACSAD 1997). About 80 per cent of the region is therefore classified as semi-desert or desert land (AOAD 1995), 16 per cent is subject to desertification, and only 10 per cent is suitable for agriculture (2.3 per cent under irrigation and 7.7 per cent under rain fed cultivation).

Estimates of conventional (surface and groundwater) and non-conventional water resources (desalinated water, wastewater and agricultural drainage) in the region as of 1995 are: Annual rainfall provides around 443000 million cubic meters (ACSAD 1997), of which 41 per cent falls in the Mashriq and 59 per cent in the Arabian Peninsula. Surface water resources are estimated to be 88300 million cubic meters in the Mashriq sub-region and 8310 million cubic meters in the Arabian Peninsula.

Groundwater exists in both sub-regions, including both shallow and deep aquifers. In the Arabian Peninsula, groundwater in the shallow alluvial aquifers, located along the main wadi channels and the floodplains of drainage basins, is the only renewable water resource, with an approximate annual recharge of 5020 million cubic meters a year. The Mashriq has frequent low to medium intensity rainfall of long duration which favors groundwater recharge. Hence the estimated annual recharge is better, at 8515 million cubic meters a year.

Shallow aquifer reserves are estimated at 130500 million cubic meters in the Arabian Peninsula; approximately 13300 million cubic meters is available in the Mashriq (ACSAD 1997). Coastal alluvial aquifers in the Arabian Peninsula are subject to salt water intrusion due to extensive groundwater withdrawal which has caused salinization of coastal agricultural lands, resulting in the reduction of agricultural production and the complete loss of some arable land. Similarly, in the Mashriq sub-region the discharge of raw and partially treated wastewater from agriculture, industry and municipalities into water courses is a cause of deep concern over its health impacts; it has subjected agricultural land and water resources to severe pollution, and has contaminated shallow aquifers.

A catastrophic water shortage could prove an even bigger threat to mankind this century than soaring food price and the relentless experts of energy reserves. Underground aquifers could run dry at the same time as melting glaciers play havoc with fresh supplies of usable water.

"The glaciers on the Himalayas are retreating, and they are the sponge that holds the water back in the rainy season. World is facing the risk of extreme run-off, which water running straight into the Bay of Bengal and taking a lot of topsoil with it,". A few hundred square miles of the Himalayas are the source for all the major rivers of Asia – the Ganges, the yellow river, and the Yangtze – where three billion people live. Water is not a renewable resource. People have been mining it without restraint because it has not been priced properly. Farming makes up 70 per cent of global water demand. Fresh water for irrigation is never returned to underground basins. Most is lost through leaks and evaporation (Stern 2008).

Water is the "petroleum for the next century", offering huge rewards for investors who know how to play the infrastructure boom. Demand for water continues to escalate at unsustainable rates. Globally water consumption is doubling every 20 years. By 2025, it is estimated that about one third of the global population will not have access to adequate drinking water. China faces an acute challenge. It makes up 21 per cent of humanity but controls just seven per cent of water supply. Disputes over cross-border water basins have already prompted Egypt to threaten military action against any country that draws water off the Nile without agreement. The shift to an animal protein diet across Asia has added to the strain. It takes 15 cubic meters of water on average to produce one kilogram of beef, compared to six poultry, and 1.5 for corn.

The global climate change was now setting off a self-feeding spiral. World have droughts combined with a psychotic excess of rainfall. There are 800 million in the world are 'food insecure'. They can't grow enough food, or can't afford to buy it. This is a seismic shift in the global economy (Stern 2008).

1.2. Water Resources in Arabian Peninsula

The main source of water for the countries of the Arabian Peninsula is non-renewable fossil groundwater stored in sedimentary deep aquifers. These store significant amounts of groundwater that is thousands of years old. Deep groundwater reserves are estimated at 2175 thousand million cubic meters, with the major portion (1919 thousand million cubic meters) in Saudi Arabia (Al Alawi and Abdulrazzak 1993). However, recharge to all deep aquifers is estimated at a very limited 2700 million cubic meters per year. The quality of the deep aquifers varies greatly; only in a few areas is it suitable for domestic consumption. Most of the water from these deep aquifers is used for agricultural purposes.

Groundwater resources in West Asia in general, and the Arabian Peninsula in particular, are in a critical condition because the volumes withdrawn far exceed natural recharge rates, resulting in a continuous decline in groundwater levels and a deterioration in water quality caused by the encroachment of sea water into coastal alluvial aquifers and the up-flow of connate waters in inland aquifers. A 1995 comparison between the Arabian Peninsula's annual groundwater recharge (7200 million cubic meters) and groundwater abstraction rates (23600 million cubic meters), indicates that the mining of groundwater reserves in the Arabian Peninsula is about 16400 million cubic meters; by country, groundwater depletion rates (in millions of cubic meters) are: Bahrain - 100; Kuwait – 200, Oman – 240, Qatar – 140, Saudi Arabia - 13558; UAE – 1495, and Yemen - 700 (FAO 1997).

In the Mashriq, there is growing evidence of groundwater depletion in many countries, such as Jordan, Syria and the Gaza Strip, where groundwater use has been increasing, largely because of a decrease in surface water availability (WRI/UNEP/UNDP/WB 1996), in addition, over-irrigation and surface dumping of partially treated wastewater has generated large volumes of contaminated water, increasing the pollution levels of shallow aquifers.

Desalination technology was introduced in the mid-1950s and has developed very rapidly to counteract the shortage in conventional water sources. The majority of the region's desalination plants are found in the Arabian Peninsula; saltwater treatment facilities in the Mashriq are few and of small capacity. The 45 desalination plants operating in the Arabian Peninsula as a whole in 1992 had a total designed capacity of 2320 million cubic meters, equivalent to 41 per cent of global capacity (Bushnak 1995), and a total 1995 output of some 1645 million cubic meters (Zubari 1997). The cost of water desalination ranges from US$1/m^3 to US$1.5/m^3. All desalination plants have some negative effects on the environment since they cause air pollution by emitting oxides and marine pollution from the rejected brine.

Wastewater treatment in the Arabian Peninsula constitutes an increasing water source driven by escalating water consumption in urban areas. Existing sewage treatment facilities, which process primary wastewater and have a processing capability estimated at 921 million cubic meters a year, could handle about 43 per cent of all domestic wastewater. However, the reused treated wastewater, which does not exceed 392 million cubic meters a year, is used mainly for irrigating fodder crops, gardens, highway landscapes and parks (Zubari 1997). The remainder is dumped at disposal areas to infiltrate shallow aquifers, or into the sea. In the Mashriq, wastewater, except in large cities, is discharged into watercourses and only part of it is used for irrigation purposes.

Recycled irrigation water is not used much in the Arabian Peninsula since excess irrigation water infiltrates the lower horizons and ultimately reaches the groundwater table; only in Saudi Arabia, in Al-Hassa Oasis, is about 30 million cubic meters a year of irrigation water reused in agriculture by mixing it with groundwater, (Al-Kuwaiti et al. 1999). In the Mashriq sub-region only Syria exploits these water sources, with some 1210 million cubic meters being recycled annually. This source has, however future potential given proper irrigation practices are applied. Other forms of non-conventional water sources, such as rainwater harvesting and weather modification are still in the research stage.

Population growth in west Asia is a major issue affecting all sustainable socio-economic development. The estimated population in 1995 was 85.6 million (UNSPD 1997) with an average growth rate of 3.73 per cent for the Arabian Peninsula (Arab Fund 1995) and 3 per cent for the Mashriq countries (UNSPD 1997).

The total water used for all purposes in the west Asia region in 1995 amounted to 96065 million cubic meters (29565 million cubic meters in the Arabian Peninsula and 66500 million cubic meters in the Mashriq), average per capita water use in the same year was estimated to be 730 cubic meters a year for the Arabian Peninsula sub-region and 1475 cubic meters a year in the Mashriq. The high population growth rate in the region exceeds by far the rate of water resource development. Consequently, the annual per capita share of water resources is decreasing, and at an increasing rate. According to the global water assessment, the share per individual in the Arab world has decreased during the last two decades from 2 200 cubic meters a year to 1100 cubic meters a year (WRI/UNEP/UNDP/WB 1996).

Five countries of west Asia have a per capita water use of less than 500 cubic meters a year, half the benchmark of 1000 cubic meters a year which indicates chronic water scarcity (WRI/UNEP/UNDP/WB 1996). Only two countries, Iraq and Syria, actually exceed the 1000 cubic meters a year benchmark; Saudi Arabia and UAE have done so only by mining their groundwater reserves.

The national economy of most countries of west Asia depends on oil and oil-related industries, commerce, light industries, and agriculture, in this descending order. Due to the fast increase in population and urbanization, domestic water and industry needs are escalating at rates with which available water resources cannot keep pace. Furthermore, the adopted policy of food self-sufficiency imposes continual constraints on the allocation of water resources, which would otherwise reduce the share for agriculture in favor of increased domestic and industrial demand. Currently the agricultural sector takes 85 per cent of available water resources in the Arabian Peninsula and 95 per cent in the Mashriq, followed by domestic water use, 14 per cent and 4 per cent respectively, with industry in both sub-regions accounting for less than 2 per cent (ACSAD 2000). This indicates that these countries have already exhausted their renewable water resources and are now exploiting non-renewable reserves.

In the Mashriq, the water stress index looks better, except for Jordan where it is over 100 per cent. However, all countries of this sub-region have critical conflicts concerning shared water resources which remain to be reconciled. Furthermore, not only are per capita water resources below 1000 cubic meters a year in 9 out of the 12 countries of west Asia, in 7 countries (Bahrain, Jordan, Kuwait, NPA, Saudi Arabia, UAE and Yemen) they are even below 500 cubic meters a year. The overall value of the water stress index for West Asia is 84.4 per cent, which is considered very critical. It is worth mentioning that groundwater reserves were depleted by over 17 000 million cubic meters in 1995 (ACSAD 2000).

The Arabian Peninsula is already suffering from a deficit in water resources. The 1995 total annual water demand of 29565 million cubic meters is estimated to grow to 47320 million cubic meters by 2015 whereas the total available water will hardly exceed 15400 million cubic meters (ACSAD 2000). Under these circumstances it will be difficult to maintain the regional emphasis on food production and the widespread import of foodstuffs will increase by necessity.

Currently, the water deficit is partially compensated for by the over-exploitation of shallow and deep fossil aquifers and by the extensive installation of highly expensive desalination plants. The negative impacts include fast depletion of aquifer reserves, possible conflicts arising from differential use of aquifers shared between states, deteriorating water quality and salinisation of agricultural lands. Furthermore, existing wastewater treatment facilities can cope with only 35 per cent of urban and industrial waste. Pollution from inappropriate disposal of untreated wastewater will create health hazards through the contamination of shallow groundwater aquifers.

These issues are all aggravated by a general weakness among the institutions dealing with water affairs. This is due to inadequate technical capabilities and unsatisfactory coordination between concerned water authorities. The Mashriq sub-region, with nearly ten times the renewable water resources of the Arabian Peninsula, is in a much better situation. Available resources can theoretically sustain the projected use of 95875 million cubic meters in 2015 (ACSAD 2000). However, strict control measures are needed to curb current problems related to over-exploitation, inefficient re-use of wastewater, untreated industrial waste and pollution of shallow aquifers. Institutional capacity building and enforcement of legislation also require attention, as well as the continuing problem of potential conflicts between neighboring states over the equitable distribution of shared water resources.

1.3. Water Resources in UAE

Three priority issues dominate water resources in the UAE, (Uncowr 2003):

1) Water shortages as the UAE is arid in nature

2) Degradation and depletion of water resources

3) Public and private sector resource management performance.

With the rapid development of domestic, industrial, and agricultural water supplies, conventional water resources have been seriously depleted. The scarcity of natural water resources and the growing gap between demand and supply of potable water in most of the UAE forced the government to face the water challenge with wise policies and decisions. The government realizes that the situation goes behind just a gap in water quantity and needs to be seen in the context of emerging environmental problems (Uncowr 2003).

Moreover, there has been an increasing concern in the UAE about the development of the water sectors and the efficient utilization of the water resources for sustainable water development. Unconventional water resources such as water desalination and effluent water reuse gained increasing role in the planning and development of additional water supplies.

Some details the challenges of UAE water resources, specifically:

A- Limited water resources

B- Inefficient water use

C- Groundwater exploitation

D- Water quality deterioration

E- Inefficient water management and lack of comprehensive water planning.

The Arabian Gulf region has the lowest per capita availability of water in the world and one of the fastest growing populations. Fortunately, many of the states in the region have the financial resources to develop solutions to solve their projected water shortage problem. Desalination plants, built through private enterprise, are recognized as a solution to the current and projected water shortages. Most of the Arab countries including GCC countries suffer from the shortage of potable water resources. UAE has one of the lowest natural renewable water resources. There is immense water demand due to infrastructure development and tourism.

Like other GCC countries, the water resources of the UAE are limited and scare. UAE is located in an area where the prevailing climate is arid. The availability of adequate water has major impact on the socio-economic development of any country. The proper assessment, planning and development of water resources are key elements in social and economic development of the country. Improper management and planning of water resources either because of lack of data or inadequate studies, have often resulted in over development, water quality deterioration and water supply problems in many areas. Moreover, since some of more important water resources and aquifers are shared between different regions, lack of cooperation and exchange of information have been a significant constraint in their planning, development and management.

The review of existing hydrological and hydro geological information and published reports and their systematic compilation in map form should greatly assist in the assessment of the water resources in the UAE particularly Ajman. UAE demand for water could only be achieved by rationalizing water consumption and its sustainable management. Since the transit labor and tourist population are major consumers of water in the Emirates, the rate of consumption may outpace the actual population growth rate.

Historically, all the UAE's water requirements were met from groundwater obtained from shallow, hand-dug wells and the traditional falaj system of aquifers. Over the past two decades, rapid economic development, coupled with steep population increases and a push to achieve self-sufficiency in food supplies, have placed ever-increasing pressure on the UAE's precious natural water resources. This is a real challenge for a country with no rivers and little rainfall.

1.4. Water Resources in Ajman

The growth in water demand is expected to be more dramatic in coming years. Ajman is facing shortage of water in each summer season because it is unable to meet the tremendous demands of ongoing project like emirates city, city tower, Al Ameera city, Hallew new city. Many commercial, industrial and residential projects are in execution as well as feasibility stage which clouds the forecasting procedure and make it more unpredictable.

Ajman infrastructure is under the stress of population growth, huge increase in the number of tourists and rampant economic development. Such stresses on it limited water resources are posing serious threats to its sustainable development. The authorities in Ajman emirate are concerned about finding sufficient water for each person living in the emirate and have great anxiety about how the limited water will meet the high water demands due to the rapidly expanding economic activities.

Imminent shortage of water resources in the emirate has been compounded by the real estate boom, with new construction projects taking a larger share of resources. This is alarming since this region is already the driest in the world. The Gulf remains the largest market for water desalination in the world and local municipalities are seriously examining ways to double the existing capacity to meet regional demand.

1.5. Objective and Scope of the Study

The management of water resources in any given area requires the availability of all related data, including among others, rainfall records, aquifers dimensions and parameters, type of aquifers, groundwater levels, layout of water distribution networks, location and capacity of desalination plants and so on. Some of the data are time-independent while others are time-dependent. Time-independent data include the geometric dimensions of aquifers, hydro geological parameters, layout of the distribution networks, locations of desalination plants and so on. Time-dependent data include, among others, groundwater levels, water quality parameters, and water consumption and demands. Such diverse data and information can only be managed and analyzed through Geographical Information Systems (GIS) databases.

The GIS database will provide the needed support for decision making process. The developed GIS database of water resources in Ajman might be regarded as a model to GIS databases in the other Emirates. Water resources databases in the different emirates can then be integrated to develop a national database.

The study attempted to develop an integrated and versatile system to handle time-expanding water resources related data; It can be used as a powerful tool by decision makers to perform a global "at a glance" updated appraisal of resource conditions via theme databases and maps.

Many utilities are increasingly realizing the advantages to using GIS to perform day-to-day functions, such as operations, maintenance and customer service. Perhaps more importantly, utilities are using GIS to make better decisions, analyze their existing and potential customer base, and plan for future expansion.

The specific objectives included:

- Collection of the available data and information related to water resources in Ajman.
- Update the time dependent data such as groundwater levels, rainfall water demands, and others. Most of the data was collected from the field.
- Reviewing, assessment and analyses of the available information was done using the advanced tools of GIS software (Arc view or Arc GIS)
- Development of a GIS database for Water Resources in Ajman encompassing all relevant information. This allows a better assessment of the water resources in Ajman.
- Analyses of the data and development of various maps related to water resources availability and potentiality using the GIS system has been done.

1.6. Organization of Thesis

This thesis is composed of seven chapters. Chapter one elaborates the importance of water resources in west Asia, Arabian Peninsula, UAE and Ajman. The general and specific objectives of the study are elaborated.

Chapter two has been devoted to use of GIS in water resource management. It reviews the GIS help in integration of multiple data and assist in decision making.

Chapter three includes the geological and hydrological aspects of Ajman. Major water resources issues, History of water resources and need for mapping in Ajman are described. Methodology of entering data in Arc GIS 9 and GWW software is discussed. Overview of chemical analysis for Hallew wells is presented. Factors of groundwater pollution in Ajman are discussed.

Chapter four elaborates the procedure of entering data in the attributes tables of the created layers in Arc GIS 9.

Chapter five discusses the available desalination plants their history and future prospects. Design capacities of Ajman sewage collection system are discussed.

Chapter six is devoted to forecasting water demands for Ajman. This chapter involves the forecast of water demands in Ajman Emirate up to 2031 based on low demand and high demand with the help of SPSS software it considers the affects of groundwater quality deterioration because of no recharge and over pumping.

Chapter seven includes the summary of work completed in the thesis. The conclusion of study is presented and several recommendations for water resource management and future studies are proposed.

Chapter 2. Use of GIS in Water Resource Management

2.1. Remote Sensing and GIS

Remote Sensing involves gathering data and information about the physical "world" by detecting and measuring radiation, particles, and fields associated with objects located beyond the immediate vicinity of the sensor devices. Remote Sensing is a technology for sampling electromagnetic radiation to acquire and interpret non-immediate geospatial data from which to extract information about features, objects, and classes on the Earth's land surface, oceans, and atmosphere (and, where applicable, on the exteriors of other bodies in the solar system, or, in the broadest framework, celestial bodies such as stars and galaxies) (Canada centre of remote sensing 1997).

Over the past two decades, a new systematic approach to gathering, storing, and manipulating the different information types, with the objective of analyzing the tasks and making and implementing decisions, has become highly popular and widespread in use: this is the methodology intrinsic to what is known as GIS or Geographic information system.

Geographic Information System (GIS) is a computer based information system used to digitally represent and analyze the geographic features present on the Earth surface and the events (non-spatial attributes linked to the geography under study) that taking place on it. The meaning to represent digitally is to convert analog (smooth line) into a digital form.

"Every object present on the earth can be geo-referenced", is the fundamental key of associating any database to GIS. Here, term 'database' is a collection of information about things and their relationship to each other and 'geo-referencing' refers to the location of a layer or coverage in space defined by the co-ordinate referencing system.

Work on GIS began in late 1950s, but first GIS software came only in late 1970s from the lab of the ESRI. Canada was the pioneer in the development of GIS as a result of innovations dating back to early 1960s. Much of the credit for the early development of GIS goes to Roger Tomlinson. Evolution of GIS has transformed and revolutionized the way in which planners, engineers and managers conduct the database management and analysis. The early mission of ESRI focused on the principles of organizing and analyzing geographic information. ESRI projects included developing plans for rebuilding the city of Baltimore, Maryland and assisting Mobil oil in selecting a site for the new town of

Reston, Virginia. From these early projects emerged concepts for processes and tools that could be applied in an automated environment (ESRI 2008).

During the 1980s, ESRI devoted its resources to developing a core set of application tools that could be applied in a computer environment to create a geographic information system (GIS).This is what is known today as GIS technology. In 1981, ESRI launched its first commercial GIS software called Arc/Info. It combined computer display geographic features, such as points, lines, and polygons, with a database management tool for assigning attributes to these features.

In 1990, ESRI grew with the release of Arc view, easy to learn desktop mapping tool. ESRI also launched the Arc Data program, designed to promote the publishing of commercial off-the-shelf high quality datasets to help users quickly build and grow their GIS applications. Arc Cad software, also released in 1992, which made GIS tools available in the Cad environment.

In 1994, ESRI addressed the needs of business-to business market with Arc SDE, which allowed the storage of spatial and tabular data in commercial DBMS products. Arc Info for Windows NT also released in 1995.

Arc Info 8 was released in December, 1999. In April 2001, ESRI released Arc GIS 8.1, a family of software products that forms a complete GIS built on industry standards providing exceptional yet easy to use capabilities. In May 2004, ESRI released Arc GIS 9, which is a scalable system for geographic data creation, management, integration, analysis and dissemination for every organization from an individual to a globally distributed network of people (ESRI 2008).

2.2. Definitions of GIS

A GIS is an information system designed to work with data referenced by spatial / geographical coordinates. In other words, GIS is both a database system with specific capabilities for spatially referenced data as well as a set of operations for working with the data. It may also be considered as a higher order map. GIS technology integrates common database operations such as query and statistical analysis with the unique visualization and geographic analysis benefits offered by maps. These abilities distinguish GIS from other information systems and make it valuable to a wide range of public and private enterprises for explaining events, predicting outcomes, and planning strategies. (ESRI 2008)

GIS is a computer based system which is used to digitally reproduce and analyze the feature present on earth surface and the events that take place on it. In the light of the fact that almost 70% of the data has geographical reference as its denominator, it becomes imperative to underline the importance of a system which can represent the given data geographically.

GIS can be understood by the help of various definitions given below:-

A GIS is a computer-based tool for mapping and analyzing things that exist and events that happen on earth (GIS Development 2008).

Burrough (1986) defined GIS as, "Set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes".

Arnoff (1989) defined GIS as a computer based system that provides four sets of capabilities to handle geo-referenced data:

- Data input
- Data management (data storage and retrieval)
- manipulation and analysis
- Data output.

Hence GIS is looked upon as a tool to assist in decision-making and management of attributes that needs to be analyzed spatially. Maps have been used for thousands of years, but it is only within the last few decades that the technology has existed to combine maps with computer graphics and databases to create geographic information systems or GIS. GIS is used to display and analyze spatial data which are tied to a relational database. This connection is what gives GIS its power maps can be drawn from the database and data can be referenced from the maps. When a database is updated, the associated map can be dynamically updated as well. GIS databases include a wide variety of information: geographic, social, political, environmental, and demographic.

2.3. Importance and Benefits of GIS

Many professionals, such as engineers, foresters, agriculturists, urban planners, and geologists, have recognized the importance of spatial dimensions in organizing and analyzing information. Whether a discipline is concerned with the very practical aspects of business, or is concerned with purely academic research, geographic information system can introduce a perspective, which can provide valuable insights as 70% of the information has geographic location as its denominator making spatial analysis an essential tool.

The geographic information system has been an effective tool for implementation and monitoring of municipal infrastructure. The use of GIS has been in vogue primarily due to the following advantages:

i. Project planning: Advantage of GIS is often found in detailed planning of project having a large spatial component, where analysis of the problem is a pre requisite at the start of the project. Thematic maps generation is possible on one or more than one base maps, example: the generation of a land use map on the basis of a soil composition, vegetation and topography. The unique combination of certain features facilitates the creation of such thematic maps. With the various modules within GIS it is possible to calculate surface, length, width and distance.

ii. Decision making: The adage "better information leads to better decisions" is as true for GIS as it is for other information systems. A GIS, however, is not an automated decision making system but a tool to query, analyze, and map data in support of the decision making process. GIS technology has been used to assist in tasks such as presenting information at planning inquiries, helping resolve in territorial disputes, and citing pylons in such a way as to minimize visual intrusion.

iii. Multiple uses of GIS: Digital Terrain Modeling (DTM) is an important utility of GIS. Using DTM/3D modeling, landscape can be better visualized, leading to a better understanding of certain relations in the landscape. Many relevant calculations, such as (potential) lakes and water volumes, soil erosion volume (Example: landslides), quantities of earth to be moved (channels, dams, roads, embankments, land leveling) and hydrological modeling becomes easier.

Not only in the previously mentioned fields but also in the social sciences GIS can prove extremely useful. Besides the process of formulating scenarios for an environmental impact assessment, GIS can be a valuable tool for sociologists to analyze administrative data such as population distribution, market localization and other related features.

iv. Organizational integration: Many organizations that have implemented a GIS have found that one of its main benefits is improved management of their own organization and resources. Because GIS has the ability to link data sets together by geography, it facilitates interdepartmental information sharing and communication. By creating a shared database one department can benefit from the work of another-data can be collected once and used many times.

As communication increases among individuals and departments, redundancy is reduced, productivity is enhanced, and overall organizational efficiency is improved. Thus, in a utility company the customer and infrastructure databases can be integrated so that when there is planned maintenance, affected people can be informed by computer-generated letters.

2.4. Philosophy and Components of GIS

The proliferation of GIS is explained by its unique ability to assimilate data from widely divergent sources, to analyze trends over time, and to spatially evaluate impacts caused by development.

For an experienced analyst, GIS is an extension one's own analytical thinking. The system has no in-built solutions for any spatial problems; it depends upon the analyst. Before the GIS implementation is considered the objectives, both immediate and long term, have to be considered. Since the effectiveness and efficiency (i.e. benefit against cost) of the GIS will depend largely on the quality of initial field data captured, organizational design has to be decided upon to maintain this data continuously. This initial data capture is most important.

GIS constitutes of five key components:

i. Hardware: It consists of the computer system on which the GIS software will run. The choice of hardware system range from 300MHz personal computer to super computers having capability in tera flops. The computer forms the backbone of the GIS hardware, which gets its input through the scanner or a digitizer board. Scanner converts a picture into a digital image for further processing. The output of scanner can be stored in many formats e.g. TIFF, BMP, JPG etc. A digitizer board is flat board used for vectorisation of a given map objects. Printers and plotters are the most common output devices for a GIS hardware setup.

ii. Software: GIS software provides the functions and tools needed to store, analyze, and display geographic information. GIS soft wares in use are MapInfo, Arc/Info, Auto Cad map, etc. The software available can be said to be application specific. When the low cost GIS work is to be carried out desktop MapInfo is the suitable option. It is easy to use and supports many GIS feature. If the user intends to carry out extensive analysis on GIS, Arc/Info is the preferred option. For the people using Auto Cad and willing to step into GIS, Auto Cad Map is a good option.

iii. Data: Geographic data and related tabular data can be collected in-house or purchased from a commercial data provider. The digital map forms the basic data input for GIS. Tabular data related to the map objects can also be attached to the digital data. A GIS will integrate spatial data with other data resources and can even use a DBMS, used by most organization to maintain their data, to manage spatial data.

iv. People and method: GIS users range from technical specialists who design and maintain the system to those who use it to help them perform their everyday work, the people who use GIS can be broadly classified into two classes. The Cad/GIS operator, whose work is to vectorise the map objects. The use of this vectorised data to perform query, analysis or any other work is the responsibility of a GIS engineer/user.

And above all a successful GIS operates according to a well-designed plan and business rules, which are the models and operating practices unique to each organization. There are various techniques used for map creation and further usage for any project. The map creation can either be automated raster to vector creator or it can be manually vectorised using the scanned images. The source of these digital maps can be either map prepared by any survey agency or satellite imagery

2.5. GIS Applications

Computerized mapping and spatial analysis have been developed simultaneously in several related fields. The present status would not have been achieved without close interaction between various fields such as utility networks, cadastral mapping, topographic mapping, thematic cartography, surveying and photogrametery remote sensing, image processing, computer science, rural and urban planning, earth science, and geography.

The GIS technology is rapidly becoming a standard tool for management of natural resources. The effective use of large spatial data volumes is dependent upon the existence of an efficient geographic handling and processing system to transform this data into usable information.

The GIS technology is used to assist decision-makers by indicating various alternatives in development and conservation planning and by modeling the potential outcomes of a series of scenarios. It should be noted that any task begins and ends with the real world. Data is collected about the real world. The product is an abstraction, it is not possible (and not desired) to handle every last detail. After the data are analyzed, information is compiled for decision-makers. Based on this information, actions are taken and plans implemented in the real world.

Major areas of application

i. Different streams of planning: Urban planning, housing, transportation, planning, architectural conservation, urban design and landscape.

ii. Street network based application: It is an addressed matched application, vehicle routing and scheduling, location, site selection and disaster planning.

ii. Natural resource based application: Management and environmental impact analysis of wild and scenic recreational resources, flood plain, wetlands, aquifers, forests, and wildlife.

iv. View shed analysis: Hazardous or toxic factories siting and groundwater modeling, Wild life habitat study and migrational route planning.

v. Land parcel based: Zoning, sub-division plans review, land acquisition, environment impact analysis, nature quality management and maintenance etc.

vi. Facilities management and utilities application: Can locate underground pipe and cables for maintenance, planning, tracking use.

2.5.1. GIS use in water utility

Organizations and utilities are performing more efficiently through the use of GIS. For example, when a customer calls in with a question or complaint, staff can punch up the customer's address and zoom to the address on the screen in a matter of seconds. Information such as where the nearest main line is, its diameter, any recent breaks, etc., can all be brought up instantaneously. Thus, a staff member can evaluate the customer's situation rapidly and serve the customer better. Customer service is just one way in which GIS has become a valuable tool. It is also facilitating endeavors in operations, maintenance, planning, emergency response, and technical service. As the use of GIS becomes more widespread in a utility, it is very easy to communicate better with other local departments, external organizations, and the general public.

2.5.2. Integration of remotely sensed data into GIS

Remote sensing and its associated image processing technology provide access to spatial and temporal information on water shed, regional, continental and global scales. Effective utilization of this large spatial data volume is dependent upon existence of an efficient, geographic handling and processing system that will transform these data into usable information. A major tool for handling spatial data is the GIS.

GIS provides appropriate methods for efficient storage, retrieval, manipulation, analysis and display of large volumes of spatially referenced data which is visible in (Figure 2.1). GIS consists of four basic components: data input and editing, storage of geographic data bases, data analysis and spatial modeling, and data visualization and presentation. The data can be collected from field work, extraction of map data, air photo interpretation, and interpretation and classification of remotely sensed images. Data input may be carried out by manual digitization or computer assisted semi automatic methods. Collected data are then organized into a series of spatially geo-registered layers, with each layer relating to a particular theme (e.g. Soils, vegetation, geology, topography, pipe, land sectors etc) or a set of layers relating to temporal variation of a theme (e.g. changes in land-use or variation of soil moisture etc). Data input and editing (i.e. to correct digitizing errors, establishing topological relationships etc) are the most time-consuming and labor intensive tasks. Data analysis and spatial modeling capability are the most important characteristics of a GIS.

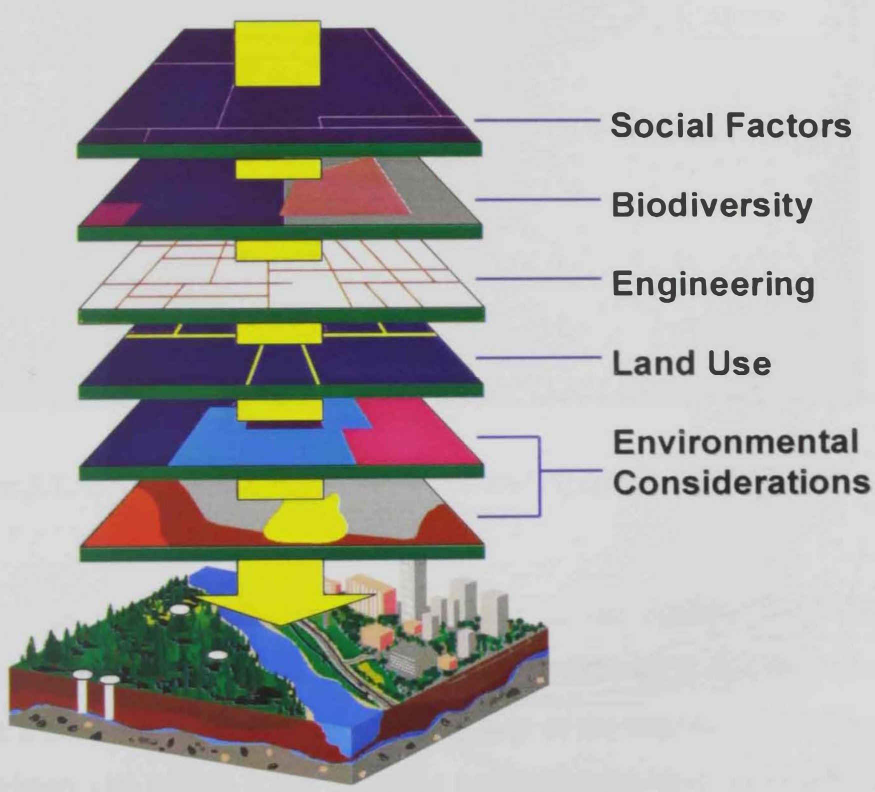

Figure 2.1. GIS is a tool to see the whole

Chapter 3. Geology and Hydrogeology of the Study Area

3.1. Geology of Ajman

United Arab Emirates is comprised of seven emirates with a total area of about 83.600 km^2 lying between latitudes approximately 22° and 26° N', and longitudes 51° and 56° E (Figure 3.1). Ajman lies on the southern Arabian Gulf. Ajman Emirate is the smallest among seven emirates constituting the UAE.

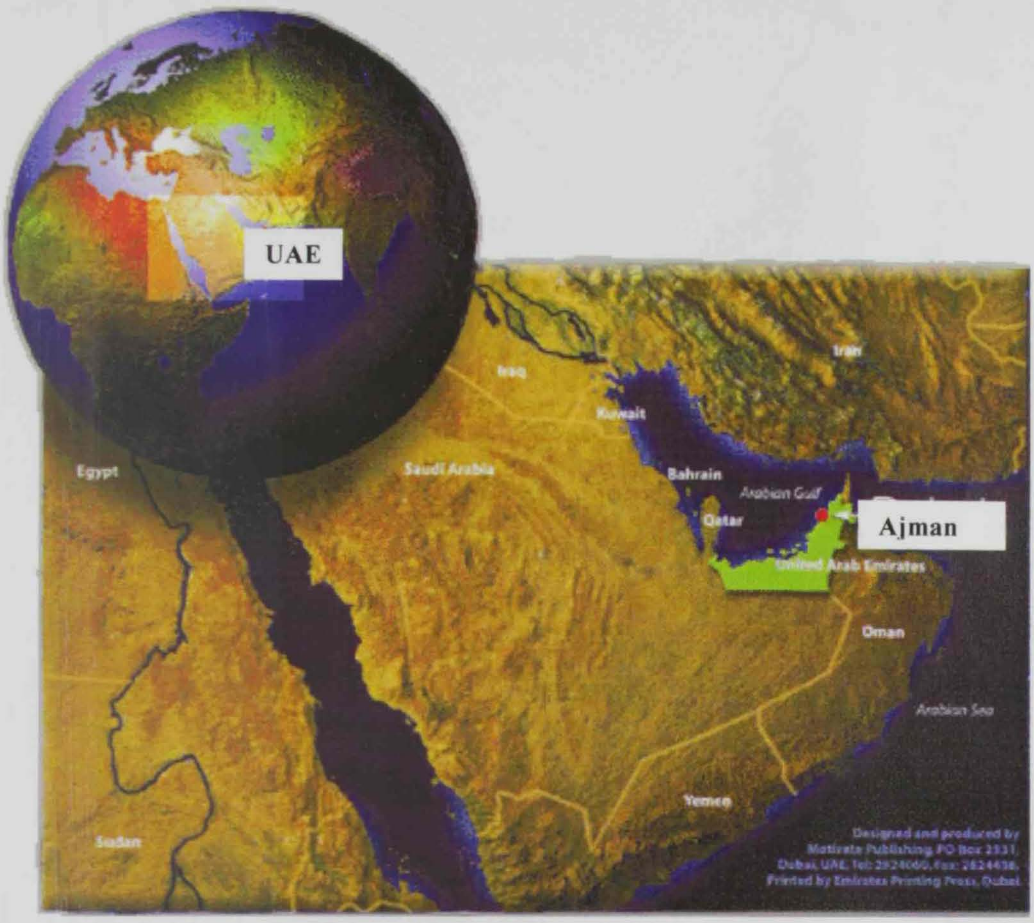

Figure 3.1. Location of UAE in the world and Ajman in the Arabian Gulf (Jones and Salman 2007)

Ajman city is located on the eastern coast of the Arabian Gulf (Figure 3.2), covering an area of 140 km^2. About 45% of the city is urbanized and the remaining land is vacant with a few farming areas on the eastern side of the emirates road (Figure 3.3 and Table 3.1). Ajman city has an 8 km coastline broken by the deep indentation of Ajman creek, which has been extended and developed as a port. The southern arm of the creek continues inland for 5 km. Ajman area is dominated by quaternary sand and gravel ranging in age from the Pleistocene to Holocene. The geologic units are discussed in details by the Kansas Geological Survey (1990) and illustrated in (Figure 3.4). These sediments constitute the main aquifer in the western region of the UAE (Rizk et al. 1997).

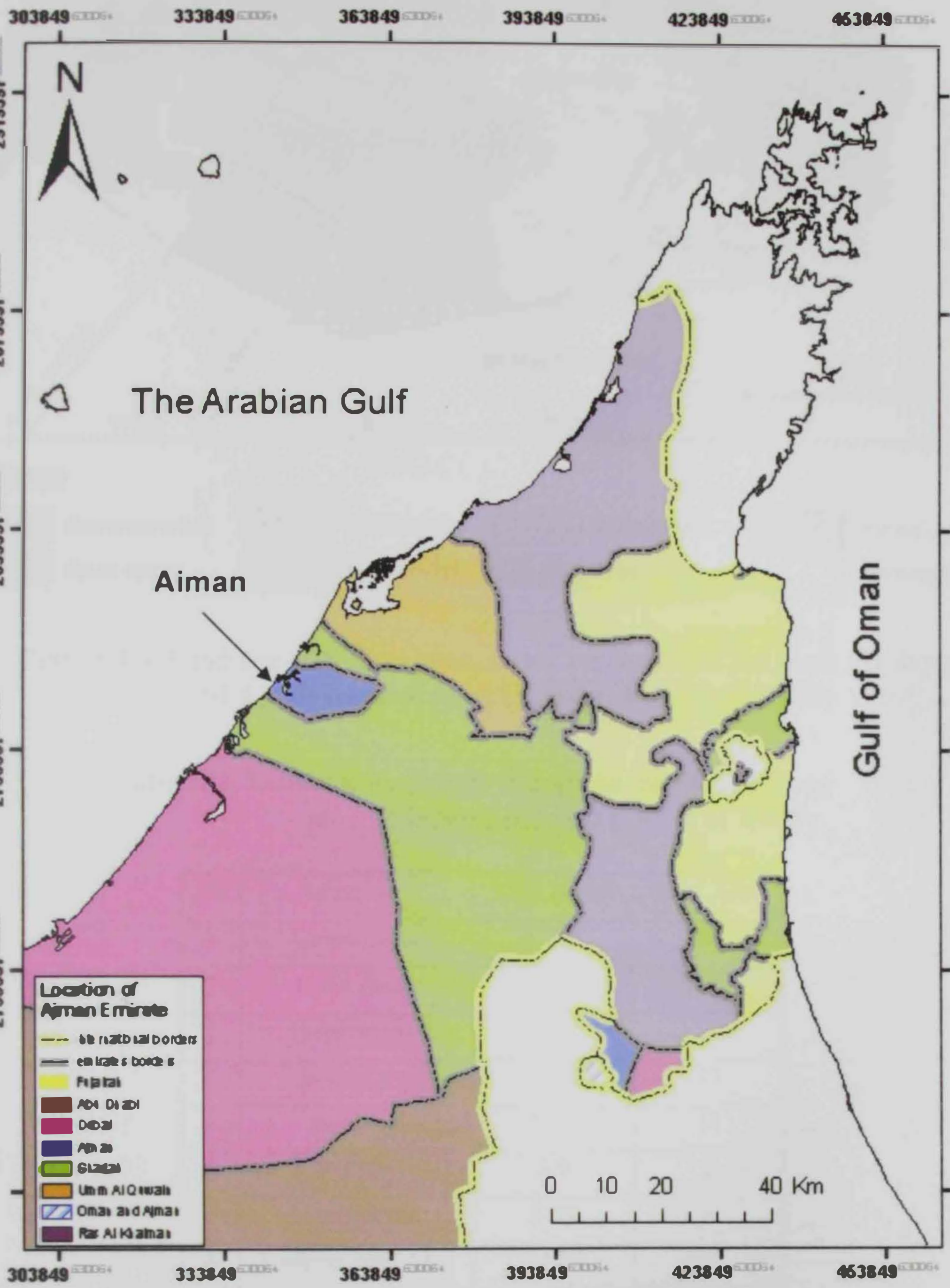

Figure 3.2. Location of Ajman in UAE

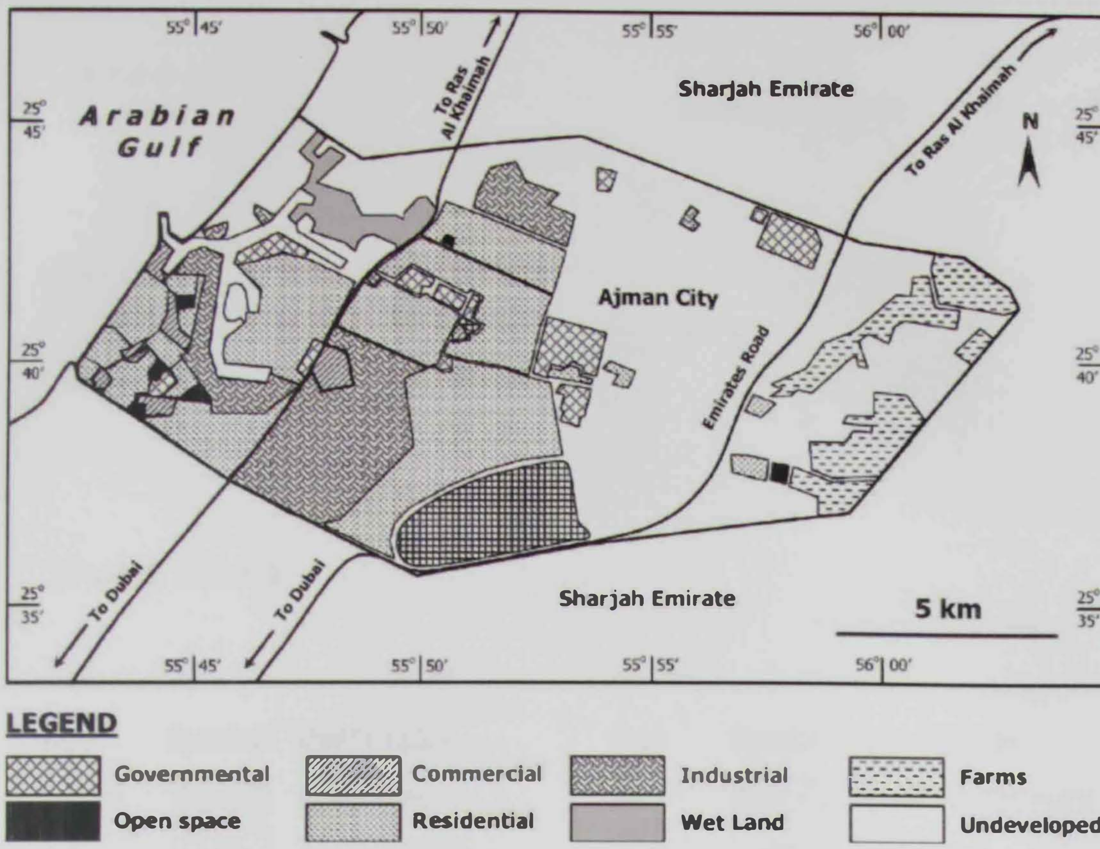

Figure 3.3. Land use map for Ajman, based on data from the planning department of Ajman Municipality, (Kansas Geological Survey 1990)

Table 3.1. Land use in Ajman, traced and calculated from satellite images (Al-Hogaraty et al. 2008)

No	Land Use	Area (Km^2)	% of Area
1	Government	12.90	9
2	Open space	25.06	18
3	Commercial	1.65	1
4	Residential	32.12	23
5	Industrial	20.13	14
6	Wet land	2.9	2
7	Agriculture	8.03	6
8	Undeveloped Area	39.88	26
Total Area		**142.67**	**100**

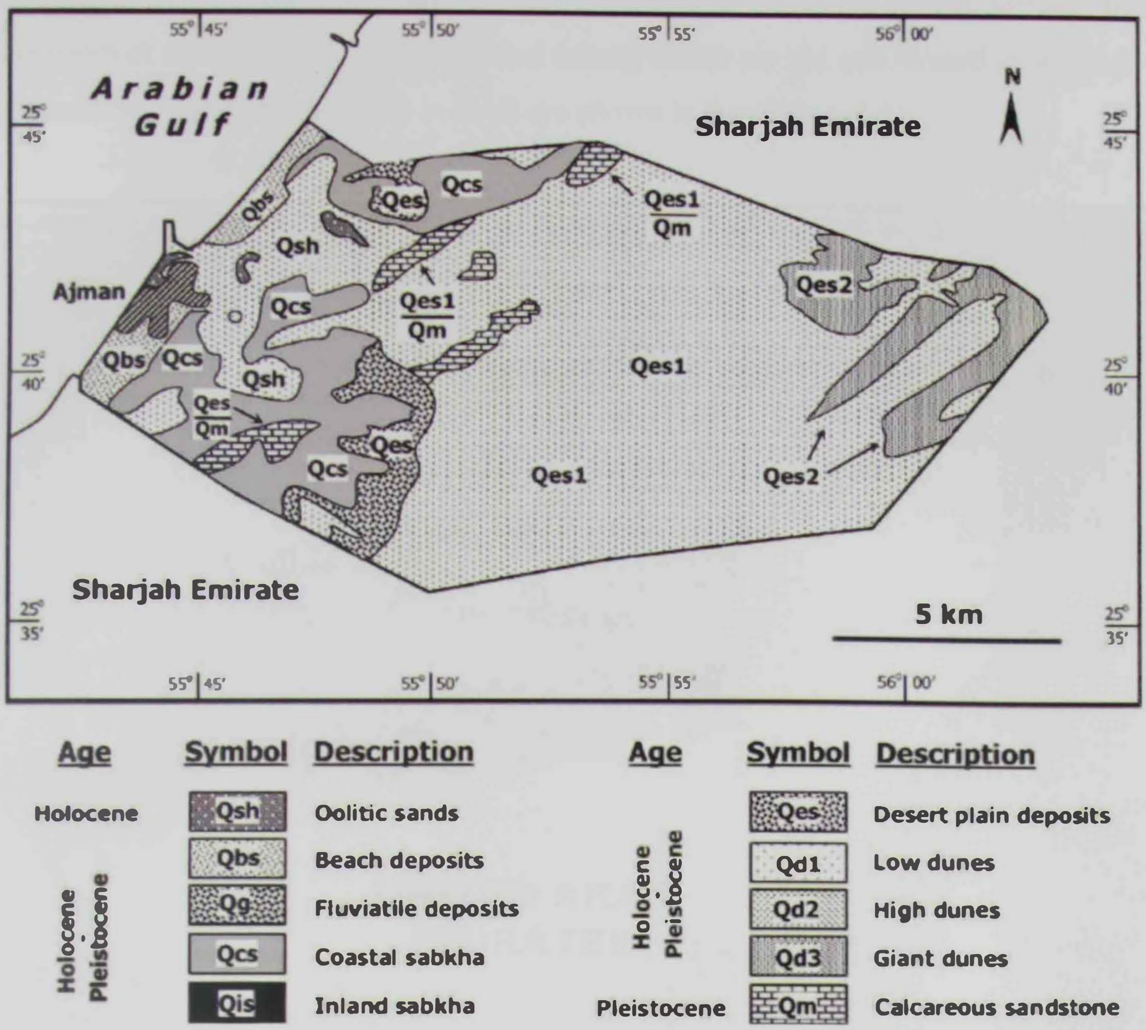

Figure 3.4. Geologic map of Ajman modified from the geologic map of UAE (Kansas Geological Survey 1990)

The terrain of UAE shows different characteristics between the western and eastern regions. The western region is mainly comprised of low plains with the highest elevation at 150 m to 250 m, while the eastern region is dominated by mountain ridges with a maximum elevation of 1500 m, and with a number of desiccated wadis. Especially along wadis Al Basseirah, Bih and Ham, a deep valley is formed. In terms of morphological characteristics, two regions: (1) an eastern mountain region with a sub-mountainous zone of outwash plains and (2) a western desert region divided into a coastal belt and inland desert.

Ajman lies in the western desert region; an alluvial belt (called the Bahada Plain) separates the mountains from the Aeolian sands of the western dune country. It is called the Jiri plain in the north and subsequent sub-divisions southwards are known as Dhaid, Gharif and Madam. The dunes in Ajman are divided into two according to origin: (i) those found along the coast are composed of white carbonate sands formed from fragments of marine shell; (ii) those found inland, which are red and formed of weathered quartz rocks. The major aquifers in UAE are shown in the (Figure 3.5).

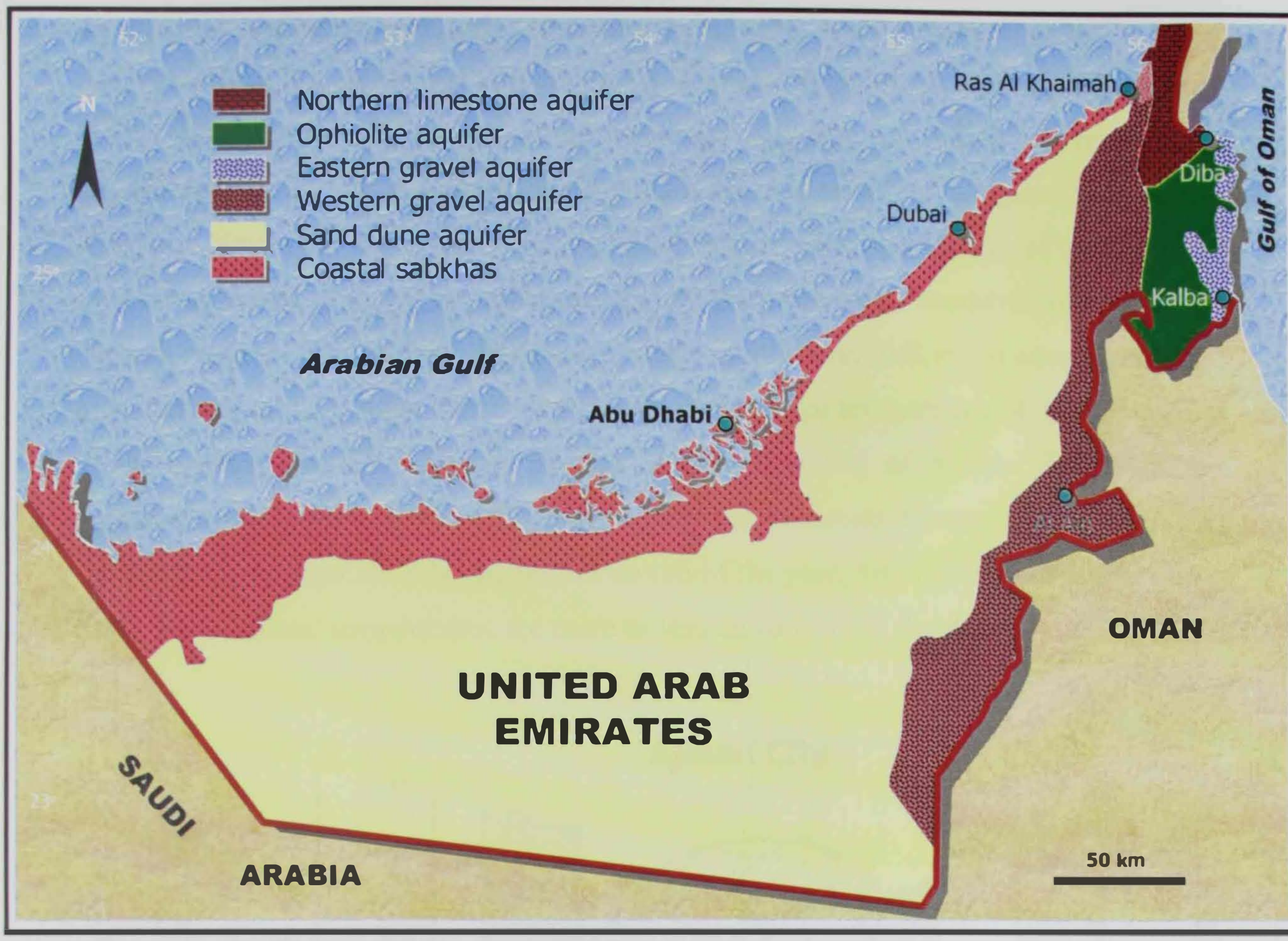

Figure 3.5. Geologic map of the UAE showing the main aquifers (Rizk et al. 1997)

3.2. Climate and Hydrogeology

The UAE is an arid country with a long hot summer and a short mild winter. The combination of high temperature, low humidity and long hours of sunshine leads to extremely high evaporation rates and the absence of surface water (Al Asam 1996). (Figure 3.6) illustrates the monthly values of air temperature, relative humidity, rainfall and evaporation at Ajman. But, the following discussion will be limited to the evaporation and rainfall because of their direct relevance to groundwater pollution. The annual average pan evaporation in Ajman city is 9.8 mm/day (Rizk and Garamoon 2006). Rainfall in Ajman emirate is rare, sporadic and highly irregular exhibiting wide variation in space and time, depending on the climatic conditions, geographic location, local topography and rainfall driving mechanism. The principal rain falls between November and March, with the maximum intensity during February. The mean annual rainfall for Ajman emirate is 120 mm (Rizk and El-Etr 1998).

Ajman emirate generally has a hyper arid climate characterized by a prolonged dry summer period of very high temperatures between April – November and a winter period between December and March of mild to warm temperatures with slight rainfall.

Ajman has a hot desert climate with high temperatures and infrequent irregular low rainfall. It has two seasons a long dry summer with very high temperatures between April and November and a winter period between December and March, of mild to warm temperatures and a slight to moderate rainfall. Summer mean temperatures across the country reaches 35°C in July, while the average monthly rainfall in the same month is 2 mm. January is the coolest month with a national average temperature of 18°C; February is the wettest month with an average monthly rainfall of 42mm. The minimum temperature never goes below 0°C in winter, but the maximum temperature reaches more than 45°C in summer. In July, the hottest month of the year, the temperature reaches up to 50°C. Mean annual temperatures are more or less uniform with slight local variations.

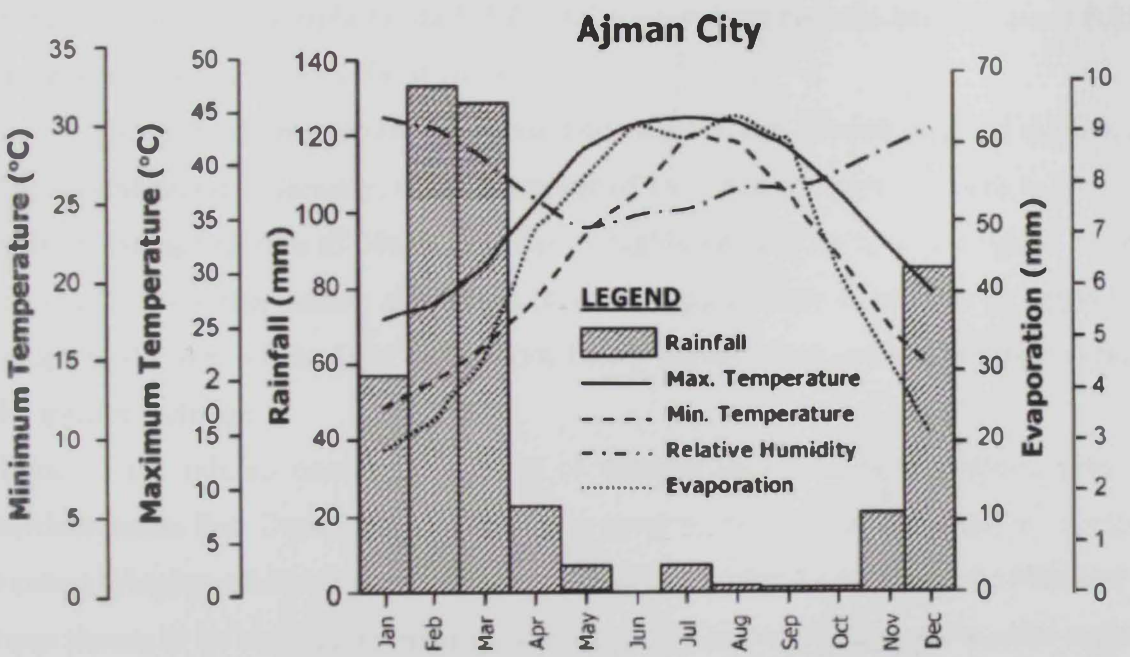

Figure 3.6. Climatic data of Ajman from year 1960 to 2006 (Al-Hogaraty et al. 2008)

Sunshine hours: The mean maximum sunshine hours appear in May, with 11.5 hours and a mean minimum of 8.4 hours occurring in December. The skies are relatively cloud–free throughout the year (MEW 2008).

Relative humidity: The relative humidity levels are higher along the Arabian Gulf coast and decrease south and eastwards. The mean annual relative humidity exceeds 60%.The variation in relative humidity is extremely high and ranges from 100% in early morning to 2% in late afternoon (MEW 2008).

Winds: The winds tend to be light or light to moderate and the mean annual wind speed is less than 10 knots. There is a tendency for winds to be stronger between March and August and predominantly from the north-west and south or south-east. The strongest winds are felt along the Arabian Gulf coast, and the desert foreland, while the lighter winds are in the interior (MEW 2008).

Rainfall: In the summer months, a north westerly flow of air develops over the Arabian Gulf in response to a trough of low pressure (Indian Monsoon) across Pakistan and into Iran. This condition is known as the summer shamal and brings hot and dusty conditions to the emirate. Later in the summer, sea breezes become the dominant feature, but conditions are still very humid and hot. Local instabilities can produce thunderstorms which usually provide light rainfall. July and August temperatures average around 35°C and average rainfall is only about 2mm.

The four winter months have unsettled weather and provide most of the rainfall. The coolest month is January, with an average of 18°C and the wettest month is February, with an average rainfall of 36mm. Rainfall is highly variable in time and space. Most of the rainfall in winter occurs as a result of convergence zones caused by an upper level trough to the west of the Gulf area. Short, heavy rainfall produces the best opportunities for aquifer recharge.

Some of the rainfall occurs as a result of thermal disturbances originating from the Mediterranean Sea. During the winter, strong north westerly winds (shamal) are a regular Feature bringing colder air from the Persian Gulf and Syria. An estimate of 100mm/yr has been shown to be required in order to activate sufficient runoff to cause aquifer recharge (Dincer et al. 1974).

Almost 90% of annual rain falls during winter and spring and the wettest months are usually February and March where 60% of the rainfall is recorded. Summer witnesses only a few monsoon rainfalls. The evaporation rates exceed rainfall totals all over Ajman.

The quaternary sand at Ajman form unconfined, water table aquifer directly connected to the atmosphere, which makes it susceptible to pollution (Al-Hogaraty et al. 2008).

3.3. Groundwater Chemistry

The groundwater levels in Ajman are given in (Figure 3.7). Chemical analysis of Hallew groundwater wells was done from the Quaternary sand aquifer at Hallew area which is the main raw water supply to Ajman RO plant and Hallew RO plant. The plants are operated by the Federal Electricity and water Authority (FEWA). Deterioration of groundwater quality occurs in the aquifer under Hallew area due to both natural and anthropogenic factors.

Field-measured parameters groundwater in the quaternary sand aquifer in the north of the UAE, including the study area, becomes gradually more saline as it moves from the main recharge area, the Northern Oman Mountains, in the east towards the main discharge area, the Arabian Gulf, in the west (Rizk et al. 1997, Rizk and El-Etr 1998, Alsharhan et al. 2001). The iso-salinity contour map reveals that groundwater in Ajman city is brackish in the east to saline in the west (Figure 3.8), which makes it unfit for use prior treatment. Groundwater salinity in the Hallew well field (57 wells) on the eastern side of emirates road ranges from 3,269 to 5,213 mg/l, and averages 4173 mg/l. However, despite its relatively high salinity, groundwater in this area has the best available quality in Ajman. On the western side of emirates road groundwater salinity steadily rises from east to west, in the direction of groundwater flow.

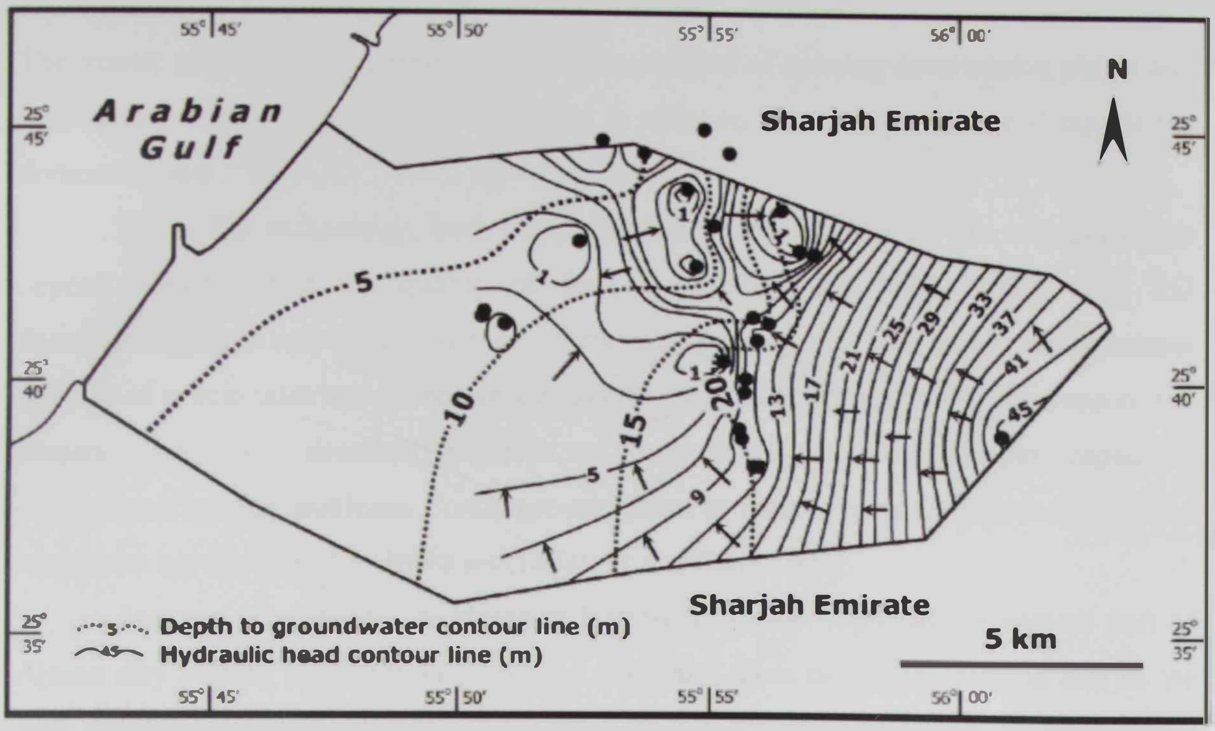

Figure 3.7. Map showing groundwater contour lines in Ajman aquifer (Al-Hogaraty et al. 2008)

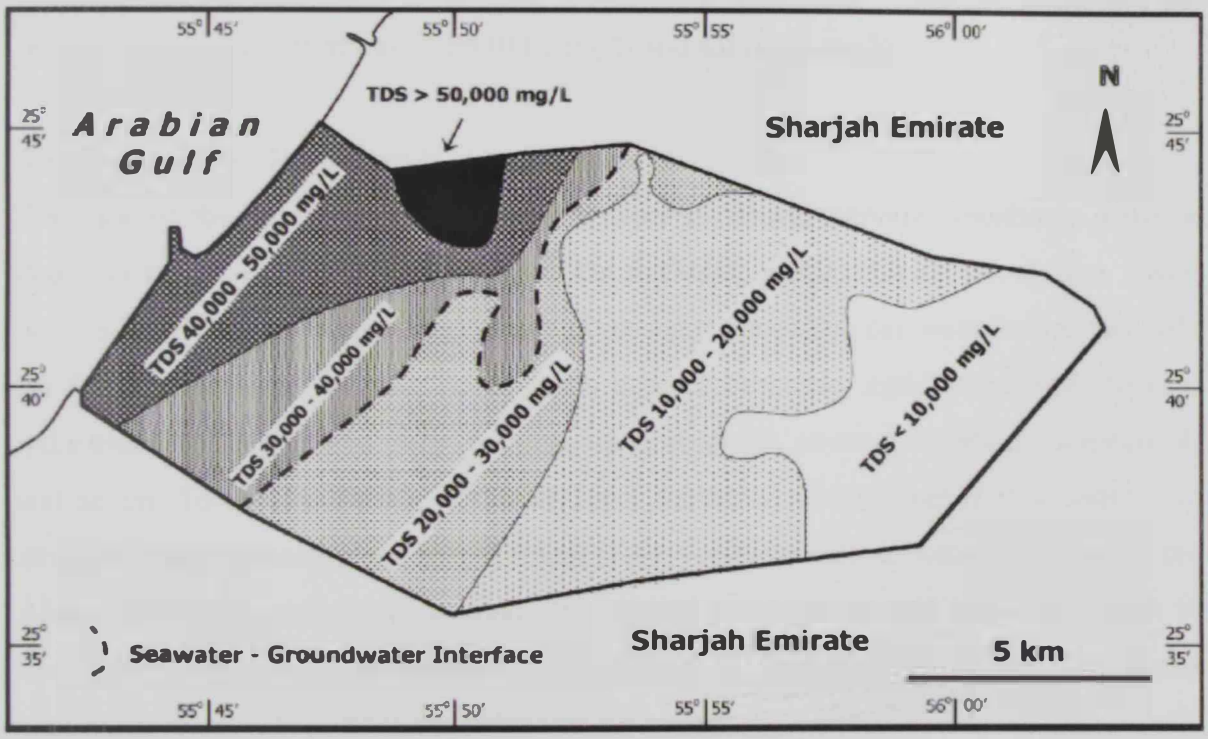

Figure 3.8. Iso-salinity contour map of groundwater in Ajman aquifer (Al-Hogaraty et al. 2008)

3.4. Groundwater Quality and Desalination Plants of Ajman

The master plan for Ajman emirate calls for expansion of existing desalination plants and installation of additional ones in the future in order to meet the increasing demands for domestic water.

In the RO technology, both the performance and the service life of membranes depend heavily upon the quality of feed water (ESCWA 2001, 2005). The RO desalination plants operating in Ajman are run with poor-quality feed water, which causes buildup of precipitates and extensive damage to membrane integrity. For this reason, the present capacities of desalination plants are lower than their initial designed capacities due to water quality problems. Costly pre-treatment is made to enhance plant capacity and extend the service life of membranes (Dolatyar and Gray 2000).

Average groundwater hardness at Hallew area (894 mg/l) in the eastern part of Ajman city .Ajman desalination plants are suffering from membrane fouling due to the high concentrations of metals (Fe and Mn), salts ($CaSO_4$, $CaCO_3$, $BaSO_4$ and $SrSO_4$) and suspended solids (Al Mutaz and Al Sultan 1997). Membrane fouling causes plugging of membrane pores by particulates (Dabbagh et al. 1994). The average concentrations of Pb (0.40 mg/l) and Cd (0.08 mg/l) in feed water are eight times higher than the recommended concentrations of Pb (0.05 mg/l) and Cd (0.01 mg/l).

3.5. Major Water Resources Issues in Ajman

The lack of the renewable freshwater resources in Ajman emirate constitutes a major deterrent to its sustainable development. On the other hand, growing population, rising standard of living, and expanding opportunities exert increasing demands for varied needs for freshwater in the emirate. These needs may be domestic, agricultural and forestry, industrial including oil and gas extraction, waste disposal, power generation, recreational, and so on. To meet demands for water for a multitude of such needs is a continuing struggle. Proper planning and management of the limited available water resources in the Ajman emirate is essential to maintain the current development and economic boom in the various sectors of the emirate. The emirate is, therefore, faced with enormous challenges to provide potable water for various needs.

Due to the tremendous increase in the living standards in the emirates over the last 2-3 decades, the per capita consumption of freshwater has reached very high levels which by far exceed the average rates. Meanwhile, the per capita share of renewable freshwater (not including the Desalinated water) in the emirate has dropped significantly due to burgeoning population and the attendant increasing need for water. Notwithstanding these severe shortages, water continues to be used unwisely, wasted and polluted. Insufficient water at the right place at the right time with the right quality requires, more than ever before, improved management, efficient utilization, and increased conservation of limited freshwater resources in the emirate. These demands can only be met if water resources are conserved, planned and properly managed.

The main reasons for the water shortage problem in Ajman emirate are related, in someway or the other, to the following:

- Rapid increase in water demands in the various water consumption sectors to cope with the booming economy and industrial development in Ajman emirate. The per capita share of freshwater consumption has tripled during the last three decades.
- The average annual precipitation over UAE and the Ajman emirate has reached its lowest levels during the last 10 years. This might be associated with the global warming Phenomenon. As a result, the natural recharge of groundwater systems in the emirate was almost absent.
- Deterioration of groundwater both quantitatively and qualitatively due to the excessive pumping mainly to meet the demands.
- Slow transfer of technologies from applied research to practice, due to miss coordination and poor networking among stakeholders. The gap between the developments in sciences related to water conservation techniques and application of the technology is still huge.
- Absence of integrated water resources management approach and practices. Long-term Strategies for water planning, management and conservation are not in place.
- Low water use efficiency and high water losses in the water distribution systems. The leakage from the distribution networks has never been properly assessed. The lack of maintenance and rehabilitation programs to improve and maintain system performance at the highest possible level has contributed to the severity of this problem.
- Shortage of available funds for water development and conservation projects. Water projects are usually massive and require high investments. On the other hand, economic returns of water development and conservation projects are generally low as compared to other investment sectors.
- Difficulties in changing the unfavorable social habits and attitudes towards water uses and conservation. This is mainly due to poor public awareness programs in the

emirate. The education curriculum at primary and elementary schools do not address water conservation in a proper manner.

The following major water management issues have been identified in developing a water resources management strategy and action plan for the emirate of Ajman:

3.5.1. Water use: policy, planning and regulation

- Reduction in quantity and quality of groundwater through over-abstraction, resulting in salinization of land, reduction in crop yields and abandonment of farms.
- Little or no effort to manage the demands for water in agriculture sector
- Lack of recognition of the true economic cost of water when assigning its use
- Uncontrolled and un-regulated well drilling, leading to dry wells and wasted Resources protection, conservation and monitoring of water resources
- Lack of a coordinated emirate-wide water resources monitoring network and program
- Lack of groundwater protection policies, e.g. no protection zones for municipal well fields that still produce drinking water
- Incomplete records, little on-site monitoring or measurement of water resources, especially whilst drilling new wells, and lack of inventories on sources and demands
- Lack of qualified, technical, on-site supervision, monitoring and data collection during drilling and general water resources monitoring
- General waste of water and leakages and water data and information management
- Non-availability or poor access to water resources information and data, and lack of a central, emirate-wide database to hold and analyze water resources data and information
- No well inventory, poor data collection when drilling wells

3.5.2. Coordination of groundwater exploration and assessment

- Need for expansion of groundwater exploration programs, especially for deeper aquifer potential
- Lack of coordination and collaboration between existing groundwater exploration and assessment programs.
- Little or no technical cooperation with neighboring emirates and countries, especially on developments on or near to the international boundaries.

3.5.3. Strategic emergency water resources

No developed strategic reserve of potable quality water in case of emergency (current reserve for less than two days) (FEWA 2007) Common to the solution of most of the issues and problems listed above is the requirement for the establishment of a central, independent authority for water management in Ajman emirate.

UAE especially Ajman is one of the most rapidly developing arid regions in the world, especially with respect to urbanization. The effects of urbanization on groundwater systems have continued to draw increased attention. The construction of buildings, roads, and sewer lines greatly affect many factors of the water cycle, however, there have been no studies conducted to evaluate the effect of rapid urbanization development on water resources, in terms of quantity and quality.

The produced wastewater is untreated and not utilized in the emirate. It can be used in amenity plantations, road verges and parks using dripping or sprinkler irrigation system. Nowadays precious groundwater is used for irrigation of road verges and parks.

3.6. History of FEWA Well Fields and Groundwater Recharge

Water is produced and supplied in Ajman by Federal Electricity and water Authority. FEWA is created in 1990 and since its creation it is trying to fulfill the water and electricity requirements in the emirates under ministry's jurisdiction and arranging construction of new projects to expand power generation and water production capacities, for efficient covering of increasing demands with the lowest possible costs.

FEWA is constantly upgrading its power generation and water production facilities, such as power stations and distribution networks, in order to increase their capacity, prevent wasting and rationalize consumption.

All of the FEWA areas have well water as one of the significant source of water supply. The central area (Dhaid, Sharjah) and East Area "B" (Dibba, Fujairah) entirely depend on well water and TRANSCO supply. In the year 1991 the groundwater usage without desalination process (direct into the distribution) was about 87% of the total water production, which has reduced to about 37% in 2006. The daily groundwater production was about 23.00 MIGD (4356 m^3/hr), which has been raised to about 30.00 MIGD (5682 m^3/hr) in late 90's. Since 2003 the daily abstraction was reduced from 27.00 MIGD (5114 m^3/hr) to 18.00 MIGD (3410 m^3/hr) (FEWA 2007).

Since UAE lacks reliable surface water resources, it needs to rely on groundwater to a certain degree and on desalination of seawater to meet the water demands. Continuous population growth, rising standard of living, mega projects and expansion in industrial activities have led to increased demand for potable water.

Rain is the main source for fresh groundwater recharge via percolation directly into bedrocks and recharging the aquifers. Available statistics show that the amount of evapotranspiration is more than 75% of the total annual rainfall. About 15% of the rainfall occurs as runoff to the sea leaving only 10% to recharge the aquifers. Abstraction of groundwater has been more than a thousand million m^3 per year. Out of this 79% is non-renewable, resulting in depletion /salination of aquifers. In addition, there is no control on drilling new wells and no regulations on the abstraction rate of well field water (Rizk and Alsharhan 2003).

A policy for farms and plantation is an important and sensitive part of the master plan process with respect to consumption of valuable groundwater and the long-term potential for replacement with desalinated water. Additionally, in this study it is assumed that in the long term, the landscaping and plantations supplied by well fields under other administration such as works department or municipality, not being under the administration of FEWA, shall not be substituted by FEWA groundwater or desalinated water in future

3.7. Need for Mapping in Ajman

3.7.1. Mapping

Mapping constitutes an integral component of the process of managing land resources, and mapped information is the common product of analysis of remotely sensed data. Natural features and manufactured infrastructures, such as transportation networks, urban areas, and administrative boundaries can be presented spatially with respect to referenced co-ordinate systems, which may then be combined with thematic information. Baseline, thematic, and topographic maps are essential for planning, evaluating, and monitoring, for military or civilian reconnaissance, or land use management, particularly if digitally integrated into a geographic information system as an information base. Integrating elevation information is crucial to many applications and is often the key to the potential success of present day mapping programs.

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A policy for farms and plantation is an important and sensitive part of the master plan process with respect to consumption of valuable groundwater and the long-term potential for replacement with desalinated water. Additionally, in this study it is assumed that in the long term, the landscaping and plantations supplied by well fields under other administration such as works department or municipality, not being under the administration of FEWA, shall not be substituted by FEWA groundwater or desalinated water in future

3.7. Need for Mapping in Ajman

3.7.1. Mapping

Mapping constitutes an integral component of the process of managing land resources, and mapped information is the common product of analysis of remotely sensed data. Natural features and manufactured infrastructures, such as transportation networks, urban areas, and administrative boundaries can be presented spatially with respect to referenced co-ordinate systems, which may then be combined with thematic information. Baseline, thematic, and topographic maps are essential for planning, evaluating, and monitoring, for military or civilian reconnaissance, or land use management, particularly if digitally integrated into a geographic information system as an information base. Integrating elevation information is crucial to many applications and is often the key to the potential success of present day mapping programs.

3.7.2. Planimetry

Planimetry consists of the identification and geo location of basic land cover (e.g. forest, marsh), drainage, and anthropogenic features (e.g. urban infrastructure, transportation networks) in the x, y plane. Planimetric information is generally required for large-scale applications - urban mapping, facilities management, military reconnaissance, and general landscape information.

Land surveying techniques accompanied by the use of a GPS can be used to meet high accuracy requirements, but limitations include cost effectiveness, and difficulties in attempting to map large, or remote areas. Remote sensing provides a means of identifying and presenting planimetric data in convenient media and efficient manner. Imagery is available in varying scales to meet the requirements of many different users. Defense applications typify the scope of planimetry applications - extracting transportation route information, building and facilities locations, urban infrastructure, and general land cover.

Concerns of the mapping community with regard to use of satellite data are spatial accuracy and the level of detail of extractable information content. The concern for information content focuses not only on interpretability of features, but on the ability to determine the correct spatial location of a feature. An example of the latter would be the difficulty associated with defining the centre of a river or precise location of a power line or pipeline right-of-way in vector format, when interpreting from a relatively coarse raster base. Spatial resolution is a critical element in this case. The turnaround time of one or two weeks will generally meet the requirements for this type of mapping, although defense requirements may be more stringent.

3.7.3. Topographic and baseline thematic mapping

There is a growing demand for digital databases of topographic and thematic information to facilitate data integration and efficient updating of other spatially oriented data. Topographic maps consist of elevation contours and planimetric detail of varied scale, and serve as general base information for civilian and military use. Baseline thematic mapping (BTM) is a digital integration of satellite imagery, land use, land cover, and topographic data to produce an "image map" with contour lines and vector planimetry information. This new concept of thematic mapping was developed to take advantage of improvements in digital processing and integration of spatial information, increased compatibility of multisource data sets, the wide use of GIS to synthesize information and execute analyses customized for the user, and increased ability to present the data in cartographic form. (Figure 3.9) describes multiple layers of data are merged over IKONOS image of Ajman in Arc GIS 9 showing GIS as a powerful tool.

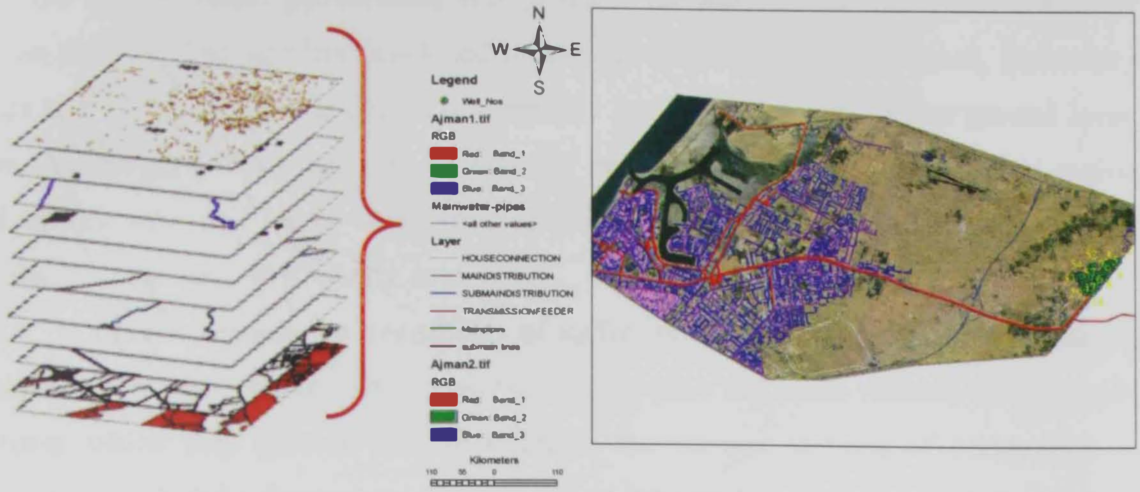


Figure 3.9. Super imposed layers to show GIS as a powerful tool

The data for baseline thematic maps are compiled from topographic, land cover, and infrastructure databases. Appropriate thematic information is superimposed on a base map, providing specific information for specific end users, such as resource managers. Various combinations of thematic information may be displayed to optimize the map information for application specific purposes, whether for land use allocation, utility site selection and route planning, watershed management, or natural resource management and operations.

As a base map, imagery provides ancillary information to the extracted planimetric or thematic detail. Sensitivity to surface expression makes radar a useful tool for creating base maps and providing reconnaissance abilities for hydrocarbon and mineralogical companies involved in exploration activities. This is particularly true in remote northern regions, where vegetation cover does not mask the micro topography and generally, information may be sparse.

Multispectral imagery is excellent for providing ancillary land cover information, such as forest cover. Supplementing the optical data with the topographic relief and textural nuance inherent in radar imagery can create an extremely useful image composite product for interpretation.

3.8. Groundwater Source for Ajman

Groundwater is an important source of water for Ajman. It was the only source of freshwater before the construction of desalination plants. Despite its heavy utilization over the last 30 years, groundwater still provides the majority of the water source for Ajman Emirate. The aquifers developed to date are primarily unconsolidated, quaternary sands and alluvium found at depths of generally less than 50 -100m below ground level. Groundwater generally originates as recharge from rainfall runoff in the eastern region and moves west and north- west towards the Arabian Gulf where it discharges into sabkhas and the sea (Al-Hogaraty et al. 2008).

In order to ensure the availability of sufficient quantity of good quality water, it becomes almost imperative in a modern society, to plan and build suitable water supply systems, which may provide potable water to the various sections of community in accordance with their demands and requirements. The updated water resources data and efficient water supply systems shall further attract industries and there by helping in industrialization and modernization of the society, consequently reducing unemployment and ensuring better living standards. Such schemes shall, therefore help in promoting wealth and welfare of the entire humanity as whole.

3.8.1. Study area for groundwater resources of Ajman

Ajman is situated on the western coast of the Arabian Gulf, extending over a distance of 16 km long, between the emirates of Umm ul Quwain and Sharjah, Hallew in Ajman emirate constitutes the major groundwater resource. It is located 10 km from Ajman city, at approximately 360947E - 2809613N and 360283E – 2809072N (Figure 3.10). The Hallew area covers about 18 square kilometers. Soil texture is dominated by sand. Visible features are Ghaf and Acacia trees, sand dunes and farms.

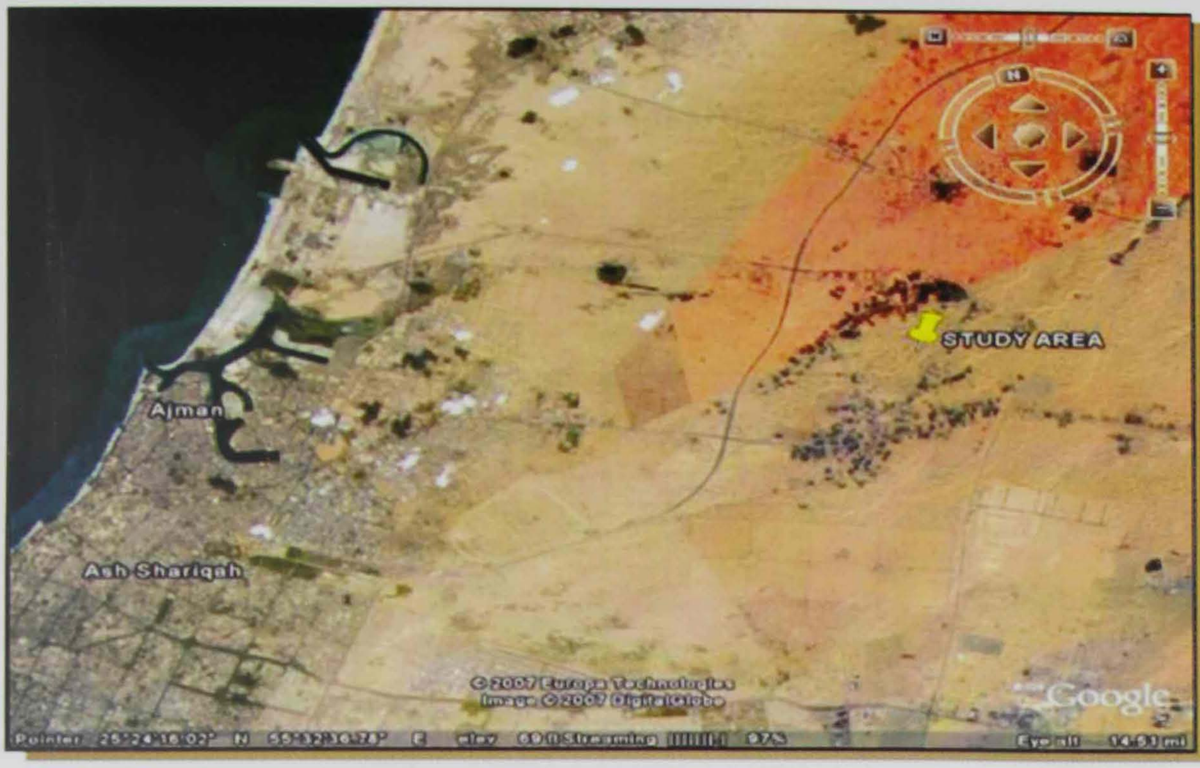


Figure 3.10. Location of study area for groundwater resources of Ajman

3.8.2. Groundwater data collection

Because of limited potable water resources in the city of Ajman, FEWA decide to expand its well fields and drill new wells. FEWA had selected the location of the pumping field in the outskirts of Ajman, which is called Hallew area. A total of 24 wells were drilled in the year of 1990. As the Ajman population increased, the water demands have also increased. FEWA drilled additional wells in the same area to meet the demands. The total numbers of production wells reached 57 wells in the year 2000.

3.9. Data Entry in Arc GIS 9 and GWW Software

Data was collected using a Magellan GPS navigator. An excel spreadsheet was created with three columns; column 1 identifies the well numbers, column 2 labeled as x which indicates eastern positions, while column 3 which labeled as y indicates the northern positions. (Table 3.2) provides the collected data.

Table 3.2. X and y coordinate of 57 wells in Hallew area

No	X- Coordinate	Y -Coordinate	No	X- Coordinate	Y -Coordinate
1	360947	2809613	30	360222	2809127
2	361014	2809673	31	360333	2809172
3	361065	2809734	32	360344	2809255
4	361107	2809801	33	360405	2809066
5	360877	2809531	34	360368	2809357
6	360828	2809458	35	360465	2809348
7	360775	2809375	36	360403	2809442
8	360687	2869295	37	359759	2809286
9	360606	2809184	38	359821	2809317
10	360534	2809104	39	359882	2809311
11	360484	2808992	40	359959	2809202
12	360375	2808880	41	359568	2809379
13	360281	2808761	42	359676	2809339
14	360141	2808788	43	359759	2809366
15	360185	2808922	44	360076	2809179
16	360319	2808997	45	360049	2809271
17	360588	2809356	46	360094	2809345
18	360651	2809530	47	360212	2809332
19	360730	2809601	48	360290	2809491
20	360957	2809780	49	360222	2809627
21	361009	2809867	50	360230	2809713
22	361224	2809923	51	360300	2809684
23	359989	2808813	52	360354	2809756
24	360773	2809688	53	359840	2809402
25	360915	2809860	54	359905	2809383
26	360034	2808934	55	360824	2809809
27	359908	2809044	56	360725	2809784
28	359966	2809122	57	360283	2809072
29	360083	2809059			

The easting, northing, and well numbers columns are formatted as numbers. The excel sheet was saved as a DBF 4 (dBase IV) file. Data was then imported to Arc view. A predefined coordinate system was selected. (Ajman is in UTM zone 40). Points of the wells taken by GPS appeared in the map view area. IKONOS image of the area has been requested and collected from GISTEC and FEWA in 10m resolution. The image is geometrically registered to a known geographic base, so that it can be combined with other mapped data in a digital environment for further analysis. The advantage of geometrically correcting an image prior to further analysis and interpretation is that it would then allow proper measurements of distances and areas to be made from features in the image. This may be particularly useful in different applications where true measurements are necessary, such as in urban mapping applications. Also, the geographic locations of features could be determined.

New line themes are created and different layers have been added including main roads, main pipe lines, sub main lines, data of wells. A base map that represents the spatial distribution of groundwater wells on IKONOS Image, of the Ajman emirate is created utilizing MS excel and Arc view tools. The ultimate objective is to develop a GIS database for water wells in Ajman to ensure the sustainability of the available water and provide technical support for researcher, professionals and decision makers in the area of water resources.

Lithology of each well in Hallew area has been entered in GWW software (Appendix D) and then linked with the Arc view. All the information about any well can be easily retrieved from the system including x, y coordinates, well number, date of drilling, depth ranges in feet, thickness of different layers, description of lithology, well construction and lithological log, and remarks about well construction method of drilling, diameter of the casing, water level at the time of drilling and so on. Eventually, the database also include data about EC in μS/cm, TDS in mg/l, PH, Total Hardness as $CaCo_3$, Total Alkalinity as $CaCo_3$, Hco_3 in mg/l, So_4, Cl, No_3, f, Ca^{++}, Mg^{++}, Na^+, K^+ and Sio_2 all in mg/l.

This study included basic survey for the wells, measurement of selected field hydrochemistry and monitoring of groundwater levels. Tasks which are accomplished are as follows:

a) GPS surveying of latitude and longitude coordinates and elevation.

b) Obtaining production well yields

c) Measurement of static and dynamic water levels (Appendix B)

d) Field measurement of water quality (EC, ph, and Temp) (Appendix C)

e) Collection of pumping and construction data of the wells (Appendix A)

f) Creating and populating a simple database of the above information

g) Using a GIS software package [(Arc GIS 9 (Arc Map)] to map and analyze the data.

For the geo-referencing of wells in well fields, Global Positioning Satellite (GPS) receivers were used. The coordinates of each single well were obtained by using GPS devices. With the GPS, the coordinates were given in the UTM format Universal-Transversal-Mercator projection. The measurement of the coordinates was done either on the head of the well or as close as possible.

The groundwater level was measured by using a SEBA electric contact meter type KLL, produced by SEBA hydrometry kaufbeuren, Germany. With this device, both the dynamic and the static water level were measured from the top of the well casing. Because in most cases the pumps were running, only the dynamic or pumping water level could be measured. This is defined as "the depth below the surface of the groundwater level in the well when the pump is operating", which is always deeper than the static water level. In the case in which the pumps were not running, the static water level (SWL) was determined.

3.10. Use of Groundwater for Windows (GWW Software) - An Overview

Groundwater for windows is a relational data base and a Groundwater Information System (GWIS). The GWW combines the principles of GIS with powerful dedicated groundwater data processing and reporting modules:

- Master data
- Chemical data (including time and depth series)
- Pumping test processing and aquifer parameters
- Well logs and well construction data
- Lithologic, hydrogeologic and stratigraphic cross sections (in two and three dimensions)
- Mapping
- Step drawdown test data
- Water level measurement data
- Grain size distribution curves and calculations of hydraulic conductivity using empirical formulas
- Various hydrogeological calculations, such as well functions, draw downs, and miscellaneous well construction data.
- User-defined storage and retrieval applications

3.10.1. Creating a new log

To create a new well log, the procedure is the following.

1. In the entry form type the new well identification name or number, using any combination of numbers and characters. Fill other fields with information. If the well identification name already exists in your data base (it will exist if you have typed some information for this well either in the master data application or in any other application),

the program will automatically fill in the fields that already have information. The new file creation in GWW is shown in (Figure 3.11).

Normally this would apply to x and y coordinates, ground surface elevation and well description.

2. Select W.L.Data and Edit Log data. Type the data into the table. On the last line with information after you type a code for Lith. Unit, override the default description by adding another in the column Comment, hold down the CTRL key and press S.

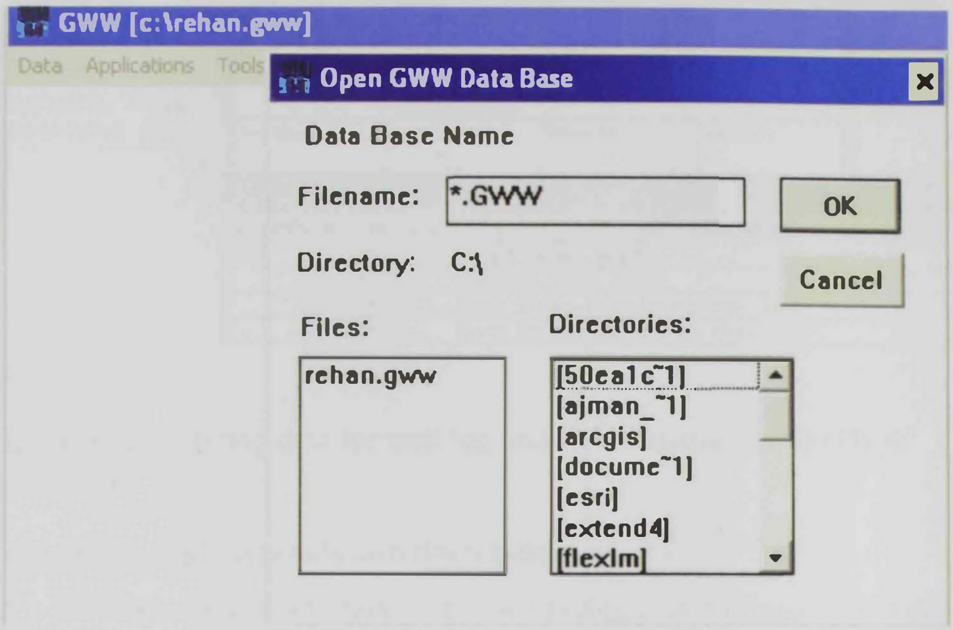


Figure 3.11. Creating a new file for well log in GWW

3.10.2. Data, well log and well construction

- Well log data (abbreviated to W.L.Data)
- Display
- Construction
- Report
- Lithologic units (abbreviated to lith.units)
- Load map

Using the well log application (Figure 3.12) on the main menu bar of the GWW software the following actions can be done:

- Create a new well log by entering drilling data (depths and lithologic description of drilled layers) and construction data (hole and casing diameters, screen positions, materials filling annulus).

- Use the existing lithologic symbols for various lithologic members and/or materials filling the annulus.
- Create new symbols directly on the screen or using a text processor.
- Display a well log with its construction details on the screen.

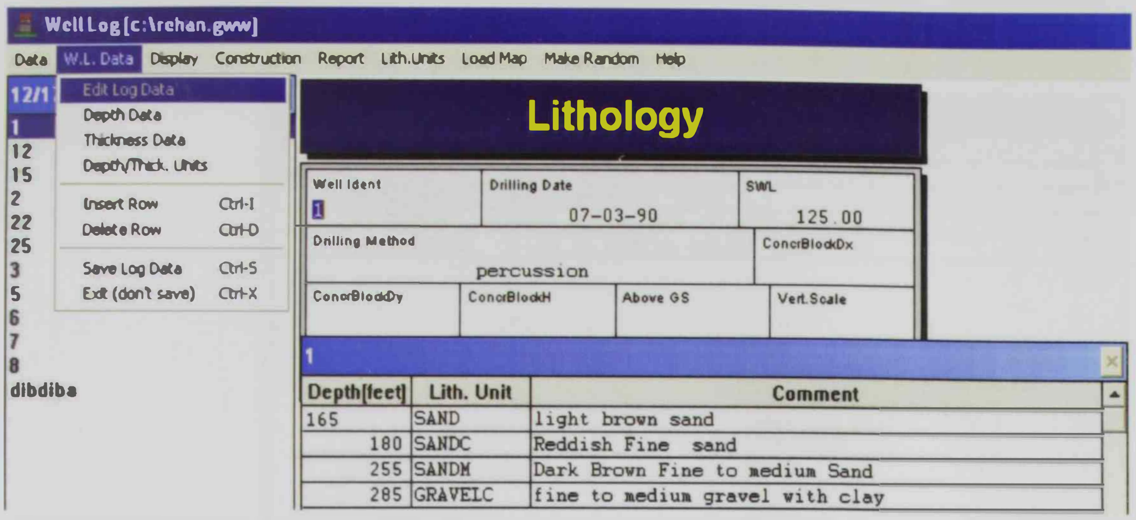


Figure 3.12. Entering data for well log and well construction in GWW

3.10.3. Editing lithologic symbols and descriptions

Editing of a lithologic unit or addition of a new lithologic unit (Figure 3.13) can be done by following way:

1. Select Lith. Units on the menu bar.
2. Select Edit Lithological Unit.

The screen will display a list with all currently available lithologic units. Editing of existing lithologic units is shown in (Figure 3.13) for a unit coded as GRAVELC. The acronym is user-definable. In this case it stands for "Fine to Medium Gravel with Clay ". You may use anything, but acronyms or codes should be easy to remember. For this unit the default description that will be typed on the log is: GRAVELC.

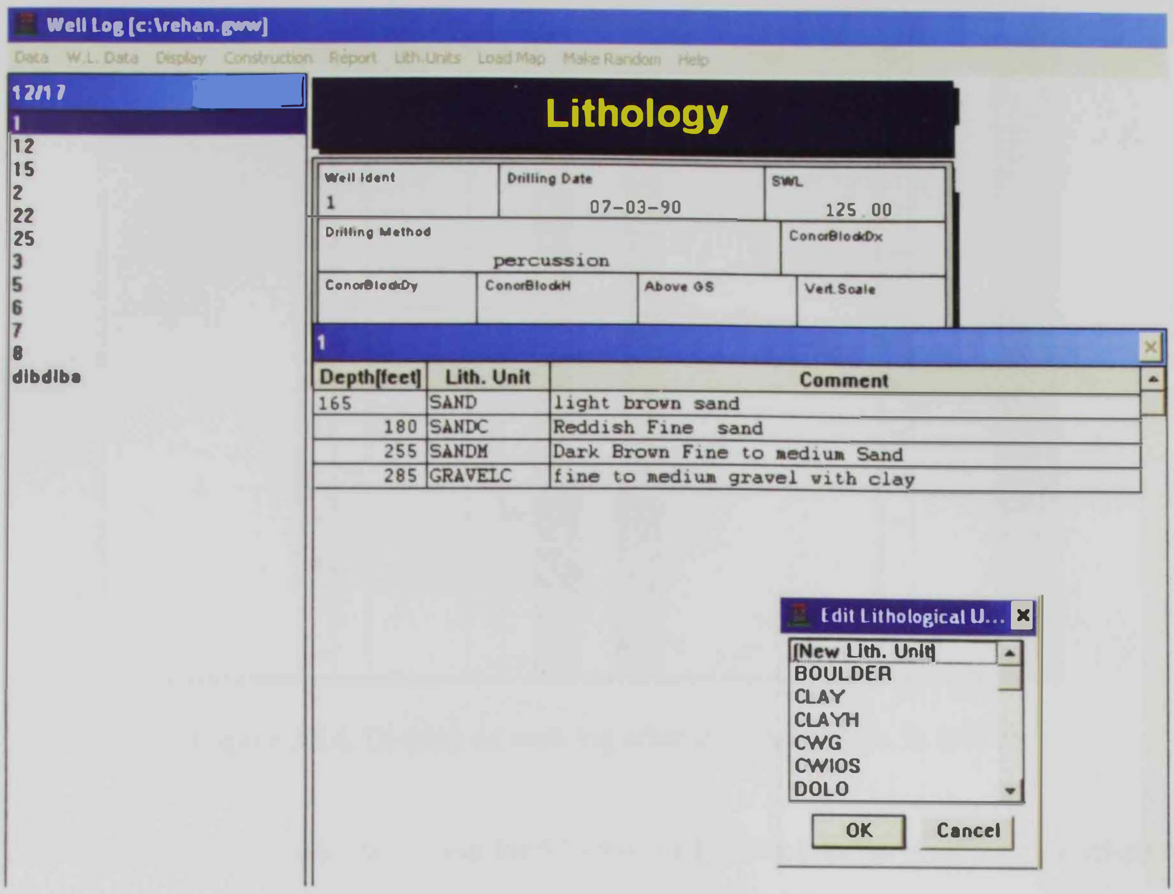


Figure 3.13. Editing lithological symbols in GWW

3.10.4. Construction data and display

You may display a well log at any time. It may show only intervals of depth without any description and symbols. This will happen if you did not input the ASCII file with codes, symbols and description of lithology. It may display intervals, lithologic symbols and description of units but without any construction details. This will happen if you did input the lithology ASCII file, but not construction details. It may display construction, annulus-filling materials, and lithology, as, if you have all associated files in the data base and have entered construction information. To display a drilling and construction log of a well you should:

1. Select, using cursor or up and down arrows, the well that you wish displayed.
2. Select **Display** from the menu bar and it will be displayed as shown in (Figure 3.14).

The log will be displayed without any further intervention. Once displayed, you may zoom a portion, or use the option **Fit Wnd** (Fit Window).

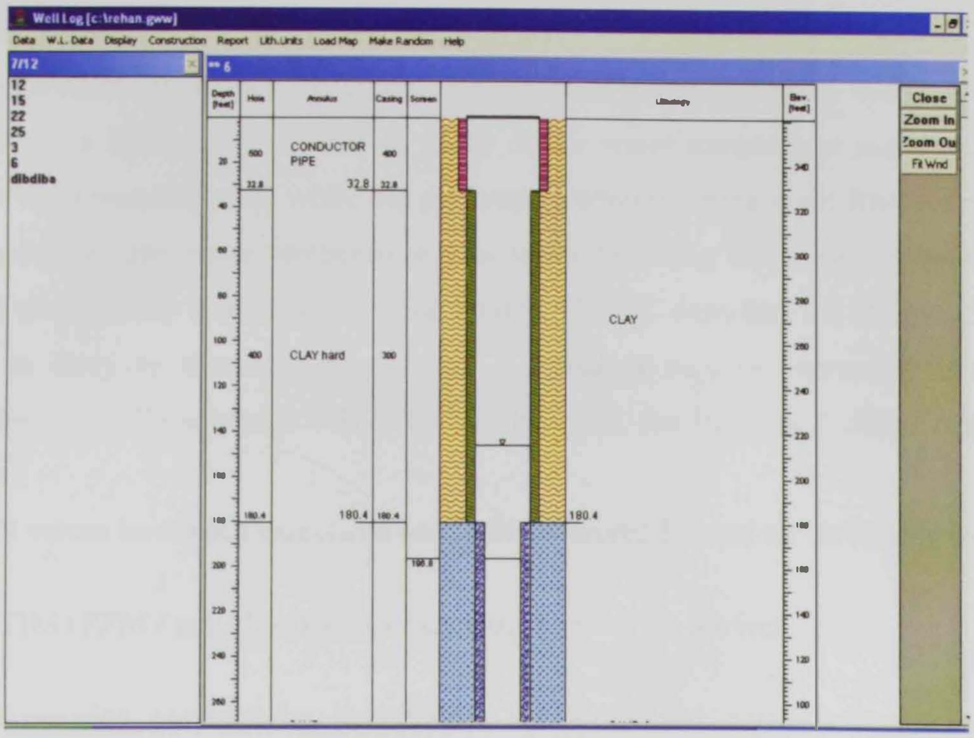


Figure 3.14. Display of well log after its construction in GWW

After entering all the data one by one for 57 wells of Hallew area the well logs are created and the sample of which can be seen in (Figure 3.15) and remaining 56 wells can be seen in (Appendix D).

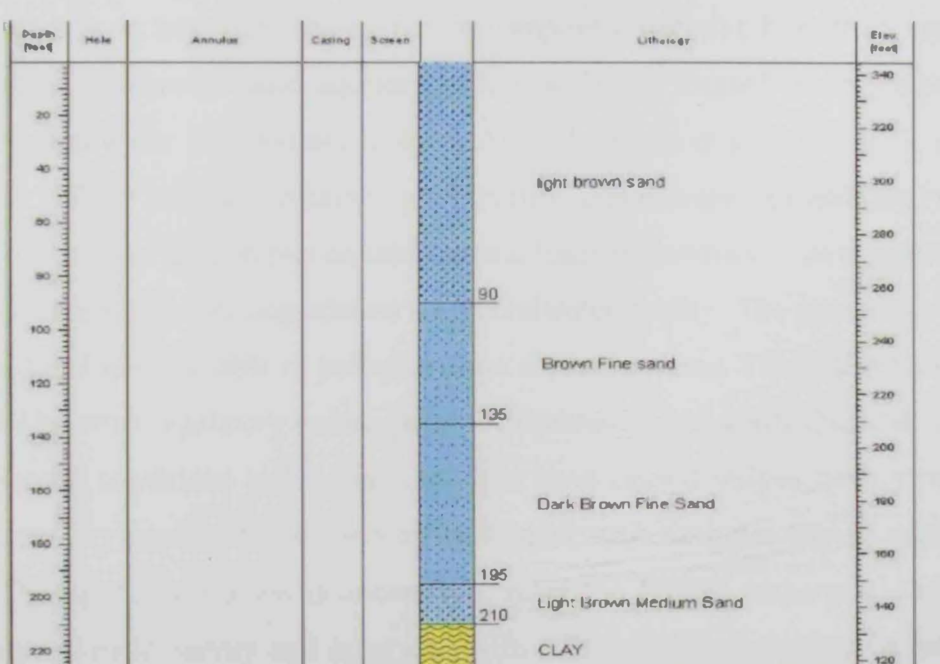


Figure 3.15. Display of well log after its construction in GWW for well no.8 Hallew

3.11. Chemical Analysis for Hallew Wells Water

The groundwater quality was measured using a multi meter 340i from WTW Weilheim, Germany. The Electrical Conductivity (EC) of the water sample was measured with a conductivity-measuring cell, while the pH was determined using a pH Electrode SenTix 20. In addition, the water temperature was taken by using the same equipment. The samples were mainly taken from running pumps. The EC describes the ability of a water sample to carry an electrical current and it increases with an increasing amount of impurities (Total Dissolved Solids "TDS"). Therefore, the EC is an indirect measure of the TDS.

The TDS values have been calculated using the measured EC and the following formula:

TDS (PPM / mg / l) = EC (µs / cm)*0.67 (water on the web 2008)

When measuring conductivity temperature variations and corrections represents the largest source potential error (US EPA 2008).Besides the data taken by the authors, extracted data of the regular laboratory analysis of the water quality are included in the results. This analysis is performed by the laboratory section of the FEWA and contains, among others, investigations of the following parameters: Sulphate, Magnesium, Calcium, Chloride, Nitrate, Ammonium, pH, TDS and Conductivity.

Ajman has been experiencing rapid economic development, urbanization and dramatic change in land use. These activities impose a negative impact on groundwater quality in the quaternary sand aquifer in Hallew. Being located down-gradient of the regional groundwater flow system in the UAE (Alsharhan et al. 2001, Rizk and El-Etr 1998), the Hallew naturally receives poor-quality groundwater. In addition, unplanned disposal of waste in unlined pits on land surface leads to downward movement of surface pollutants, causing further degradation of groundwater quality. The quaternary aquifer is unconfined and is vulnerable to pollution from surface sources. This vulnerability can be minimized by strict regulatory enforcement to eliminate illegal waste disposal.

Natural conditions and human activities have caused serious quality degradation of the quaternary aquifer in the north of the United Arab Emirates (UAE) specifically in Ajman. The aquifer in Hallew is unconfined, receiving limited recharge (12542 m^3/day) from the east. Field survey and laboratory analyses revealed anomalies in groundwater salinity (TDS), total hardness (TH), dissolved oxygen (DO), cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+), anions (Hco_3 ,So_4 , Cl and No_3) and trace elements (Fe, Pb, Cd and Cr) which can be correlated to point and nonpoint pollution sources. Concentrations of trace elements are more responsive to anthropogenic sources than natural ones (Al-Hogaraty et al. 2008).

3.11.1. Field work and materials and methods

Field work for the chemical analysis was started in June 2006 and completed in August 2007. Hallew area hydrogeology and hydrogeochemistry was surveyed and investigated. Depths of the groundwater were measured in 57 FEWA water wells in Hallew area (detail of well inventory data and water levels in Hallew wells year wise can be seen in Appendix A and Appendix B). 37 groundwater samples were collected for chemical analysis with the help of FEWA central Lab. The physical parameters of water such as temperature (°C), electrical conductivity (EC) in micro siemens per centimeters (μs/cm) and hydrogen ion concentration (ph) were directly measured in the field because they change after sample collection (Hem 1985).

3.11.2. Laboratory analysis

The chemical analysis of groundwater samples collected for this study was conducted in the central laboratory at FEWA Stores Sharjah (Table 3.3). Standard analytical techniques described in (Rainwater and Thatcher 1960), (FAO 1970), (APHA 1995) and (Skoog et al. 2004) were applied. Chemical analysis of major, minor and trace chemical constituents was performed using titration methods, ion chromatography (Weiss 1986), atomic absorption spectrophotometry (Ediger 1973) and inductively coupled plasma-atomic emission spectrometry (Wolf and Grosser 1997).

For measurement of total dissolved solids (TDS), a 100 ml of well-mixed water sample was filtered through a standard glass fiber. The filtrate was evaporated to dryness in a weighed dish and dried to a constant weight at 180°C. The increase in dish weight represented the total dissolved solid (APHA 1995). The detail of chemical analysis of Hallew wells for the year 2003 can be seen as a sample in (Table 3.3) and chemical analysis for all Hallew wells are shown in (Appendix C) in which the spread sheets are created for year wise with their graphical representation.

For determination of alkalinity, soluble carbonate (CO_3) and bicarbonate (HCO_3) anions were measured by titration of 50ml water sample against 0.02 N HCl solution using phenolphthalein and methyl orange indicators (Skoog et al. 2004). Total hardness was measured by addition of 2ml of the buffer solution ph-10 and three to four drops of

Erichrome Black T indicator to 10ml water sample, and titration with standard 0.01 M EDTA solution.

3.12. Groundwater Pollution

Groundwater pollution depends on topography, hydrogeology, the sources of groundwater recharge and the amount of groundwater pumping. Both point and non-point groundwater pollution sources in Hallew are discussed in the following:

3.12.1. Point pollution sources

During field survey, special emphasis was given to inspection of old and operating waste disposal sites because of their direct negative impact on groundwater quality. Unfortunately, all waste disposal sites are unlined and directly conveying their leachates to the underlying groundwater which are near to Hallew area.

3.12.2. Non-point pollution sources

Farmland covers 40 km^2 on the eastern side of the emirates road which is adjacent to Hallew and represents the main potential diffuse source of groundwater pollution in Hallew area. The residential (32 km^2) and industrial (20 km^2) areas are also potential non-point groundwater pollution sources because of the unregulated waste disposal and lack of a sewage network in the city (Al-Hogaraty et al. 2008).

Point and non-point pollution sources are not the only factors contributing to groundwater pollution at Ajman. Natural factors such as the geographic location, prevailing climate and hydrogeologic setting also have a negative influence on groundwater quality in the study area.

Table 3.3. Hallew area chemical analysis for the year 2003

No	EC	TDS	Ph	T.H	T.Alk	Hco_3	So_4	Cl	No_3	F	Ca	Mg	Na	K	Sio_2
1	5350	3344	7.65	630	202.1	246.6	525	1247	4.4	0.96	66	113	819	21.5	27
2	5230	3269	7.59	620	204.8	249.9	500	1195	3.96	0.89	66	110.6	804	20.9	27
3	5280	3300	7.55	615	206.2	251.6	515	1217	2.2	0.80	66	109.4	820	21.1	29
4	5340	3338	7.76	665	212.9	257.7	515	1233	0.88	0.65	66	121.5	834	21.3	24
5	6140	3838	7.53	800	202.1	246.6	575	1484	3.52	0.94	80	145.8	951	24.5	27
6	5990	3744	7.60	740	234.5	286.1	575	1405	3.52	0.85	68	138.5	931	24	28
7	5030	3144	7.58	780	226.4	276.2	575	1432	3.08	0.91	78	142.2	771	20.1	27
8	5780	3612	7.61	790	188.7	230.2	560	1330	1.32	0.89	80	143.4	857	23.2	27
9	5920	3700	7.54	830	180.6	220.3	575	1388	3.08	0.89	86	149.5	885	23.6	27
10	6500	4063	7.55	935	173.8	212.1	625	1572	4.4	0.97	98	167.7	1016	26	28
11	6980	4363	7.55	1035	163.1	198.9	700	1722	8.8	0.94	108	185.9	1019	28	28
12	7420	4638	7.48	1120	175.2	213.7	750	1845	7.04	0.98	126	195.6	1083	29.7	28
13	7960	4975	7.31	1265	163.1	198.9	800	2003	2.64	0.94	136	224.8	1165	31.9	27
14	5940	3713	7.61	725	206.2	251.5	575	1370	1.32	0.93	74	131.2	935	23.8	28
15	8110	5069	7.52	1300	171.1	208.8	800	2099	6.16	0.95	136	233.3	1190	32.5	29
16	8010	5006	7.50	1260	165.7	202.2	800	2020	3.08	0.95	128	228.4	1174	32.1	31
17	6780	4238	7.48	1025	172.5	210.4	700	1669	3.96	0.94	108	183.5	1083	27.3	28
18	6710	4194	7.61	980	188.7	230.2	650	1607	3.08	0.99	98	178.6	982	26.9	26
19	6960	4350	7.58	1010	192.69	235.08	685	1695	2.2	0.93	98	185.9	1022	28	26
20	6530	4081	7.63	870	207.5	253.15	650	1563	1.76	0.92	84	160.4	999	26.1	28
21	5460	3413	7.60	685	207.5	253.15	525	1265	0.88	0.89	62	128.8	862	21.8	28
22	5590	3494	7.73	675	225.03	274.54	525	1300	0.88	0.81	68	122.7	886	22.4	27
23	5700	3563	7.66	715	215.6	263.03	525	1353	1.32	0.89	72	130	904	22.8	27
24	8030	5019	7.62	1240	172.48	210.43	800	2038	3.96	0.94	126	224.8	1198	32.1	28
25	6520	4075	7.57	855	215.6	263.03	650	1563	0.88	0.97	82	158	1035	26.2	24
26	8030	5019	7.56	1220	169.78	207.13	800	2020	2.64	0.85	128	218.7	1174	31.8	29
27	7590	4744	7.58	1070	191.34	233.44	740	1862	1.76	0.92	114	190.8	1167	30.4	28
28	6830	4269	7.60	920	198.08	241.66	660	1651	0.88	0.92	90	168.9	1029	27.3	27
29	7530	4706	7.58	1130	175.17	213.71	730	1888	1.32	0.92	114	205.3	1099	30.1	27
30	7080	4425	7.57	1060	183.28	223.6	700	1748	4.4	0.87	120	184.7	1045	28.4	26
31	6720	4200	7.48	995	179.22	218.65	675	1634	6.16	0.80	106	177.4	1014	26.9	26
32	6540	4088	7.43	950	188.65	230.15	675	1685	6.16	0.80	96	172.5	977	26.1	25
33	6740	4213	7.46	990	172.48	210.43	675	1639	7.04	0.86	104	177.4	1000	26.9	26
34	6970	4356	7.43	1070	184.61	225.22	675	1739	5.72	0.74	110	193.2	1015	28	27
35	7630	4769	7.40	1200	191.34	233.43	750	1915	6.16	0.89	126	224.8	1116	30.1	29
36	7320	4575	7.56	1085	199.43	243.3	700	1662	6.16	0.82	112	195.6	1121	29.5	28
37	6580	4113	7.56	910	190	231.8	675	1581	7.92	0.79	92	105.2	996	26.3	25

Where

EC = Electrical conductivity in µs/cm

TDS = Total dissolved solids in mg/l

T.H = Total hardness as $caco_3$ in mg/l

T.ALK = Total alkalinity as $caco_3$ in mg/l

Remaining all chemical elements units are in mg/l

Chapter 4. Spatial Database for Water Resources in Ajman

4.1. Methodology

IKONOS image of the area has been requested from GISTEC and FEWA in 10m resolution then image is geometrically registered to a known geographic base, so that it can be combined with other mapped data in a digital environment for further analysis.

The advantage of geometrically correcting an image prior to further analysis and interpretation is that it would then allow proper measurements of distances and areas to be made from features in the image. This may be particularly useful in different applications where true measurements are necessary, such as in urban mapping applications. Also, the geographic locations of features could be determined.

In view menu choose new themes, select point then added attributes to point features so all the wells which are having x y coordinates scattered exactly on the same position (Figure 4.1) as they are in field because the image was digitized before and geo referenced

Then new line themes are created and the following layers have been added which are main road, main pipe lines, sub main lines.

During the different phases of this study nine (9) GIS layers of were created. All the layers are co-registered to the UTM projection system, UTM zone 40.GIS layers are brought together and integrated in a GIS database using Arc GIS version9 software. Remote sensing and GIS have been successfully used to quantify change extent, store geo-spatial information in separate layers and integrate the whole dataset in one container (i.e. geo-database).

4.2. Ajman Groundwater Wells Layer

The layer contains the detail of groundwater wells of Ajman Emirates.

4.2.1. Sub layers of 57 wells

57 sub layers of groundwater wells each layer showing one well were developed (Figure 4.1). In each layer the detail information about well records, water levels, depth of well (Figure 4.2 and Figure 4.3) as well as a link with lithology of well (Figure 4.4) [which was prepared in GWW software (Figure 4.5) and then linked with Arc GIS 9] is available and these are entered into attributes of each well. By clicking information button in the

menu tool bar and then clicking on any well all the information about the well can be retrieved.

4.2.2. Data for wells

Data was collected by taking Magellan GPS Navigator to each well in Hallew area which consists of 57 wells. All x and y coordinates of wells have been collected by GPS and then exported from Ms excel to ArcGIS9 the wells locations exactly come on the IKONOS image of the area as shown in (Figure 4.1).

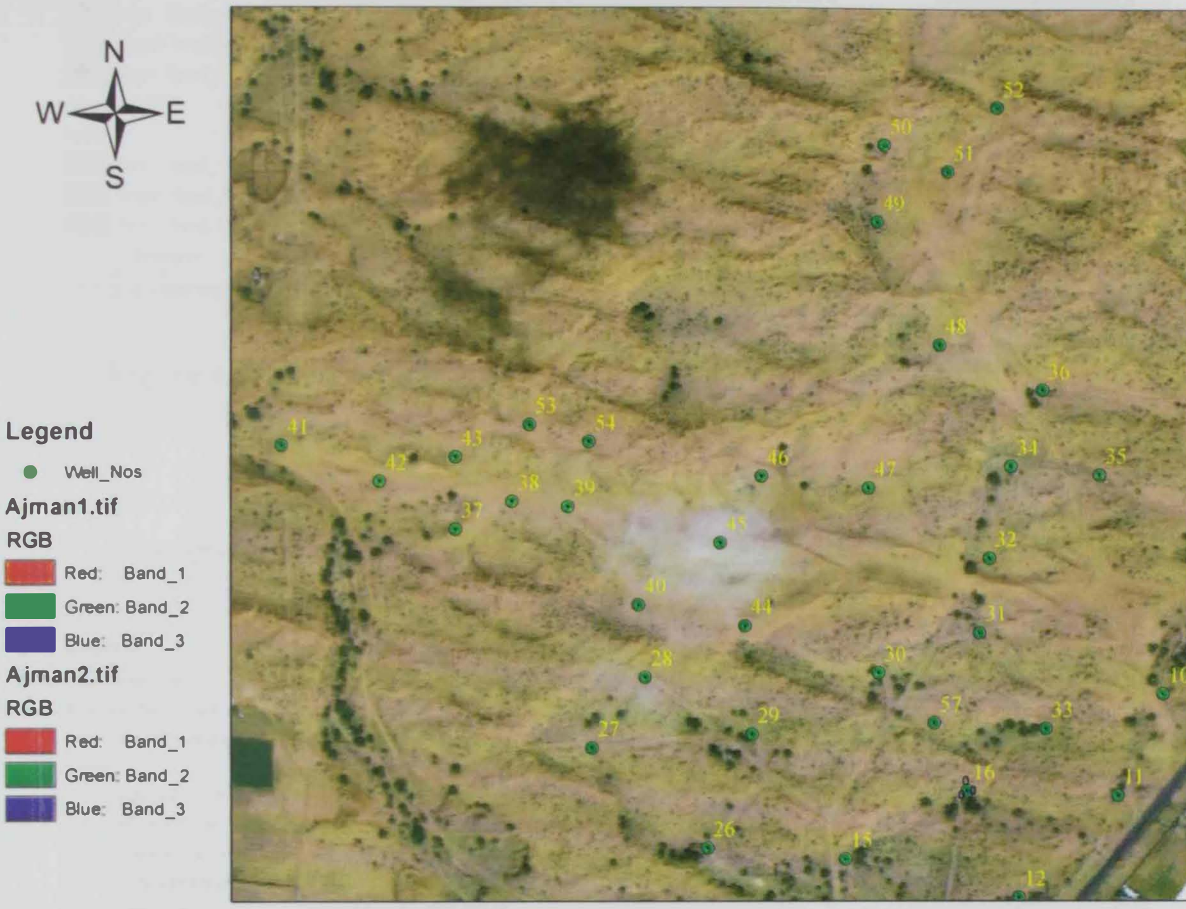
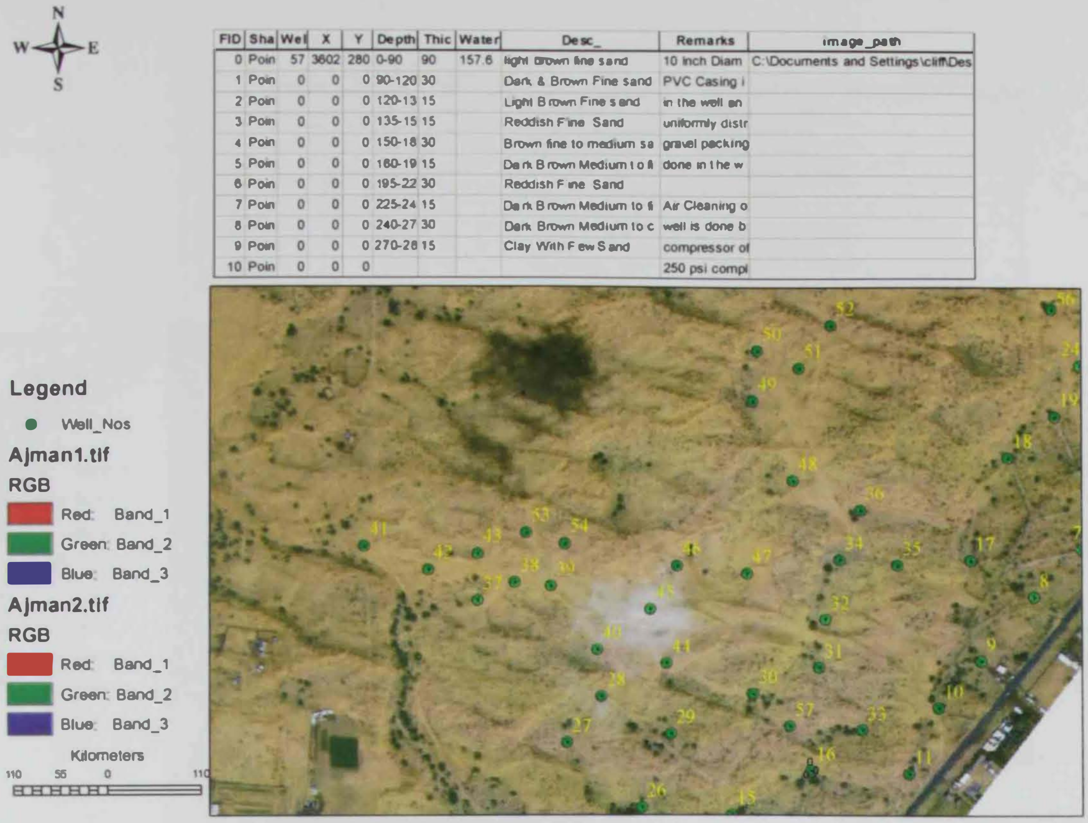


Figure 4.1. Wells imported into Arc GIS 9 on IKONOS image



FID	Sha	Wel	X	Y	Depth	Thic	Water	Desc_	Remarks	image_path
0	Poin	57	3602	280	0-90	90	157.6	light brown fine sand	10 Inch Diam	C:\Documents and Settings\cliff\Des
1	Poin	0	0	0	90-120	30		Dark & Brown Fine sand	PVC Casing i	
2	Poin	0	0	0	120-13	15		Light Brown Fine sand	in the well an	
3	Poin	0	0	0	135-15	15		Reddish Fine Sand	uniformly distr	
4	Poin	0	0	0	150-18	30		Brown fine to medium sa	gravel packing	
5	Poin	0	0	0	160-19	15		Dark Brown Medium to fi	done in the w	
6	Poin	0	0	0	195-22	30		Reddish Fine Sand		
7	Poin	0	0	0	225-24	15		Dark Brown Medium to fi	Air Cleaning o	
8	Poin	0	0	0	240-27	30		Dark Brown Medium to c	well is done b	
9	Poin	0	0	0	270-28	15		Clay With Few Sand	compressor of	
10	Poin	0	0	0					250 psi compl	

Figure 4.2. Attributes of wells and entering data of the wells in Arc view

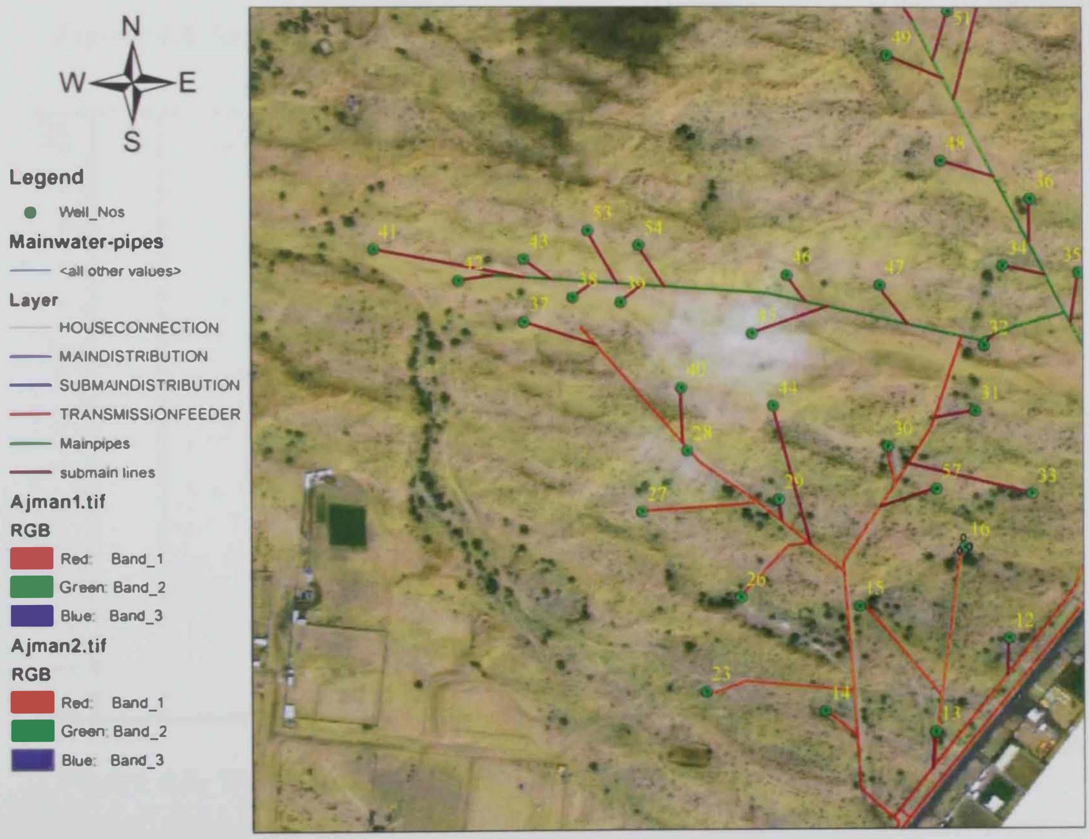


Figure 4.3. Water wells connected through pipe network

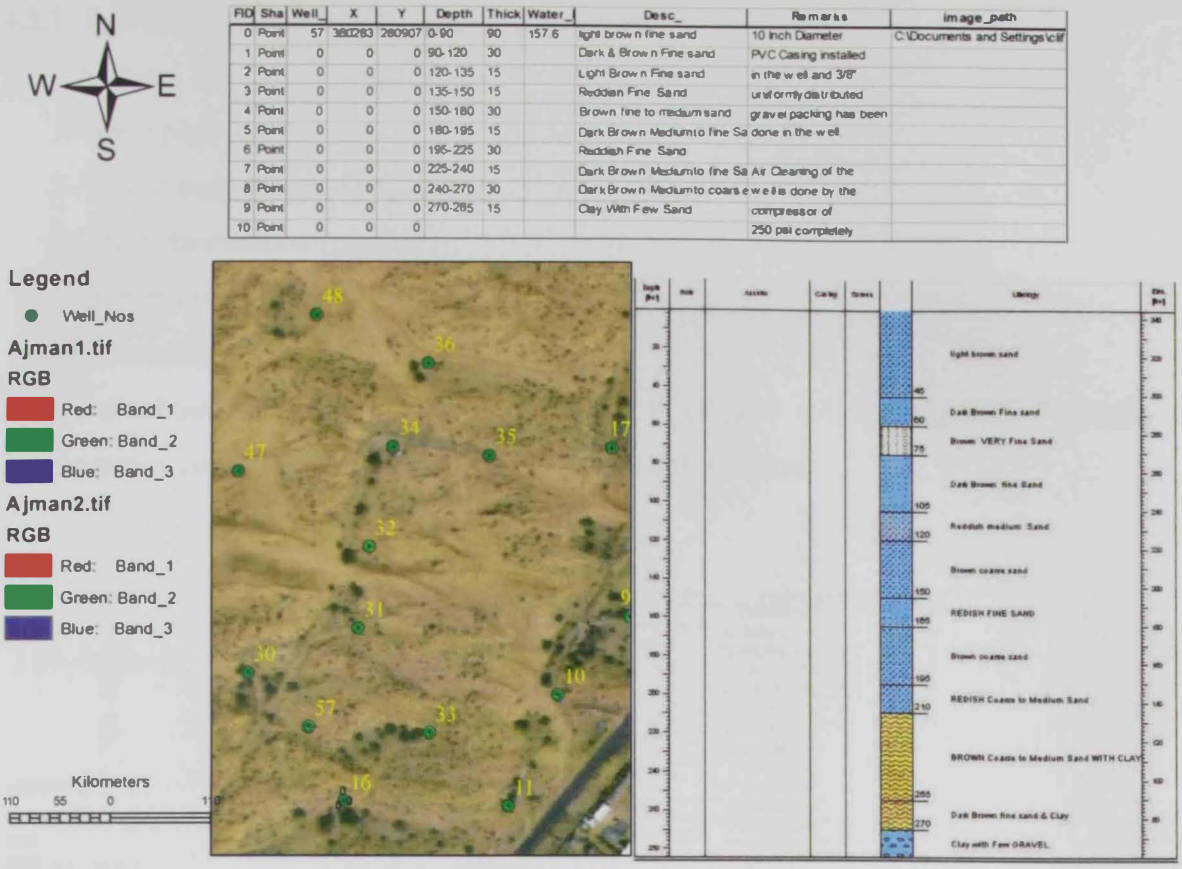


Figure 4.4. Wells lithology constructed in GWW linked with Arc view GIS

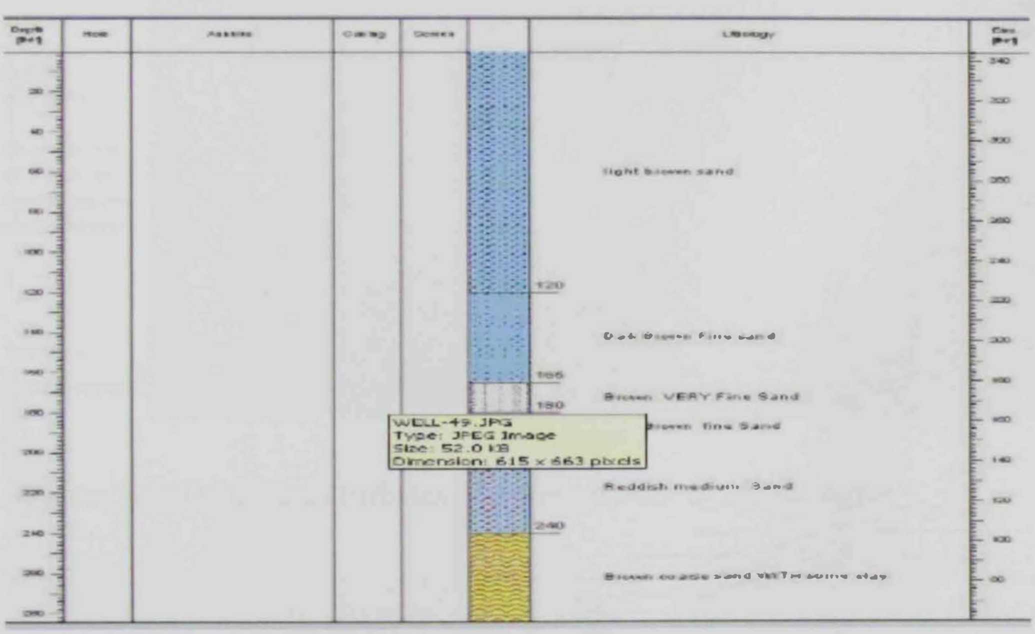


Figure 4.5. Wells lithology constructed in GWW

4.3. Water network of Ajman layer

4.3.1. Sub layers of multiple types of pipe lines

There are five layers which are:

1- Main pipe line

2- House connections (pink color)

3- Main distribution (purple)

4- Sub main distribution (blue)

5- Transmission feeder (red)

Detail about water network layer is shown in (Figure 4.6 and Figure 4.7) pipeline diameter, color, location is visible in attributes of pipelines.

FID	Shape*	FID	E	Handl	Layer	Color	Linetype	Elev	Thickn	Text
0	Polyline	0	P	21	SUBMAINDISTRIBUTION	3	CONTINUOUS	0	0	
1	Polyline	0	P	26	SUBMAINDISTRIBUTION	3	CONTINUOUS	0	0	
2	Polyline	0	P	2B	HOUSECONNECTION	10	CONTINUOUS	0	0	
3	Polyline	0	P	32	SUBMAINDISTRIBUTION	3	CONTINUOUS	0	0	
4	Polyline	0	P	36	HOUSECONNECTION	10	CONTINUOUS	0	0	
5	Polyline	0	P	3A	HOUSECONNECTION	10	CONTINUOUS	0	0	
6	Polyline	0	P	3F	MAINDISTRIBUTION	5	CONTINUOUS	0	0	
7	Polyline	0	P	43	HOUSECONNECTION	10	CONTINUOUS	0	0	
8	Polyline	0	P	47	SUBMAINDISTRIBUTION	3	CONTINUOUS	0	0	
9	Polyline	0	P	4B	HOUSECONNECTION	10	CONTINUOUS	0	0	
10	Polyline	0	P	4F	SUBMAINDISTRIBUTION	3	CONTINUOUS	0	0	
11	Polyline	0	P	53	MAINDISTRIBUTION	5	CONTINUOUS	0	0	
12	Polyline	0	P	58	HOUSECONNECTION	10	CONTINUOUS	0	0	

Figure 4.6. Detail and attributes of water network in Ajman layer

Figure 4.7. Water network of Ajman layer

4.3.2. Data for water network of Ajman

Data is collected for water network of Ajman was collected from FEWA head office Dubai, FEWA office Ajman As well the files available in Planning department of FEWA in Auto Cad files that were transferred to Arc GIS 9.

4.4. Pumping Stations of Ajman Layer

4.4.1. Sub layers of pumping stations, desalination plant and water tanks

There are four layers which are:

Sub layer 1- new pumping station

Sub layer 2- old pumping station

Sub layer 3- Ajman RO desalination plant

Sub layer 4- Four layers for water tanks in Ajman

(Figure 4.8) describes the location of pumping stations, desalination plant and water tanks in Ajman.

Figure 4.8. Desalination plants, pumping station and storage tanks layer

4.4.2. Data for pumping station, desalination plants and storage tanks

Data is collected for pumping stations, desalination tanks of Ajman by Magellan GPS Navigator as well from the previous old records available in FEWA Ajman pumping station and desalination plants as well the collecting data from planning department of FEWA Dubai office.

4.5. Sewerage Network of Ajman Layer

4.5.1. Sub layers of sewerage pumping stations and disposal pond site

There are eleven sub layers which are:

Sub layer 1: ten layers of sewerage pumping stations.

Sub layer 2: one layer of disposable pond site.

Detail of sewerage network of Ajman is entered in eleven layers (Figure 4.9) and detail is entered in attribute tables.

Figure 4.9. Sewerage network of Ajman layer

4.5.2. Data for sewerage network of Ajman

Data is collected for sewerage network from the following organizations:

1- Ajman sewerage (private) company limited (employer)

2- Black and Veatech (construction contractor)

3- Six construct limited (contractor)

4- Mott MacDonald (employer representative)

5- Halcrow (independent consulting engineer)

4.6. Ajman Land Details Layer

4.6.1. Sub layers of Ajman land details

There are five sub layers which are:

Sub layer 1- roads

Sub layer 2- sub roads

Sub layer 3- parcels

Sub layer 4- sectors

Sub layer 5- administrator

Detail of Ajman land details layer is entered in five layers (Figure 4.10) and detail is entered in attribute tables.

Figure 4.10. Ajman land details layer

4.6.2. Data for Ajman land details

Data is collected for land details were from cad drawings of FEWA and Ajman municipality.

4.6. Ajman Land Details Layer

4.6.1. Sub layers of Ajman land details

There are five sub layers which are:

Sub layer 1- roads

Sub layer 2- sub roads

Sub layer 3- parcels

Sub layer 4- sectors

Sub layer 5- administrator

Detail of Ajman land details layer is entered in five layers (Figure 4.10) and detail is entered in attribute tables.

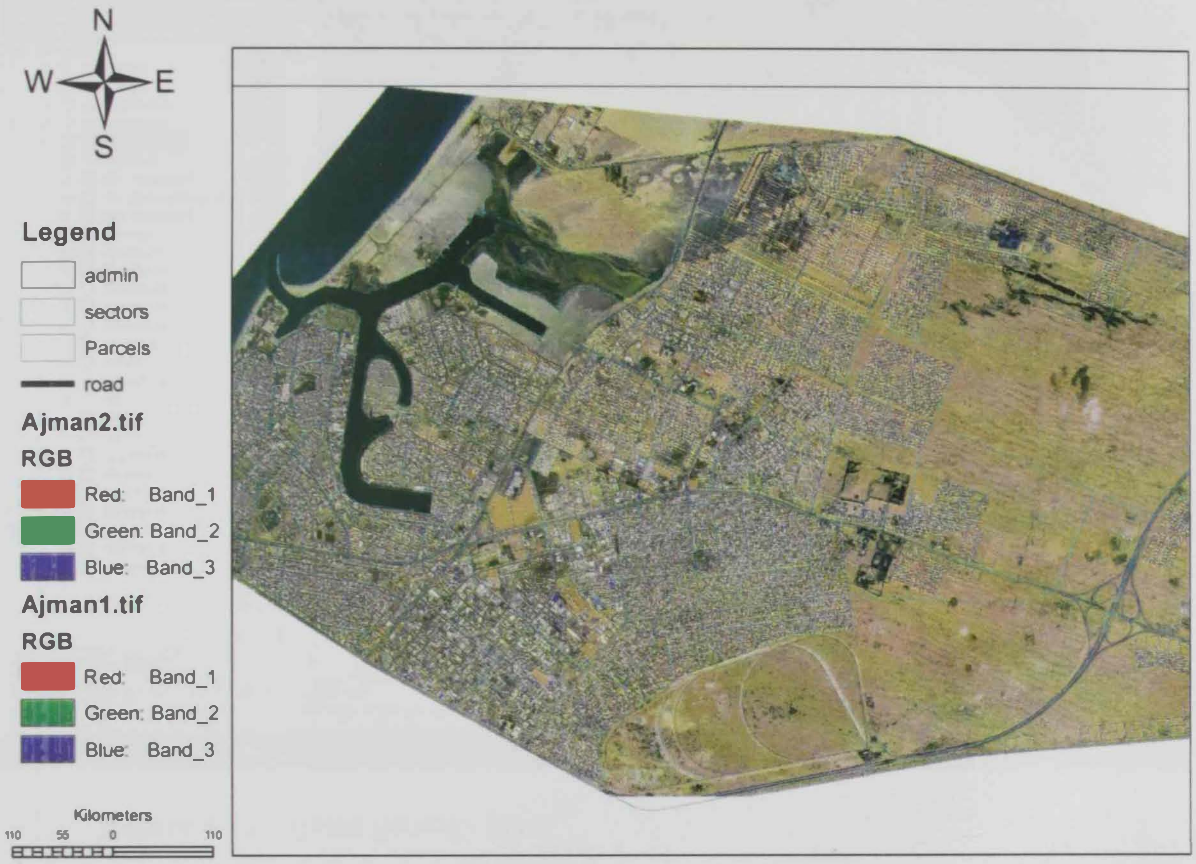


Figure 4.10. Ajman land details layer

4.6.2. Data for Ajman land details

Data is collected for land details were from cad drawings of FEWA and Ajman municipality.

4.7. Ajman Hydrogeology Layer

4.7.1. Sub layers of Ajman hydrogeology

There are two layers which are:

Sub layer 1- Ajman hydrogeology

Sub layer 2-Ajman geology

Ajman geology composed of Aeolian sand (orange dots), Alluvium (blue patches) and some green vegetation (green patches) and these are visible in Ajman geology layer (Figure 4.11).

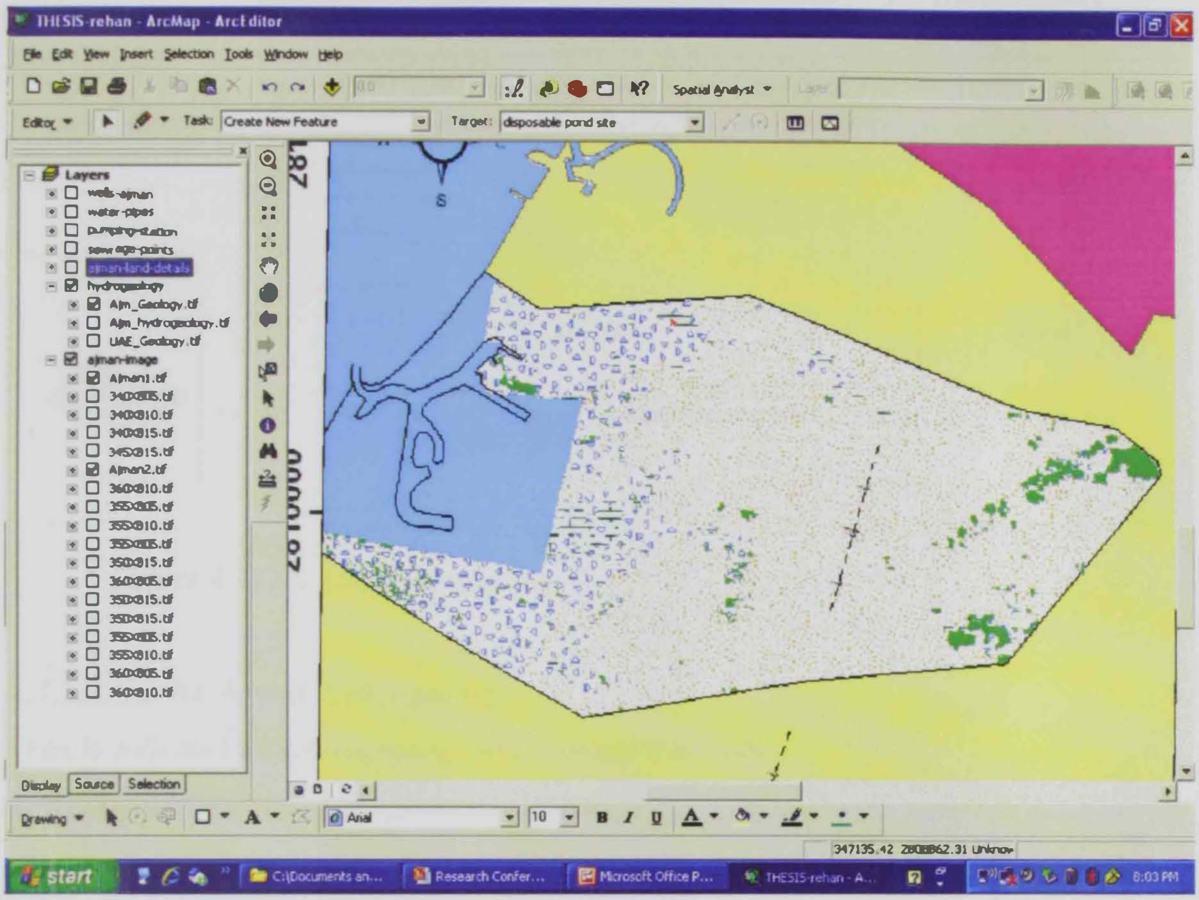


Figure 4.11. Ajman geology layer

Ajman hydrogeology composed of high sand (light blue) and high sabkha (dark blue) and these are visible in Ajman hydrogeology layer (Figure 4.12).

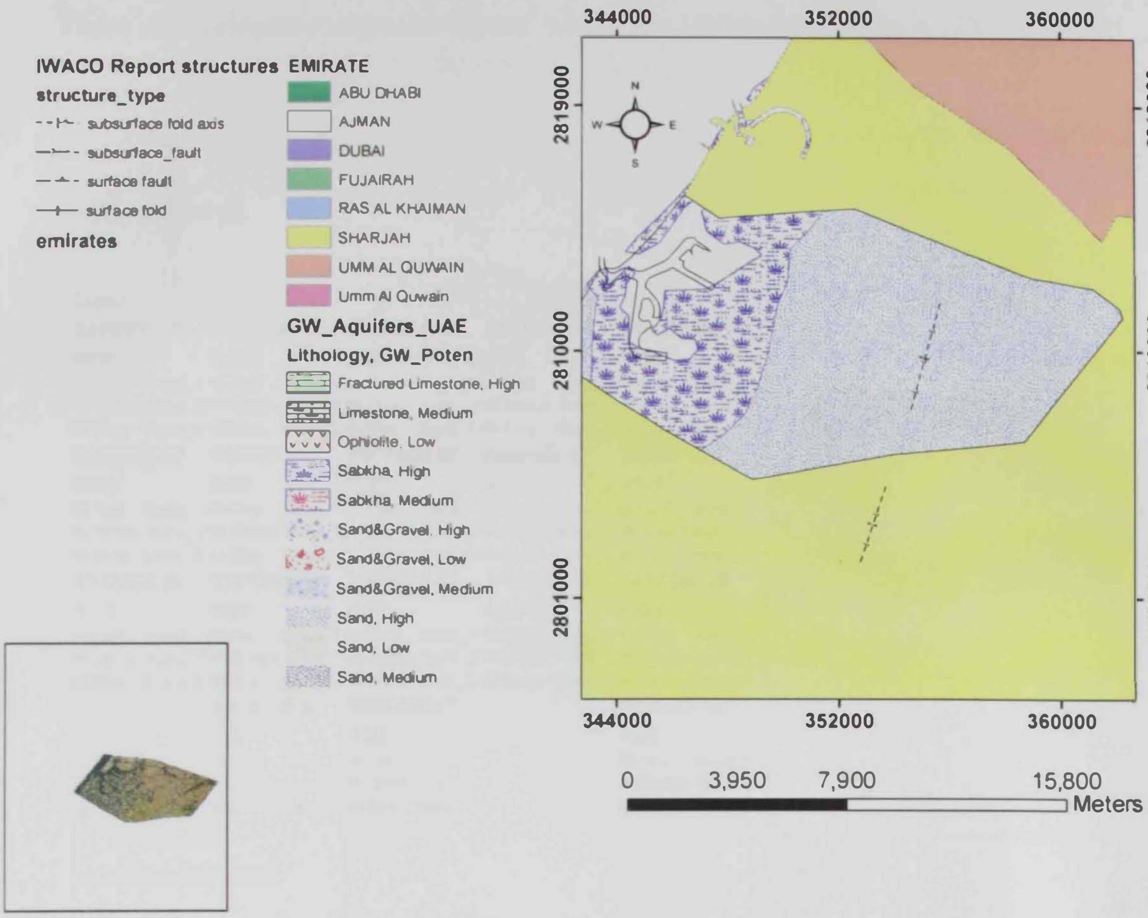


Figure 4.12. Ajman hydrogeology

4.7.2. Data for Ajman hydrogeology

Data is collected for hydrogeology and geology was from

1- Ministry of water and environment, Dubai

4.8. Ajman Satellite Image Layer

4.8.1. Sub layers of Ajman satellite image

There are eighteen composite layers, which are visible in (Figure 4.13).

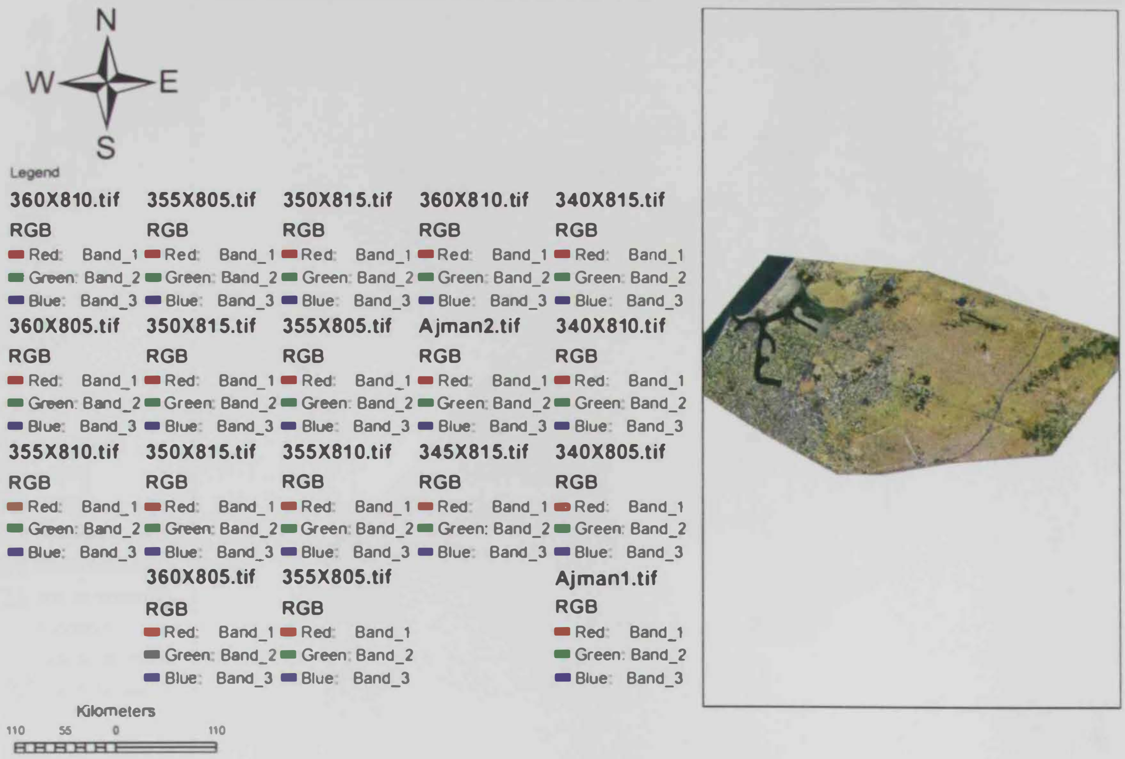


Figure 4.13. IKONOS image of Ajman area

4.8.2. Data for Ajman satellite image

Data is collected was from IKONOS image of the area has been requested and collected from GISTEC and FEWA.

4.9. Emirates Layer

Layer showing all emirates of UAE in different colors with their respective boundaries. Ajman emirate is visible in pink color in (Figure 4.14).

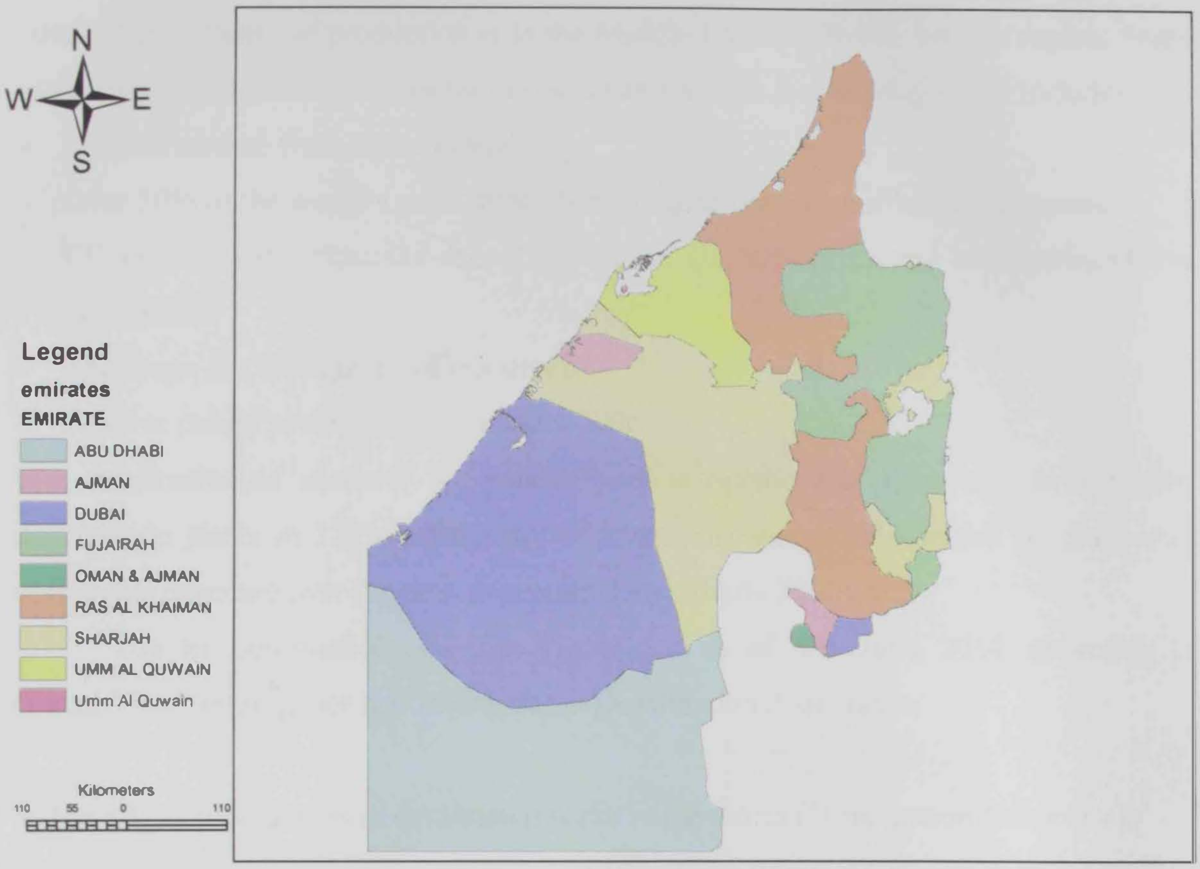


Figure 4.14. Layer showing all emirates of UAE in different colors

Chapter 5. Desalination and Sewage in Ajman

5.1. Introduction

Worldwide, over 23 million cubic meters of desalinated water is produced per day (Smith 2005). The majority of production is in the Middle East and North African region. Some of the reasons advanced to consider the ocean as a source for drinking water includes:

- Limited surface fresh water availability;
- Over 50% of the world's population lives in urban centre's bordering the ocean;
- Climate change – extended drought cycles of 10 years compared to a historical five year period.
- The ocean is a drought proof resource;
- Positive public perception.(Voutchkov 2005)

The desalination of seawater for potable uses is on the rise. Currently, over 17,000 desalination plants in 120 countries are in operation, with US$10 billion investment in new plants expected over the next five years. (Voutchkov 2005)

Top ten desalination countries (Table 5.1) as of 30th June, 2008, according to Global Water Intelligence and International Desalination Association

Table 5.1. Top producers of desalinated water in the world (Desalination News 2008)

No	Country	Desalinated Water Produced in m^3/d (MIGPD)	% Age Share in the World
1	Saudi Arabia	10,759,693 (2367)	17 %
2	UAE	8,428,456 (1854)	13 %
3	USA	8,133,415 (1789)	13 %
4	Spain	5,249,536 (1154)	8 %
5	Kuwait	2,876,625 (632)	5 %
6	Algeria	2,675,958 (588)	4 %
7	China	2,259,741 (497)	4 %
8	Qatar	1,712,886 (376)	3 %
9	Japan	1,493,158 (328)	2 %
10	Australia	1,184,812 (260)	2 %

Total desalination capacity is expected to double by 2015, with reverse osmosis the dominating technology. 62% of the desalination capacity of the world is in the Middle

East / North Africa (MENA) region. Countries in the gulf region (the gulf cooperation council countries – Bahrain, Kuwait, Qatar, Oman, Saudi Arabia, and the United Arab Emirates) alone account for 53% of worldwide desalination capacity. The UAE has 55.5 m^3 of natural renewable water resources per capita (Earth Trends 2005).

Industry data shows that demands for desalinated water are growing at an annual average of 6% double the global average, and regional governments have already invested an estimated 10 billion in existing and new projects to boost capacity. However, with a surging population and large-scale economic diversification across the Gulf, a further investment of around $100 billion is required over the next 10 years to meet the rapidly escalating demand for water. Desalination is the top technological approach for increasing water supplies in the region, but other measures, such as recycling water and reducing consumption should also be considered (Desalination News 2008).

At present, the Federal Electricity and Water Authority (FEWA), which serves the northern emirates of Ajman, Umm Al Quwain, Ras Al Khaimah and Fujairah, operates six power generation and three water desalination plants. Work to increase capacity across the board is being undertaken with the major element slated to be located in Ajman, at the Al Zawra power plant, which is expected to be completed by mid-2009. By global standards, energy consumption in the Ajman emirate and throughout the UAE is exceptionally high in per capita terms. Prospering businesses and real estate developments are creating a growing demand for power. The Abu Dhabi water and electricity authority anticipate the demand for electricity will grow by 7% to 7.5% each year until 2012 (ADWEA 2001). Power and water are still sold well below market rates for UAE nationals. Due in part to low revenues, investments in capacity have not kept up with demand, leading to shortages. This has led to a need for rationing with some businesses having to rely on diesel generators. As a result, developers are looking more seriously at alternatives for high demand uses such as air conditioning. The use of centrally located chilled water used to cool buildings is catching on, despite initial resistance because of high start-up costs.

5.2. Ajman Desalination – An Overview

The following (Tables 5.2, 5.3 and 5.4) describe the present capacities of desalination plants, pumping stations and water tanks in Ajman.

Table 5.2. Existing distribution and transfer pump capacities, Ajman

No	Pumping Station	Number Of Pumps		Individual Pump Capacity m^3/hr (MIGD)	Actual Flow m^3/hr (MIGD)
		Distribution	Transfer		
1	MED Power Station		From MED Condenser		1042 (5.5)
2	Al Zawra RO Plant		3	85 (0.45)	171 (0.90)
3	Ajman Central Distribution Station	3		400(2.11)	400 (2.11)
		4		800(4.22)	800 (4.22)

Table 5.3. Existing desalination plants in Ajman

No	Location of Plant	Desalination Technology	Source	Year Commissioned	Firm Production in m^3/hr (MIGD)	
					Year Commissioned	2006
1	Ajman	RO	Well Water	1995	328 (1.73)	583 (3.08)
2	Power Station	MED	Sea Water	2000	288 (1.52)	1513 (7.99)
3	Al Zawra	RO	Sea Water	1991	123 (0.65)	176 (0.93)
4	Hallew	RO	Well Water	1998	1.25 (0.0066)	7.38 (0.039)

Table 5.4. Existing water storage capacities of reservoirs

No	Location	Year Constructed	Capacity m^3 (Gallons)	Type of Tank	Status	Tank Height
1	Rumeila	2003	909 (200,000)	Welded Steel	In Service	35 meter
2	Al Zober	1981	46 (10,000)	Welded Steel	not in service	20 meter
3	Al Helaw	1982	46 (10,000)			20 meter
4	Al Zawra Plant Tank No. 1	1984	2273 (500,000)	Welded Steel	In Service	Ground tank
5	Al Zawra Plant Tank No. 2	1990	2273 (500,000)	Welded Steel	In Service	Ground tank
6	Al Gurf	1990	455 (100,000)	Spherical Steel	In Service	35 meter
7	Hamedia	1992	909 (200,000)	Welded Steel	In Service	15 meter
8	Ajman Dist. Center	1996	11365 (2.5 Million)	Concrete	In Service	Ground tank
9	Ajman Dist. Center	2002	18184 (4 Million)	Concrete	In Service	Ground tank
10	Ajman Dist. Center	2002	18184 (4 Million)	Concrete	In Service	Ground tank
11	Ajman Dist. Center	2002	18184 (4 Million)	Concrete	In Service	Ground tank
12	New Al Hallew	2004	91 (20,000)	Welded Steel	In Service	20 meter
13	Old Al Hallew	2004	46 (10,000)	G.R.P.	In Service	20 meter
14	Old Al Hallew	2005	91 (20,000)	Welded Steel	In Service	Ground tank

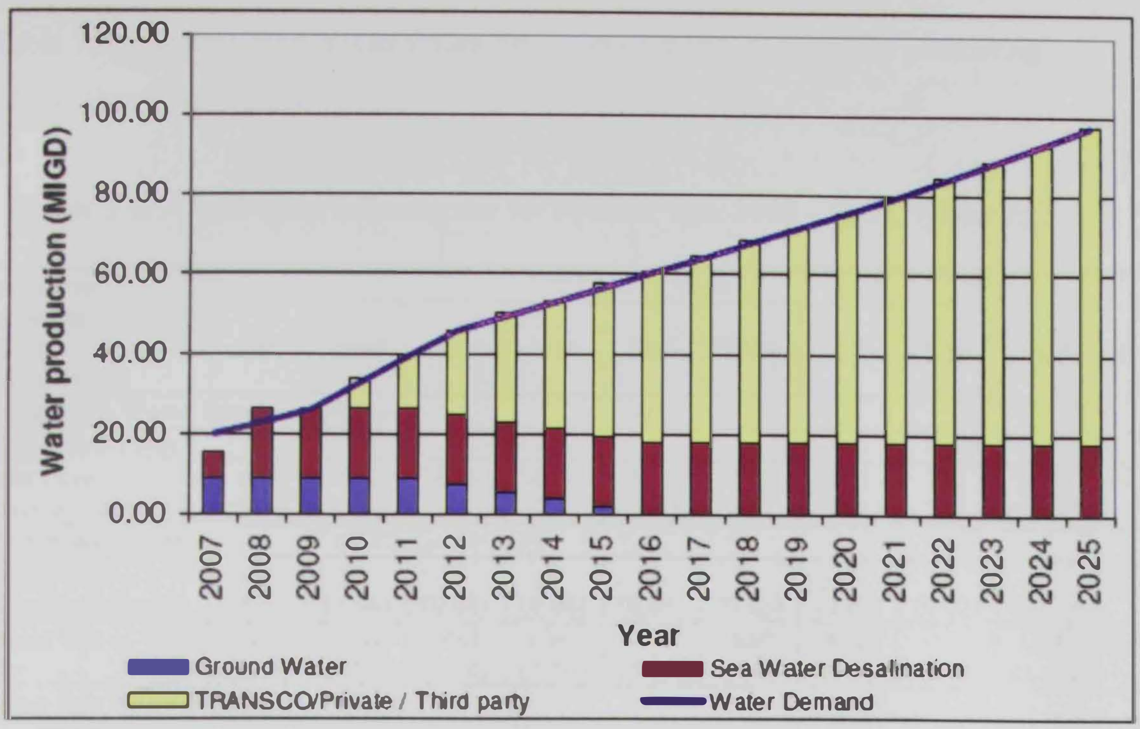


Figure 5.1. Combined yearly water production of Ajman plants and future forecasted scenarios, Tebodin (2007)

(Figure 5.1) shows the source wise present and future desalinated water requirement of Ajman.

5.3. Existing and Future Desalination Plants of Ajman

(Table 5.5) presents the Year 2000 – 2006 historical data of water production from desalination plants using well field water and seawater as source for desalination process for Ajman.

Table 5.5. Firm production capacities of existing desalination plants in Ajman

Location	Firm Water Production Capacity in m^3/hr (MIGD)						
	2000	2001	2002	2003	2004	2005	2006
RO-Ajman	441 (2.33)	520 (2.75)	574 (3.03)	566 (2.99)	578 (3.05)	582 (3.07)	583 (3.08)
MED-Ajman	288 (1.52)	754 (3.98)	1046 (5.52)	993 (5.24)	972 (5.13)	1125 (5.94)	1514 (7.99)
Al Zawra	169 (0.89)	125 (0.66)	157 (0.83)	130 (0.69)	161 (0.85)	155 (0.82)	176 (0.93)
Hallew	3.8 (0.02)	3.8 (0.02)	3.8 (0.02)	6 (0.03)	8 (0.04)	8 (0.04)	8 (0.04)
Total Production	**901.8 (4.75)**	**1402.8 (7.40)**	**1780.8 (9.40)**	**1695 (8.95)**	**1719 (9.08)**	**1870 (9.88)**	**2283 (12.04)**

(Table 5.6) presents the planned future firm water production capacity of existing desalination plants Ajman

Table 5.6. Future water balance plan for Ajman (Year 2008 – 2016) (Tebodin 2007)

Firm Water Production Capacity m^3/hr (MIGD)	Year									
	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Existing Well Water Desalination Plants										
a. Ajman RO Plant										
Present Firm Production Capacity	644 (3.4)	644 (3.4)	644 (3.4)	644 (3.4)	644 (3.4)	515 (2.72)	386 (2.04)	258 (1.36)	129 (0.68)	0.00
b. Hallew RO Plant										
Present Firm Production Capacity	8 (0.04)	8 (0.04)	8 (0.04)	8 (0.04)	8 (0.04)	6 (0.03)	4 (0.02)	4 (0.02)	2 (0.01)	0.00
c. Direct Use of Well Water	1042 (5.50)	1042 (5.50)	1042 (5.50)	1042 (5.50)	1042 (5.50)	834 (4.4)	625 (3.3)	417 (2.2)	208 (1.10)	0.00
Existing Sea Water Desalination Plants										
a. Power Station MED Plant										
Present Firm Production Capacity	1042 (5.50)	2042 (10.78)	2042 (10.78)	2042 (10.78)	2042 (10.78)	2042 (10.78)	2042 (10.78)	2042 (10.78)	2042 (10.78)	2042 (10.78)
b. Al Zawra RO Plant										
Present Firm Production Capacity	176 (0.93)	176 (0.93)	176 (0.93)	176 (0.93)	176 (0.93)	176 (0.93)	176 (0.93)	176 (0.93)	176 (0.93)	176 (0.93)
Augmentation of Firm Capacity		1114 (5.88)	1114 (5.88)	1114 (5.88)	1114 (5.88)	1114 (5.88)	1114 (5.88)	1114 (5.88)	1114 (5.88)	1114 (5.88)
New Sea Water Desalination Plant										
(FEWA/TRANSCO/ 3rd Party/ADWEA)				1326 (7)	2463 (13)	3978 (21)	5115 (27)	6062 (32)	7198 (38)	8145 (43)
Total Water Production	**2912 (15.37)**	**5025 (26.53)**	**5025 (26.53)**	**6351 (33.53)**	**7488 (39.53)**	**8664 (45.74)**	**9462 (49.95)**	**10072 (53.17)**	**10869 (57.38)**	**11477 (60.59)**
Total Water Demand	3770 (19.90)	4298 (22.69)	5056 (26.06)	6190 (32.68)	7446 (39.31)	8643 (45.63)	9337 (49.29)	10009 (52.84)	10706 (56.52)	11426 (60.32)
Excess/Deficit (+/-)	-858 (-4.53)	727 (3.84)	89 (0.47)	161 (0.85)	42 (0.22)	21 (0.11)	125 (0.66)	63 (0.33)	163 (0.86)	51 (0.27)

5.4. Sewage Collection System in Ajman

5.4.1. Anthropogenic factors

The fast pace of urban evolution in land use at Ajman city during the last few years have directly caused groundwater pollution. The large volumes of waste generated in association with municipal activities were disposed into unlined pits on land surface. Leachates from these holes carry large amounts of pollutants towards groundwater in the underlying aquifer. On the other hand, diffuse pollution sources are attributed to dense septic systems in residential areas, uncontrolled waste disposal in industrial areas and the wide application of chemical fertilizers on farmlands in the eastern part of the city.

5.4.2. Municipal activities

Two old landfill sites with a total surface area of 5,007 m^2 are in the Al Jarf area. A used tires disposal site covers an area of 2,403 m^2 and occurs between the old landfills and close to the cement factory .Both the fertilizer factory (27,348 m^2) and cement factory (123,004 m^2) produce large volumes of solids waste. Untreated sewage water disposal sites are two; an abandoned old site and an operating one. The old site covers an area of 440,693 m^2 and the active site has an area of 301692 m^2 (Al-Hogaraty et al. 2008).Waste from the operating site move downward polluting groundwater underneath. Despite the pollution caused by this site, it has been diluted in the surrounding area.

5.4.3. Agricultural activities

Non-point pollution sources refer to pollutants that come from a widespread area and cannot be tracked to a single point or source. Application of agrochemicals on farmland, widespread septic tanks and illegal disposal of industrial waste are examples of non-point pollution sources. Too many septic systems in any given area will overload the soil's natural purification systems and allow large amounts of wastewater to contaminate groundwater (Hamouda 1995). The high density of buildings and lack of a sewage network in the Ajman, at the present time, will lead to a widespread of septic systems and subsequent pollution of groundwater. The total area of point pollution sources is only 1 km^2, while the total area of nonpoint pollution sources is about 92 km^2. The diffuse sources include septic systems in residential areas (32 km^2), uncontrolled disposal in industrial areas (20 km^2) and application of various types of agrochemicals on farmland (40 km^2). The pollution resulting from non-point sources is difficult to define and hard to control (Al-Hogaraty et al. 2008).

5.5. Pollution Control

Sewage treatment plants are necessary for larger cities such as Ajman, which has witnessed remarkable urban expansion during the last few years. Sewage network and sewage treatment plant at Ajman are under construction. Treatment plants remove approximately 90% of the organic waste and suspended solids, less than 70% of the toxic metals and synthetic organic chemicals, 50% of the nitrogen in the form of nitrates and 30% of the phosphorus in the form of phosphates (Al Saati 1995). The remaining discharge is still high in nutrients, and the remaining sludge is sent to a landfill as waste or applied to the land as a soil additive.

The department of environment at Ajman municipality keeps a close eye on illegal, uncontrolled waste disposal practices by companies and individuals. Violators have to be identified and charged for their violations. The disposal of untreated sewage water on land surface has to be panned immediately after completion of the sewage treatment plant.

The RO desalination plants operating in Ajman city are running with poor-quality feed water, which causes extensive damage to membranes. Costly pre-treatment is made to enhance plant capacity and to extend the service life of membranes.

5.6. Introduction about Ajman Sewage System

Until now no sewage collection system is available in Ajman. The sewage from homes, factories, hotels, commercial buildings etc is collected in septic tanks and then collected by tankers and conveyed to the disposal site near city. Mostly the septic tanks are in streets, near boundary lines of the buildings and most of the cases old water pipe lines are crossing these septic tanks. Since there is system of intermittent supply in Ajman due to shortage of water, there is serious threat of sewage intrusion in low-pressure sections of the pipes.

The construction of a new sewerage treatment plant in Ajman has started in February 2006. The design parameters are given in (Table 5.7 and Table 5.8) and disposable pond site and sewerage network is visible in (Figure 5.2).

Sewer network consists of gravity sewers, pumping station and pressurized force mains, which collect the wastewater, generated within the initial service area and convey the waste water to the treatment plant.

Initial service area is divided into a number of individual drainage basins. A network of gravity sewers is installed in each drainage basin to collect the waste water from each registered property located within the respective drainage basin and convey the flow by gravity to a common collection point. A pumping station is provided at each collection point to discharge the collected wastewater into a pressurized force main either to the next pump station or re-lift the sewage into a nearby manhole to allow continuation of gravity flow within the adjacent basin. The individual pumping stations and force mains are interconnected to convey the collected wastewater to the treatment Plant. The system complies with the requirement of "sewer for adoption" published by water services association and amended by Thames water.

Treatment plant consists of a complete tertiary plant with effluent disinfection and handling facilities. In normal operation the effluent will be discharged either to an effluent pipeline provided by others which will connect to the treatment plant pipeline at the delivery point or to a tanker loading facility subject to design capacity 350,000 IGPD. Effluent discharged to the effluent pipeline shall be gravity discharged. Disposal ponds are provided at the site with treatment plant and emergency disposal pipeline from the treatment plant to a discharge point at khor-Ajman.

Table 5.7. Initial phase parameters of Ajman treatment plant

Initial Phase Parameters	Average Conditions	Maximum Month Conditions
Average Flow rate, m^3/d	49,073	
Max Month hydraulic flow rate ,m^3/d		58,888(682 l/s)
BOD_5, kg/d	15,295	
TSS, kg/d	15,295	
TKN, kg/d	3,150	

Peak Instantaneous hydraulic capacity = 81,000 m^3/d (938 l/s)

Table 5.8. Future phase parameters of Ajman treatment plant

Future Phase Parameters	Average Conditions	Maximum Month Conditions
Average Flow rate, m^3/d	73,610	
Max Month hydraulic flow rate ,m^3/d		88,331(1022 l/s)
BOD_5, kg/d	22,944	
TSS, kg/d	22,944	
TKN, kg/d	4,724	

Peak Instantaneous hydraulic capacity = 112,000 m^3/d (1296 l/s)

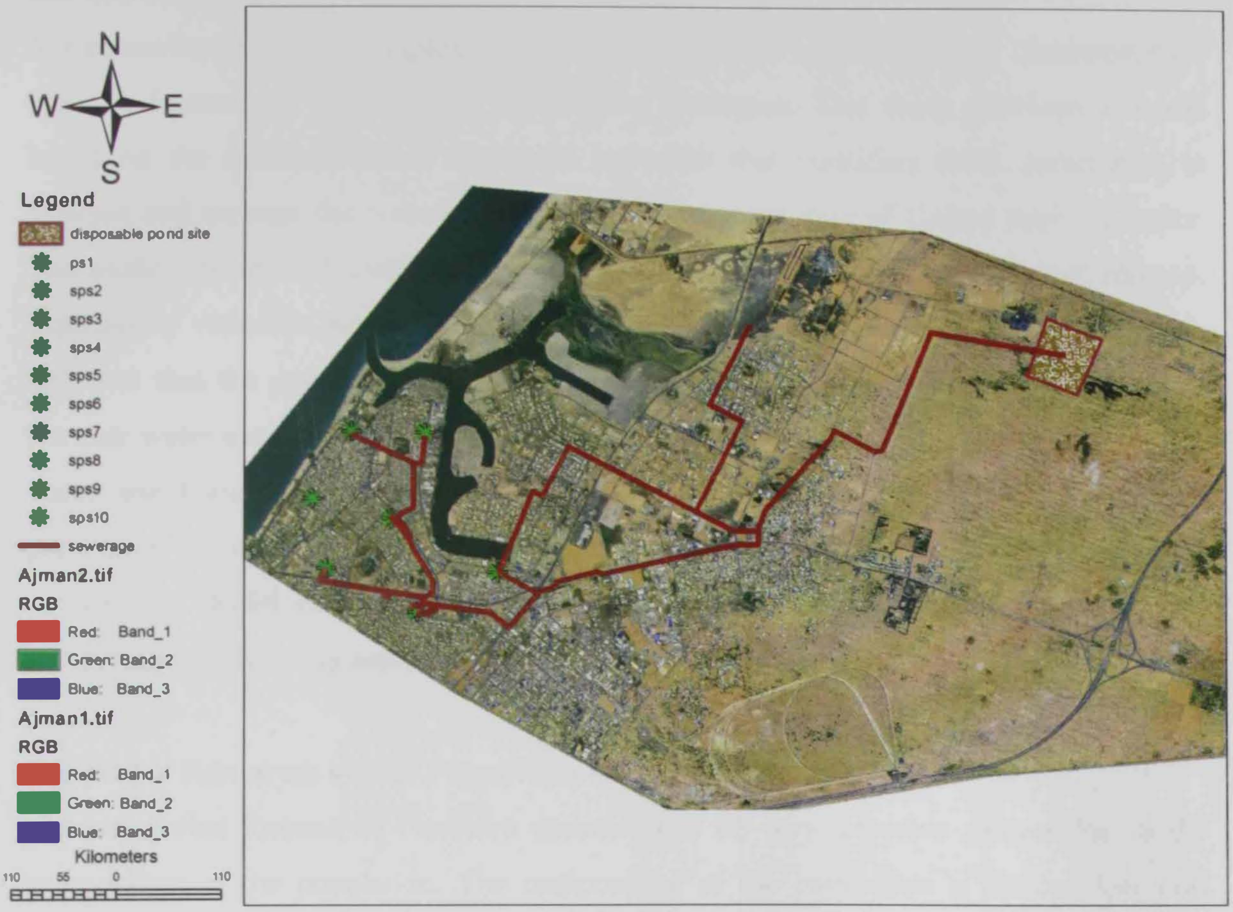


Figure 5.2. Layer showing sewerage network of Ajman

Chapter 6. Forecasting of Water Demands for Ajman

6.1. Introduction

Water use/demand is a complex function dependent on socio-economic characteristics, climatic factors and public water policies and strategies. This study develops a model based on the multiple linear regression approach that considers these parameters to forecast and manage the water use/demand in Ajman emirate of United Arab Emirates. The model applies statistical tools to select suitable demand function and most relevant explanatory variables that have strong relationship with water use/demand. The analysis indicates that the population, conductivity, total dissolved solids, water levels in wells, summer water use, winter water use, and average temperature are significant variables of water use/demand. The demands are forecasted for moderate and high levels of population growth. The study further analyzes the effect of length of data series on accuracy of model results. The developed model is used to forecast the future water use/demand in the study area.

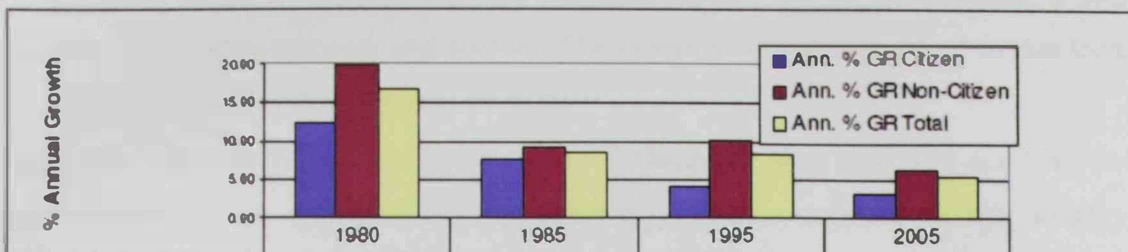
6.2. Water Resources versus Population Growth in Ajman

The population forecast of Northern emirates can be very intensive subject due to the composition of the population. The composition of the population is divided into two main categories including citizen and non-citizen population. The growth rate of citizen population is expected to follow a certain trend of birth and death, however due to the migration of the citizen population to the other large emirates of Abu Dhabi and Dubai the trend of growth is not constant. Moreover, from time to time the UAE government issues naturalization to Arabs from neighboring countries which may have an impact on the balance of population growth of citizen and non citizen, but this change in the balance is not considerable and has minimal impact on the overall population growth.

The non-citizens are generally labours on single or married status and hold residence visa. The growth of non-citizen population is driven by economic growth and job opportunity. The population census of the northern emirates was carried out by the ministry of planning/economy every five years starting from 1970 to 2005.

Recently, its has been decided by the ministry of planning/economy to carry out the population Census every ten years, therefore the next census is expected to be in year 2015 (Source: Ministry of Planning/Economy UAE).

The percentage annual growth rate for the split in citizen, non-citizen and total population of Ajman or historical population growth rate of Ajman emirate is shown in (Figure 6.1).



	1980	1985	1995	2005
Ann. % GR Citizen	12.44	7.56	4.12	3.13
Ann. % GR Non-Citizen	19.70	9.20	10.13	6.12
Ann. % GR Total	16.68	8.61	8.34	5.47

Figure 6.1. Historical citizen and non citizen population growth rate of Ajman (Source: Ministry of Planning/Economy UAE)

6.3. Water Quantity in the Distribution Network-(Sector Wise)

The water supplied to all areas of Ajman is from central distribution storage tanks. The water supply to all area in Ajman is not 24-hour supply

Rumailah and Karama: The current estimated population of Rumailah and Karama is 16987 and 18953 residents respectively living in villas, apartments and shabiat. The quantity of water supplied to Rumailah and karama is 3.465 MIGD (656 m^3/hr). (Source: FEWA).

Suwan, Bustan, Rashidia and Mushairif (trading area): The estimated population of Suwan, Bustan, Rashadia and Mushariaf- Trading area is 18420, 25323, 8388 and 9867 residents repectively living in apartments villas, and shabiat The quantity of water supplied to (Suwan, Bustan, Rashadia and Mushariaf- trading area) is 4.004 MIGD (759 m^3/hr). (Source: FEWA).

Jurf: The current estimated population of Jurf is 5,773 residents living in villas and shabiat. The quantity of water supplied to this locality is 1.760 MIGD (334m^3/hr) (Source: FEWA).

Hamidia: The current estimated population of Hamidia is 7,796 residents living in villas and shabiat. The quantity of water supplied to this locality is 0.462 MIGD (88m^3/hr) (Source: FEWA).

Zahra and Mowihat: The current estimated population of Zahra and Mowihat is 16,080 and 4,443 residents respectively living in apartments, villas and shabiat. The quantity of water supplied to these localities is 1.848 MIGD (350m^3/hr) (Source: FEWA).

Industrial area Domestic: The current estimated population Industrial Area is 39,208 residents living in apartments and shabiat. The quantity of water supplied to this locality is 1.925 MIGD (365m^3/hr) (Source: FEWA).

Nuaimiah: The current estimated population of Nuaimiah Area is 41,175 residents living in apartments, villas and shabiat. The quantity of water supplied to this locality is 2.860MIGD (544m^3/hr) (Source: FEWA).

Hallew: The current estimated population of Al Hallew Area is 1,125 residents living in villas and shabiat. The water supplied to Al Hallew Area is from the tanks at Helew RO plant. The quantity of water supplied to this locality is 0.075 MIGD (14m^3/hr) (Source: FEWA).

6.4. Forecasting of Water Demands for Ajman

In Ajman, the emphasis on accurate water forecasts is particularly important. There is an increased need for water demand forecasts as the areas of population and economic activities are growing, the need for supply should be more accurately quantified, and additional uses and needs of water should be identified.

No serious attempts have been made so far to forecast the water demands in Ajman. Such forecast should include the following:

- How many desalination plants required up to 2031
- Forecasting groundwater usage up to 2031.
- Forecasting sea water usage up to 2031.
- Effects of conductivity and TDS on water usage as well as on production of groundwater source in Ajman.
- Water usage in summer and winter seasons in Ajman
- Base forecast on groundwater and sea water uses.

In the current study, the relevant data has been collected from different sources then the data available from 1990 to 2006 was used to forecast water demands in Ajman up to 2031 with 5 years increment. SPSS software has been used to make forecasting and get the independent variables and then their response on water use in Ajman emirate has been evaluated.

This study involves the forecast of water demands in Ajman Emirate up to 2031 based on low demand and high demand; it considers the effects of groundwater quality deterioration because of no recharge. The study also considers the tremendous increase in population and its effects on water consumption.

6.4.1. Growth in development of villas and mega projects in Ajman

(Table 6.1) shows the numbers of ongoing and future projects with respective population and water demand in Ajman. The historical growth in the construction of Villas and Arabic houses in Ajman is shown in (Figure 6.2) for years 2000 to 2005. (Figure 6.3) Show the linear extrapolation in the growth of development of Villas and Arabic houses up to year 2025.

Table 6.1. Total water demand for mega projects in Ajman

No	Name of Project	Location	Starting year	Completion year	Total Water Demand MIGD (m^3/hr)	Population	Remarks
1	Emirates Home	Jurf	2007	2009	0.37 (70)	5000	Badri and Bansouda, 7 Towers (70 G/C/D)
2	Al Ameera Village	Hallew	2008	2010	0.52 (99)	30000	Tameer
3	Ajman Marina	Nakheel				20000	Mouchal Parkman, No irrigation No District Cooling (70 G/C/D)
	Phase 1		Under study	2010	0.55 (104)		
	Phase 2		Under Study	2010	0.55 (104)		
4	Ajman1	Alsawan	2007	2009	0.78 (148)	9000	Rami Dabbas, 70 G/C/D
5	Al zawra Project Ajman 1	Alzawra	2010	2026	8.80 (1667)	160,000	Rami Dabbas, (70 G/C/D)
6	Emirates city	Hallew				150,000	Adnan suferini, 25 towers (80 G/C/D)
	Phase 1		2007	2009	1.76 (334)		
	Phase2		2008	2010	5.72 (1091)		
7	Ajman Pearl	Musehrif	2011	2011		9,500	Adnan suferini (80 G/C/D)
	Phase1		2008	2010	0.15 (29)		
	Phase2		2008	2011	0.32 (61)		
8	R Tower Mixed Used Building	Musherif	2007	2009	0.04 (8)		Proarc (65 G/C/D)
9	Ethihad Village	Hallew	2008	2011		4000	Adnan suferini, (80 G/C/D)
		Phase1	2008	2010	0.07 (13)		
		Phase 2	2008	2011	0.15 (29)		
10	Boulevard City	Hallew	2008	2011		15,000	Adnan Suferini , (80 G/C/D)
	Phase1		2008	2010	0.31 (59)		
	Phase2		2008	2011	0.44 (83)		
11	Ajman Green City	Hallew	2008	2011	0.22 (42)	4000	Adnan Suferini (80 G/C/D)
12	Ajman Up Town	Hallew	2008	2010	1.32 (250)	26,000	Adnan Suferini (80 G/C/D)
Total					**22.07 (4181)**	**432,500**	

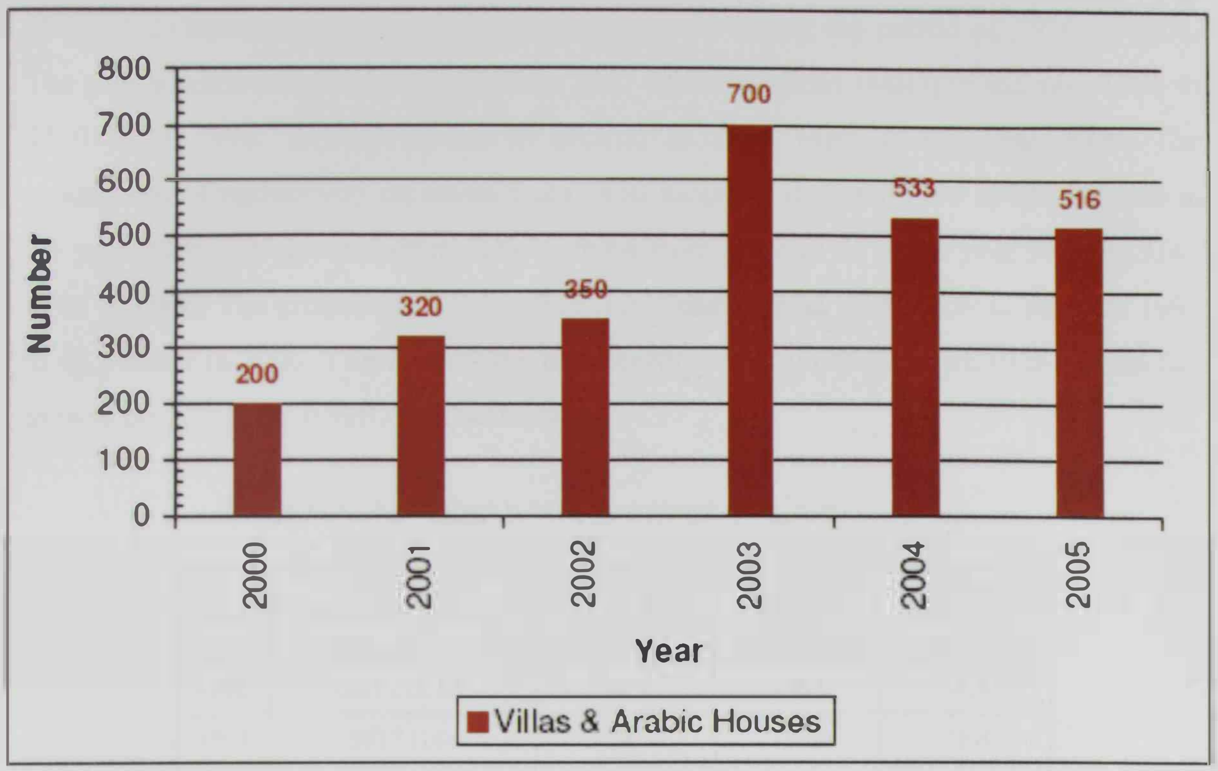


Figure 6.2. Yearly building permissions issued in Ajman, (Tebodin 2007)

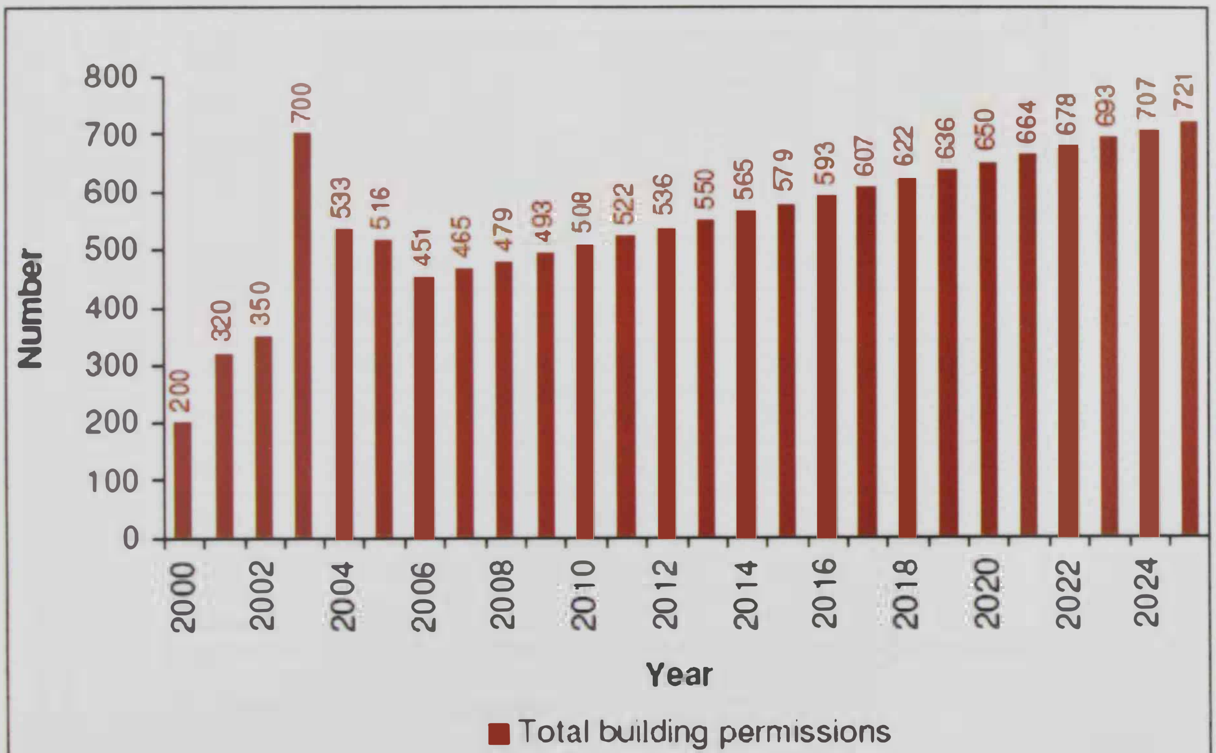


Figure 6.3. Growth in developments of villas and Arabic houses in Ajman, (Tebodin 2007)

6.4.2. Groundwater data

(Table 6.2) summarizes the main groundwater data during the period of 1990 to 2006. The groundwater use has increased from 2867 million gallons (MIG) in the year 1990 to 4420 MIG 1998. It then started to decline to 2296 MIG in the year 2006. The groundwater Conductivity increases from 3450 μs/cm in the year 1990 to 9132 μs/cm in the year 2006. The groundwater TDS increase from 1567 PPM in the year 1990 to 3345 PPM in 2006. The groundwater level drop significantly from 38.4 meter in the year 1990 to 47.5 meter in 2006. This reflects the deterioration of groundwater quality in Ajman due to over pumping and insufficient recharge.

Table 6.2. Annual groundwater usage in Ajman

Year	Water use (Million Gallons) /(Million M^3/Year)	Average Conductivity (μs/cm)	Average TDS in GW (PPM)	Average GW Level (Meters)
1990	2867 (13.03)	3450	1567	38.4
1991	3077 (14)	3565	1578	38.8
1992	3251 (14.77)	3574	1678	39
1993	3234 (14.70)	3875	1690	39.1
1994	3901 (17.73)	3965	1789	39.4
1995	4463 (20.29)	4267	1876	40.0
1996	4445 (20.20)	4635	2034	40.2
1997	4415 (20.06)	4987	2199	41.0
1998	4420 (20.09)	5378	2386	41.6
1999	3870 (17.60)	5897	2456	41.9
2000	3789 (17.22)	6378	2567	42.3
2001	3750 (17.04)	6784	2678	43.5
2002	3300 (15)	7345	2765	44.0
2003	2765 (12.57)	7869	2876	44.6
2004	2587 (11.76)	8452	2976	44.9
2005	2456 (11.16)	8745	3011	45.6
2006	2296 (10.43)	9132	3345	47.5

GW denotes groundwater.

6.4.3. Desalinated water data

(Table 6.3) summarizes the main desalination water use data during the period of 1990 to 2006. The desalinated water use has increased from 239 MIG in the year 1990 to 824 MIG 2000. It then started to increase to 2576 MIG in the year 2006 to compensate the shortage of groundwater production.

Table 6.3. Annual desalination water usage in Ajman

Year	Water used from Sea Water Source MIGallons/Year (Million M^3/Year)	Year	Water used from Sea Water Source MIGallons/Year (Million M^3/Year)
1990	239 (1.08)	1999	289 (1.31)
1991	245 (1.11)	2000	824 (3.74)
1992	262 (1.20)	2001	1711 (7.78)
1993	253 (1.15)	2002	2264 (10.30)
1994	194 (0.88)	2003	2345 (10.66)
1995	324 (1.48)	2004	2354 (10.70)
1996	334 (1.52)	2005	2487 (11.30)
1997	331 (1.50)	2006	2576 (11.71)
1998	297 (1.35)		

6.4.4. Scenario-A moderate population growth in Ajman

Table 6.4. Forecasted groundwater usage for moderate population growth

Year	Population	Water used from GW Source MIGallons/Year (Million M^3/Year)	Conductivity (µs/Cm)	TDS in GW (PPM)	GW Level (Meters)	Temperature (C^0)
1990	67897	2867 (13.03)	3450	1567	38.4	35.5
1991	82354	3077 (14)	3565	1578	38.8	36.7
1992	95467	3251 (14.77)	3574	1678	39	36.8
1993	99657	3234 (14.70)	3875	1690	39.1	37.6
1994	110567	3901 (17.73)	3965	1789	39.4	37.5
1995	121590	4463 (20.29)	4267	1876	40	36.5
1996	141567	4445 (20.20)	4635	2034	40.2	35.5
1997	156786	4415 (20.06)	4987	2199	41	35.8
1998	171567	4420 (20.09)	5378	2386	41.6	37.4
1999	185786	3870 (17.60)	5897	2456	41.9	38.1
2000	196879	3789 (17.22)	6378	2567	42.3	37.5
2001	205456	3750 (17.04)	6784	2678	43.5	36.5
2002	218676	3300 (15)	7345	2765	44	35.4
2003	235879	2765 (12.57)	7869	2876	44.6	34.4
2004	245786	2587 (11.76)	8452	2976	44.9	36.5
2005	256789	2456 (11.16)	8745	3011	45.6	37.8
2006	263456	2296 (10.43)	9132	3345	47.5	38.6
2011	318935	1737 (7.9)	10837	4030	41	39
2016	374415	1385 (6.3)	12542	4715	41.8	40.5
2021	435519	1287 (5.85)	14247	5400	42.5	41.8
2026	496615	1213 (5.51)	15952	6085	43	42.25
2031	557709	1150 (5.22)	17657	6770	44	43.4

(Table 6.4) shows the forecasted groundwater usage if the population of Ajman increases with Moderate growth. The groundwater use will decrease from 2296 MIG in the year 2006 to 1150 MIG 2031. The groundwater Conductivity will increase from 9132 µs/cm in the year 2006 to17657 µs/cm in the year 2031. The groundwater TDS will increase from 3345 PPM in the year 2006 to 6770 PPM in 2031. This reflects the deterioration of groundwater quality in Ajman if the same practice of over pumping and insufficient recharge continues.

Table 6.5. Forecasted sea water usage for moderate population growth

Year	Population	Water used from Sea Water Source M.I.Gallons/Year (Million M^3/Year)	Year	Population	Water used from Sea Water Source M.I.Gallons/Year (Million M^3/Year)
1990	67897	239 (1.08)	2001	205456	1711 (7.78)
1991	82354	245 (1.11)	2002	218676	2264 (10.30)
1992	95467	262 (1.20)	2003	235879	2345 (10.66)
1993	99657	253 (1.15)	2004	245786	2354 (10.70)
1994	110567	194 (0.88)	2005	256789	2487 (11.30)
1995	121590	324 (1.48)	2006	263456	2576 (11.71)
1996	141567	334 (1.52)	2011	318935	3315 (15.07)
1997	156786	331 (1.50)	2016	374415	4065 (18.48)
1998	171567	297 (1.35)	2021	435519	4892 (22.24)
1999	185786	289 (1.31)	2026	496615	5719 (26)
2000	196879	824 (3.74)	2031	557709	6545 (29.75)

(Table 6.5) shows the forecasted sea water or desalinated water usage if the population of Ajman increases with Moderate growth and there will be increase in the production from year 2006 to 2031 to compensate the shortage of groundwater production. (Figure 6.4) is the graphical representation of the (Table 6.4 and Table 6.5).

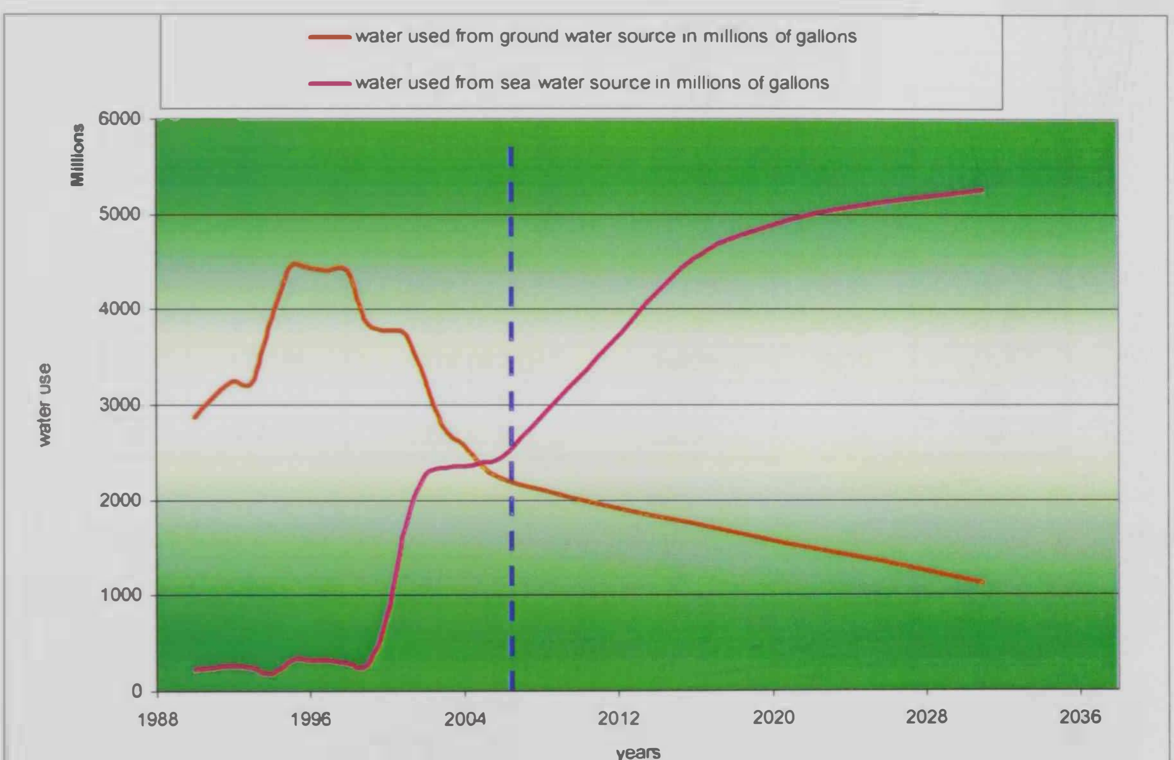


Figure 6.4. Forecasted annual desalinated and groundwater use for Ajman (Moderate population growth scenario)

6.4.5. Scenario-B high population growth in Ajman

This scenario explains about extra ordinary population growth in Ajman considering the previous year's data and also taking 7.5% extra population increase and extrapolating it to 2031 by regression analysis. In this scenario we consider the unforeseen circumstances like huge numbers of expatriate purchasing lands and living in Ajman plus undisclosed projects etc.

Table 6.6. Forecasted groundwater usage for high population growth

Year	Population	Water used from GW Source in Millions of Gallons/Year (Million M^3/Year)	Average Conductivity (µs/Cm)	Average TDS in GW (PPM)	GW Level (Meters)
1990	67897	2867 (13.03)	3450	1567	38.4
1991	82354	3077 (13.98)	3565	1578	38.8
1992	95467	3251 (14.77)	3574	1678	39
1993	99657	3234 (14.70)	3875	1690	39.1
1994	110567	3901 (17.73)	3965	1789	39.4
1995	121590	4463 (20.290	4267	1876	40
1996	141567	4445 (20.20)	4635	2034	40.2
1997	156786	4415 (20.06)	4987	2199	41
1998	171567	4420 (20.09)	5378	2386	41.6
1999	185786	3870 (17.60)	5897	2456	41.9
2000	196879	3789 (17.22)	6378	2567	42.3
2001	205456	3750 (17.04)	6784	2678	43.5
2002	218676	3300 (15)	7345	2765	44
2003	235879	2765 (12.57)	7869	2876	44.6
2004	245786	2587 (11.76)	8452	2976	44.9
2005	256789	2456 (11.16)	8745	3011	45.6
2006	263456	2296 (10.43)	9132	3345	47.5
2011	345787	2577 (11.71)	11378	4231	41
2016	405938	1884 (8.56)	13169	4945	41.8
2021	472186	1812 (8.23)	14959	5670	42.5
2026	538426	1741 (7.91)	17068	6325	43
2031	604664	1728 (7.85)	18539	7124	44

(Table 6.6) shows the forecasted groundwater usage if the population of Ajman increases with high growth.

Table 6.7. Forecasted sea water usage for high population growth

Year	Population	Water used from Sea Water Source in Millions of Gallons (Million M^3/Year)	Year	Population	Water used from Sea Water Source in Millions of Gallons (Million M^3/Year)
1990	67897	239 (1.08)	2001	205456	1711 (7.78)
1991	82354	245 (1.11)	2002	218676	2264 (10.30)
1992	95467	262 (1.2)	2003	235879	2345 (10.66)
1993	99657	253 (1.15)	2004	245786	2354 (10.70)
1994	110567	194 (0.88)	2005	256789	2487 (11.30)
1995	121590	324 (1.48)	2006	263456	2576 (11.71)
1996	141567	334 (1.52)	2011	345787	3434 (15.60)
1997	156786	331 (1.50)	2016	405938	4205 (19.11)
1998	171567	297 (1.35)	2021	472186	5055 (23)
1999	185786	289 (1.31)	2026	538426	5904 (27)
2000	196879	824 (3.74)	2031	604664	6754 (30.70)

(Table 6.7) shows the forecasted sea water or desalinated water usage if the population of Ajman increases with high growth. (Figure 6.5) is the graphical representation of the (Table 6.6 and Table 6.7).

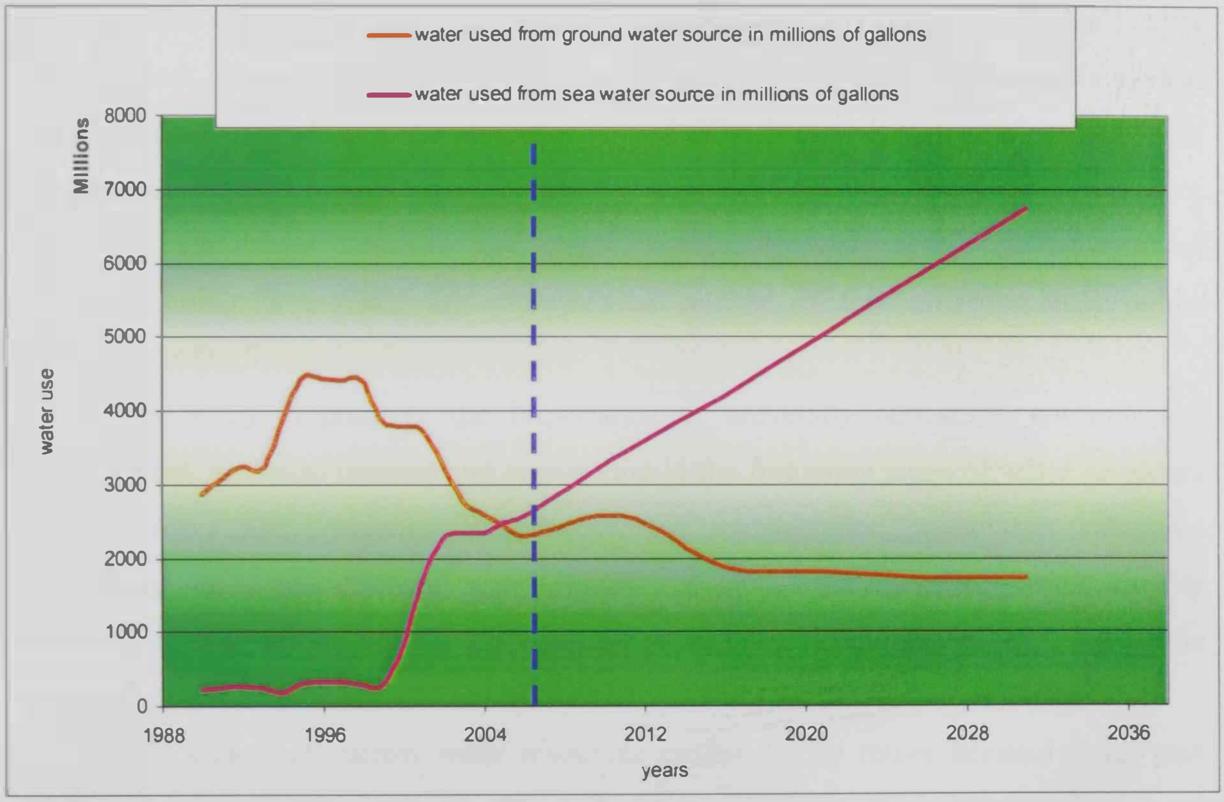


Figure 6.5. Forecasted annual desalinated and groundwater use for Ajman (High population growth scenario)

Chapter 7. Conclusions and Recommendations

7.1. Conclusions

Growing water scarcity requires sustainable water use especially in urban areas where domestic use requires high quality characteristics. To design effective water policy, urban water demand should be sufficiently analyzed and broken down. The case of Ajman area presents certain interesting aspects in this context. In Ajman, the population density is high, the climatologically conditions lead to intensified water use, while water resources are substantially scarce and the various economic growth scenarios alter water use patterns and habits. Indeed, The Ajman water system will face severe problems in the future, if current trends continue. In this context, the design of a sustainable water policy is vital for the future of the city. The present study identifies the factors (i.e. population increase, economic growth, mega projects, water quality deterioration and temperature) that determine water demand in Ajman. Future demand is estimated under certain plausible assumptions concerning its crucial determinants.

The socio-economic welfare of Ajman is largely based upon groundwater resources adequacy. Regulatory authorities have been alarmed as increasing water demand over the last decade has resulted in considerable head decline and quality deterioration. The current study attempted to develop an integrated and versatile system to handle time-expanding water resources related data; It can be used as a powerful tool by decision makers to perform a global "at a glance" updated appraisal of resource conditions via theme databases and maps. Sustainable water resources management policy planning is assisted and necessitated raising of low environmental public awareness is facilitated.

The study emphasizes the importance of university education, research and development, technical training and networking in the following areas of water resources to help solve the problems: Water resources management, wastewater treatment technology and management, groundwater resources management, water quality monitoring, use of Irrigation water management, and management of distribution systems.

It is clear that current water resources cannot satisfy future demand much past 2020 without alternative policies. The GIS database will be of specific interest to all researchers and scientist involved in practical research and applications related to water resources in Ajman and will provide the needed support to the decision making process in the Emirate in various issues related to Water Resources.

The results of the current study will serve as a model for the development of water resources databases in the other Emirates. Further future studies, is to integrate the Ajman Water Resources GIS database into other related databases in the country.

The ultimate achieved objective of this study is the development of a GIS database for water resources in Ajman to ensure the sustainability of the available water and provide technical support for researcher, professionals and decision makers in the area of Water Resources.

It is concluded that water use will increase regardless. If correct, these conclusions could lead to policy-relevant recommendations.

7.2. Recommendations

The importance of water resources in the sustainable development in Ajman Emirate and UAE can not be over emphasized. The results of this study are expected to have a direct and significant impact on the water resources management in Ajman. These results will help professionals and researchers to conduct advanced research to assess, develop, protect and sustain the available water resources in Ajman. The GIS database will provide the needed support for decision making process. The developed GIS database of water resources in Ajman might be regarded as a model to GIS databases in the other emirates. Water resources databases in the different emirates can then be integrated to develop a national database.

Major review and shift in water policies in Ajman and UAE emphasizes conservation and demand management, with the overall objective of securing long term water supplies while meeting strict criteria for socio-economic, financial and environmental sustainability and public health requirements.

More efficient use and improved quality of water resources are the main strategic objectives identified. Further details on these strategic objectives are specifically:

1) Improve public management, including appropriate policies.

2) Increase public participation in water resources management programs.

3) Increased wastewater treatment and water reuse by public and private sectors.

4) Increase use of pollution prevention techniques.

The following are the major recommendations for the sustainable water resource management in Ajman:

a) Protect water resource from over-exploitation, quality degradation, and irreversible damage.
b) Allocate water resources among different uses to sustain economic growth with equitable distribution of benefits and balance demographic distribution.
c) Satisfy society's need for water, food and ecological stability by meeting drinking water requirements, by providing for safe disposal of wastewater and solid waste, by increasing productivity per units of land and water, and by maintaining an ecological balance.
d) Pumping of groundwater resources in Ajman should be reduced as much as possible. Groundwater pumping should be controlled, regulated and monitored to ensure its sustainability.

The most cogent aspect is that water saving plans should be based on quantitative restrictions and on voluntary actions prompted by information campaigns focusing on increasing the environmental awareness of inhabitants. On the other hand, the study introduces prospects for further demand analysis and forecasting so that policy makers are able to define focus groups and other factors that could shape an effective water demand policy.

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List of Acronyms and Abbreviations

AAS	Atomic Absorption Spectrometry
ACSAD	Arab Center for the Studies of Arid Zones and Dry Lands
ADWEA	Abu Dhabi Water and Electric Authority
APHA	American Public Health Association
ERWDA	Environmental Research and Wildlife Development Agency
AOAD	Arab Organization for Agricultural Development
BOD	Biological Oxygen Demand
BTM	Base Line Thematic Mapping
DBMS	Data Base Management Systems
DO	Dissolved Oxygen
DTM	Digital Terrain Modeling
EC	Electrical Conductivity
ESRI	Environmental System Research Institute
ESCWA	Economic and Social Commission for Western Asia
FAO	Food and Agriculture Organization
FEWA	Federal electricity and Water Authority
GIS	Geographic Information system
GPS	Global Positioning System
GWW	Groundwater for Windows
ICP	Inductively Coupled Plasma
L/c/d	Liter/capita/day
M^3/Day	Cubic Meter per Day
MED	Multi Effect Distillation
MIGD	Million Imperial Gallons per Day
MEW	Ministry of Water and Environment
Mm^3/y	Million cubic meters per year
NPA	National Palestine authority
RO	Reverse Osmosis
SDM	Supply-demand model
SPSS	Statistical Package For the social Sciences
SWL	Static Water Level
TDS	Total Dissolved Solids

TKN	Total Kjeldahl Nitrogen (Sum of organic Nitrogen, Ammonia NH_3 and Ammonium NH_4 in Biological waste water Treatment)
UNEP	United Nation Environment Program
US EPA	United States Environmental Protection Agency
µs/cm	Micro Siemens / Centimeter
WRI	Water Research Institute

Appendix A

Hallew Wells Inventory Data

Production of each well with

installed submersible (pumps and motors)

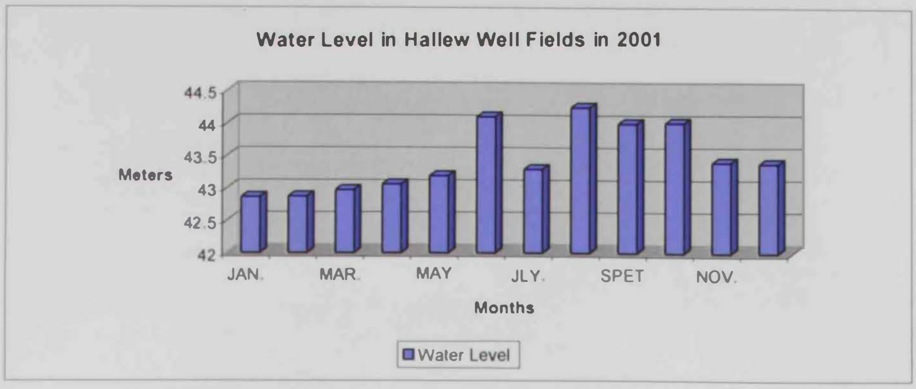
Production of each well with installed submersible (pumps and motor)

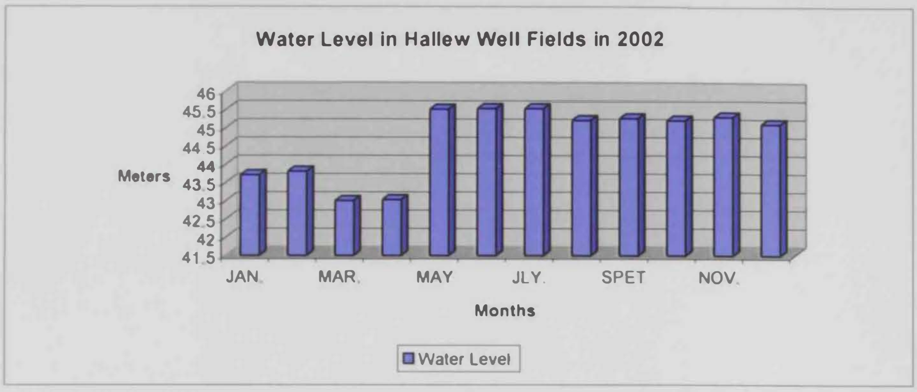
No	Production in year 2007 (GPH)	Motor make with H.P.	Pump make with model no	No	Production in year 2007 (GPH)	Motor make with H.P.	Pump make with model no
1	7200	Franklin 20H.P	Grundfos SP17-14	30	10350	Franklin 25HP	Lowara Z630-12
2	10500	Lowara 20HP	Lowara Z621-13	31	10200	Franklin 20HP	Lowara Z630/12
3	11200	Franklin 30HP	Lowara Z642-12	32	9800	Franklin 25H.P	Lowara Z642-10
4	10500	Franklin 25HP	Lowara Z642-10	33	9900	Franklin 25HP	Lowara Z642/11
5	7200	Franklin 20HP	Grundfos SP27-16	34	10300	Franklin 25HP	Lowara Z642/12
6	7300	Franklin 25HP	Lowara Z630-11	35	7200	Franklin 25HP	Lowara Z642-10
7	9700	Franklin 10HP	Lowara Z621-9	36	10100	Franklin 25HP	Lowara Z630-12
8	7300	Franklin 20HP	Lowara Z621-17	37	10200	Franklin 25HP	Lowara Z630-12
9	9870	Franklin 25HP	Grundfos SP45-12	38	10300	Franklin 25HP	Lowara Z642-10
10	9870	Franklin 25HP	Lowara Z642-10	39	10100	Franklin 20HP	Lowara Z642-10
11	6300	Franklin 15HP	Lowara Z621-17	40	10200	Franklin 25HP	Lowara Z642-10
12	10700	Franklin 25HP	Lowara Z642-10	41	10100	Franklin 25HP	Lowara Z642-10
13	6500	Franklin 20HP	Grundfos SP45-12	42	10200	Franklin 25HP	Lowara Z642-10
14	10100	Franklin 25HP	Lowara Z642-10	43	9900	Franklin 25HP	Lowara Z642-10
15	7100	Franklin 15HP	Lowara Z621-13	44	10100	Franklin 25HP	Lowara Z642-10
16	10700	Franklin 25HP	Lowara Z642-10	45	10300	Franklin 25HP	Lowara Z642-10
17	10050	Franklin 20HP	Lowara Z621-17	46	10200	Franklin 25HP	Lowara Z642-10
18	7300	Franklin 20HP	Lowara Z621-17	47	10300	Franklin 25HP	Lowara Z642-10
19	10400	Franklin 20HP	Lowara Z621-17	48	10200	Franklin 25HP	Lowara Z642-10
20	7400	Franklin 20HP	Grundfos SP29-14	49	10100	Franklin 25HP	Lowara Z642-10
21	10700	Lowara 25HP	Lowara Z642-10	50	10300	Franklin 25HP	Lowara Z642-10
22	10800	Franklin 25HP	Lowara Z630-13	51	10100	Franklin 25HP	Lowara Z642-10
23	10500	Franklin 25HP	Lowara Z642-10	52	10200	Franklin 25HP	Lowara Z642-10
24	10700	Franklin 15HP	Grundfos SP27-14	53	10300	Franklin 25HP	Lowara Z642-10
25	10100	Franklin 25HP	Lowara Z642-10	54	10100	Franklin 25HP	Lowara Z642-10
26	10300	Franklin 25HP	Lowara Z642-10	55	10200	Franklin 25HP	Lowara Z642-10
27	10300	Franklin 25HP	Lowara Z642-10	56	10300	Franklin 25HP	Lowara Z642-10
28	10200	Franklin 25HP	Lowara Z642-10	57	10200	Franklin 25HP	Lowara Z642-10
29	10100	Franklin 25HP	Lowara Z642-10				

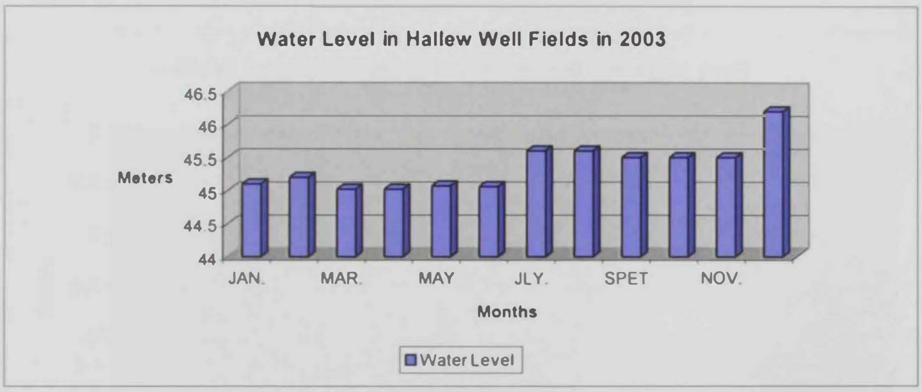
Where GPH stands for Imperial Gallon per Hour and H.P. Stands for Horse Power

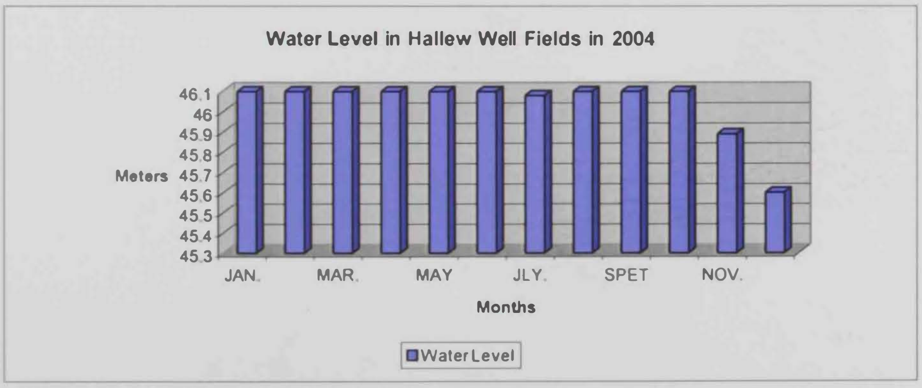
Appendix B

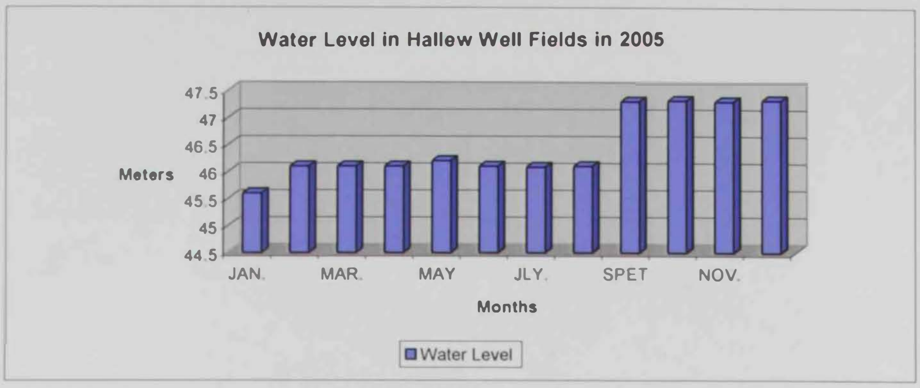
Water Levels of Hallew Well Field


Water Level in Hallew Well Fields in 2001
Meters
44.5
44
43.5
43
42.5
42
JAN.
MAR.
MAY
JLY.
SPET
NOV.
Months
Water Level

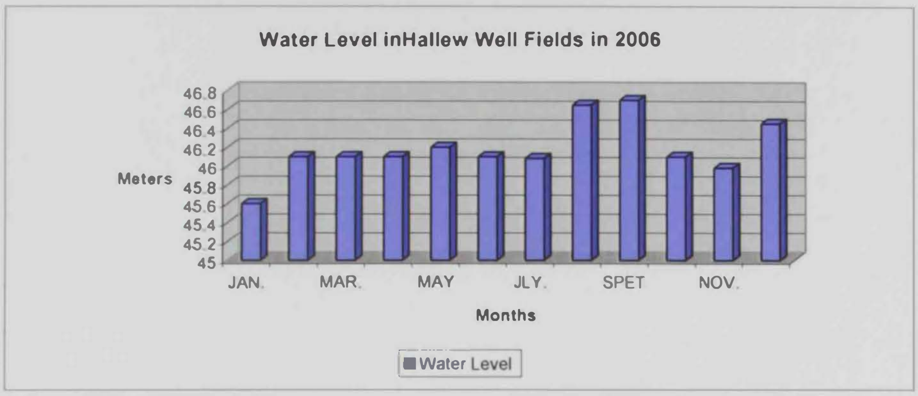

Water Level in Hallew Well Fields in 2002
Meters
46
45.5
45
44.5
44
43.5
43
42.5
42
41.5
JAN.
MAR.
MAY
JLY.
SPET
NOV.
Months
Water Level


Water Level in Hallew Well Fields in 2003
Meters
46.5
46
45.5
45
44.5
44
JAN.
MAR.
MAY
JLY.
SPET
NOV.
Months
Water Level

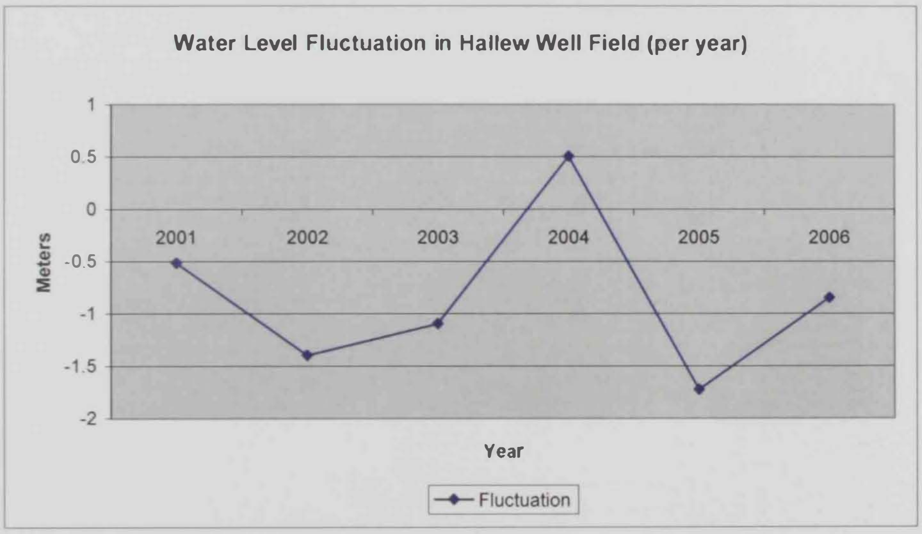

Water Level in Hallew Well Fields in 2004
Meters
46.1
46
45.9
45.8
45.7
45.6
45.5
45.4
45.3
JAN.
MAR.
MAY
JLY.
SPET
NOV.
Months
Water Level



Water Level in Hallew Well Fields in 2005
Meters
47.5
47
46.5
46
45.5
45
44.5
JAN.
MAR.
MAY
JLY.
SPET
NOV.
Months
Water Level



Water Level inHallew Well Fields in 2006
Meters
46.8
46.6
46.4
46.2
46
45.8
45.6
45.4
45.2
45
JAN.
MAR.
MAY
JLY.
SPET
NOV.
Months
Water Level



Water Level Fluctuation in Hallew Well Field (per year)
Meters
1
0.5
0
-0.5
-1
-1.5
-2
2001
2002
2003
2004
2005
2006
Year
Fluctuation

Appendix C

Hydrochemistry of Hallew Wells

Year	EC	TDS	PH	TH	TALK	Hco$_3$	So$_4$	Cl	No$_3$	F	Ca	Mg	Na	K	Sio$_2$
Well No 1															
1994	5450	3477	7.65	740	223	3.08	1.4	80	130	829	19	30	845	15.8	22
1995	5710	3643	7.72	815	185	225.7	500	1417	4.4	1	82	148	856	17.1	30
1996	5610	3579	7.92	750	186	226.9	440	1361	6.6	1.1	80	134	822	16.8	13
1997	5660	3538	7.86	800	190	231.8	610	1376	3.5	0.8	84	143	891	17	12
1998	5400	3648	7	689	187	245	613	1400	4	0.7	87	155	899	16	24
1999	5800	3625	7.88	755	192.2	234.5	625	1441	4.4	0.7	72	145	952	17.4	26
2000	5780	3613	7.81	740	191	233	590	1394	1.3	0.5	80	131	939	25.9	26
2001	5730	3580	7.77	730	196.8	240.1	500	1402	4.4	0.8	72	134	946	25.4	26
2002	5300	3313	7.52	655	197.8	241.4	490	1243	4.8	0.7	70	117	833	21.2	22
2003	5350	3344	7.65	630	202.1	246.6	525	1247	4.4	1	66	113	819	21.5	27
2004	5310	3319	7.75	610	208.9	254.9	600	1264	4	0.8	70	106	907	23.9	25
2005	5210	3257	7.82	643	205	250.1	550	1309	5.7	0.8	64	117	896	23.4	26
2006	5190	3244	7.42	643	210.3	256.5	650	1239	5.3	0.8	70	113	863	15.6	28
2007	5260	3288	7.82	628	194.8	237.6	575	1266	6.6	0.9	72	109	905	15.9	24
Well No 2															
1994	5440	3471	7.81	730	183	223	490	1298	3.1	0.7	94	119	814	19	30
1995	5350	3413	7.67	715	192.5	234.9	470	1311	3.1	0.8	80	125	823	16	25
1996	5310	3388	7.85	670	186	226.9	417	1252	7	1.1	76	117	779	15.9	13
1997	5250	3282	7.86	690	186	226.9	550	1259	4	0.8	80	119	837	15.8	12
1998	5280	3300	7.88	675	195.9	239	550	1269	5.7	0.8	116	93.6	855	15.8	25
1999	5240	3275	7.62	645	191	233	500	1218	4.4	0.4	70	114	852	23.6	26
2000	5230	3269	7.7	635	195.5	238.5	465	1260	5.7	0.7	64	115	834	23.9	25
2001	5240	3275	7.81	475	1217	5.28	0.7	68	113	830	21	25	833	21.2	22
2002	5230	3269	7.59	620	204.8	249.9	500	1195	4	0.9	66	111	804	20.9	27
2003	5310	3319	7.75	610	208.9	254.9	600	1264	4	0.8	70	106	907	23.9	25
2004	5230	3269	8	596	210.2	256.4	580	1233	2.2	0.8	63	107	887	23.8	25
2005	5140	3212	7.78	598	210.4	256.7	525	1273	4.8	0.8	56	111	884	23.1	25
2006	5230	3269	7.66	578	211.6	258.1	650	1232	3.1	0.8	66	100	882	16.6	28
2007	5140	3213	7.86	603	205.8	251.1	550	1235	4	0.8	64	107	872	15.4	25
Well No 3															
1994	5360	3420	7.77	750	191	233	463	1287	2.6	0.8	80	132	788	18.8	29
1995	5320	3394	7.77	705	200	244	470	1307	4.4	1	76	125	829	16	30
1996	5320	3394	7.89	650	192	234.2	418	1264	5.7	1.1	80	109	799	16	13
1997	5290	3307	7.89	670	191	233	560	1259	3.5	0.7	76	117	853	15.9	12
1998	5250	3281	7.91	680	197.2	240.6	550	1239	7	0.8	96	107	835	15.8	25
1999	5260	3288	7.76	660	199.9	243.9	535	1235	1.3	0.2	68	119	855	23.7	26
2000	5260	3288	7.75	660	194.3	237.1	465	1247	3.1	0.6	68	119	845	23.7	25
2001	5300	3300	7.57	550	1213	3.08	0.6	64	115	895	17	20	833	21.2	22
2002	5280	3300	7.55	615	206.2	251.6	515	1217	2.2	0.8	66	109	820	21.1	29
2003	5310	3319	7.75	610	208.9	254.9	600	1264	4	0.8	70	106	907	23.9	25
2004	5280	3300	7.77	596	581	271	590	1246	0.4	0.7	63	103	909	23.8	25
2005	5210	3246	7.81	624	211.6	258.1	600	1355	0.9	0.6	63	113	964	15.6	23
2006	5200	3250	7.72	592	216.7	264.4	650	1239	2.2	0.8	68	102	895	15.6	28
2007	5230	3269	7.89	578	209.5	255.6	550	1249	3.1	0.8	68	98.9	893	15.6	25
Well No 4															
1994	5280	3369	7.84	710	183	223	598	1261	14	1	90	116	856	18.5	30
1995	5280	3369	7.74	695	205	250.1	465	1276	3.5	0.6	72	125	813	15.8	30
1996	5270	3362	7.77	660	197	240.3	414	1238	3.5	1	84	109	777	15.8	13
1997	5250	3282	7.97	650	198	241.6	550	1237	1.3	0.6	84	107	846	15.8	12
1998	5250	3281	7.91	680	197.2	240.6	550	1239	7	0.8	96	107	835	15.8	25
1999	5300	3313	7.88	640	205.8	251.1	540	1249	1.8	0.7	68	114	857	15.9	25
2000	5250	3281	7.85	650	200.9	245.1	535	1219	2.2	0.6	72	114	853	23.6	26
2001	5290	3306	7.79	705	210	256.2	515	1265	3.1	0.6	68	130	858	23.7	25
2002	5340	3338	7.76	665	212.9	257.7	515	1233	0.9	0.7	66	122	834	21.3	24
2003	5310	3319	7.75	610	208.9	254.9	600	1264	4	0.8	70	106	907	23.9	25
2004	5340	3338	8.06	596	219.6	267.9	610	1264	1.8	0.7	63	107	922	24	25
2005	5560	3475	7.83	668	210.4	256.7	600	1391	3.5	0.8	72	118	962	25	25
2006	5550	3469	7.69	703	215.4	262.8	650	1341	2.6	0.9	70	123	917	16.9	28
2007	5460	3413	7.93	663	208.3	254.1	575	1339	2.2	0.8	72	117	922	16.5	24

Note: All Measruments are in mg/l except E.C. which is in µs/cm

TH and TALK stands for total hardness and total alkalinity respectively

Year	EC	TDS	PH	TH	TALK	HCO_3	SO_4	Cl	NO_3	F	Ca	Mg	Na	K	SiO_2
Well No 5															
1994	5570	3554	7.79	820	178	217	644	1406	4	1.1	112	130	913	19.5	30
1995	5740	3662	7.76	850	187.5	228.8	500	1426	4	1.1	92	151	846	17.2	30
1996	5810	3707	7.88	800	180	219.6	457	1414	6.2	1.1	92	139	839	17.4	13
1997	5940	3714	7.85	930	180	219.6	650	1458	8.8	0.6	100	1652	900	17.8	13
1998	5250	3281	7.91	680	197.2	240.6	550	1239	7	0.8	96	107	835	15.8	25
1999	5810	3631	7.88	760	198.4	242	625	1390	4.4	0.8	96	126	930	17.4	26
2000	5920	3700	7.74	820	192.2	234.5	605	1407	5.3	0.7	90	145	962	26.6	26
2001	6060	3788	7.62	810	196.8	240.1	525	1527	6.2	0.7	84	146	991	27	26
2002	6060	3788	7.63	525	198	243	527	1589	6.9	0.7	89	147	834	21.3	24
2003	6140	3838	7.53	800	202.1	246.6	575	1484	3.5	0.9	80	146	951	24.5	27
2004	6200	3875	8.06	763	214.3	261.4	675	1521	2.2	0.7	76	139	1038	27.9	27
2005	6020	3763	8.01	809	211.5	258.1	675	1619	5.3	0.8	74	151	936	18.1	26
2006	6070	3794	7.38	804	215.4	262.8	700	1517	3.1	0.8	86	143	985	18.2	29
2007	6210	3881	7.55	783	208.3	254.1	675	1543	4	0.9	90	135	1046	18.9	25
Well No 6															
1994	5350	3413	7.82	775	166	203	633	1244	2.6	1.1	94	130	818	18.7	30
1995	5640	3598	7.76	855	184	224.5	495	1395	2.6	1.1	92	152	820	16.9	30
1996	6030	3847	7.89	890	169.2	206.4	474	1458	7.9	1.1	96	158	829	18.1	14
1997	5740	3589	7.85	805	189	230.6	625	1345	4	0.8	88	142	875	17.2	13
1998	5240	3275	7.81	475	1217	5.28	0.7	68	113	830	21	25	833	21.2	22
1999	5550	3469	7.91	750	193.4	235.9	600	1321	3.1	0.8	106	118	876	17.4	25
2000	5790	3619	7.56	750	212	258.7	590	1396	3.1	0.6	82	132	941	26.1	26
2001	5950	3719	7.56	730	227.7	271.7	550	1447	1.8	0.8	74	132	970	26.5	26
2002	6000	3750	7.57	620	204.8	249.9	540	1412	6.6	0.7	68	131	975	24	26
2003	5990	3744	7.6	740	234.5	286.1	575	1405	3.5	0.9	68	139	931	24	28
2004	5900	3688	7.97	634	245.2	291.1	650	1394	0.9	0.7	63	116	1018	26.6	26
2005	5860	3663	8.01	657	238.5	291	625	1555	4.8	0.8	61	123	1061	17.6	24
2006	6040	3775	7.38	728	229.6	280.1	700	1496	4	0.8	76	130	1018	18.1	29
2007	6140	3838	7.76	783	216.8	264.5	625	1567	4	0.9	86	138	1042	18.5	25
Well No 7															
1994	5470	3490	7.74	780	166	203	610	1304	4	1.1	100	127	845	19.1	29
1995	5420	3458	7.8	770	184	224.5	485	1324	2.6	1.1	74	142	809	16.3	30
1996	5500	3509	7.71	775	174	212.3	432	1313	4.4	1.1	100	128	770	16.5	13
1997	5560	3476	7.85	775	176	214.7	605	1312	2.2	0.7	84	137	852	16.7	12
1998	5280	3300	7.88	675	195.9	239	550	1269	5.7	0.8	116	93.6	855	15.8	25
1999	5600	3500	7.87	780	178.6	217.9	575	1345	2.6	0.8	148	99.6	859	16.8	25
2000	6050	3781	7.74	900	173.6	211.8	615	1456	3.5	0.6	108	153	983	27.2	27
2001	6050	3781	7.66	815	189.1	230.7	565	1419	4.4	0.9	92	142	970	27.3	26
2002	5930	3706	7.51	785	208.7	254.6	550	1403	5.3	0.7	82	141	916	23.7	25
2003	5030	3144	7.58	780	226.4	276.2	575	1432	3.1	0.9	78	142	771	20.1	27
2004	5230	3269	8	596	210.2	256.4	580	1233	2.2	0.8	63	107	887	23.8	25
2005	5770	3606	7.78	708	251.9	306.7	650	1486	4.8	0.8	72	128	907	26	25
2006	5860	3663	7.38	703	246.4	300.6	675	1405	2.2	0.8	86	118	1017	17.6	28
2007	5880	3675	7.88	768	236.4	288.4	600	1464	4	0.8	82	137	1020	17.8	24
Well No 8															
1994	5630	3592	7.78	825	166	203	656	1346	2.6	1	108	133	873	19.7	29
1995	5540	3535	7.76	810	178.9	218.3	490	1346	2.2	0.9	86	145	804	16.6	30
1996	5510	3515	7.81	770	167	203.7	433	1308	3.5	1	92	131	766	16.5	13
1997	5500	3438	7.93	800	166	202.5	600	1332	1.3	0.7	88	141	846	16.5	12
1998	5250	3281	7.91	680	197.2	240.6	550	1239	7	0.8	96	107	835	15.8	25
1999	5630	3519	7.88	855	176.1	214.8	650	1360	5.7	0.8	120	135	869	16.9	26
2000	5690	3556	7.8	805	174.8	213.3	580	1350	5.3	0.5	88	142	925	25.6	26
2001	5710	3569	7.66	765	176.1	214.8	500	1393	4	0.8	78	139	910	25.8	25
2002	5670	3544	7.48	770	180.2	219.8	525	1443	3.1	0.7	82	137	925	22.6	25
2003	5780	3612	7.61	790	188.7	230.2	560	1330	1.3	0.9	80	143	857	23.2	27
2004	5820	3638	7.88	734	204.8	249.9	640	1403	1.3	0.7	74	133	954	26.2	26
2005	5700	3563	7.92	738	214.4	261.6	650	1450	5.7	0.8	72	128	949	25.7	21
2006	5780	3613	7.61	753	192.2	234.5	675	1412	4.4	0.8	88	129	990	17.3	28
2007	5840	3650	7.81	778	189.9	231.7	650	1432	4	0.8	86	137	1005	17.6	25

Note : All Measruments are in mg/l except E.C. which is in µs/cm
TH and TALK stands for total hardness and total alkalinity respectively

Year	EC	TDS	PH	TH	TALK	HCO_3	SO_4	Cl	NO_3	F	Ca	Mg	Na	K	SiO_2
Well No 9															
1994	5880	3751	7.68	855	171	209	702	1397	3.1	1.1	112	138	916	20.6	28
1995	5790	3694	7.78	865	177.5	216.6	520	1399	3.5	0.9	96	152	827	17.4	30
1996	5780	3688	7.69	830	164.4	200.6	454	1383	4.4	1.1	92	146	795	17.3	13
1997	5870	3670	7.95	870	162	197.6	670	1450	0.9	0.8	96	153	921	17.6	13
1998	5250	3281	7.91	680	197.2	240.6	550	1456	0.8	0.8	96	145	835	15.8	25
1999	5800	3625	7.72	840	166.2	202.8	675	1406	1.8	0.8	126	128	912	17.4	27
2000	5790	3619	7.57	840	163.7	199.7	590	1385	4.4	0.5	88	151	941	26	26
2001	5880	3675	7.69	830	168.4	205.4	550	1451	3.1	0.7	84	151	910	26.5	26
2002	5830	3644	7.54	815	176.2	214.9	575	1386	4.4	0.8	84	147	905	23.4	27
2003	5920	3700	7.54	830	180.6	220.3	575	1388	3.1	0.9	86	150	885	23.6	27
2004	5790	3619	7.84	738	188.7	230.2	620	1403	0.9	0.7	80	131	935	26.1	26
2005	5660	3538	7.71	779	186.3	227.2	650	1554	5.3	0.8	72	145	1029	25.5	23
2006	5740	3588	7.4	829	181.4	221.3	675	1415	4.8	0.8	86	149	950	17.3	28
2007	5840	3650	7.69	809	177.6	216.7	650	1436	5.7	0.9	84	145	966	17.7	25
Well No 10															
1994	6240	3981	7.76	780	171	209	690	1525	3.1	1.2	102	126	1027	21.8	28
1995	6290	4013	7.8	950	181.2	221.1	585	1575	4.8	1.1	100	170	934	18.9	31
1996	6360	4058	7.87	900	166	202.5	500	1545	4.8	0.9	100	158	890	19.2	14
1997	6360	4058	7.88	1000	168.6	205.7	570	1592	5.3	0.8	120	170	909	19.1	13
1998	6320	3800	7.81	878	171	276	645	1598	3.5	0.8	123	170	833	21.2	22
1999	6300	3938	7.92	950	243	296.5	725	1537	3.5	0.8	120	158	1004	18.9	26
2000	6370	3981	7.78	910	167.4	204.2	650	1543	5.7	0.6	98	162	1035	28.7	27
2001	6460	4038	7.71	900	167.1	203.9	625	1606	4.4	0.8	110	152	1020	29	27
2002	6480	4050	7.48	905	169.4	206.7	700	1563	4.8	0.7	94	163	1009	25.9	27
2003	6500	4063	7.55	935	173.8	212.1	625	1572	4.4	1	98	168	1016	26	28
2004	7140	4463	7.69	1067	186	266.9	850	1795	9.2	0.6	124	184	1200	24	26
2005	7330	4581	7.87	1039	168.2	276	870	1856	14	0.7	110	185	1234	27	28
2006	7080	4425	7.59	1029	166.4	203	775	1788	20	0.8	122	176	1139	21.2	28
2007	6910	4319	7.59	984	161.7	197.3	775	1747	20	0.8	108	173	1124	20.7	26
Well No 11															
1994	6400	4083	7.56	1050	171	209	771	1602	4	1	110	186	991	22.4	29
1995	6390	4077	7.72	900	182	222	610	1628	4	1.1	102	157	999	22.4	29
1996	6480	4134	7.66	950	162	197.6	509	1599	7	1	108	165	905	19.4	14
1997	6530	4082	7.73	1000	161	196.4	710	1656	5.7	0.6	104	180	1014	19.6	14
1998	6300	4024	7.91	880	197.2	240.6	680	1689	7	0.8	96	107	1022	19.9	25
1999	6600	4125	7.74	970	179.8	219.4	710	1681	7.5	0.7	96	177	1053	19.8	28
2000	6660	4163	7.65	965	157.5	192.1	680	1631	8.4	0.6	110	168	1082	30	27
2001	6860	4288	7.74	995	163.2	199.1	665	1748	6.6	0.7	112	174	1108	30.7	27
2002	6830	4269	7.8	1025	165.9	202.4	650	1722	10	0.8	108	184	1008	27.3	25
2003	6980	4363	7.55	1035	163.1	198.9	700	1722	8.8	0.9	108	186	1019	28	28
2004	7330	4581	7.87	1039	168.2	205.4	700	1856	14	0.7	110	185	1119	33	28
2005	7200	4501	7.64	1080	162.1	197.8	850	1932	22	0.8	102	200	1167	25.9	24
2006	7540	4713	7.5	1165	162.5	198.3	825	1939	24	0.8	130	204	1183	22.6	29
2007	7700	4813	7.76	1175	155.6	189.8	850	1972	30	0.9	128	208	1209	23.1	24
Well No 12															
1994	6630	4230	7.18	990	171	209	713	1653	4	0.9	130	160	1023	23.2	30
1995	6720	4287	7.74	1045	175	213.5	630	1712	7.9	1.1	108	188	997	20.2	31
1996	6780	4326	7.72	1000	160	195.2	533	1677	7.5	1.3	120	170	942	20.3	14
1997	6860	4290	7.69	1055	164	200.1	750	1738	3.5	0.6	112	188	1060	20.6	14
1998	6785	4180	7.91	1001	167	197	690	1745	4.5	0.8	111	145	1034	20.9	25
1999	6973	4356	7.88	1000	162.4	198.1	750	1753	6.6	0.9	140	158	1096	20.9	27
2000	7120	4450	7.6	1070	160	195.2	750	1780	4.9	0.3	112	192	1157	32	28
2001	7340	4588	7.66	1150	168.4	205.4	715	1886	1.8	0.8	116	209	1219	32.9	28
2002	7400	4625	7.33	1105	159.9	195	750	1836	3.5	0.7	112	201	1090	29.6	28
2003	7420	4638	7.48	1120	175.2	213.7	750	1845	7	1	126	196	1083	29.7	28
2004	7520	4700	7.71	1082	169.8	207.2	750	1917	8.4	0.7	112	195	1160	33.8	28
2005	7690	4806	7.62	1200	164.8	201.1	850	2064	11	0.8	104	228	1247	26.8	24
2006	8230	5144	7.56	1376	162.5	198.3	850	2179	16	0.8	151	243	1269	24.7	30
2007	8270	5169	7.55	1376	155.6	189.8	900	2166	17	0.8	151	243	1275	25	26

Note : All Measruments are in mg/l except E.C. which is in μs/cm
TH and TALK stands for total hardness and total alkalinity respectively

Year	EC	TDS	PH	TH	TALK	Hco_3	So_4	Cl	No_3	F	Ca	Mg	Na	K	Sio_2
Well No 13															
1994	6820	4351	7.68	1030	164	200	794	1824	4.4	1.1	136	166	1151	23.9	29
1995	6890	4396	7.73	1075	175	213.5	645	1760	2.6	0.9	114	192	1020	20.7	31
1996	7050	4498	7.83	1050	160	195.2	554	1756	6.6	1.1	124	180	979	21.2	14
1997	7190	4495	7.75	1100	161	194.4	790	1854	1.8	0.5	132	187	1132	21.6	14
1998	7080	4545	7.88	1100	165	196	756	1789	5.7	0.8	134	167	1156	15.8	25
1999	7370	4606	7.86	1110	156.2	190.6	750	1874	3.1	0.7	152	177	1119	22.1	27
2000	7520	4700	7.68	1155	153.8	187.6	770	1876	7	0.5	122	207	1222	33.8	28
2001	7760	4850	7.68	1200	158	192.8	740	2050	1.3	0.8	134	210	1260	34.9	28
2002	7880	4925	7.48	1220	154.5	188.5	775	2239	8.4	0.7	130	218	1220	31.6	28
2003	7960	4975	7.31	1265	163.1	198.9	800	2003	2.6	0.9	136	225	1165	31.9	27
2004	8140	5088	7.83	1225	153.6	187.4	850	2125	7	0.8	130	219	1268	36.6	28
2005	8620	5388	7.51	1461	154.1	188	950	2385	11	0.8	153	262	1374	25.9	24
2006	8720	5450	7.45	1441	153	186.4	950	2263	12	0.8	161	252	1312	26.2	24
2007	9020	5638	7.59	1471	148.2	180.8	950	2401	14	0.8	165	257	1414	27.1	25
Well No 14															
1994	5800	3700	7.78	800	188	229	610	1414	3.5	1	86	140	917	20.3	29
1995	5690	3630	7.82	780	212.5	259.3	510	1386	3.1	0.9	80	141	869	17.1	30
1996	5580	3560	7.9	675	199.2	243	439	1317	5.7	1.1	72	120	834	16.7	13
1997	5640	3526	7.84	740	201	245.2	610	1371	11	0.7	72	136	923	16.9	12
1998	5250	3281	7.91	680	197.2	240.6	550	1239	7	0.8	96	107	835	15.8	25
1999	5730	3581	7.82	740	238.7	291.2	618	1419	3.1	0.7	68	139	973	17.2	26
2000	5800	3625	7.85	735	198.4	242.1	590	1377	3.1	0.5	76	132	943	26.1	26
2001	5820	3638	7.84	860	163.2	199.1	540	1538	1.3	0.7	74	164	949	26.1	26
2002	5690	3556	7.74	695	203.3	248	525	1334	4.8	0.7	68	128	927	22.8	25
2003	5940	3713	7.61	725	206.2	251.5	575	1370	1.3	0.9	74	131	935	23.8	28
2004	5640	3525	8.04	653	215.6	263	630	1342	1.8	0.7	63	121	953	25.4	25
2005	5330	3331	7.76	663	211.7	258.3	650	1310	4.4	0.8	60	124	877	24	22
2006	5510	3444	7.72	648	134	163.5	625	1270	1.8	0.8	76	111	874	16.5	22
2007	5750	3594	7.8	703	207	252.6	650	1412	0.4	0.8	78	123	986	17.2	26
Well No 15															
1994	6810	4345	7.76	1060	171	209	690	1821	5.7	1.1	106	191	1089	23.8	30
1995	6880	4389	7.74	1060	175	213.5	645	1764	3.5	0.8	104	194	1029	20.6	31
1996	6970	4447	7.76	1020	166	202.5	548	1734	7.5	1.1	118	176	979	20.9	14
1997	7110	4536	7.81	1070	167.4	204.2	695	1818	6.6	1	120	187	1081	21.3	14
1998	7345	3800	7.81	1111	171	234	645	1789	3.5	0.8	123	170	1009	21.2	22
1999	7300	4563	7.83	1115	155	189.1	750	1857	1.3	0.8	152	179	1104	21.9	27
2000	7430	4644	7.6	1135	167.7	199.7	760	1870	5.3	0.5	120	203	1207	33.4	28
2001	7050	4410	7.67	995	194.3	237.1	625	1819	1.3	0.6	102	180	1148	31.5	27
2002	7570	4700	7.42	1150	170.7	208.3	850	1897	5.3	0.8	114	210	1280	28.2	20
2003	8110	5069	7.52	1300	171.1	208.8	800	2099	6.2	1	136	233	1190	32.5	29
2004	8320	5200	7.68	1262	175.2	213.7	800	2161	7	0.8	128	229	1259	37.6	28
2005	8460	5288	7.65	1391	160.8	196.2	###	2313	10	0.9	141	253	1315	25.8	22
2006	8660	5413	7.32	1406	158.7	193.6	875	2302	14	0.8	153	249	1326	29	30
2007	8660	5413	7.5	1406	166.4	203	950	2295	15	0.9	149	251	1357	24	21
Well No 16															
1994	6700	4275	7.72	1000	166	203	644	1853	4.4	1.2	106	176	1114	23.5	30
1995	6850	4345	7.76	1045	175	213.5	645	1742	4.4	1.1	116	184	1023	20.6	31
1996	5410	3452	7.72	670	208	253.8	425	1295	6.6	1.1	80	114	820	16.2	13
1997	7130	4457	7.87	1070	161	196.4	770	1831	7.9	0.8	124	185	1123	21.4	14
1998	7200	4024	7.91	1009	178	198	776	1879	7	0.8	96	107	1123	19.9	25
1999	7380	4613	7.83	1170	156.2	190.6	775	1874	4	0.8	146	196	1103	22.1	27
2000	7500	4688	7.67	1175	156.2	190.6	765	1912	5.7	0.3	126	209	1219	33.5	28
2001	7650	4781	7.65	1185	158	192.8	775	1970	2.2	0.8	124	213	1215	34.5	28
2002	8150	5094	7.33	1295	150.4	183.5	775	2057	8.8	0.7	134	233	1274	32.6	29
2003	8010	5006	7.5	1260	165.7	202.2	800	2020	3.1	1	128	228	1174	32.1	31
2004	8150	5094	7.65	1220	167.1	203.9	790	2100	5.3	0.8	124	221	1230	36.7	28
2005	8380	5238	7.65	1366	162.1	197.8	975	2270	7	0.8	139	248	1342	25.1	23
2006	8660	5413	7.38	1436	160	195.2	875	2295	10	0.8	156	254	1299	24	30
2007	6690	4181	7.93	874	203.4	248.1	700	1668	0.9	0.9	96	154	1094	17.8	27

Note All Measruments are in mg/l except E C. which is in µs/cm
TH and TALK stands for total hardness and total alkalinity respectively

Year	EC	TDS	PH	TH	TALK	Hco_3	So_4	Cl	No_3	F	Ca	Mg	Na	K	Sio_2
Well No 17															
1994	6600	4249	7.77	1000	170	207	793	1649	2.6	0.9	96	185	1048	24.4	29
1995	6600	4211	7.73	1045	177.5	216.6	650	1685	2.2	0.9	106	190	989	19.8	31
1996	6660	4249	7.83	1005	188	229.4	546	1665	4.4	1.1	112	176	950	20	14
1997	6800	4251	7.71	990	162	197.6	745	1706	8.8	0.6	120	168	1070	20.4	14
1998	6789	4354	7.81	1111	171	234	645	1789	3.5	0.8	123	170	1009	21.2	22
1999	6850	4281	7.83	1060	131.4	160.3	750	1701	4.8	0.8	118	186	1020	20.6	26
2000	6990	4369	7.69	1125	158.7	193.6	715	1736	5.3	0.5	106	209	1136	31.5	27
2001	6100	3813	7.72	845	183.9	224	565	1500	1.3	0.7	90	151	980	27.3	27
2002	7560	4725	7.64	1165	154.5	188.5	800	1896	4.8	0.6	120	210	1180	30.3	27
2003	6780	4238	7.48	1025	172.5	210.4	700	1669	4	0.9	108	184	1083	27.3	28
2004	7540	4713	7.73	1096	168	205.4	750	1935	4.4	0.8	112	198	1163	34	28
2005	7650	4781	7.68	1240	156.8	191.3	850	2154	10	0.8	112	233	1172	22.9	24
2006	7850	4906	7.4	1225	160.8	196.2	850	2010	12	0.8	136	215	1206	23.6	24
2007	7689	4999	7.68	1256	170	199	870	2154	11	0.8	156	234	1189	25	26
Well No 18															
1994	6470	4128	7.63	915	183	223	690	1776	3.5	1	112	152	1133	22.6	29
1995	6410	4090	7.76	980	190	231.8	620	1610	2.6	0.8	106	174	962	19.4	31
1996	6340	4045	7.83	940	200	244	520	1550	3.1	1	106	164	899	19	14
1997	6400	4000	7.74	900	175	213.5	700	1615	10	0.8	104	156	1037	19.2	14
1998	6300	4024	7.91	880	197.2	215	680	1689	7	0.8	96	107	1022	19.9	25
1999	6270	3919	7.81	850	186	226.9	675	1572	3.1	0.5	88	153	1023	18.8	27
2000	6190	3869	7.75	920	173.6	211.8	630	1523	8.8	0.6	92	168	1006	27.9	27
2001	6180	3863	7.73	870	176.1	214.8	600	1531	3.8	0.7	94	154	1001	27.8	26
2002	6510	4069	7.49	930	176.2	214.9	625	1576	5.7	0.6	92	170	1045	26	26
2003	6710	4194	7.61	980	188.7	230.2	650	1607	3.1	1	98	179	982	26.9	26
2004	6680	4175	7.96	896	210.2	256.4	720	1726	1.3	0.7	84	167	1127	30.1	27
2005	6950	4344	7.98	952	206.2	251.5	765	1747	4.4	0.8	101	170	1148	24.4	27
2006	7220	4513	7.57	1035	209	255	770	1841	2.6	0.8	120	178	1166	21.7	29
2007	7560	4725	7.72	1100	196	239.1	800	1917	1.8	0.9	124	192	1231	22.7	25
Well No 19															
1994	6390	4077	7.65	960	183	223	679	1676	3.1	1.1	120	158	1042	22.4	28
1995	6360	4058	7.78	950	183	223.2	595	1610	3.1	0.9	104	168	961	19.1	31
1996	6420	4096	7.8	940	173	211.1	505	1568	6.6	1.2	92	173	892	19.3	14
1997	6480	4050	7.82	940	175	213.5	715	1622	7.5	0.7	106	164	1029	19.4	14
1998	6489	4354	7.88	1100	165	196	756	1599	5.7	0.8	134	167	1156	15.8	25
1999	6560	4100	7.83	1010	179.8	219.4	625	1580	1.3	0.8	120	173	926	19.7	26
2000	6900	4313	7.63	1050	177.3	216.3	705	1729	13	0.7	100	194	1121	31.1	27
2001	7000	4375	7.63	1025	181.3	221.2	640	1757	2.2	0.7	104	186	1100	31.5	27
2002	7020	4388	7.43	1005	189.7	231.4	700	1724	3.1	0.8	106	180	1165	28.1	27
2003	6960	4350	7.58	1010	192.7	235.1	685	1695	2.2	0.9	98	186	1022	28	26
2004	7040	4400	7.66	943	202.1	246.7	700	1743	2.2	0.7	99	169	1102	31.7	28
2005	7340	4588	7.88	970	199.4	243.3	725	1960	4.4	0.7	101	175	1230	25.8	26
2006	7210	4506	7.57	1035	205.1	250.2	775	1820	1.3	0.8	110	184	1154	21.7	29
2007	7560	4725	7.72	1100	196	239.1	800	1917	1.8	0.9	124	192	1231	22.7	25
Well No 20															
1994	6280	4007	7.76	940	171	209	587	1651	3.5	1.1	112	158	986	22	29
1995	6200	3956	7.71	915	188	229.4	583	1536	3.1	1	96	164	926	18.6	31
1996	6360	4058	7.66	910	179	218.4	500	1558	6.2	1.1	96	163	900	19.1	14
1997	6540	4088	7.64	950	175	213.5	720	1638	7	0.6	108	165	1037	19.6	14
1998	6300	4024	7.91	880	197.2	240.6	680	1689	7	0.8	96	107	1022	19.9	25
1999	6850	4281	7.87	970	178.6	217.9	680	1690	7	0.9	102	174	1043	20.6	26
2000	6720	4200	7.69	1000	181	220.9	685	1694	10	0.7	100	182	1092	30.2	27
2001	6700	4190	7.7	945	176.1	214.8	600	1669	0.9	0.8	92	1737	1065	30.7	26
2002	6550	4094	7.44	875	195.1	238.1	675	1585	4	0.7	86	160	1075	26.2	27
2003	6530	4081	7.63	870	207.5	253.2	650	1563	1.8	0.9	84	160	999	26.1	28
2004	6800	4250	7.86	891	208.9	254.9	690	1665	1.8	0.7	90	162	1074	30.6	27
2005	6780	4238	7.67	990	199.7	243.6	800	1725	3.5	0.8	92	184	1108	20.1	23
2006	7210	4506	7.57	1035	205.1	250.2	775	1820	1.3	0.8	110	184	1154	21.7	29
2007	7380	4613	7.73	1065	196	239.1	825	1848	0.9	0.9	108	193	1213	22.2	25

Note All Measruments are in mg/l except E.C. which is in µs/cm
TH and TALK stands for total hardness and total alkalinity respectively

Year	EC	TDS	PH	TH	TALK	HCO_3	SO_4	Cl	NO_3	F	Ca	Mg	Na	K	SiO_2
Well No 21															
1994	5350	3413	7.8	670	190	232	495	1480	3.5	1	80	113	965	18.7	29
1995	5350	3413	7.72	675	208	253.8	480	1307	1.8	0.8	66	124	850	16.1	29
1996	5290	3375	7.88	660	216	263.5	434	1323	4.8	1.1	74	115	851	15.9	13
1997	5340	3378	7.94	650	200	244	570	1263	7.9	0.5	76	112	875	16	12
1998	5240	3275	7.81	680	234	245	557	1256	8	1	77	123	833	21.2	22
1999	5420	3380	7.99	720	210.8	257.2	550	1278	0.9	0.8	118	103	845	16.3	26
2000	5420	3388	7.67	710	200.9	245.1	555	1287	7	0.5	68	131	880	24.4	26
2001	5450	3406	7.66	685	212.4	259.1	500	1300	1.3	0.8	68	125	890	24.4	25
2002	5360	3350	7.51	640	210.2	256.2	490	1239	1.3	0.6	64	117	854	21.4	25
2003	5460	3413	7.6	685	207.5	253.2	525	1265	0.9	0.9	62	129	862	21.8	28
2004	5520	3450	7.97	634	221	269.6	600	1307	1.8	0.7	65	115	928	24.8	25
2005	5380	3363	7.73	673	213.1	259.9	625	1319	3.1	0.8	62	126	925	17	22
2006	5460	3413	7.77	678	218	266	650	1324	0.9	0.8	82	115	917	16.4	28
2007	5340	3338	7.94	608	219.7	268	525	1278	2.2	0.7	84	96.5	896	15.9	27
Well No 22															
1994	5400	3445	7.82	650	195	238	518	1495	3.1	1	82	107	997	18.9	29
1995	5420	3458	7.8	720	218	266	485	1324	1.8	1	80	126	847	16.3	30
1996	5390	3439	7.93	650	219	267.2	442	1348	4	1.1	72	114	876	16.2	13
1997	5450	3406	7.89	660	206	251.3	580	1289	5.7	0.5	80	112	894	16.4	12
1998	5240	3275	7.81	680	234	245	557	1256	8	1	77	123	833	21.2	22
1999	5540	3463	7.73	705	210.8	257.2	520	1301	2.2	0.6	72	128	583	16.6	21
2000	5540	3463	7.91	665	214.5	261.7	565	1313	7.5	0.4	72	118	900	24.9	26
2001	5580	3488	7.85	695	217.6	265.5	500	1349	1.8	0.6	68	128	916	25.1	25
2002	5860	3663	7.7	715	216.8	264.5	500	1373	3.1	0.7	68	132	951	23.4	25
2003	5590	3494	7.73	675	225	274.5	525	1300	0.9	0.8	68	123	886	22.4	27
2004	5520	3450	7.97	667	221	274	700	1412	7.5	0.7	70	120	1027	30	27
2005	5490	3431	7.74	663	226.5	276.3	600	1373	2.2	0.8	63	123	947	17.2	23
2006	5500	3438	7.57	673	237.4	289.6	625	1327	2.2	0.8	70	121	940	16.5	28
2007	5480	3425	8.27	638	219.7	268	550	1312	1.8	0.7	88	101	942	16.5	26
Well No 23															
1994	6470	4128	7.75	950	171	209	535	1790	4	1.1	116	158	1047	22.6	30
1995	5400	3445	7.62	800	218	266	485	1307	3.1	0.7	80	146	800	16.3	30
1996	5420	3458	7.96	660	209	255	426	1278	6.2	1.2	76	114	815	16.3	13
1997	5420	3388	7.93	780	191	233	575	1294	5.7	0.8	92	134	832	16.3	12
1998	5560	3367	7.91	768	197.2	240.6	589	1289	7	0.8	96	107	878	19.9	25
1999	5450	3406	7.8	710	210.8	257.2	575	1282	0.4	0.7	80	124	864	16.4	28
2000	5480	3425	7.6	665	205.8	251.1	560	1300	4.8	0.5	72	118	891	24.7	26
2001	5500	3438	7.66	690	215	262.3	500	1314	0.9	0.7	72	124	895	24.8	26
2002	5330	3456	7.65	655	214.1	261.2	515	1273	3.1	0.8	62	122	778	22.2	25
2003	5700	3563	7.66	715	215.6	263	525	1353	1.3	0.9	72	130	904	22.8	27
2004	6800	3267	7.86	667	223	276	700	1434	7.5	0.7	74	123	1027	30.6	27
2005	5810	3631	7.74	738	217.1	264.8	650	1463	8.8	0.8	70	137	994	17.5	25
2006	5860	3663	7.71	733	216.7	264.4	675	1422	6.6	0.8	78	131	998	17.6	28
2007	5930	3706	7.93	748	210.7	257.1	650	1446	7	0.9	80	133	1011	17.7	25
Well No 24															
1994	6880	4389	7.74	1050	166	203	667	1803	4	1	130	174	1068	24.1	28
1995	7070	4511	7.56	1100	177	215.9	660	1808	2.6	0.8	120	194	1047	21.2	31
1996	7240	4619	7.66	1050	163.2	199.1	570	1809	7.5	1.1	116	185	1023	21.7	14
1997	7340	4683	7.66	1070	167.4	204.2	670	1827	4	1	130	181	1074	22	14
1998	7080	4545	7.88	1100	165	196	756	1789	5.7	0.8	134	167	1156	15.8	25
1999	7460	4663	7.68	1160	171.1	208.7	750	1891	4.4	0.8	144	194	1114	22.4	26
2000	7590	4744	7.49	1145	164.9	201.2	775	1948	10	0.6	122	204	1233	34.2	27
2001	7790	4869	7.69	1150	169.6	206.9	750	2024	4	0.8	122	205	1256	35	29
2002	7820	4888	7.74	1175	168	205	775	1949	5.7	0.8	120	213	1210	31.4	26
2003	8030	5019	7.62	1240	172.5	210.4	800	2038	4	0.9	126	225	1198	32.1	28
2004	8150	5094	7.76	1262	172.5	210.5	825	2057	###	0.7	128	229	1287	27.7	24
2005	9100	5688	7.63	1441	172.9	210.9	###	2520	11	0.8	147	261	1475	30.1	23
2006	9390	5869	7.52	1497	174.2	212.5	925	2492	11	0.8	157	269	1436	28.2	30
2007	9630	6019	7.72	1532	169.1	206.2	###	2567	17	0.9	165	272	1534	29	26

Note : All Measruments are in mg/l except E.C. which is in µs/cm
TH and TALK stands for total hardness and total alkalinity respectively

Year	EC	TDS	PH	TH	TALK	HCO_3	SO_4	Cl	NO_3	F	Ca	Mg	Na	K	SiO_2
Well No 25															
1994	6070	3873	7.89	850	177	216	734	1465	2.6	1.1	82	157	975	22.2	30
1995	5950	3796	7.69	870	203	247.7	525	1483	-	1	96	153	1891	17.9	28
1996	5980	3815	7.66	800	198	241.6	470	1423	7	0.9	88	141	859	17.9	13
1997	6120	3825	7.7	640	203	247.7	670	1483	5.3	0.8	84	105	1070	18.4	14
1998	6300	4024	7.91	880	197.2	240.6	680	1689	7	0.8	96	107	1022	19.9	25
1999	6340	3963	7.93	900	198.4	242.1	675	1555	3.5	0.7	110	152	995	19	26
2000	6210	3881	7.6	800	200.9	245.1	635	1523	13	0.6	80	146	1009	27.9	27
2001	6340	3963	7.58	810	200.7	244.9	615	1559	5.3	0.7	76	151	1042	28.5	27
2002	6400	4000	7.47	815	208.7	254.6	615	1533	3.1	0.8	80	150	1061	26	26
2003	6520	4075	7.57	855	215.6	263	650	1563	0.9	1	82	158	1035	26.2	24
2004	6800	4250	7.86	891	208.9	254.9	690	1665	1.8	0.7	90	162	1074	30.6	27
2005	5820	3638	7.83	688	230.5	281.2	650	1450	2.6	0.8	64	128	1014	26.2	22
2006	7020	4388	7.66	954	209	255	750	1767	2.6	0.8	100	171	1165	21.1	29
2007	6820	4263	8.09	874	217.1	264.8	725	1704	4.8	0.9	124	137	1132	20.5	27
Well No 26															
1994	5510	3515	7.82	725	181	221	512	1524	3.5	1	78	127	973	19.3	28
1995	5540	3535	7.72	730	212	258.6	480	1355	3.5	0.9	76	131	858	16.6	30
1996	5540	3535	7.72	730	212	258.6	480	1355	3.5	0.9	76	131	858	16.6	30
1997	5580	3488	7.71	675	201	245.2	600	1337	1.8	0.6	88	111	924	16.7	13
1998	5560	3367	7.91	768	197.2	240.6	589	1289	7	0.8	96	107	878	19.9	25
1999	5730	3281	7.7	830	205.8	251.1	525	1373	0.9	0.7	90	147	841	17.2	27
2000	5790	3619	7.8	735	208.3	254.2	590	1409	6.6	0.5	70	136	941	26.1	26
2001	5850	3660	7.84	715	217.6	265.5	550	1411	0.4	0.6	74	130	949	26.2	26
2002	5880	3675	7.45	750	200.5	244.7	550	1473	3.5	0.6	80	134	949	23.5	26
2003	5700	3563	7.66	715	215.6	263	525	1353	1.3	0.9	72	130	904	22.8	27
2004	6800	3689	7.86	789	223	276	700	1434	7.5	0.7	74	136	1027	30.6	27
2005	6770	3800	7.8	790	234	278	775	1638	5.7	0.7	107	169	1143	23.8	24
2006	5710	3569	7.8	708	233.5	284.9	675	1387	0.4	0.8	76	126	948	17.1	28
2007	5700	3563	8.08	638	240.2	293	650	1406	2.6	0.8	84	104	946	17.2	27
Well No 27															
1994	6980	4453	7.76	1100	159	194	713	1830	4	0.9	120	192	1082	24.4	29
1995	7160	4568	7.58	1135	176	214.7	690	1839	4.4	0.8	120	203	1065	21.5	31
1996	7290	4651	7.66	1070	167	203.7	573	1830	8.4	1	124	185	1031	21.9	14
1997	7490	4682	7.64	1120	165	201.3	800	1910	3.5	0.6	136	190	1165	22.5	14
1998	7500	4700	7.91	1111	165	198	776	1879	7	0.8	96	107	1123	19.9	25
1999	7810	4881	7.68	1290	162.4	198.1	800	1995	7	0.8	156	219	1141	23.4	27
2000	7830	4894	7.61	1210	160	195.2	775	2022	5.7	0.6	118	222	1272	35.2	28
2001	7950	4969	7.53	1210	170.9	208.5	800	2059	4	0.8	128	216	1310	35.7	29
2002	7920	4950	7.3	1200	168	205	800	1962	7.9	0.7	116	221	1208	30.9	27
2003	8030	5019	7.56	1220	169.8	207.1	800	2020	2.6	0.9	128	219	1174	31.8	29
2004	8340	5213	7.58	1186	176.5	214.2	850	2161	8.4	0.6	122	214	1319	33.4	28
2005	8260	5163	7.71	1228	180.6	220.3	975	2319	11	0.8	126	222	1237	24.8	27
2006	8570	5356	7.37	1321	174.2	212.5	850	2228	10	0.8	139	237	1352	25.7	30
2007	9030	5644	7.56	1336	169.1	206.2	975	2367	15	0.8	157	229	1558	27.1	26
Well No 28															
1994	6960	4440	7.75	1020	171	209	763	1825	3.5	1.2	102	184	1144	24.4	29
1995	7060	4504	7.66	1100	177	216	955	1758	2.6	1	102	205	1154	24.5	28
1996	7080	4517	7.63	1010	174	212.3	556	1765	7.9	0.9	112	177	1012	21.2	14
1997	7160	4475	7.63	1020	173	211.1	750	1805	1.8	0.8	112	180	1123	21.5	14
1998	7080	4545	7.88	1100	165	196	756	1789	5.7	0.8	134	167	1156	15.8	25
1999	7180	4488	7.65	1050	181	220.8	775	1814	3.1	0.8	122	181	1131	21.5	28
2000	7240	4525	7.49	1055	177.3	216.3	740	1838	8.8	0.5	112	188	1177	32.6	28
2001	7400	4625	7.62	1035	183.9	224.4	715	1873	4	0.7	110	185	1194	33.2	28
2002	7470	4669	7.44	1080	181.6	221.5	725	1841	5.3	0.8	106	198	1199	29.9	27
2003	7590	4744	7.58	1070	191.3	233.4	740	1862	1.8	0.9	114	191	1167	30.4	28
2004	7650	4781	7.54	1110	188.7	230.2	850	1900	8.8	0.7	134	189	1245	26.9	22
2005	8040	5025	7.53	1240	182.2	222.3	950	2172	8.8	0.9	118	229	1270	25.5	24
2006	8000	5000	7.35	1165	187.1	228.2	800	2070	12	0.8	126	206	1267	24	30
2007	8400	5250	7.55	1230	175.2	213.7	925	2190	9.7	0.9	134	217	1374	25.3	27

Note : All Measruments are in mg/l except E.C. which is in μs/cm
TH and TALK stands for total hardness and total alkalinity respectively

Year	EC	TDS	PH	TH	TALK	HCO_3	SO_4	Cl	NO_3	F	Ca	Mg	Na	K	SiO_2
Well No 25															
1994	6070	3873	7.89	850	177	216	734	1465	2.6	1.1	82	157	975	22.2	30
1995	5950	3796	7.69	870	203	247.7	525	1483	-	1	96	153	1891	17.9	28
1996	5980	3815	7.66	800	198	241.6	470	1423	7	0.9	88	141	859	17.9	13
1997	6120	3825	7.7	640	203	247.7	670	1483	5.3	0.8	84	105	1070	18.4	14
1998	6300	4024	7.91	880	197.2	240.6	680	1689	7	0.8	96	107	1022	19.9	25
1999	6340	3963	7.93	900	198.4	242.1	675	1555	3.5	0.7	110	152	995	19	26
2000	6210	3881	7.6	800	200.9	245.1	635	1523	13	0.6	80	146	1009	27.9	27
2001	6340	3963	7.58	810	200.7	244.9	615	1559	5.3	0.7	76	151	1042	28.5	27
2002	6400	4000	7.47	815	208.7	254.6	615	1533	3.1	0.8	80	150	1061	26	26
2003	6520	4075	7.57	855	215.6	263	650	1563	0.9	1	82	158	1035	26.2	24
2004	6800	4250	7.86	891	208.9	254.9	690	1665	1.8	0.7	90	162	1074	30.6	27
2005	5820	3638	7.83	688	230.5	281.2	650	1450	2.6	0.8	64	128	1014	26.2	22
2006	7020	4388	7.66	954	209	255	750	1767	2.6	0.8	100	171	1165	21.1	29
2007	6820	4263	8.09	874	217.1	264.8	725	1704	4.8	0.9	124	137	1132	20.5	27
Well No 26															
1994	5510	3515	7.82	725	181	221	512	1524	3.5	1	78	127	973	19.3	28
1995	5540	3535	7.72	730	212	258.6	480	1355	3.5	0.9	76	131	858	16.6	30
1996	5540	3535	7.72	730	212	258.6	480	1355	3.5	0.9	76	131	858	16.6	30
1997	5580	3488	7.71	675	201	245.2	600	1337	1.8	0.6	88	111	924	16.7	13
1998	5560	3367	7.91	768	197.2	240.6	589	1289	7	0.8	96	107	878	19.9	25
1999	5730	3281	7.7	830	205.8	251.1	525	1373	0.9	0.7	90	147	841	17.2	27
2000	5790	3619	7.8	735	208.3	254.2	590	1409	6.6	0.5	70	136	941	26.1	26
2001	5850	3660	7.84	715	217.6	265.5	550	1411	0.4	0.6	74	130	949	26.2	26
2002	5880	3675	7.45	750	200.5	244.7	550	1473	3.5	0.6	80	134	949	23.5	26
2003	5700	3563	7.66	715	215.6	263	525	1353	1.3	0.9	72	130	904	22.8	27
2004	6800	3689	7.86	789	223	276	700	1434	7.5	0.7	74	136	1027	30.6	27
2005	6770	3800	7.8	790	234	278	775	1638	5.7	0.7	107	169	1143	23.8	24
2006	5710	3569	7.8	708	233.5	284.9	675	1387	0.4	0.8	76	126	948	17.1	28
2007	5700	3563	8.08	638	240.2	293	650	1406	2.6	0.8	84	104	946	17.2	27
Well No 27															
1994	6980	4453	7.76	1100	159	194	713	1830	4	0.9	120	192	1082	24.4	29
1995	7160	4568	7.58	1135	176	214.7	690	1839	4.4	0.8	120	203	1065	21.5	31
1996	7290	4651	7.66	1070	167	203.7	573	1830	8.4	1	124	185	1031	21.9	14
1997	7490	4682	7.64	1120	165	201.3	800	1910	3.5	0.6	136	190	1165	22.5	14
1998	7500	4700	7.91	1111	165	198	776	1879	7	0.8	96	107	1123	19.9	25
1999	7810	4881	7.68	1290	162.4	198.1	800	1995	7	0.8	156	219	1141	23.4	27
2000	7830	4894	7.61	1210	160	195.2	775	2022	5.7	0.6	118	222	1272	35.2	28
2001	7950	4969	7.53	1210	170.9	208.5	800	2059	4	0.8	128	216	1310	35.7	29
2002	7920	4950	7.3	1200	168	205	800	1962	7.9	0.7	116	221	1208	30.9	27
2003	8030	5019	7.56	1220	169.8	207.1	800	2020	2.6	0.9	128	219	1174	31.8	29
2004	8340	5213	7.58	1186	176.5	214.2	850	2161	8.4	0.6	122	214	1319	33.4	28
2005	8260	5163	7.71	1228	180.6	220.3	975	2319	11	0.8	126	222	1237	24.8	27
2006	8570	5356	7.37	1321	174.2	212.5	850	2228	10	0.8	139	237	1352	25.7	30
2007	9030	5644	7.56	1336	169.1	206.2	975	2367	15	0.8	157	229	1558	27.1	26
Well No 28															
1994	6960	4440	7.75	1020	171	209	763	1825	3.5	1.2	102	184	1144	24.4	29
1995	7060	4504	7.66	1100	177	216	955	1758	2.6	1	102	205	1154	24.5	28
1996	7080	4517	7.63	1010	174	212.3	556	1765	7.9	0.9	112	177	1012	21.2	14
1997	7160	4475	7.63	1020	173	211.1	750	1805	1.8	0.8	112	180	1123	21.5	14
1998	7080	4545	7.88	1100	165	196	756	1789	5.7	0.8	134	167	1156	15.8	25
1999	7180	4488	7.65	1050	181	220.8	775	1814	3.1	0.8	122	181	1131	21.5	28
2000	7240	4525	7.49	1055	177.3	216.3	740	1838	8.8	0.5	112	188	1177	32.6	28
2001	7400	4625	7.62	1035	183.9	224.4	715	1873	4	0.7	110	185	1194	33.2	28
2002	7470	4669	7.44	1080	181.6	221.5	725	1841	5.3	0.8	106	198	1199	29.9	27
2003	7590	4744	7.58	1070	191.3	233.4	740	1862	1.8	0.9	114	191	1167	30.4	28
2004	7650	4781	7.54	1110	188.7	230.2	850	1900	8.8	0.7	134	189	1245	26.9	22
2005	8040	5025	7.53	1240	182.2	222.3	950	2172	8.8	0.9	118	229	1270	25.5	24
2006	8000	5000	7.35	1165	187.1	228.2	800	2070	12	0.8	126	206	1267	24	30
2007	8400	5250	7.55	1230	175.2	213.7	925	2190	9.7	0.9	134	217	1374	25.3	27

Note : All Measruments are in mg/l except E.C. which is in µs/cm
TH and TALK stands for total hardness and total alkalinity respectively

Year	EC	TDS	PH	TH	TALK	HCO_3	SO_4	Cl	NO_3	F	Ca	Mg	Na	K	SiO_2
Well No 25															
1994	6070	3873	7 89	850	177	216	734	1465	2.6	1.1	82	157	975	22.2	30
1995	5950	3796	7 69	870	203	247 7	525	1483	-	1	96	153	1891	17 9	28
1996	5980	3815	7.66	800	198	241.6	470	1423	7	0 9	88	141	859	17 9	13
1997	6120	3825	7.7	640	203	247.7	670	1483	5.3	0 8	84	105	1070	18 4	14
1998	6300	4024	7.91	880	197.2	240.6	680	1689	7	0 8	96	107	1022	19 9	25
1999	6340	3963	7.93	900	198.4	242.1	675	1555	3.5	0.7	110	152	995	19	26
2000	6210	3881	7 6	800	200 9	245 1	635	1523	13	0 6	80	146	1009	27 9	27
2001	6340	3963	7 58	810	200 7	244 9	615	1559	5.3	0 7	76	151	1042	28 5	27
2002	6400	4000	7 47	815	208 7	254 6	615	1533	3.1	0 8	80	150	1061	26	26
2003	6520	4075	7 57	855	215 6	263	650	1563	0.9	1	82	158	1035	26 2	24
2004	6800	4250	7.86	891	208.9	254.9	690	1665	1.8	0.7	90	162	1074	30.6	27
2005	5820	3638	7.83	688	230.5	281.2	650	1450	2.6	0.8	64	128	1014	26 2	22
2006	7020	4388	7.66	954	209	255	750	1767	2.6	0.8	100	171	1165	21 1	29
2007	6820	4263	8 09	874	217 1	264 8	725	1704	4.8	0 9	124	137	1132	20 5	27
Well No 26															
1994	5510	3515	7 82	725	181	221	512	1524	3 5	1	78	127	973	19 3	28
1995	5540	3535	7 72	730	212	258 6	480	1355	3 5	0 9	76	131	858	16 6	30
1996	5540	3535	7 72	730	212	258 6	480	1355	3 5	0 9	76	131	858	16 6	30
1997	5580	3488	7 71	675	201	245 2	600	1337	1 8	0 6	88	111	924	16 7	13
1998	5560	3367	7 91	768	197 2	240 6	589	1289	7	0 8	96	107	878	19 9	25
1999	5730	3281	7 7	830	205 8	251 1	525	1373	0 9	0 7	90	147	841	17 2	27
2000	5790	3619	7.8	735	208.3	254.2	590	1409	6.6	0.5	70	136	941	26.1	26
2001	5850	3660	7.84	715	217.6	265.5	550	1411	0.4	0.6	74	130	949	26.2	26
2002	5880	3675	7 45	750	200 5	244 7	550	1473	3 5	0 6	80	134	949	23 5	26
2003	5700	3563	7 66	715	215 6	263	525	1353	1 3	0 9	72	130	904	22 8	27
2004	6800	3689	7 86	789	223	276	700	1434	7 5	0 7	74	136	1027	30 6	27
2005	6770	3800	7 8	790	234	278	775	1638	5 7	0.7	107	169	1143	23 8	24
2006	5710	3569	7.8	708	233.5	284.9	675	1387	0.4	0.8	76	126	948	17.1	28
2007	5700	3563	8 08	638	240.2	293	650	1406	2 6	0 8	84	104	946	17 2	27
Well No 27															
1994	6980	4453	7 76	1100	159	194	713	1830	4	0 9	120	192	1082	24 4	29
1995	7160	4568	7.58	1135	176	214.7	690	1839	4.4	0.8	120	203	1065	21.5	31
1996	7290	4651	7.66	1070	167	203.7	573	1830	8.4	1	124	185	1031	21.9	14
1997	7490	4682	7.64	1120	165	201.3	800	1910	3.5	0.6	136	190	1165	22.5	14
1998	7500	4700	7.91	1111	165	198	776	1879	7	0.8	96	107	1123	19 9	25
1999	7810	4881	7 68	1290	162 4	198 1	800	1995	7	0 8	156	219	1141	23 4	27
2000	7830	4894	7 61	1210	160	195 2	775	2022	5.7	0 6	118	222	1272	35 2	28
2001	7950	4969	7 53	1210	170 9	208 5	800	2059	4	0 8	128	216	1310	35.7	29
2002	7920	4950	7 3	1200	168	205	800	1962	7 9	0 7	116	221	1208	30 9	27
2003	8030	5019	7.56	1220	169.8	207.1	800	2020	2.6	0.9	128	219	1174	31.8	29
2004	8340	5213	7 58	1186	176 5	214 2	850	2161	8 4	0 6	122	214	1319	33 4	28
2005	8260	5163	7 71	1228	180 6	220 3	975	2319	11	0 8	126	222	1237	24 8	27
2006	8570	5356	7 37	1321	174.2	212 5	850	2228	10	0 8	139	237	1352	25 7	30
2007	9030	5644	7 56	1336	169 1	206 2	975	2367	15	0 8	157	229	1558	27 1	26
Well No 28															
1994	6960	4440	7 75	1020	171	209	763	1825	3.5	1 2	102	184	1144	24 4	29
1995	7060	4504	7 66	1100	177	216	955	1758	2 6	1	102	205	1154	24 5	28
1996	7080	4517	7 63	1010	174	212 3	556	1765	7 9	0 9	112	177	1012	21 2	14
1997	7160	4475	7 63	1020	173	211 1	750	1805	1.8	0 8	112	180	1123	21 5	14
1998	7080	4545	7 88	1100	165	196	756	1789	5 7	0 8	134	167	1156	15.8	25
1999	7180	4488	7 65	1050	181	220 8	775	1814	3 1	0 8	122	181	1131	21 5	28
2000	7240	4525	7 49	1055	177 3	216 3	740	1838	8 8	0 5	112	188	1177	32 6	28
2001	7400	4625	7 62	1035	183 9	224 4	715	1873	4	0 7	110	185	1194	33 2	28
2002	7470	4669	7 44	1080	181 6	221 5	725	1841	5 3	0 8	106	198	1199	29 9	27
2003	7590	4744	7 58	1070	191 3	233 4	740	1862	1 8	0 9	114	191	1167	30 4	28
2004	7650	4781	7 54	1110	188 7	230 2	850	1900	8 8	0 7	134	189	1245	26 9	22
2005	8040	5025	7 53	1240	182 2	222 3	950	2172	8 8	0 9	118	229	1270	25 5	24
2006	8000	5000	7 35	1165	187 1	228 2	800	2070	12	0 8	126	206	1267	24	30
2007	8400	5250	7.55	1230	175.2	213.7	925	2190	9.7	0.9	134	217	1374	25.3	27

Note : All Measruments are in mg/l except E.C which is in µs/cm
TH and TALK stands for total hardness and total alkalinity respectively

Year	EC	TDS	PH	TH	TALK	Hco_3	So_4	Cl	No_3	F	Ca	Mg	Na	K	Sio_2
Well No 29															
1994	6940	4428	7.73	1030	178	217	790	1820	2.6	1.2	104	185	1152	24.3	29
1995	6940	4428	7.79	1095	169	206	943	1745	3.5	0.8	114	197	1137	24.3	30
1996	6970	4447	7.72	990	178	217.2	548	1710	7.9	1.3	108	175	983	20.9	14
1997	6920	4350	7.64	980	177	215.9	740	1745	2.2	0.7	108	173	1100	20.9	14
1998	6700	4024	7.91	950	197.2	240.6	735	1708	7	0.8	96	180	1022	19.9	25
1999	6860	4288	7.63	985	193.4	236	725	1701	2.2	0.8	132	159	1070	20.7	27
2000	6890	4306	7.5	1010	178.6	217.8	705	1725	8.8	0.4	98	186	1120	31	27
2001	7050	4406	7.66	990	183.9	224.4	690	1802	4	0.7	100	180	1105	31.7	28
2002	6940	4338	7.58	985	195.2	238.1	700	1680	4.8	0.7	90	185	1147	27.7	26
2003	6830	4269	7.6	920	198.1	241.7	660	1651	0.9	0.9	90	169	1029	27.3	27
2004	6770	4231	7.8	962	204.8	249.9	775	1638	5.7	0.7	107	169	1143	23.8	24
2005	6820	4263	7.66	919	201	245.2	800	1757	4.4	0.8	80	175	1140	24	25
2006	6780	4238	7.71	884	211.7	258.3	825	1647	2.6	0.8	96	156	1138	20.3	25
2007	8180	5113	8.01	1200	183.7	224.1	850	2173	11	0.8	153	199	1372	24.2	28
Well No 30															
1994	6840	4364	7.76	1055	177	209	748	1892	1.1	3.5	106	192	1160	23.9	29
1995	6980	4453	7.62	1080	180	219.6	655	1804	3.5	0.8	104	199	1053	20.9	31
1996	7070	4511	7.69	1040	171.6	209.4	556	1735	8.4	1.1	112	185	977	21.2	14
1997	7150	4470	7.81	1070	164	200.1	750	1814	3.5	0.8	112	192	1102	21.5	14
1998	7345	3800	7.81	1111	171	234	645	1789	3.5	0.8	123	170	1009	21.2	22
1999	7220	4513	7.63	1065	176.1	214.8	750	1831	2.6	0.8	130	180	1121	21.7	27
2000	7370	4606	7.7	1170	164.9	201.2	750	1891	8.4	0.5	114	215	1198	33.2	28
2001	7920	4950	7.57	1235	158	192.8	800	2067	5.3	0.7	124	225	1282	36	29
2002	7670	4794	7.47	1205	168	205	750	1915	6.6	0.8	122	219	1128	30.7	26
2003	7530	4706	7.58	1130	175.2	213.7	730	1888	1.3	0.9	114	205	1099	30.1	27
2004	7570	4731	7.66	1181	183.3	223.6	750	1917	7.9	0.7	130	208	1232	26.7	24
2005	8130	5081	7.6	1311	171.5	209.3	950	2213	8.4	0.8	127	242	1279	28.2	22
2006	7870	4919	7.38	1220	180.6	220.3	800	2031	4.4	0.8	132	216	1232	23.6	30
2007	8760	5475	7.59	1366	161.7	197.3	950	2287	14	0.9	159	235	1416	26.3	26
Well No 31															
1994	6850	4370	7.73	1050	166	203	665	1894	1.3	3.5	106	191	1121	24	29
1995	6820	4351	7.61	1055	177	215.9	642	1733	3.1	0.9	102	194	1011	20.5	31
1996	6860	4377	7.61	1010	168	205	539	1683	7.5	1.1	110	179	948	20.6	14
1997	6890	4306	7.62	1010	169	206.2	725	1723	3.1	0.7	108	180	1062	20.7	14
1998	6700	4024	7.91	1000	197.2	240.6	735	1708	7	0.8	96	180	1022	19.9	25
1999	6810	4256	7.66	1030	173.6	211.8	750	1684	3.5	0.8	140	165	1042	20.4	27
2000	6930	4331	7.73	1020	167.4	204.2	705	1742	8.4	0.4	110	181	1126	31.2	27
2001	7420	4638	7.68	1125	164.5	200.7	715	1908	4	0.8	120	201	1194	33	28
2002	7230	4519	7.36	1145	176.2	217.9	750	1810	1.8	0.7	114	209	1086	28.9	27
2003	7080	4425	7.57	1060	183.3	223.6	700	1748	4.4	0.9	120	185	1045	28.4	26
2004	6840	4275	7.58	1020	196.7	240	700	1682	4.8	0.7	130	169	1155	24	23
2005	6580	4133	7.94	905	199.4	243.3	775	1776	5.3	0.7	86	168	1012	19.7	28
2006	6990	4369	7.38	1035	197.4	240.8	750	1774	0.4	0.7	100	191	1105	20.9	29
2007	7230	4519	7.58	1040	180.1	219.7	825	1830	4.4	0.9	114	183	1170	21.6	27
Well No 32															
1994	6610	4217	7.74	980	166	203	702	1828	1.2	2.6	100	177	1130	23.1	28
1995	6500	4147	7.56	1000	181	220.8	610	1654	3.1	0.7	100	182	972	19.5	31
1996	6500	4143	7.71	950	171.6	209.4	511	1595	8.4	1.1	108	165	908	19.5	14
1997	6470	4045	7.65	960	166	202.5	710	1610	2.2	0.5	104	170	1003	19.4	14
1998	6500	4024	7.91	950	197.2	240.6	735	1708	7	0.8	96	180	1022	19.9	25
1999	6420	4013	7.69	950	164.9	201.2	700	1525	1.8	0.8	130	152	948	19.3	26
2000	6600	4125	7.54	985	168.6	205.7	690	1655	3.5	0.5	106	175	1073	29.7	27
2001	7010	4381	7.65	1065	168.4	205.5	665	1775	4	0.7	114	190	1134	31.5	27
2002	6910	4319	7.4	1035	170.7	208.3	775	1706	3.5	0.7	106	187	1063	27.6	27
2003	6720	4200	7.48	995	179.2	218.7	675	1634	6.2	0.8	106	177	1014	26.9	26
2004	6650	4156	7.72	891	188.9	230.1	680	1647	6.6	0.8	90	162	1051	29.9	27
2005	6370	3981	7.57	914	180.9	220.7	775	1653	7	0.8	90	167	1018	19.3	22
2006	6600	4125	7.42	954	185.8	226.6	725	1661	4.4	0.7	101	171	1055	19.8	29
2007	6600	4125	7.66	944	172.7	210.7	725	1650	11	0.9	108	164	1083	19.8	26

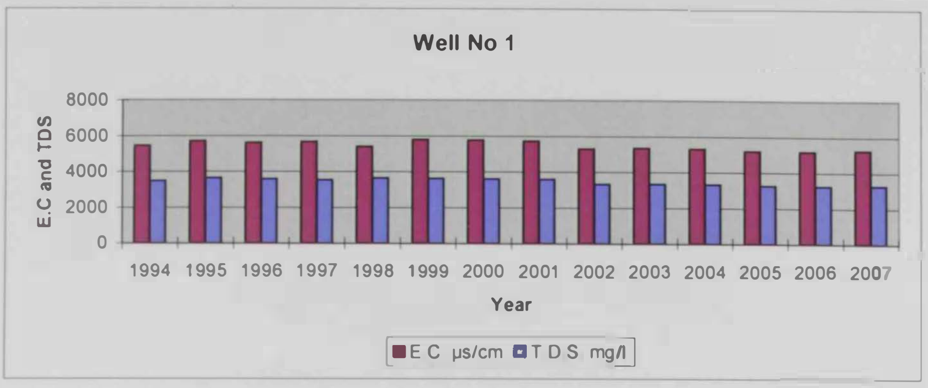
Note : All Measruments are in mg/l except E.C. which is in µs/cm
TH and TALK stands for total hardness and total alkalinity respectively

Year	EC	TDS	PH	TH	TALK	Hco$_3$	So$_4$	Cl	No$_3$	F	Ca	Mg	Na	K	Sio$_2$
Well No 33															
1994	5370	3426	7.8	680	205	250	506	1485	1.2	2.6	84	114	974	18.8	29
1995	6440	4109	7.65	1020	184	224.5	600	1646	3.1	0.8	102	186	955	19.3	31
1996	6460	4121	7.63	940	170.4	207.9	508	1585	7	1.2	100	168	903	19.4	14
1997	6500	4063	7.77	950	169	206.2	715	1610	1.3	0.7	120	158	1012	19.5	14
1998	6500	4024	7.91	950	197.2	240.6	735	1708	7	0.8	96	180	1022	19.9	25
1999	6250	4075	7.73	990	176.1	214.8	700	1709	2.2	0.7	130	162	1054	19.4	26
2000	6540	4088	7.33	945	177.3	216.3	690	1628	13	0.7	100	169	1063	24.9	27
2001	6640	4150	7.72	960	181.3	221.2	640	1669	4.8	0.8	96	175	1099	29.9	27
2002	6630	4144	7.61	945	186.3	227.3	650	1602	2.6	0.7	94	173	1048	26.5	26
2003	6540	4088	7.43	950	188.7	230.2	675	1685	6.2	0.8	96	173	977	26.1	25
2004	6530	4081	7.69	853	196.7	240	675	1612	2.6	0.7	88	154	1046	29.4	27
2005	6390	3994	7.32	903	195.6	238.7	700	1653	4.4	0.8	84	168	1062	24.4	26
2006	6380	3988	7.64	869	194.3	237.1	750	1552	4.4	0.8	90	156	1041	19.1	27
2007	6260	3913	7.84	869	181.1	221	675	1563	9.7	0.9	118	139	1021	18.7	26
Well No 34															
1994	6600	4211	7.74	1050	166	203	782	1725	1.8	3.5	112	187	1069	23.1	30
1995	6570	4192	7.71	990	175	211.1	620	1646	3.1	0.6	96	182	973	19.7	31
1996	6640	4236	7.67	965	152.4	185.9	521	1629	7.9	1.1	104	171	918	19.9	14
1997	6660	4249	7.74	965	164	200.1	532	1664	4.8	0.8	108	169	951	20	14
1998	6700	4024	7.91	1000	197.2	240.6	735	1708	7	0.8	96	180	1022	19.9	25
1999	6410	4006	7.85	920	179.8	219.4	675	1580	4.4	0.9	108	158	993	19.3	24
2000	6700	4188	7.62	985	158.7	193.6	685	1672	9.2	0.6	112	171	1089	30.2	27
2001	6500	4289	7.68	1125	164.5	200.7	715	1908	4	0.8	120	201	1194	33	28
2002	6910	4319	7.54	1000	164.6	200.8	725	1663	5.3	0.7	104	180	1022	27.6	27
2003	6740	4213	7.46	990	172.5	210.4	675	1639	7	0.9	104	177	1000	26.9	26
2004	6870	4294	7.67	939	168.4	205.4	680	1717	7.9	0.7	103	169	1065	30.9	27
2005	6780	4238	7.58	984	166.2	202.7	775	1770	9.2	0.8	90	184	1130	24.6	26
2006	7220	4513	7.42	1105	166.4	203	775	1841	11	0.8	110	202	1196	19.6	29
2007	7420	5638	7.83	1125	169.6	206.9	825	1926	22	1	163	174	1228	20.2	24
Well No 35															
2000	6590	4119	7.83	970	177.3	216.3	670	1650	7.9	0.6	100	175	1071	29.7	27
2001	6830	4269	7.75	1030	174.8	213.3	650	1740	4.4	0.8	112	182	1124	30.7	27
2002	6660	4163	7.59	965	186.3	227.3	675	1628	1.3	0.6	94	177	1088	26.7	25
2003	6970	4356	7.43	1070	184.6	225.2	675	1739	5.7	0.7	110	193	1015	28	27
2004	6790	4244	7.98	924	199.4	243.3	670	1691	3.1	0.7	95	167	1063	30.6	27
2005	7180	4488	7.55	1090	183.6	224	850	1920	4.8	0.7	78	217	1139	23.9	25
2006	7010	4381	7.4	1055	194.8	237.6	750	1795	5.8	0.7	108	203	1131	21.1	29
2007	7290	4556	8.01	1090	196.5	239.8	800	1900	4.4	1	177	157	1186	22	26
Well No 36															
2000	6400	4000	7.75	900	182.3	222.4	655	1571	8.8	0.7	92	163	1040	28.8	27
2001	6400	4000	7.78	930	176.1	214.8	625	1606	4.4	0.7	92	170	1030	28.7	27
2002	6680	4175	7.46	1010	185	225.7	690	1633	2.2	0.7	96	187	1065	27.1	26
2003	7630	4769	7.4	1200	191.3	233.4	750	1915	6.2	0.9	126	225	1116	30.1	29
2004	7120	4450	7.7	986	191.3	233.3	700	1778	8.4	0.7	97	181	1102	32	28
2005	7140	4463	7.53	1050	187.6	228.9	850	1879	4.8	0.7	108	189	1150	24.8	23
2006	7120	4450	7.38	1065	194.8	237.6	775	1802	1.3	0.7	112	191	1126	21.4	29
2007	7100	4434	7.57	999	187.4	228.7	775	1782	2.2	0.8	110	176	1154	21.4	25
Well No 37															
2000	6490	4056	7.76	900	186	226.9	660	1611	7.5	0.6	90	164	1055	29.2	27
2001	6750	4219	7.69	995	181.3	221.2	640	1713	4.8	0.7	100	181	1101	30.3	28
2002	6670	4169	7.41	945	195.8	238.9	665	1618	1.3	0.7	84	179	1073	26.7	26
2003	7320	4575	7.56	1085	199.4	243.3	700	1662	6.2	0.8	112	196	1121	29.5	28
2004	6880	4300	7.73	891	202.1	246.6	240	1708	5.3	0.7	92	161	1124	31	27
2005	7480	4675	7.51	1150	182.2	222.3	875	2019	6.6	0.7	114	210	1177	25.1	25
2006	7000	4375	7.33	989	201	245.2	800	1754	3.1	0.8	106	176	1142	21	21
2007	7110	4444	7.56	1029	201.2	245.5	800	1837	4.4	0.9	86	198	1177	21.3	18

Note All Measruments are in mg/l except E.C. which is in µs/cm
TH and TALK stands for total hardness and total alkalinity respectively

Year	EC	TDS	PH	TH	TALK	Hco_3	So_4	Cl	No_3	F	Ca	Mg	Na	K	Sio_2
Well No 38															
2007	6740	4213	7.91	849	205.8	251.1	725	1654	0.9	0.8	98	147	1149	24.9	27
Well No 39															
2007	7020	4388	7.94	889	214.5	261.7	700	1781	4	0.9	139	132	1200	21.1	26
Well No 40															
2007	6890	4306	7.86	899	211 9	258.6	725	1734	4	0.8	122	144	1170	23.1	26
Well No 41															
2007	6630	4144	7.91	854	205.8	251.1	775	1612	5.3	0.8	84	156	1120	22.2	26
Well No 42															
2007	6920	4325	7.84	859	213.2	260.1	750	1730	4	0.9	120	136	1176	20.8	25
Well No 43															
2007	6720	4200	7.83	839	207	252.6	725	1618	4.8	0.9	90	149	1149	24.5	27
Well No 44															
2007	6700	4188	7.84	869	207	252.6	750	1635	4.4	0.8	106	147	1147	24.5	26
Well No 45															
2007	6780	4238	7.77	934	198.5	242.1	750	1671	4.8	0.9	98	167	1147	22.7	24
Well No 46															
2007	6570	4106	8.19	879	215.8	263.3	700	1649	1.3	0.9	112	145	1115	21.7	25
Well No 47															
2007	6540	4088	7.81	874	205.8	251.1	700	1598	3.5	0.9	96	154	1112	21.9	25
Well No 55															
2004	6390	3994	7.72	777	215.6	263	650	1547	1.3	0.6	76	142	1036	28.8	27
2005	6710	4194	7.56	929	211.7	258.3	800	1712	5.3	0.7	72	182	1113	20.5	25
2006	6560	4100	7.43	919	216.7	264.4	750	1605	1.8	0.7	90	168	1094	19.7	28
2007	6570	4106	7.7	980	220	270	725	1602	3.5	0.8	92	159	1125	24	24
Well No 56															
2004	6400	4000	7.75	743	215.6	263	670	1543	4	0.6	76	134	1060	28.8	27
2005	6820	4263	7.54	909	209.9	255	825	1770	4.8	0.8	90	166	1100	21.1	25
2006	6950	4344	7.54	984	214.1	261.3	750	1742	3.1	0.8	82	189	1123	20.8	28
2007	7340	4588	7.83	1055	201.7	246	750	1857	2.6	0.9	128	178	1233	25.7	25
Well No 57															
2004	6690	4181	7.7	815	222.4	271.2	680	1434	2.2	0.7	87	150	962	30.1	27
2005	7580	4738	7.63	1205	156.8	191.3	900	2028	7	0.7	122	219	1216	24.2	26
2006	7560	4725	7.66	1215	154.8	188.9	825	1925	6.6	0.8	118	223	1167	22.7	29
2007	7670	4890	7.89	1245	176	198	879	2011	8	0.8	123	229	1234	24.4	26

Note All Measruments are in mg/l except E.C. which is in µs/cm
TH and TALK stands for total hardness and total alkalinity respectively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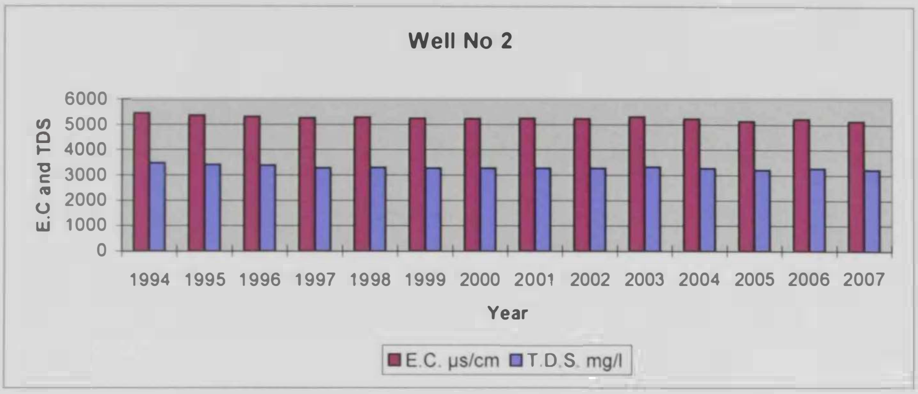
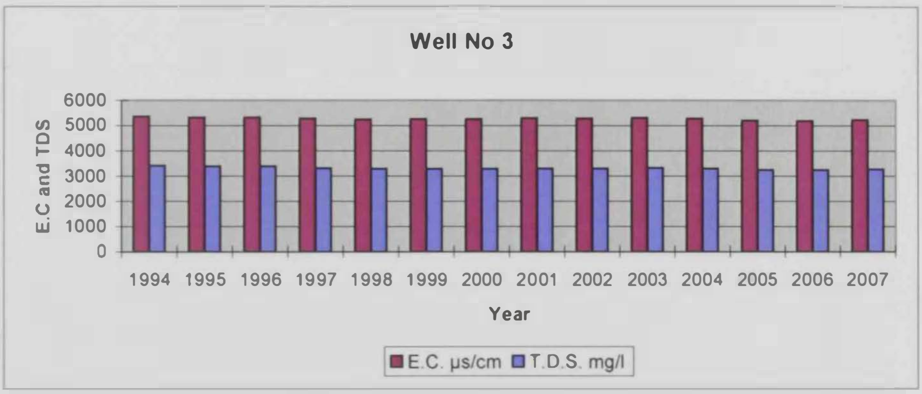
6000
4000
2000
0
E.C and TDS
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Year
E C μs/cm
T D S mg/l


Well No 2
6000
5000
4000
3000
2000
1000
0
E.C and TDS
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Year
E.C. μs/cm
T.D.S. mg/l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5000
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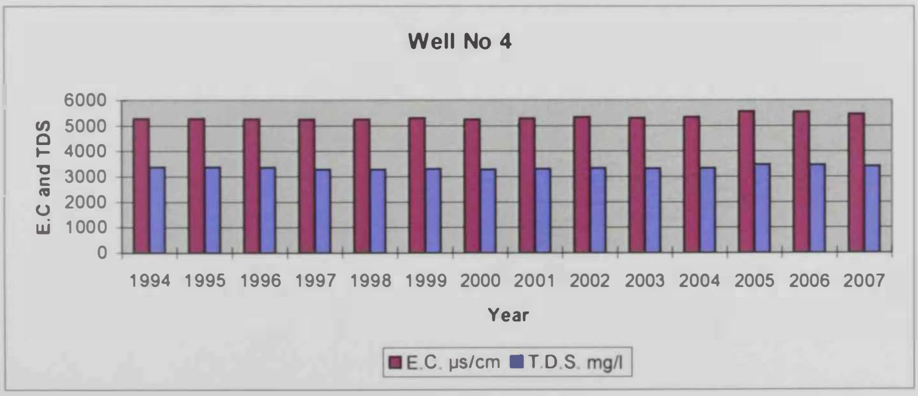
E.C and TDS
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Year
E.C. μs/cm
T.D.S. mg/l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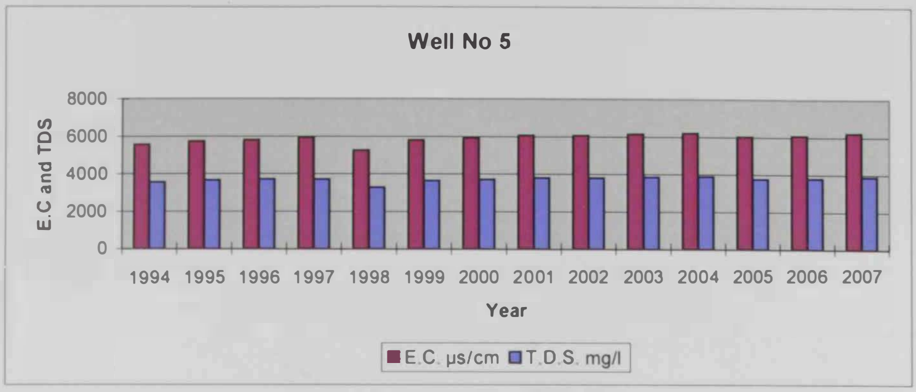
E.C and TDS
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Year
E.C. μs/cm
T.D.S. mg/l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2000
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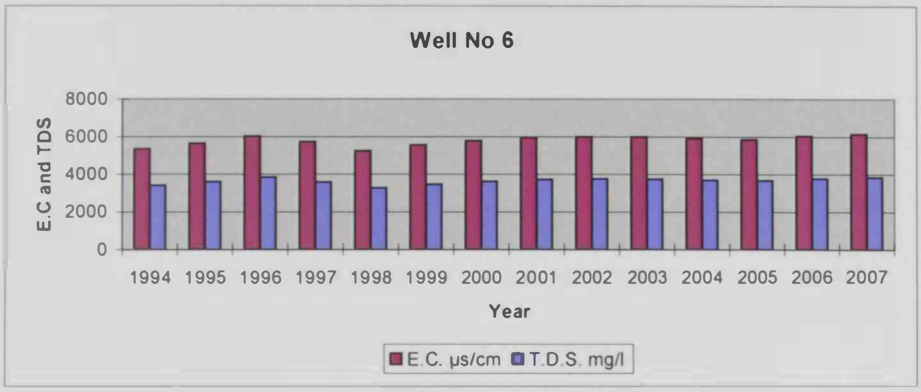
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Year
E.C. µs/cm
T.D.S. mg/l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E.C and TDS
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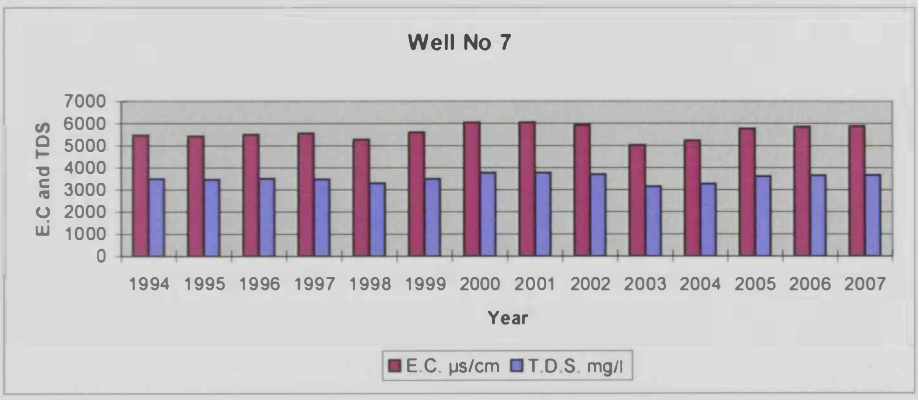
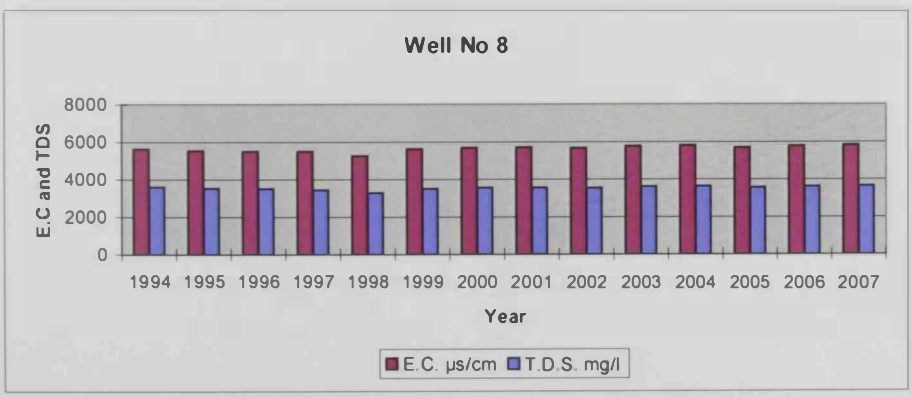
6000
4000
2000
0
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Year
E.C. µs/cm
T.D.S. mg/l


Well No 7
E.C and TDS
7000
6000
5000
4000
3000
2000
1000
0
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Year
E.C. µs/cm
T.D.S. mg/l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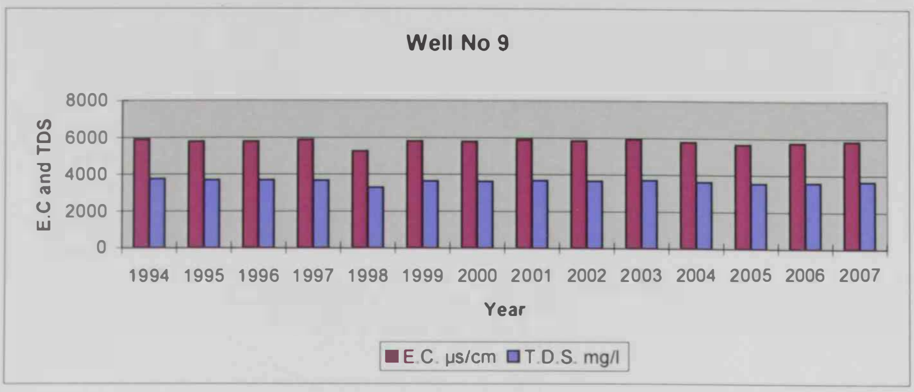
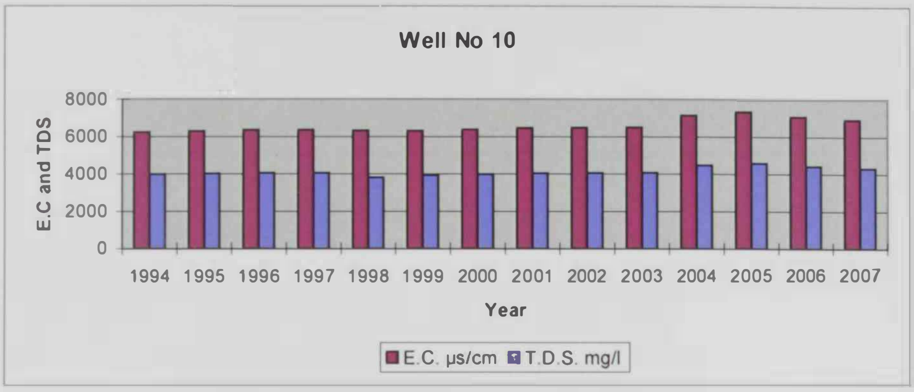
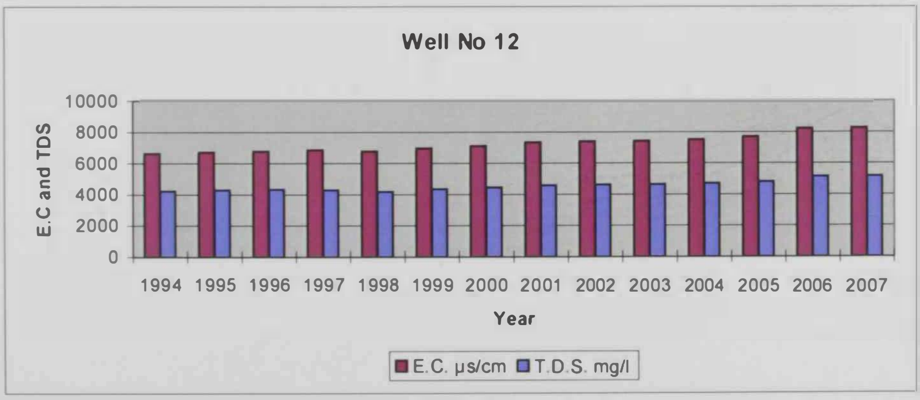
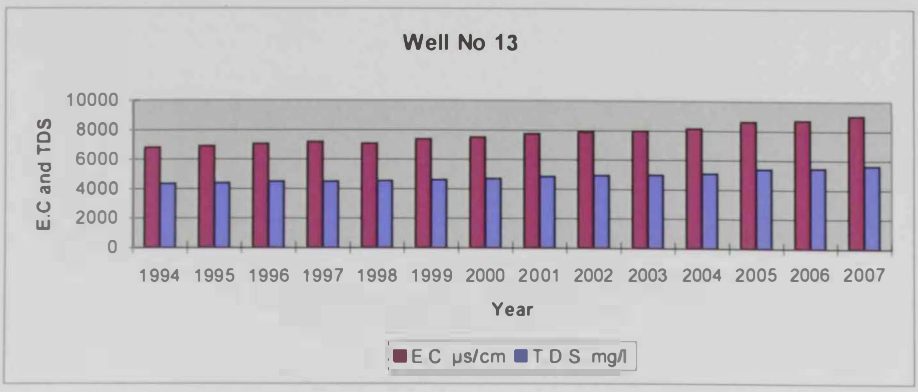
E.C and TDS
8000
6000
4000
2000
0
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Year
E.C. µs/cm
T.D.S. mg/l


Well No 9
E.C and TDS
8000
6000
4000
2000
0
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Year
E.C. µs/cm
T.D.S. mg/l

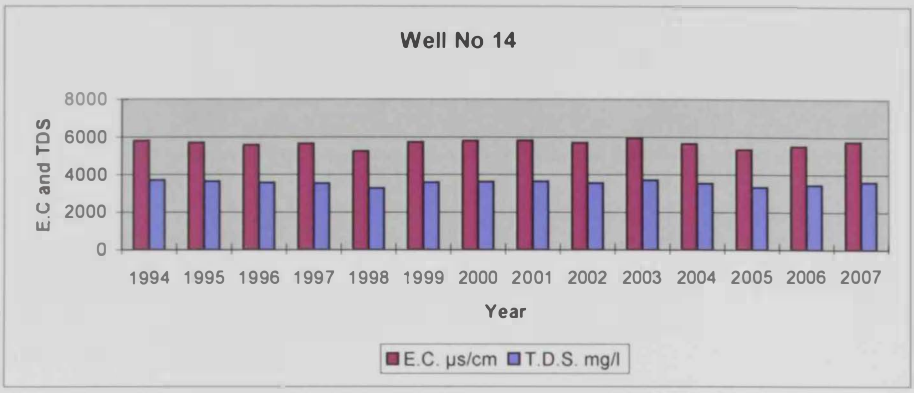

Well No 10
E.C and TDS
8000
6000
4000
2000
0
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Year
E.C. µs/cm
T.D.S. mg/l


Well No 11
E.C and TDS
10000
8000
6000
4000
2000
0
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Year
E.C. µs/cm
T.D.S. mg/l

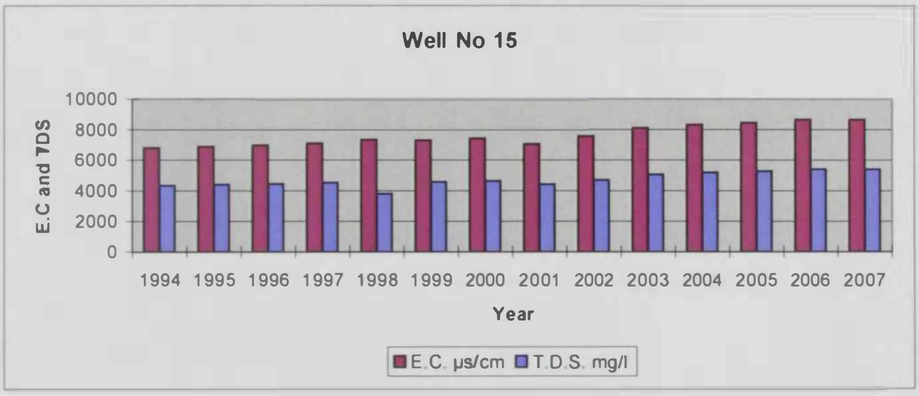

Well No 12
E.C and TDS
10000
8000
6000
4000
2000
0
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Year
E.C. µs/cm
T.D.S. mg/l



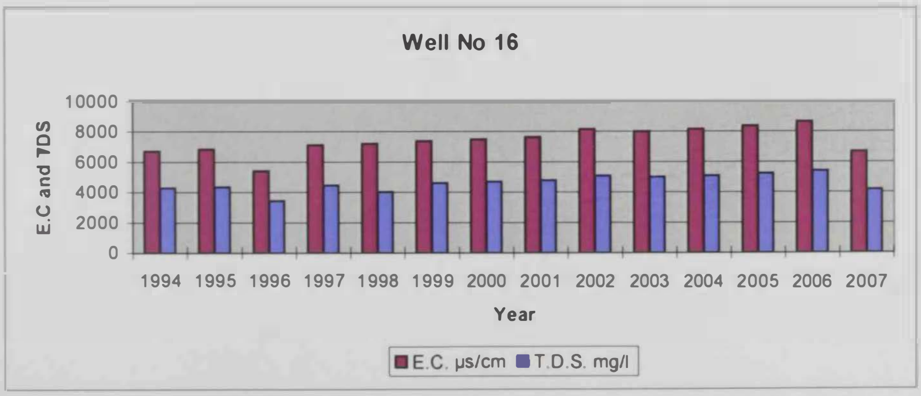
Well No 13
E.C and TDS
10000
8000
6000
4000
2000
0
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Year
E.C μs/cm T.D.S mg/l



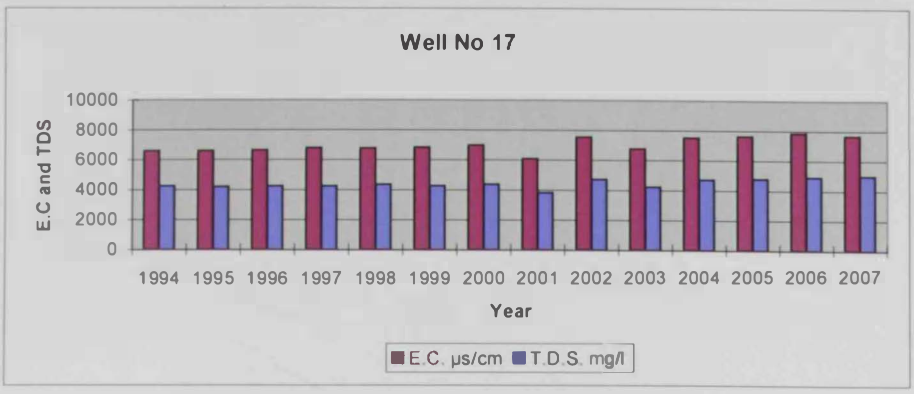
Well No 14
E.C and TDS
8000
6000
4000
2000
0
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Year
E.C. μs/cm T.D.S. mg/l



Well No 15
E.C and TDS
10000
8000
6000
4000
2000
0
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Year
E.C. μs/cm T.D.S. mg/l



Well No 16
E.C and TDS
10000
8000
6000
4000
2000
0
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Year
E.C. μs/cm T.D.S. mg/l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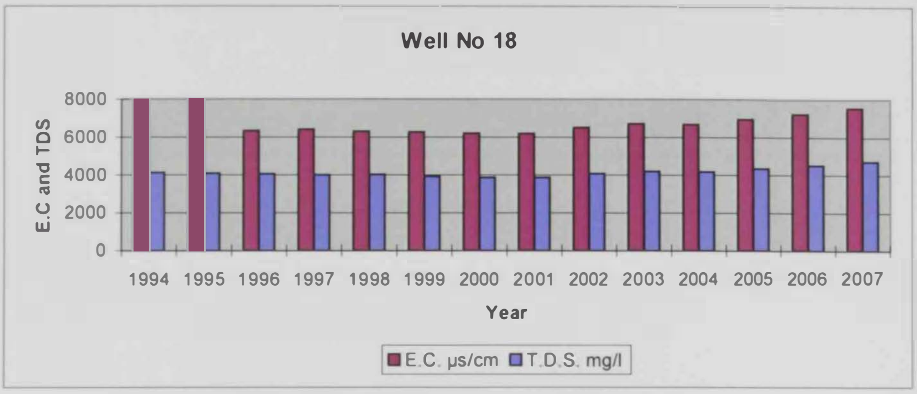
E.C and TDS
10000
8000
6000
4000
2000
0
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Year
E.C. μs/cm
T.D.S. mg/l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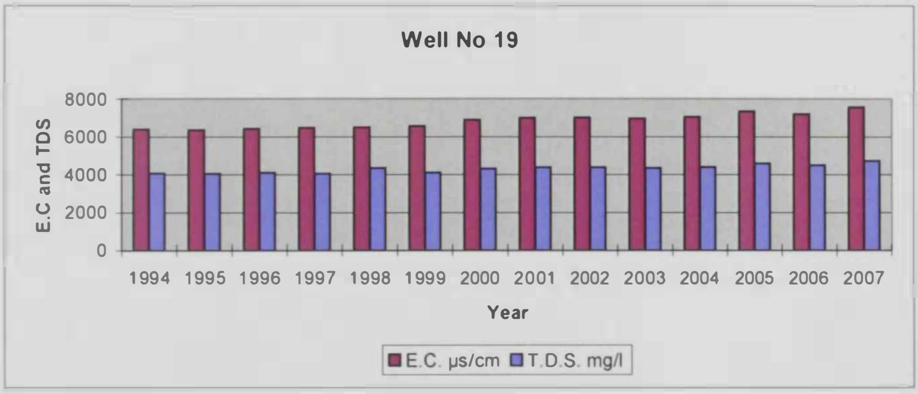
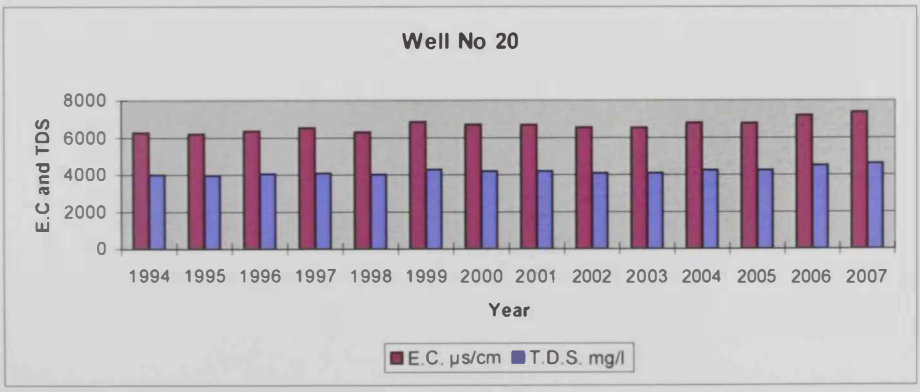
8000
6000
4000
2000
0
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Year
E.C. μs/cm
T.D.S. mg/l


Well No 19
E.C and TDS
8000
6000
4000
2000
0
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Year
E.C. μs/cm
T.D.S. mg/l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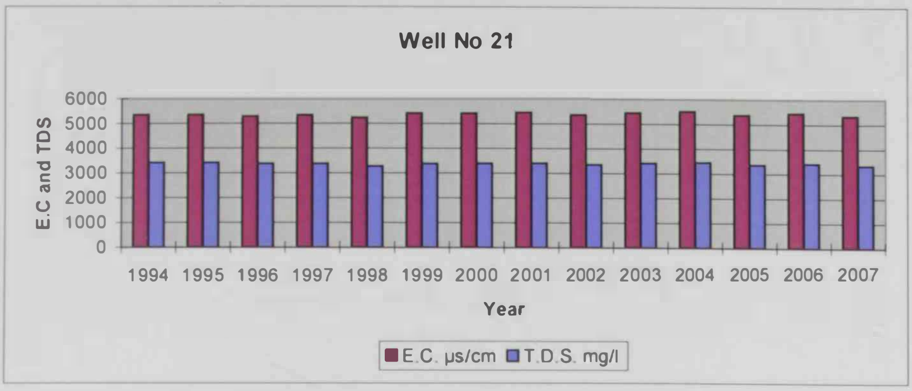
2000
0
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Year
E.C. μs/cm
T.D.S. mg/l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5000
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1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
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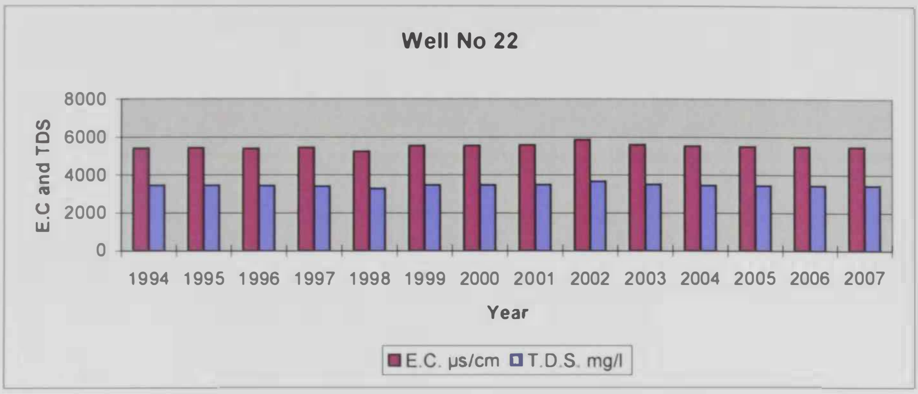
T.D.S. mg/l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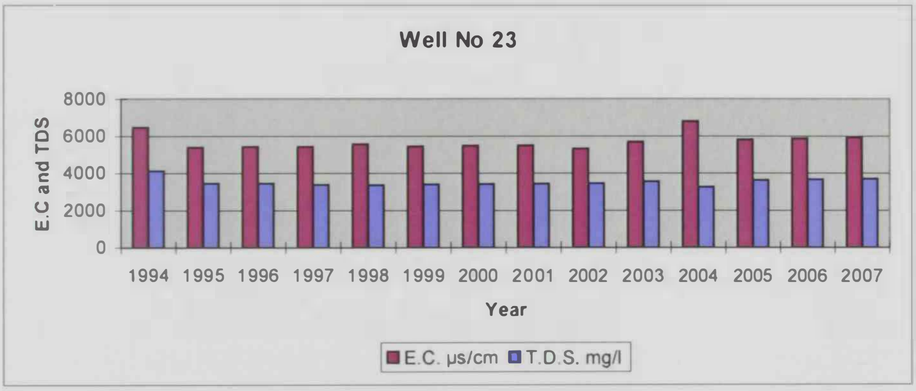
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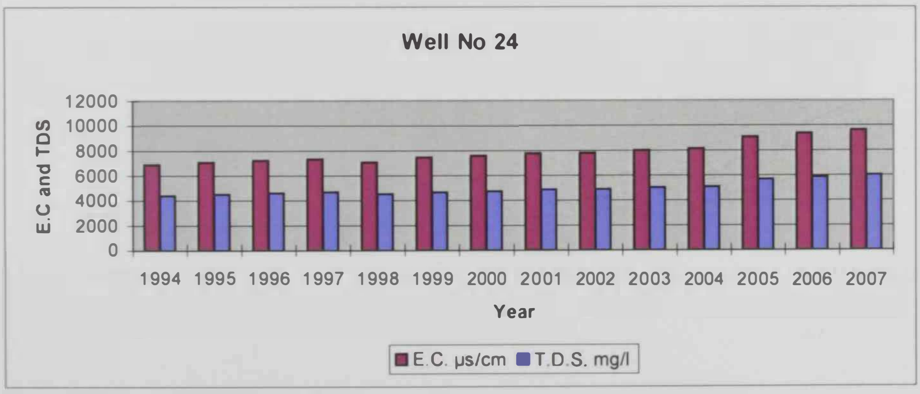
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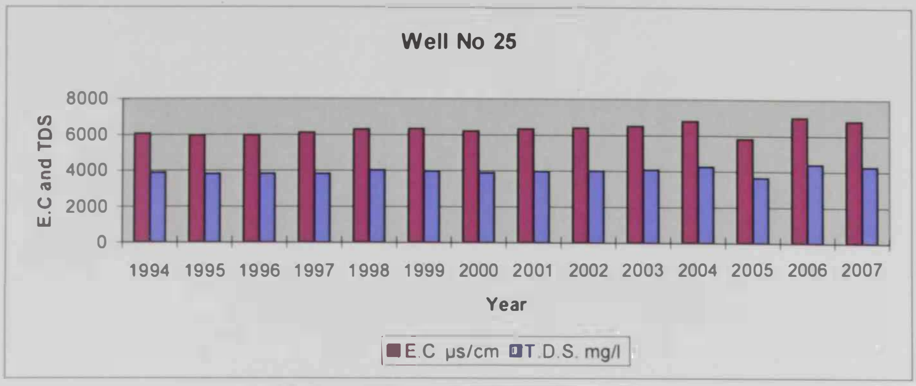

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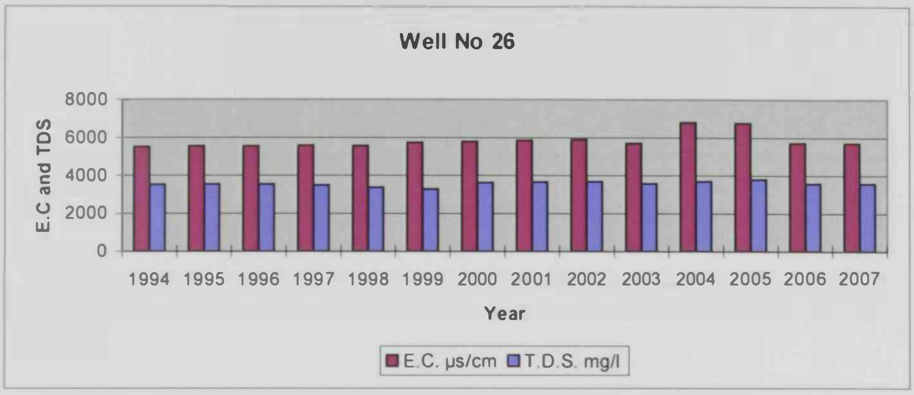

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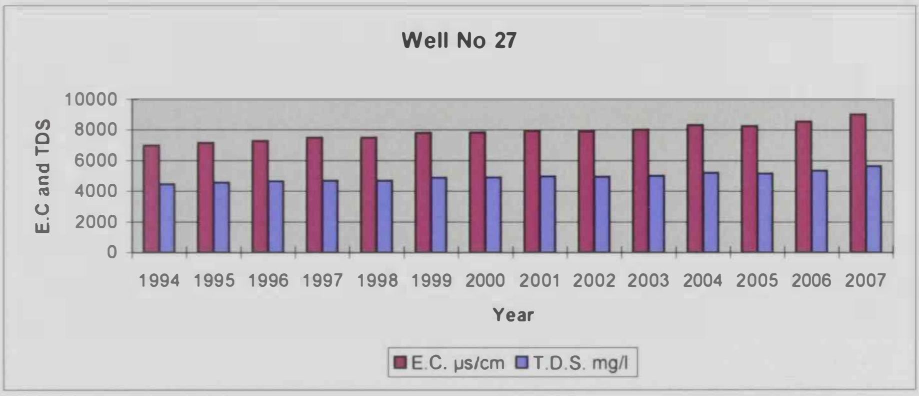

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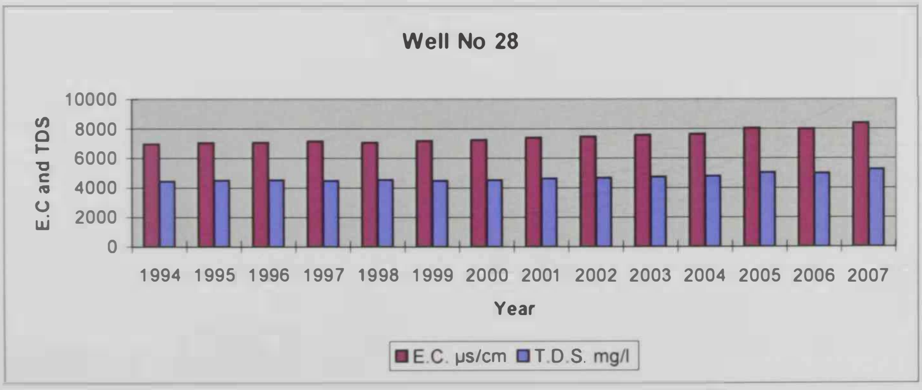

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Year
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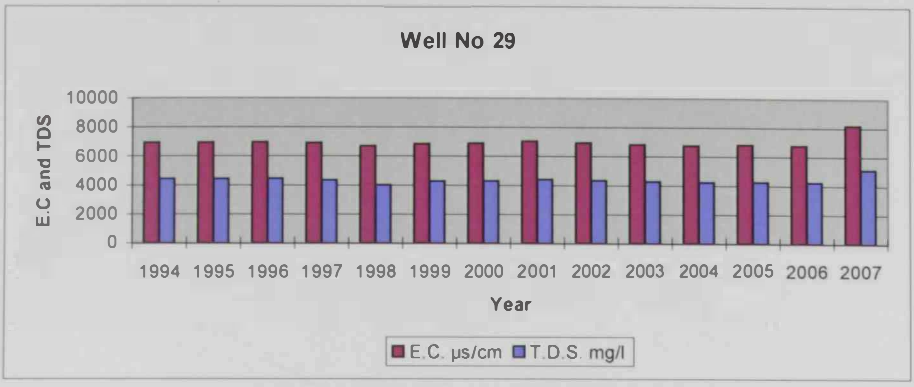
T.D.S. mg/l



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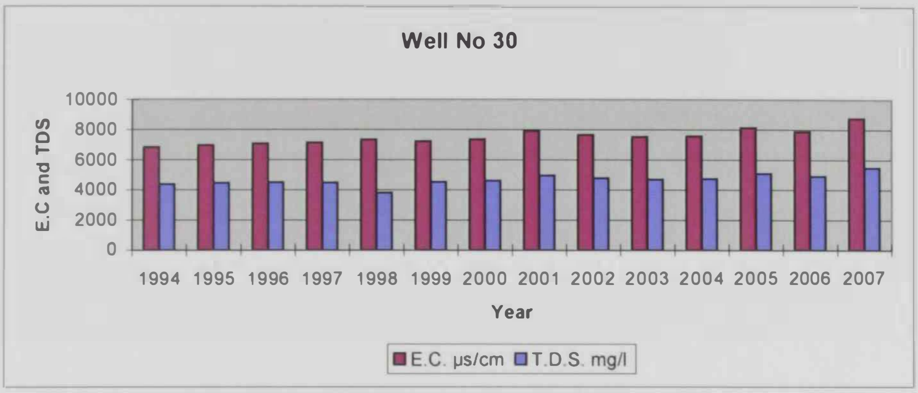
T.D.S. mg/l



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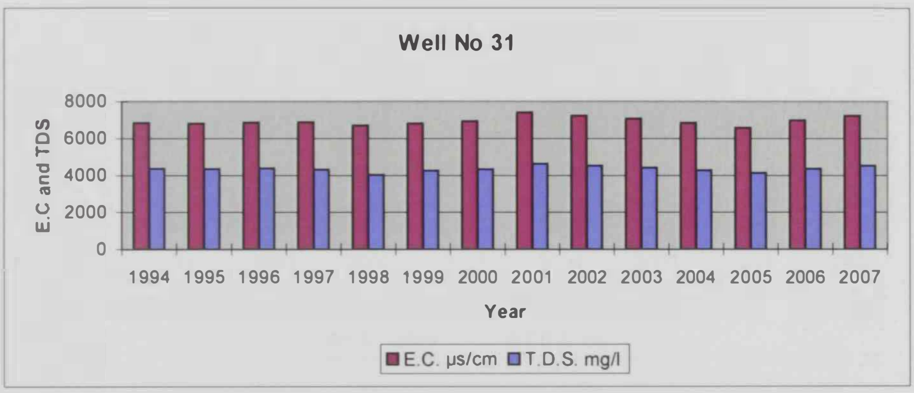
T.D.S. mg/l



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Year
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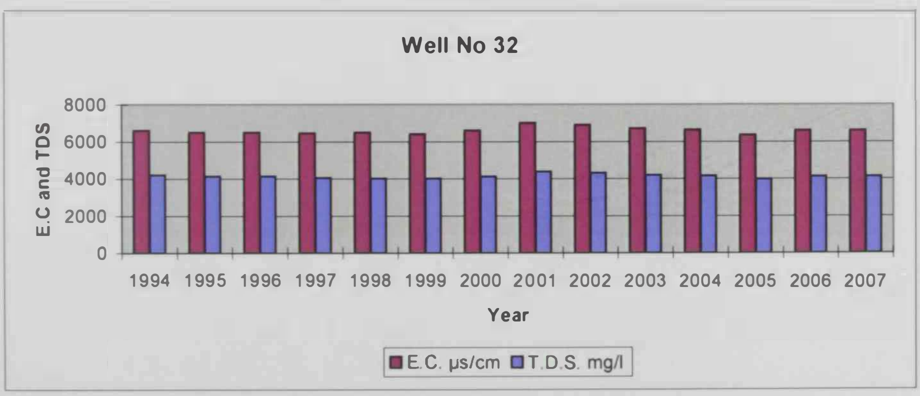
T.D.S. mg/l



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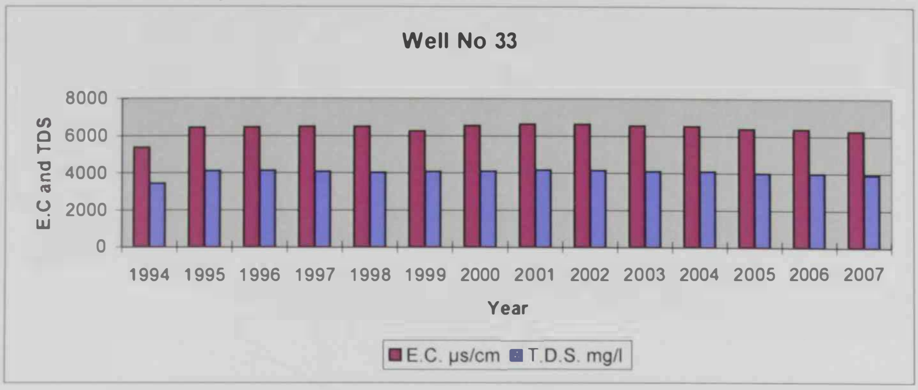
T.D.S. mg/l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0
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Year
E.C. µs/cm
T.D.S. mg/l


Well No 34
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2000
0
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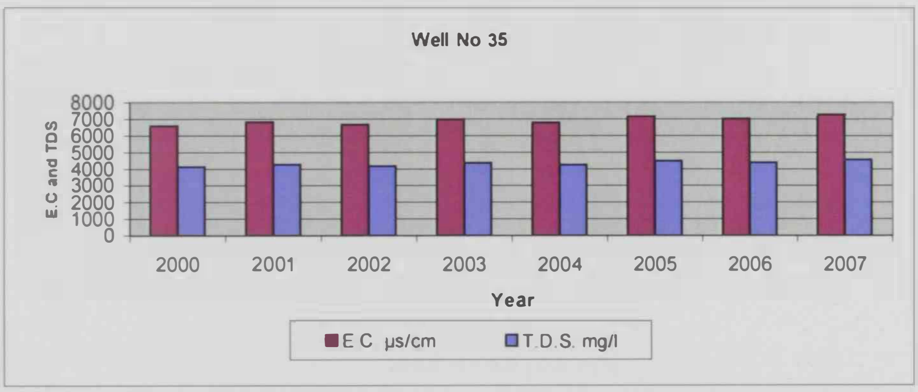
Year
E C. µs/cm
T.D.S. mg/l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2000 2001 2002 2003 2004 2005 2006 2007
Year
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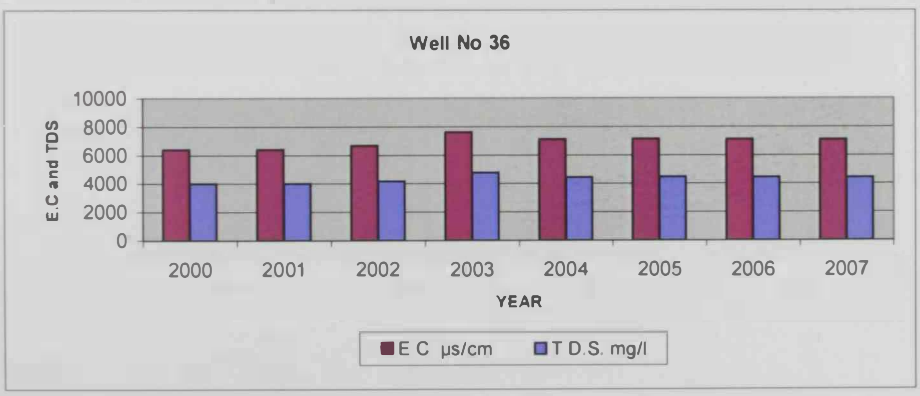
T.D.S. mg/l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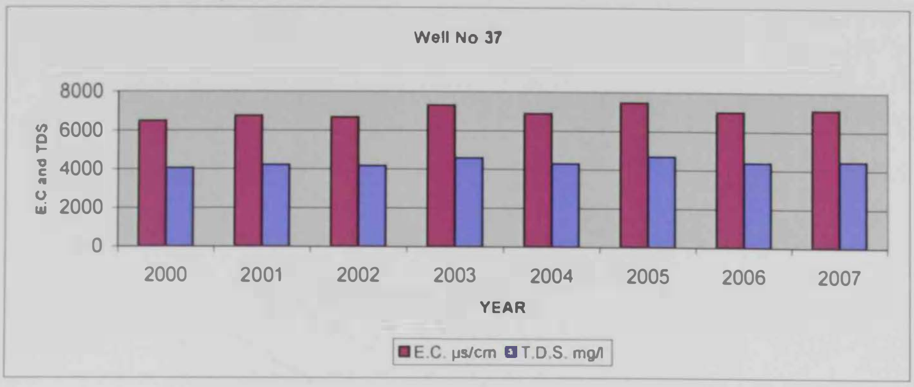
YEAR
E C µs/cm
T D.S. mg/l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2001
2002
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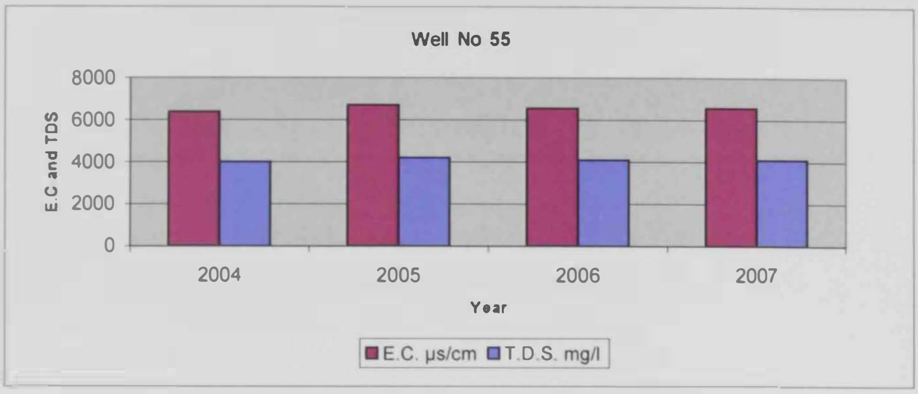
2004
2005
2006
2007
YEAR
E.C. µs/cm
T.D.S. mg/l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E.C and TDS
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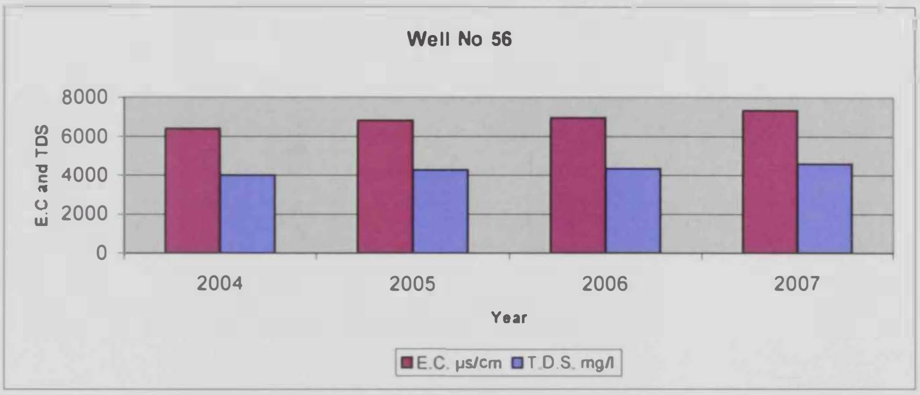
2005
2006
2007
Year
E.C. µs/cm
T.D.S. mg/l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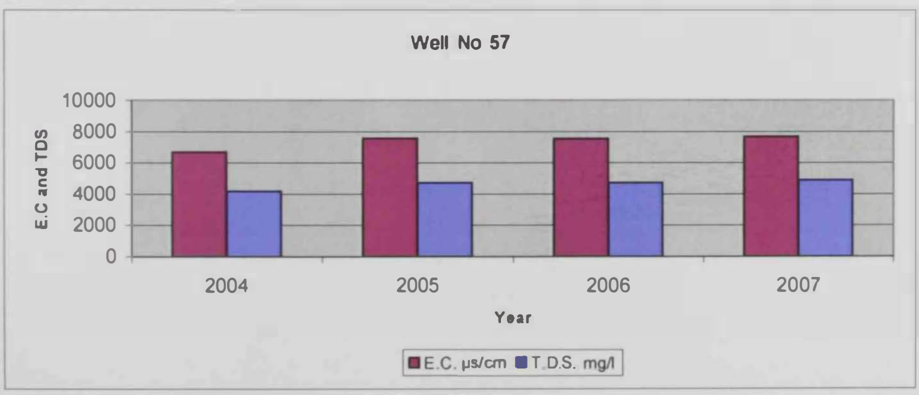
E.C and TDS
2004
2005
2006
2007
Year
E.C. µs/cm
T.D.S. mg/l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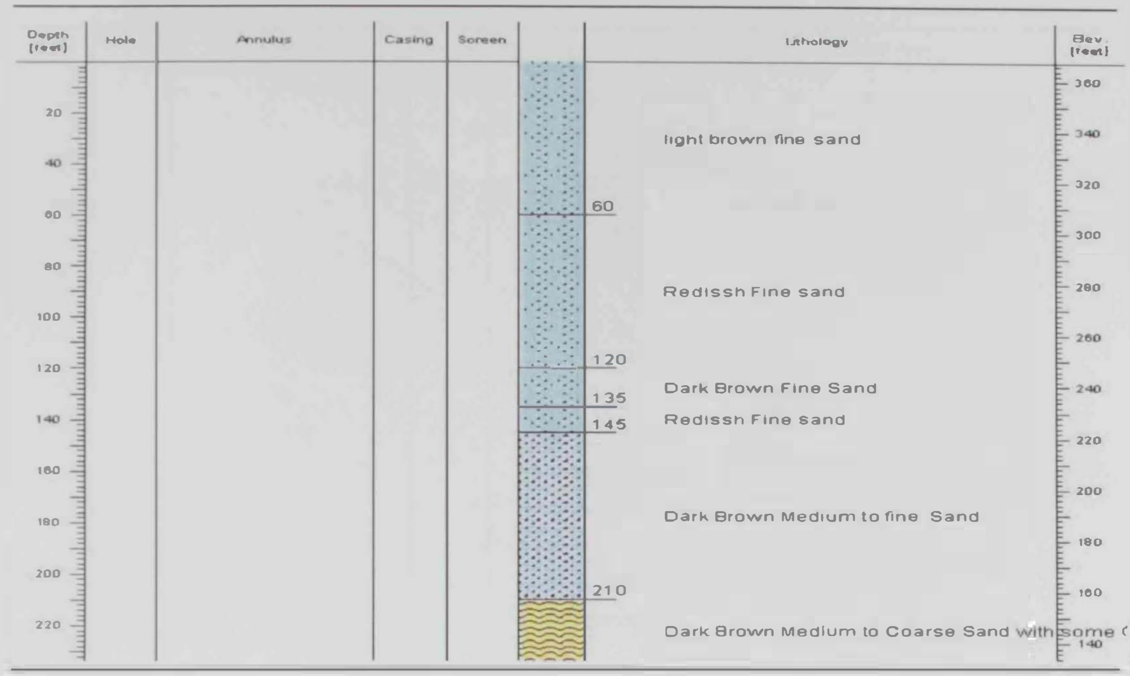
10000
8000
6000
4000
2000
0
E.C and TDS
2004
2005
2006
2007
Year
E.C. µs/cm
T.D.S. mg/l

Appendix D

Lithological Sections of Hallew Wells from GWW Software

WELL NO 1



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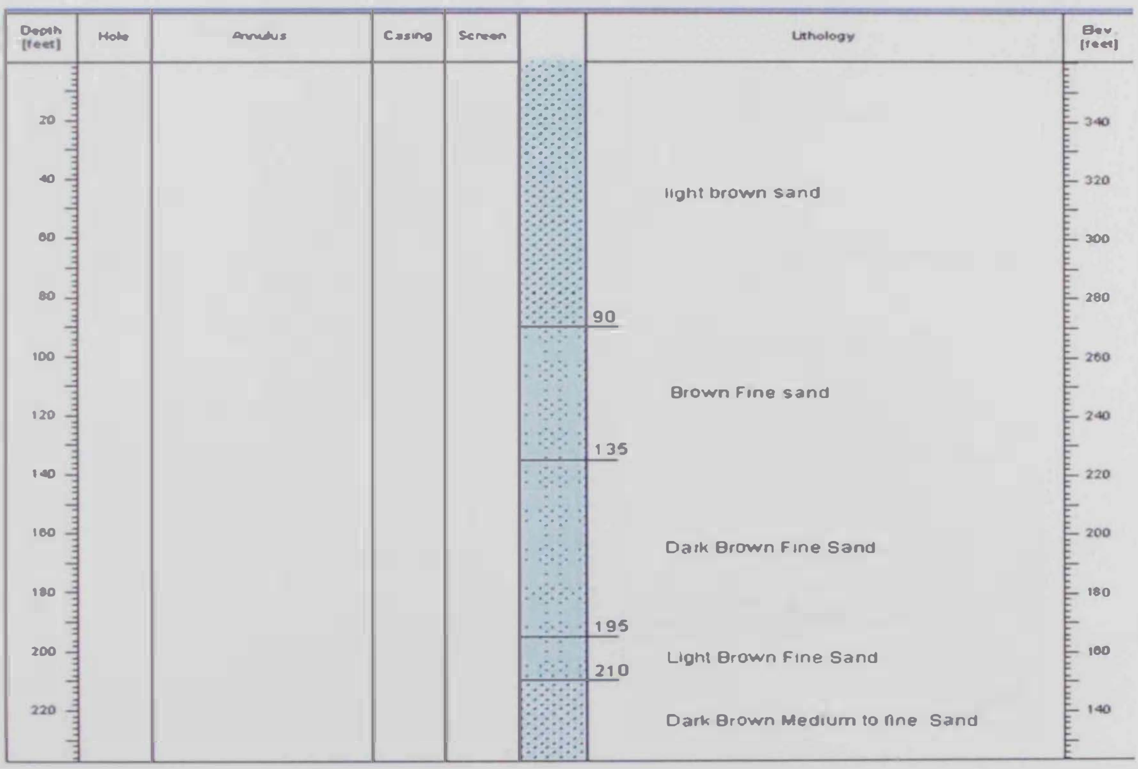

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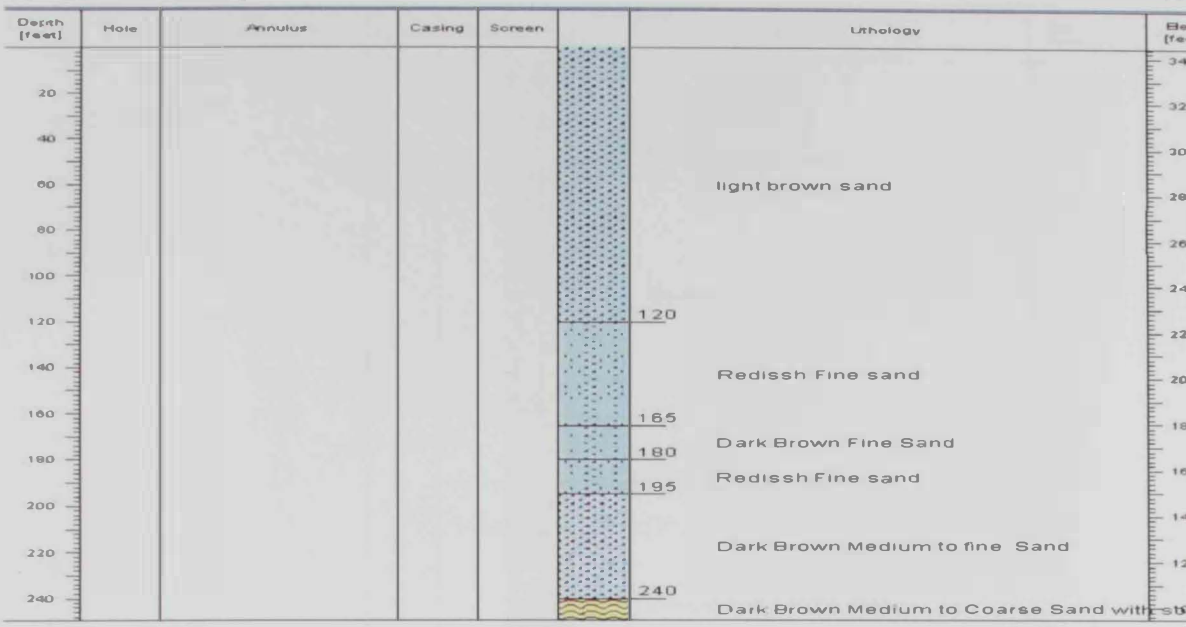

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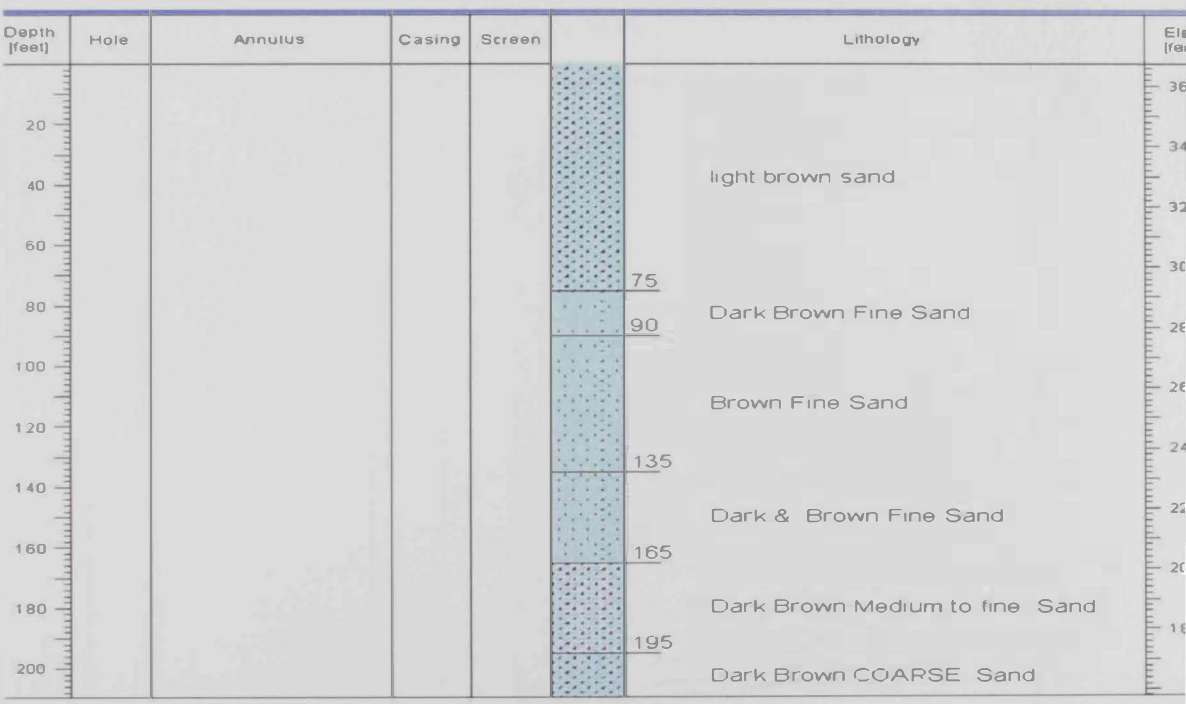

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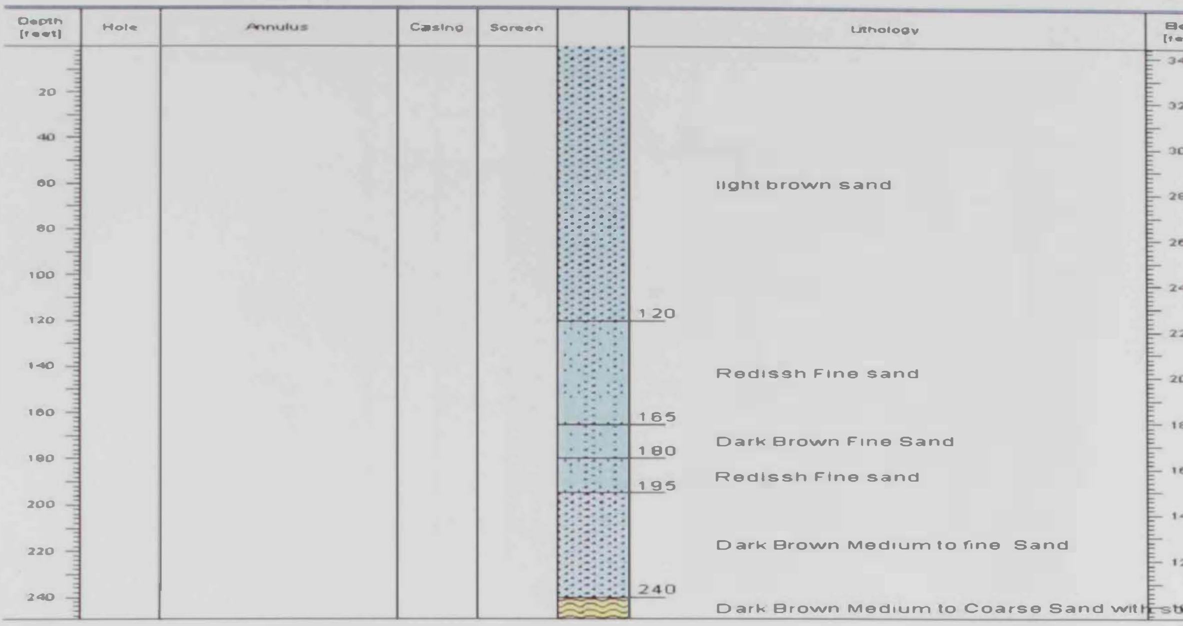

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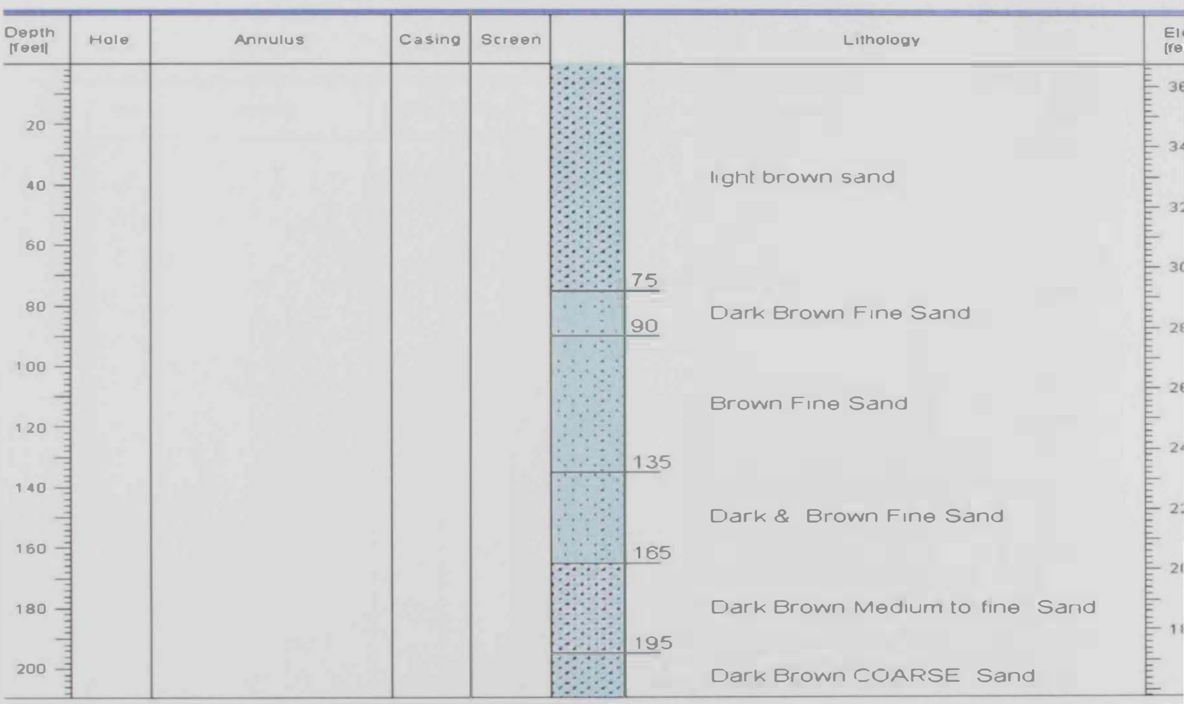

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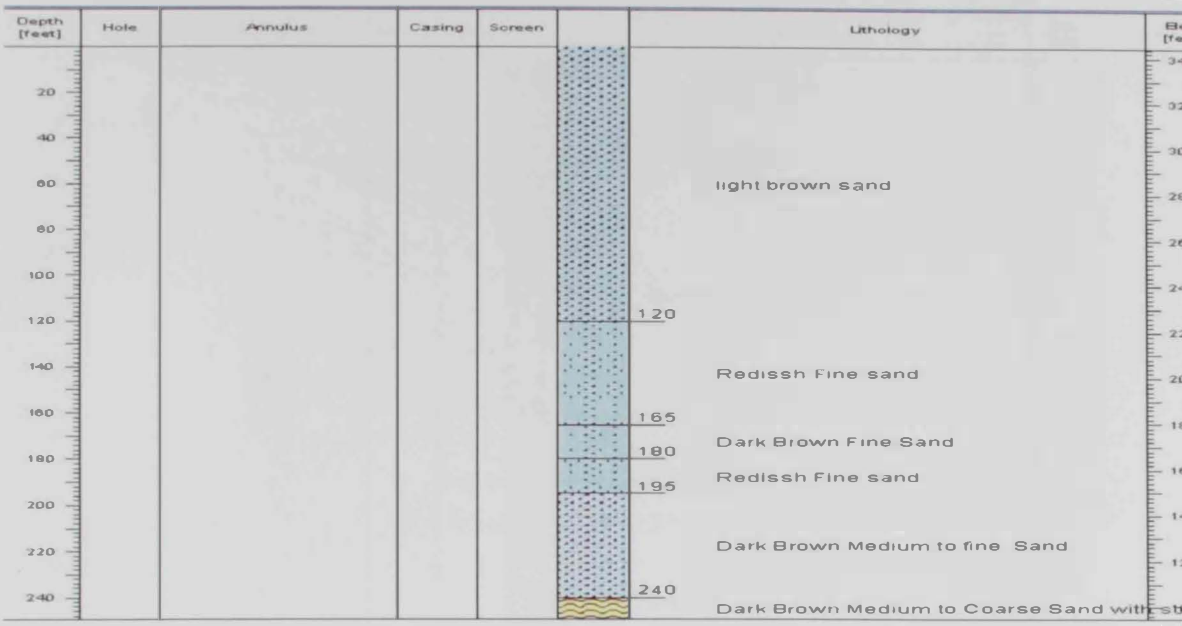

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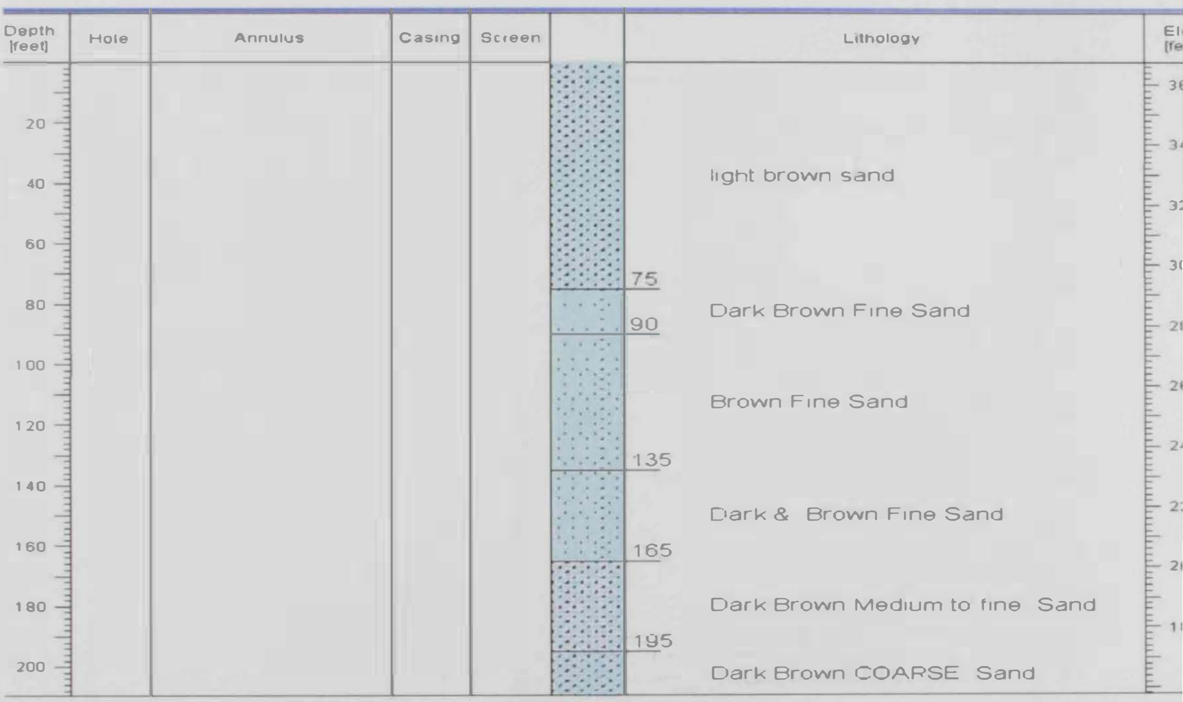

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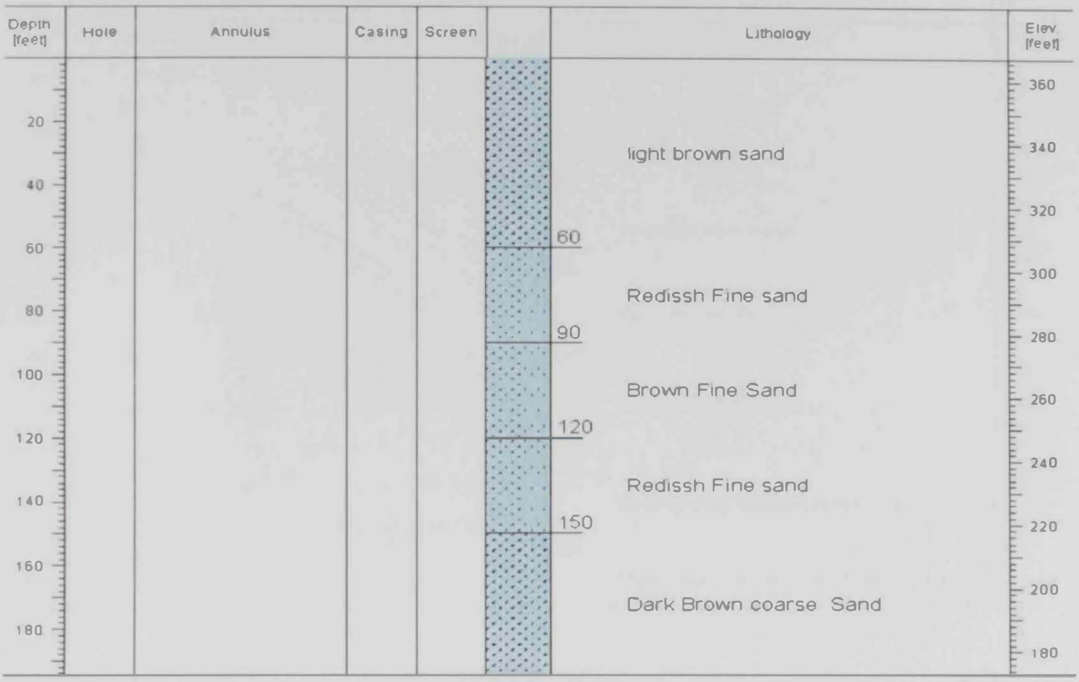

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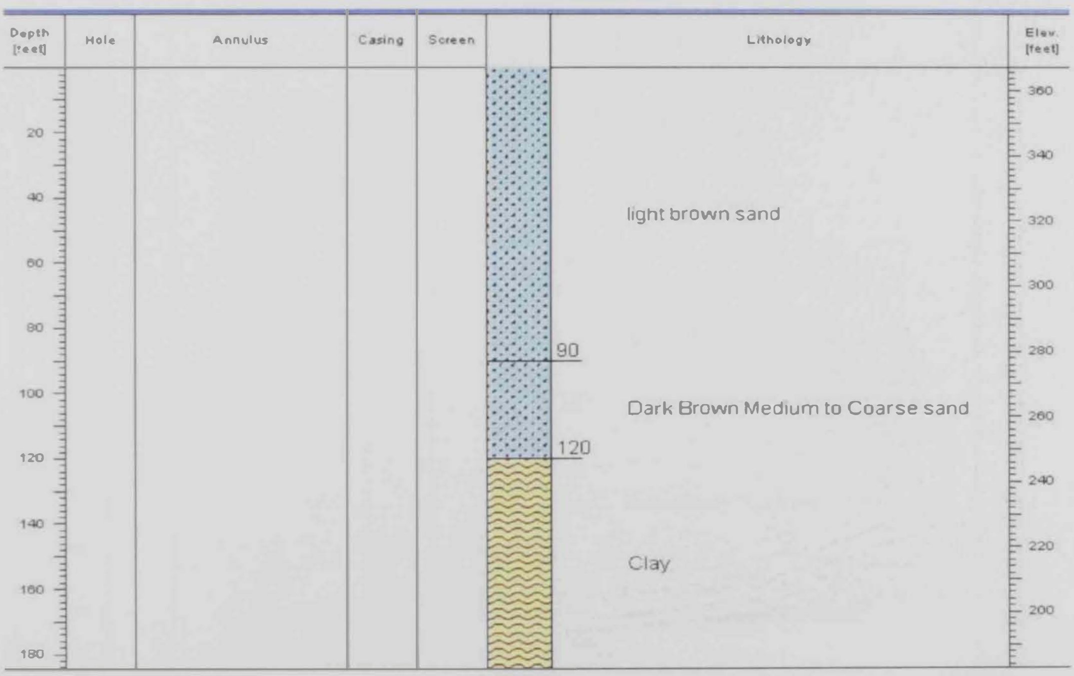

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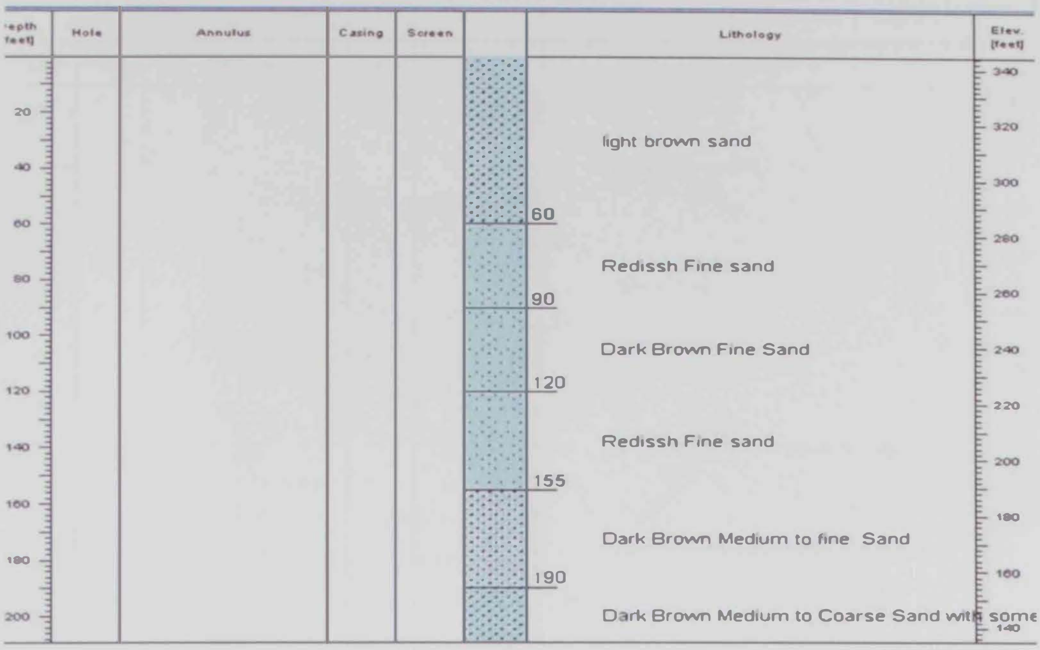

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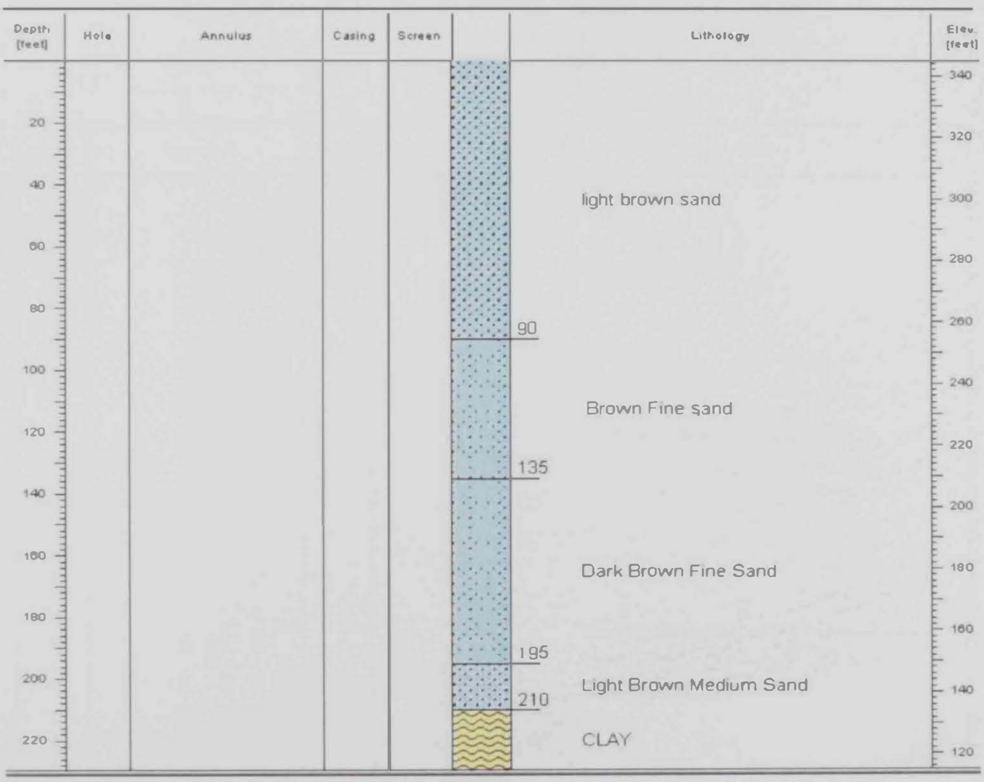

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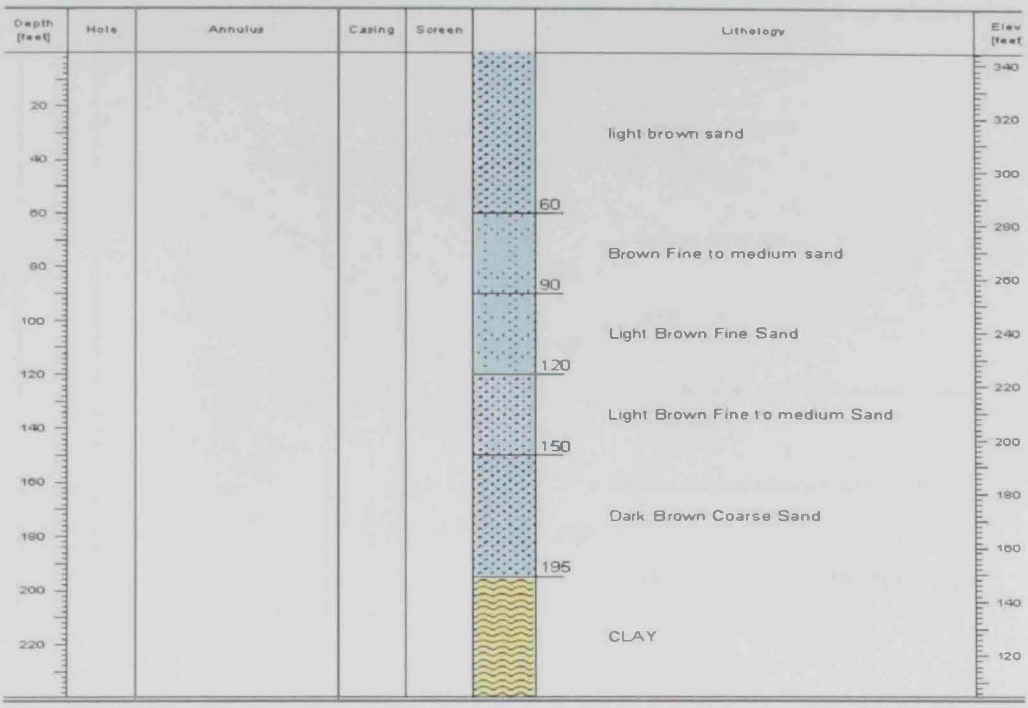

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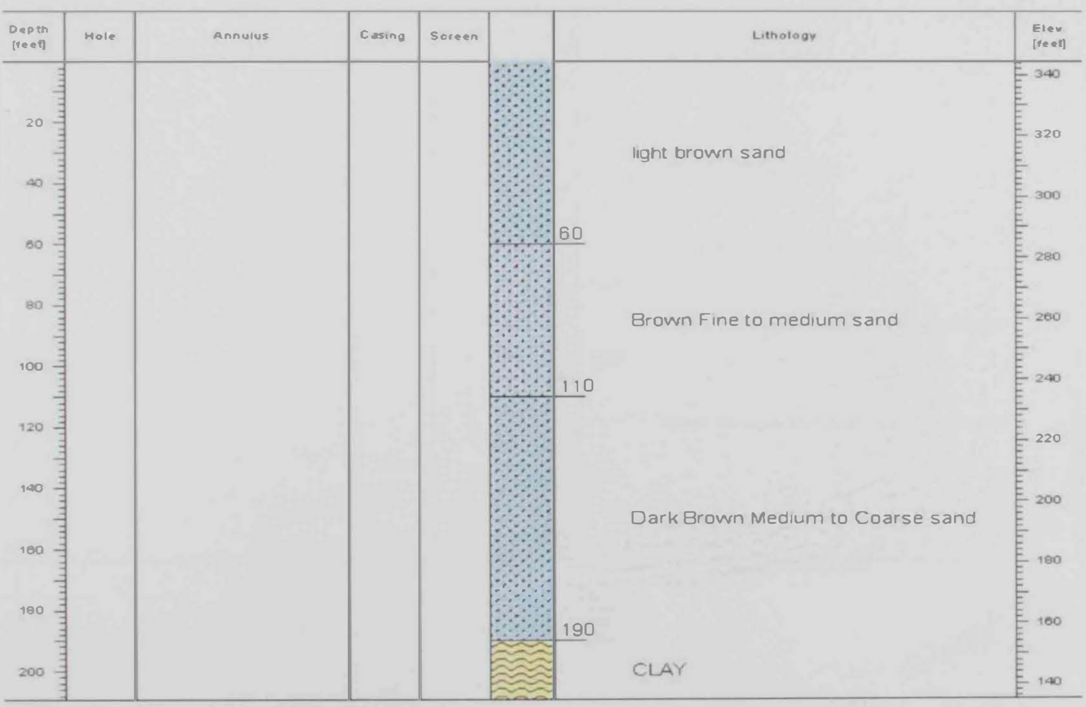

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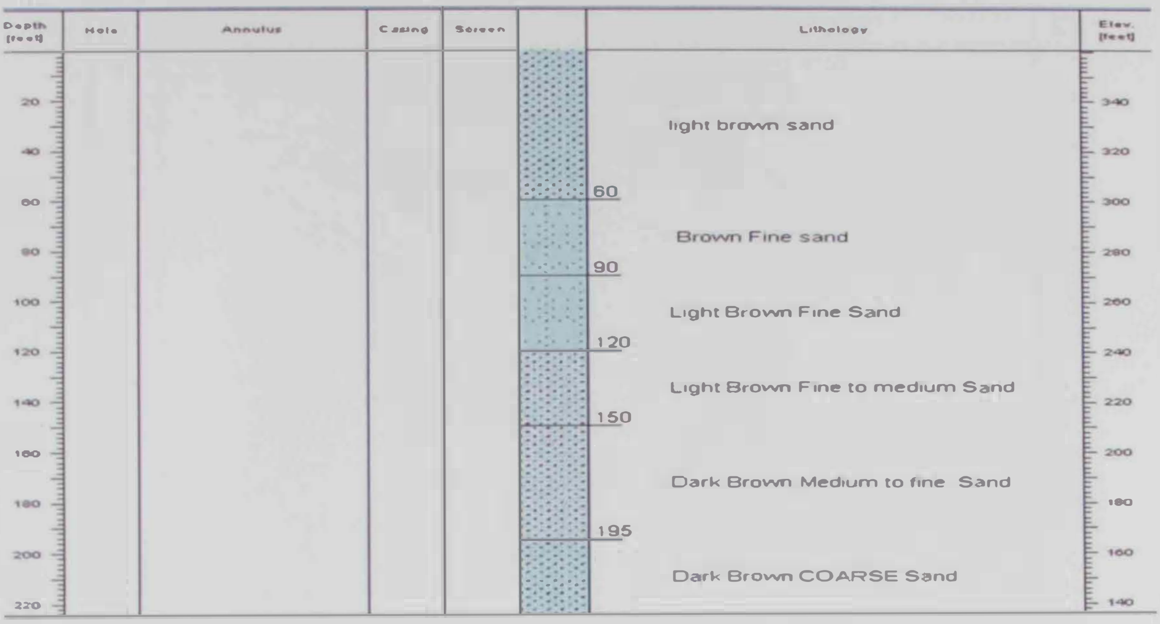

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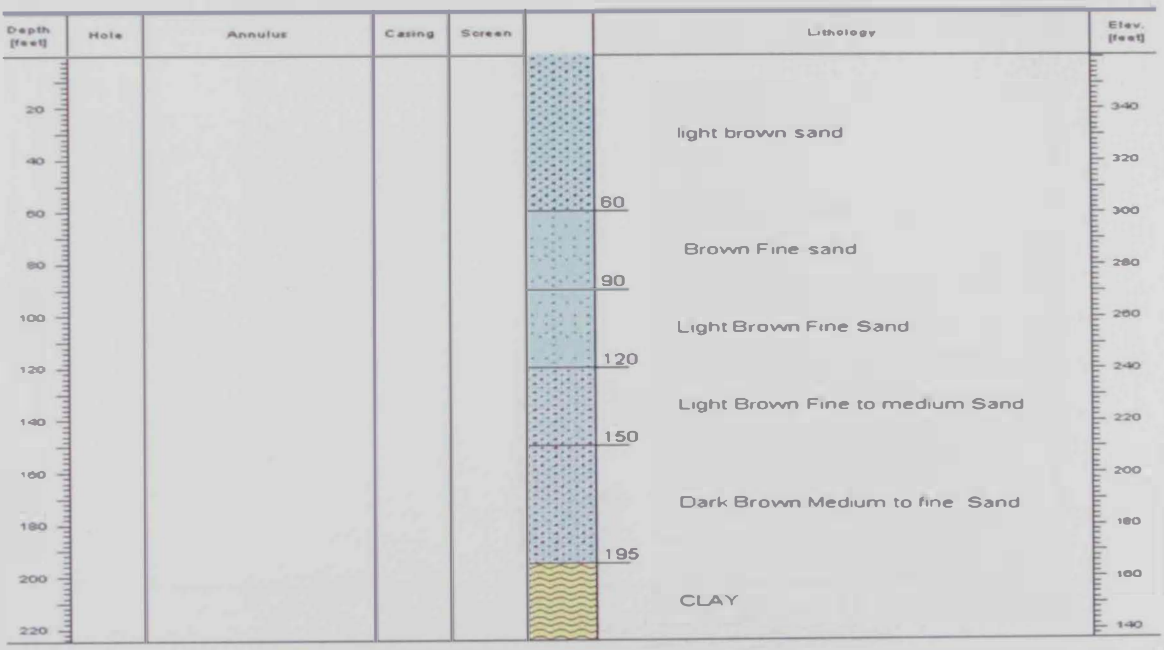

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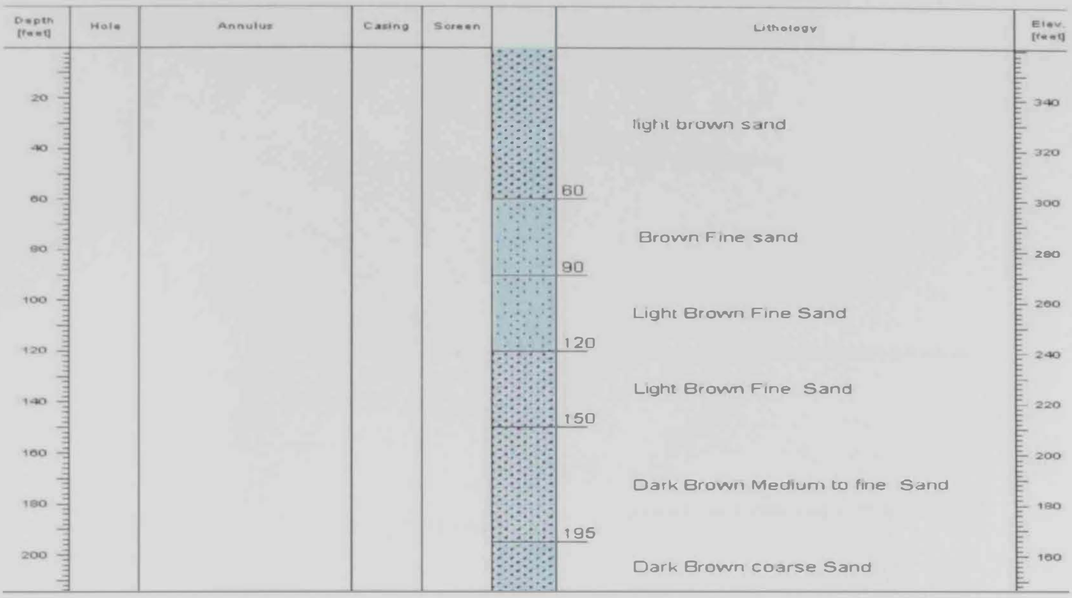

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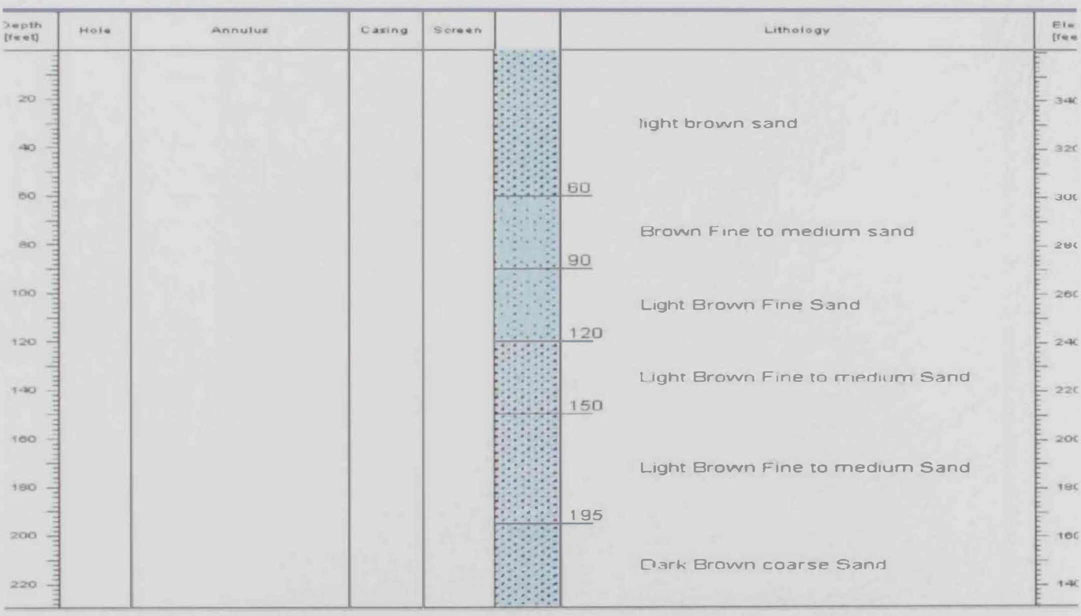

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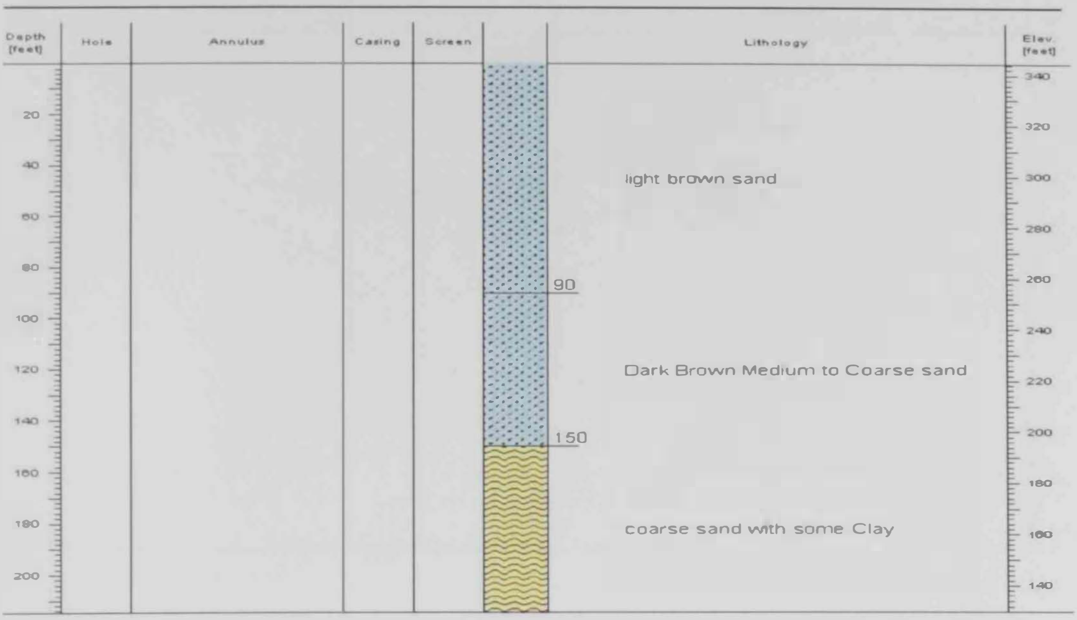

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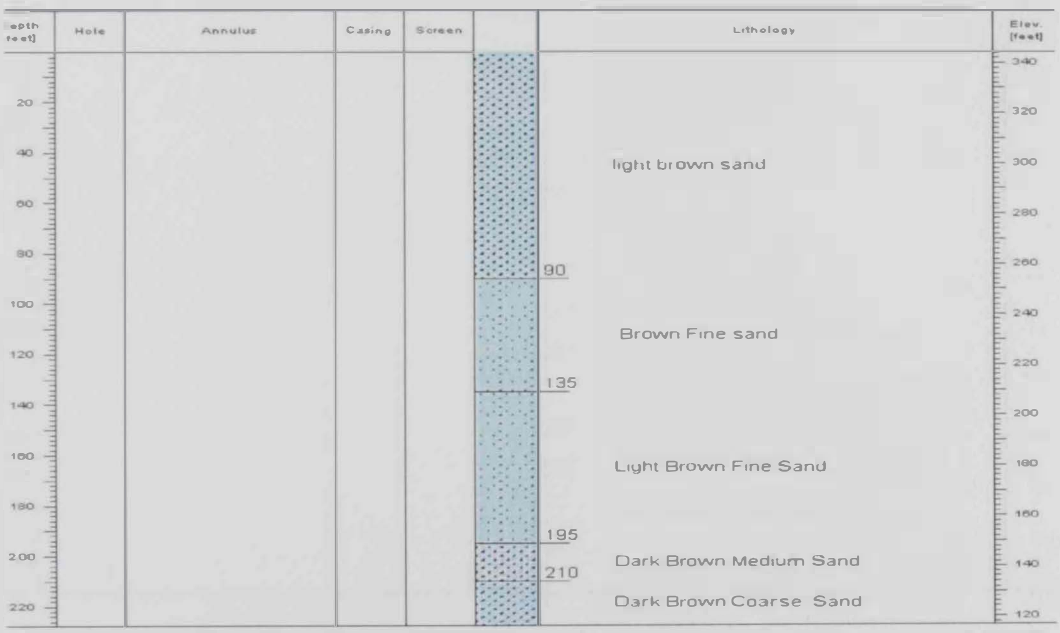

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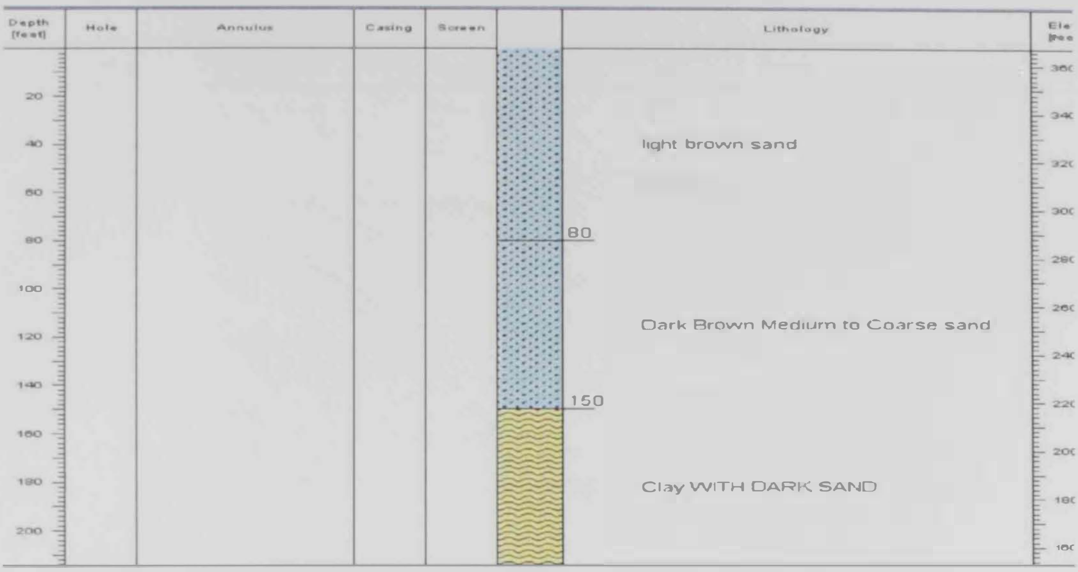

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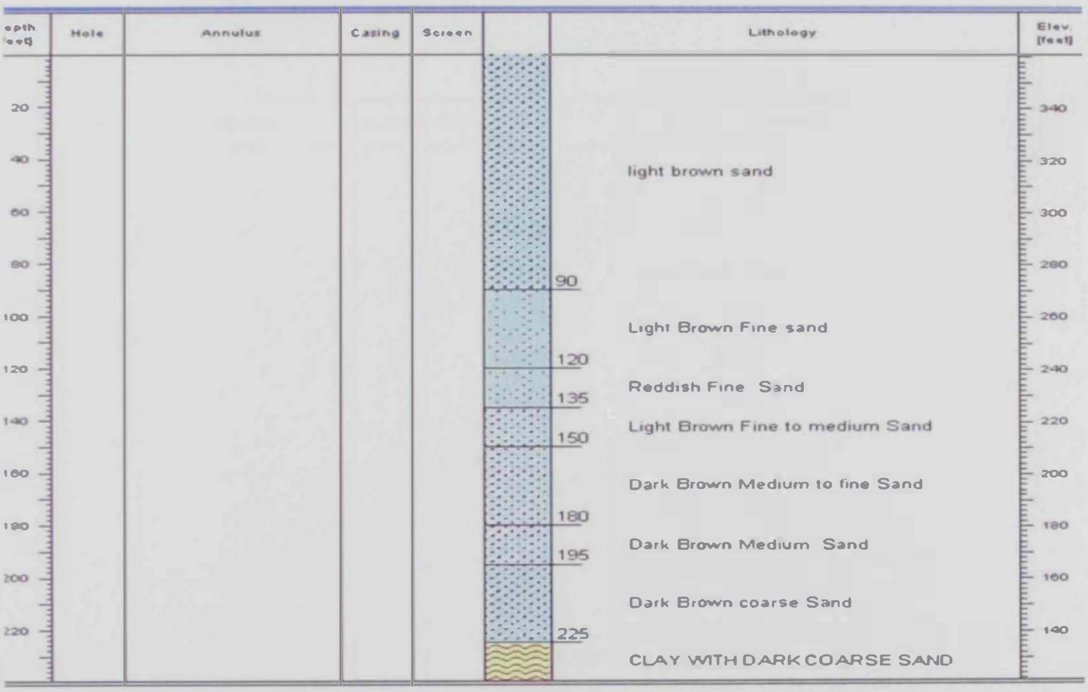

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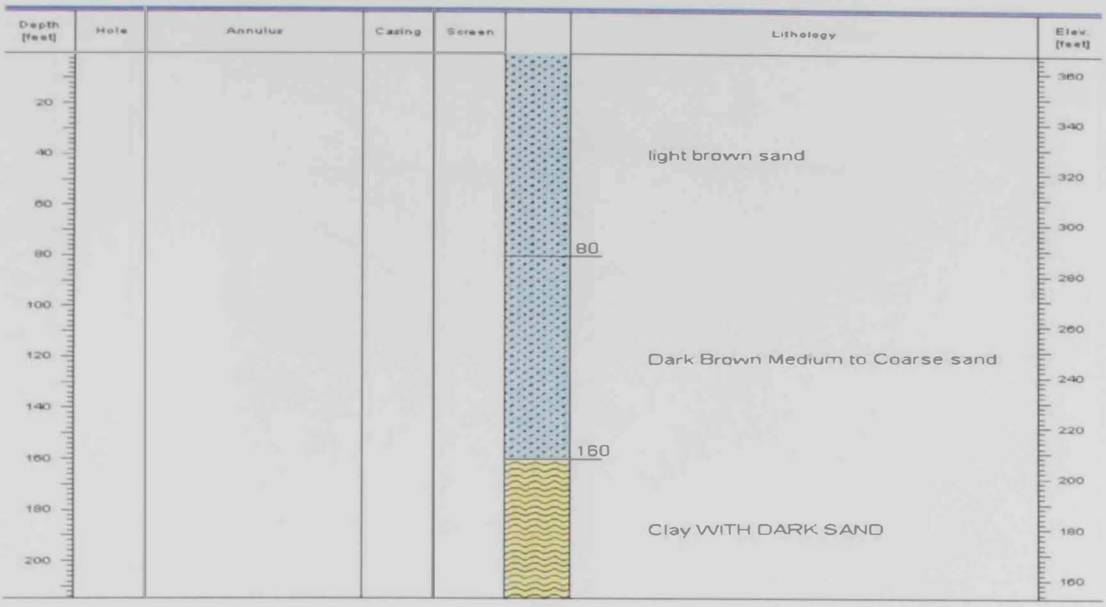

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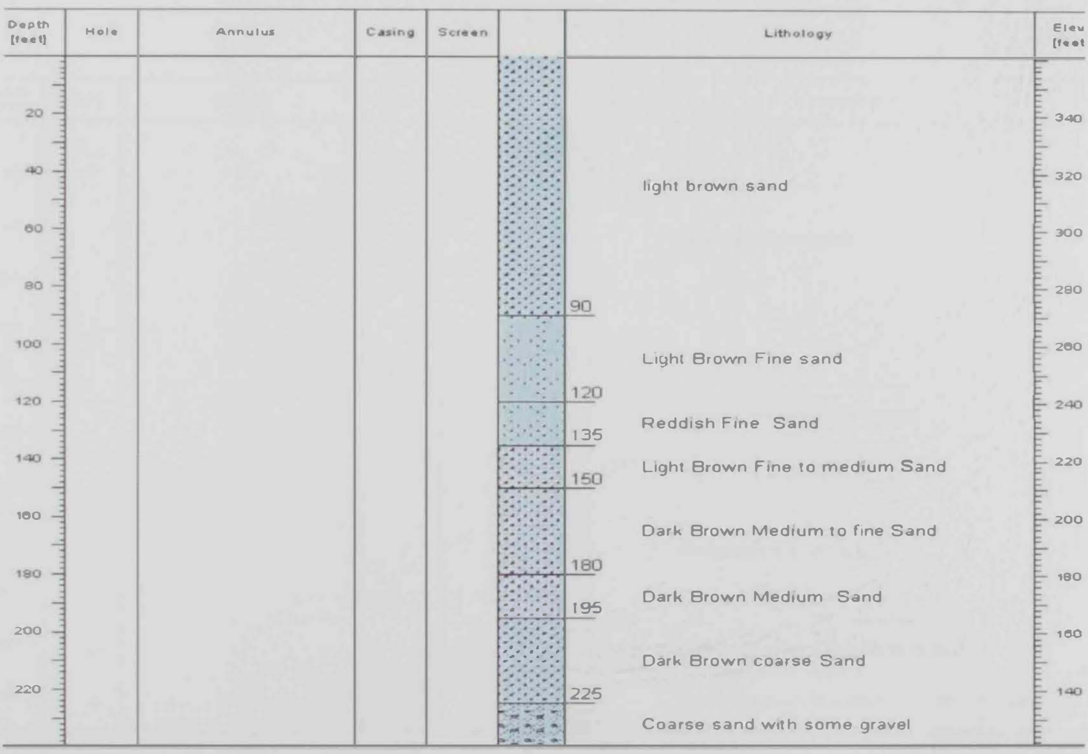

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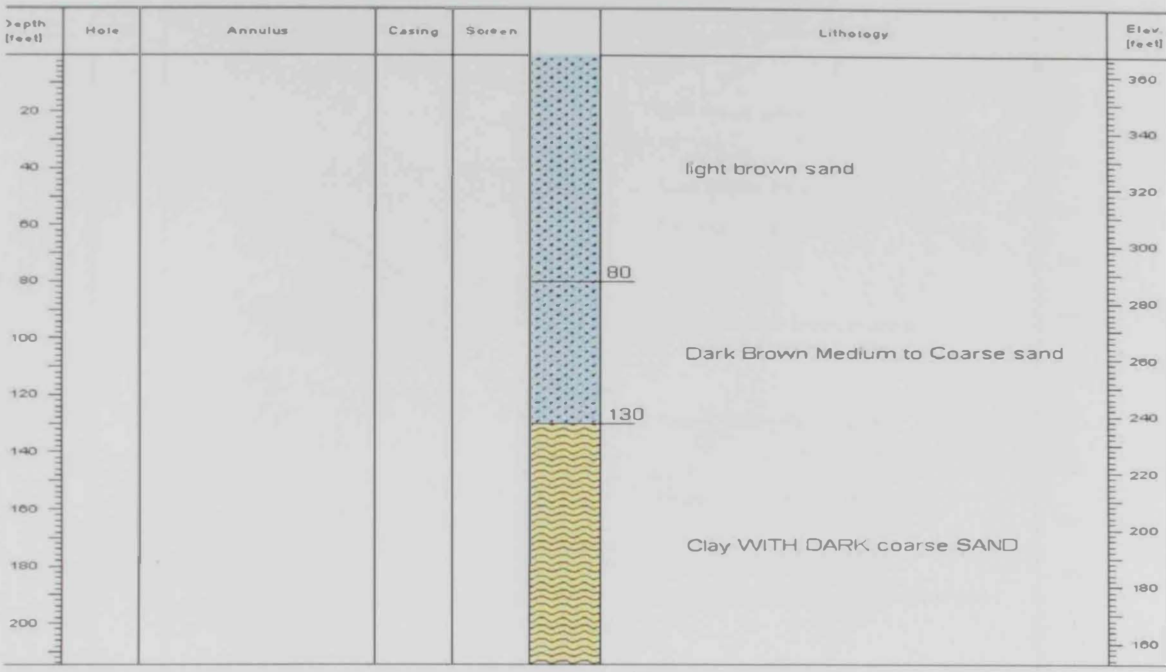

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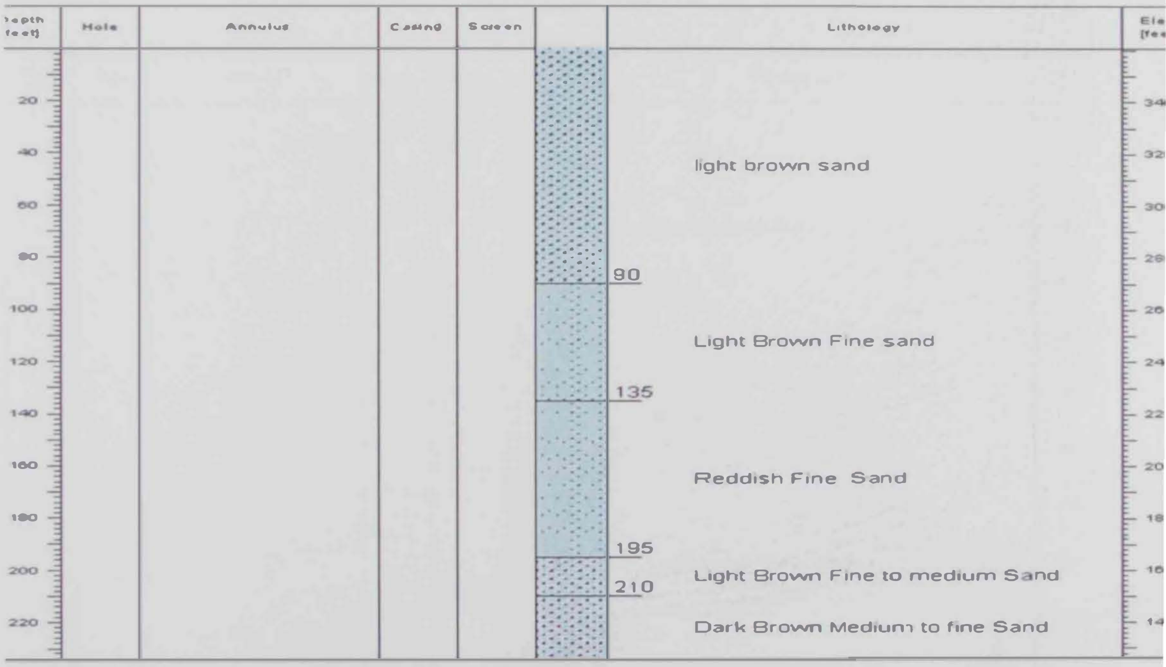

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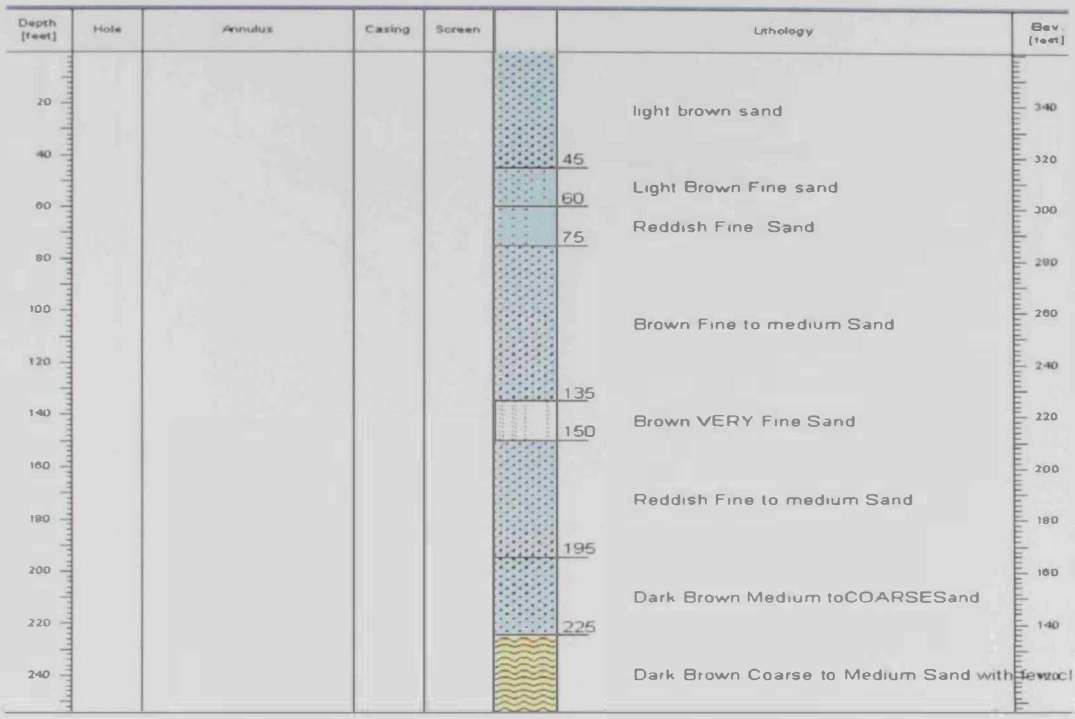

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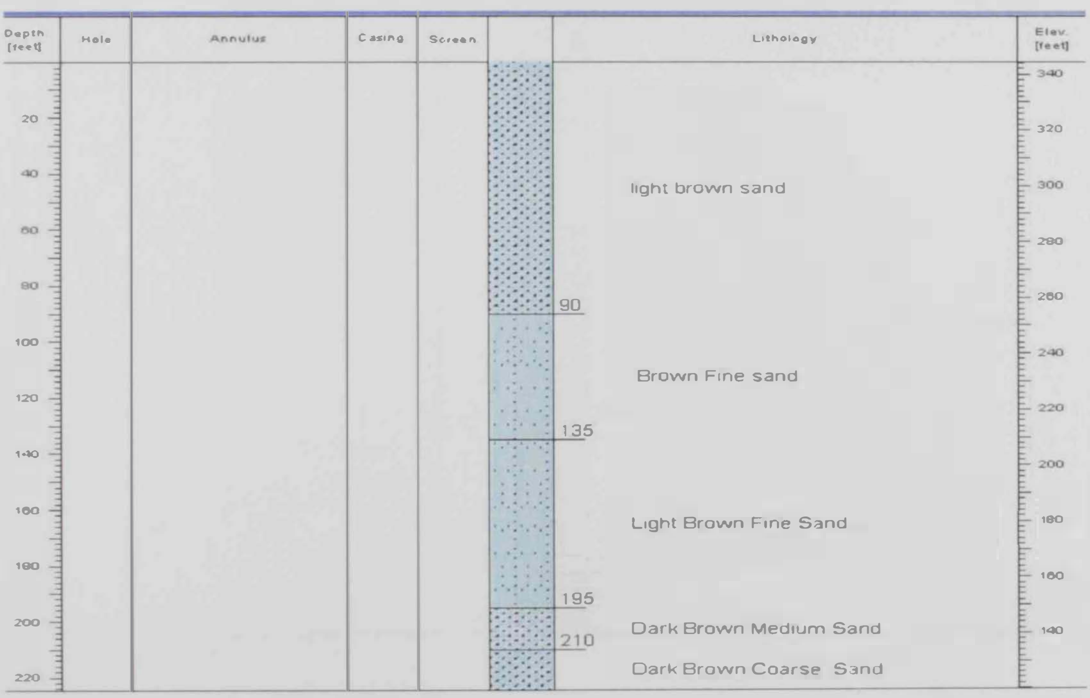

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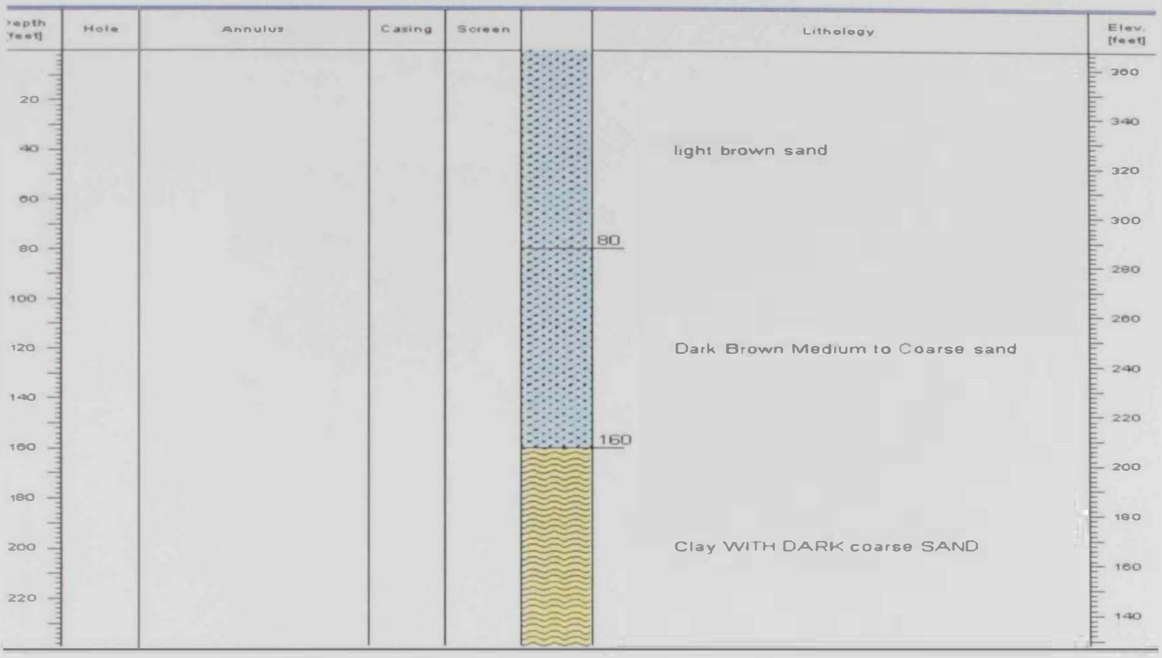

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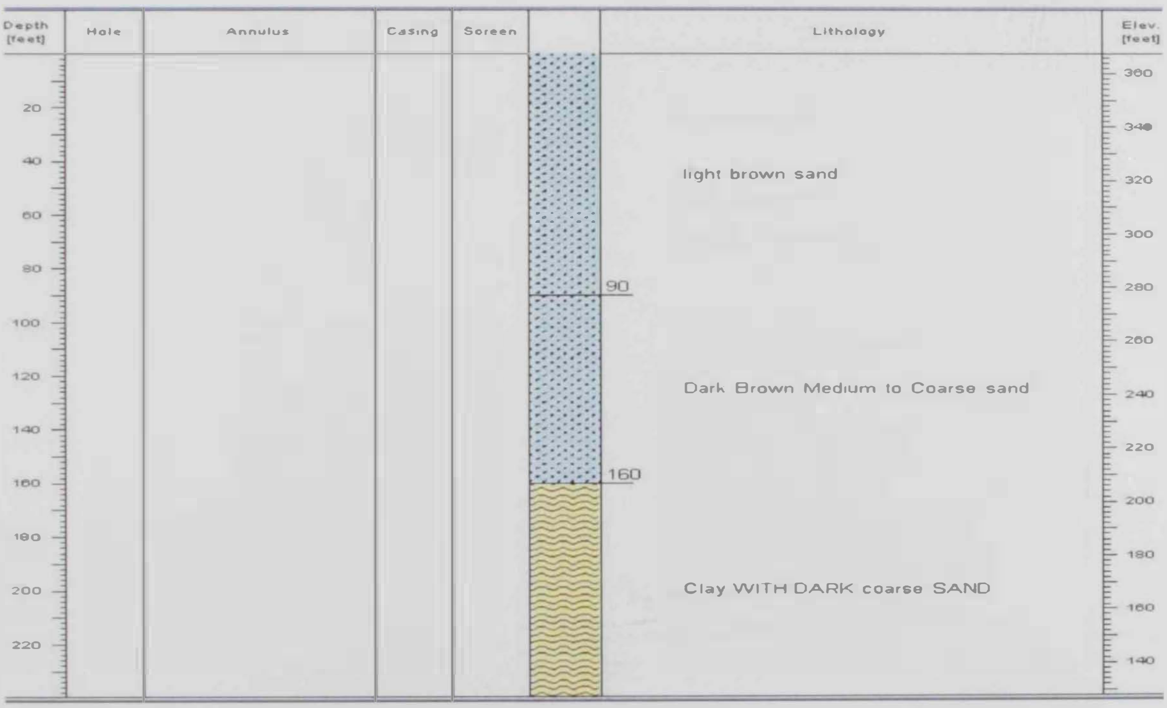

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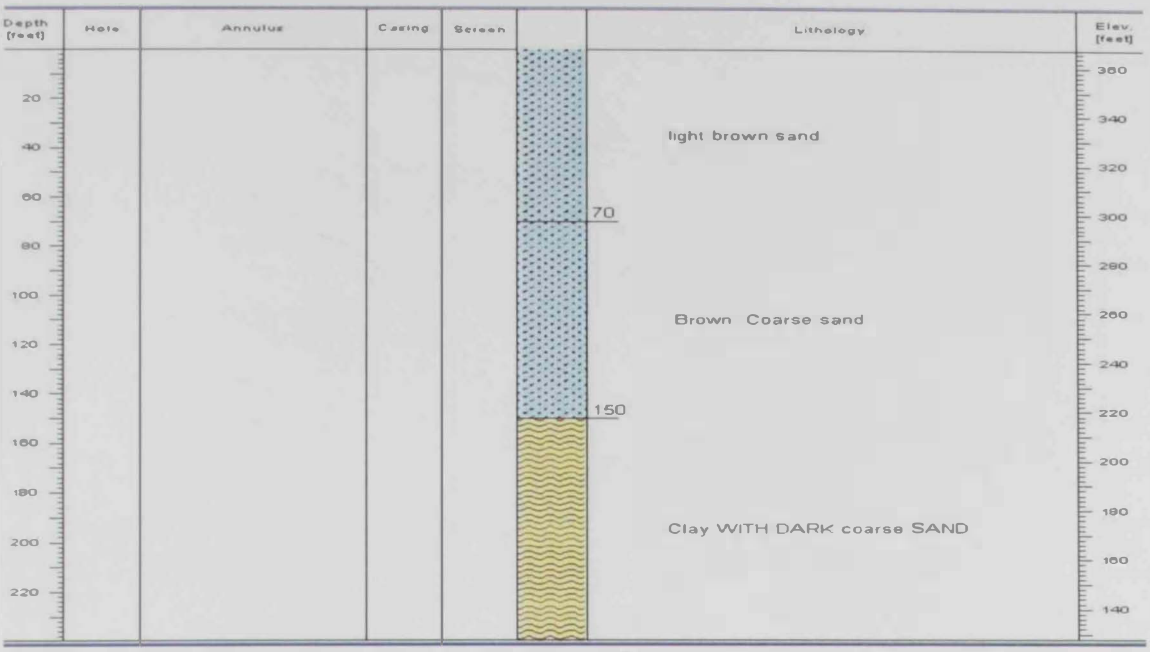

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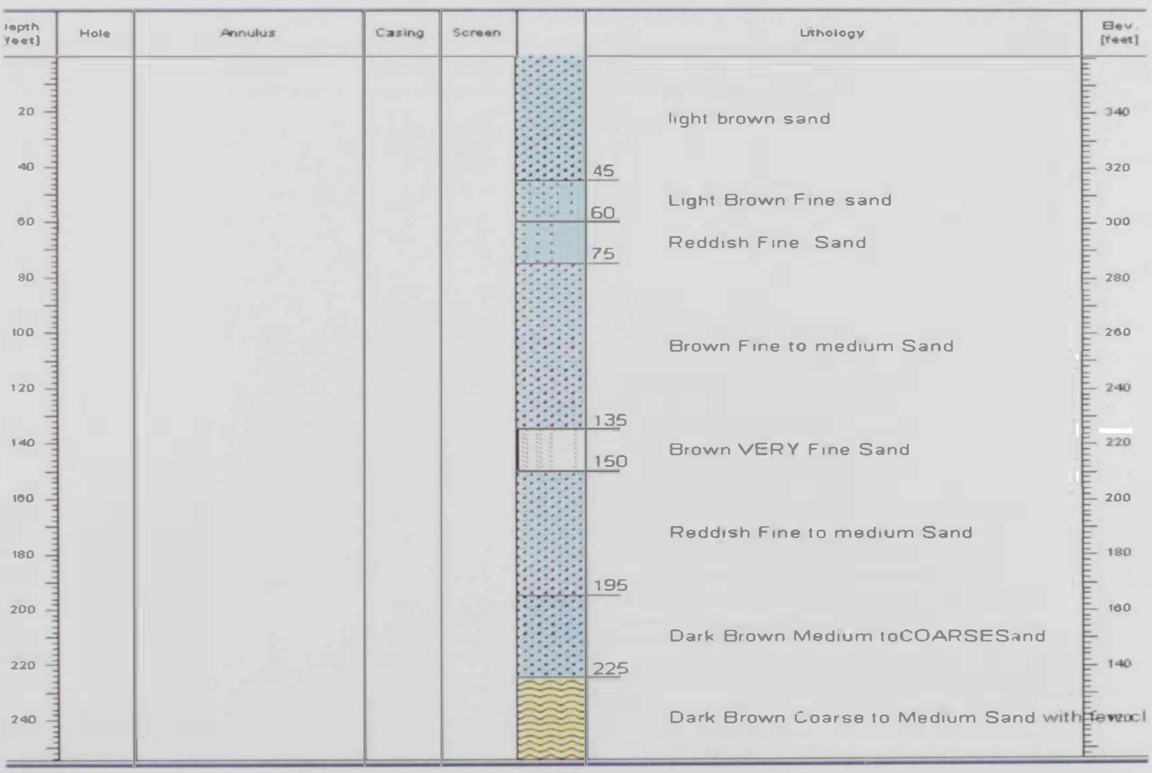

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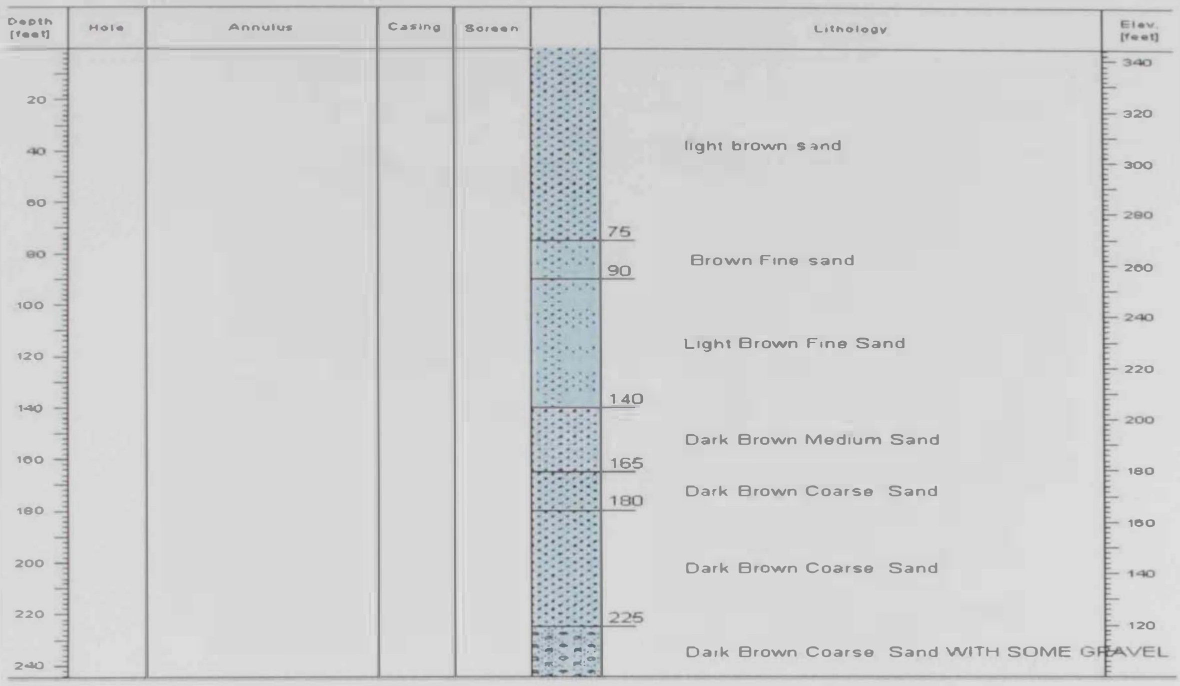

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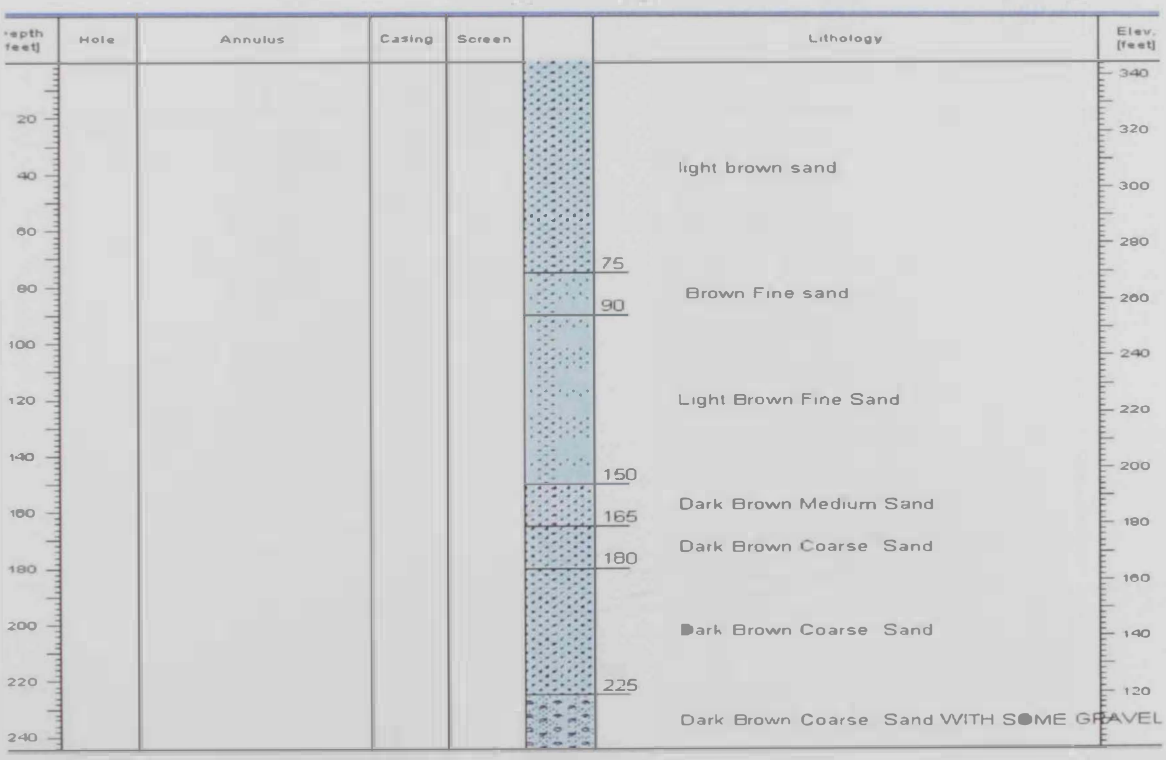

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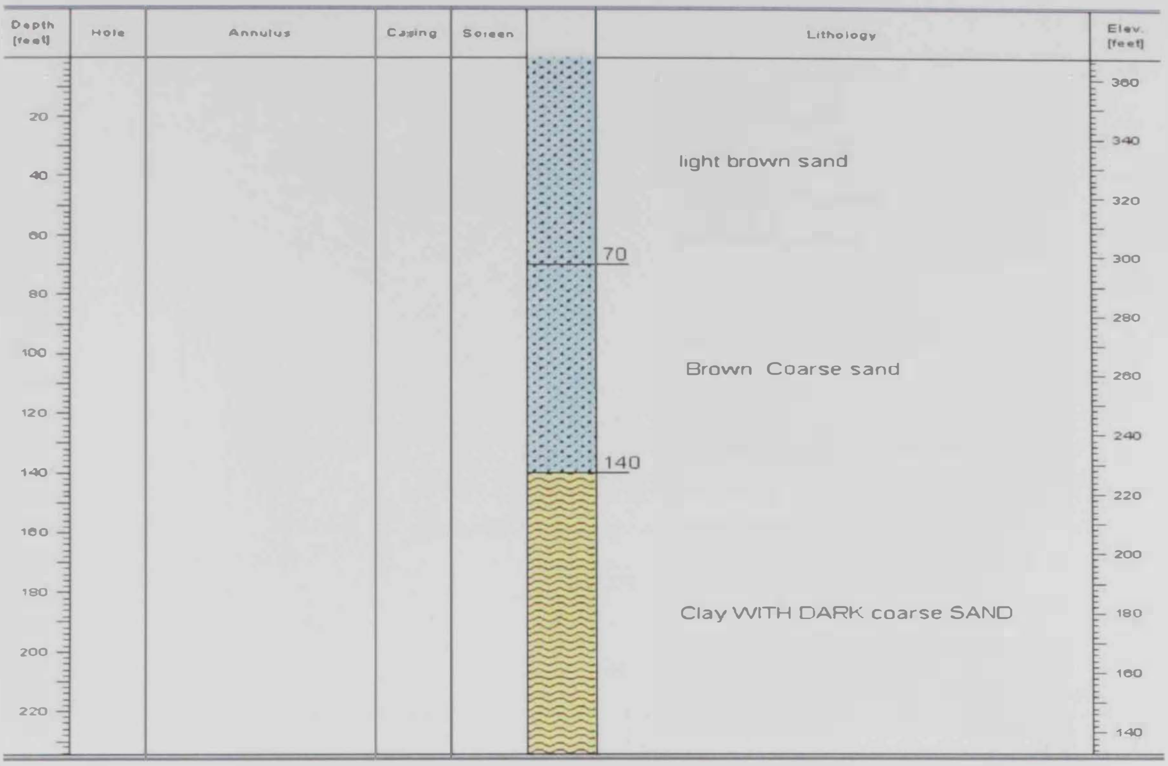

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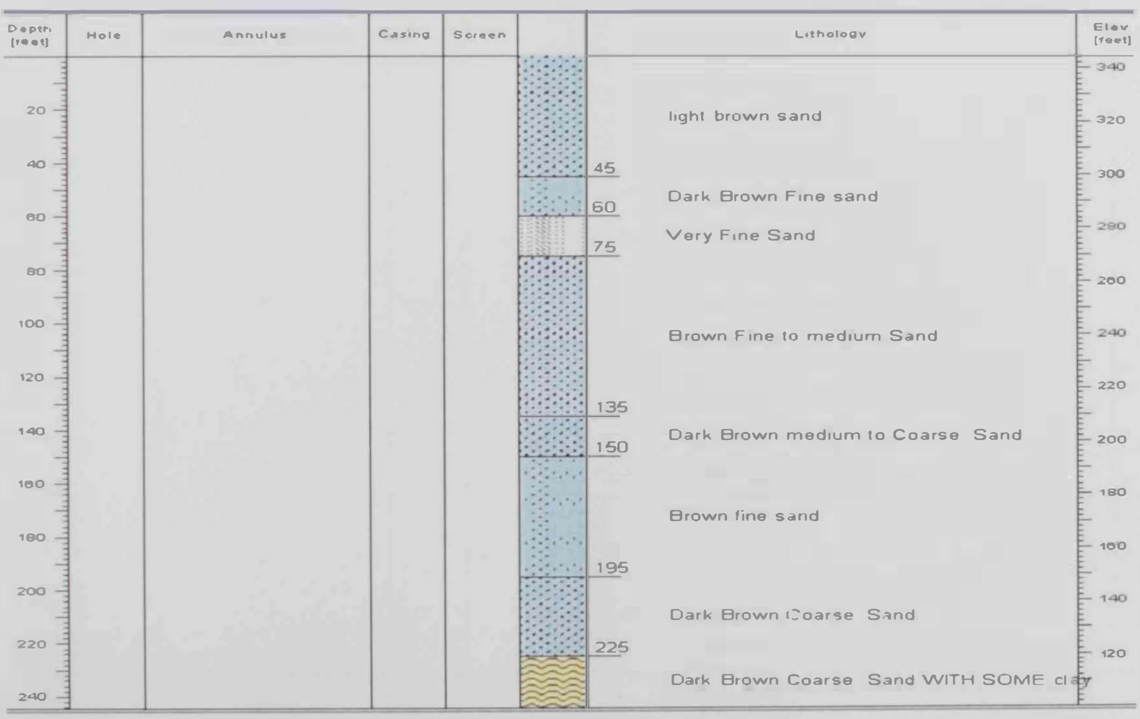

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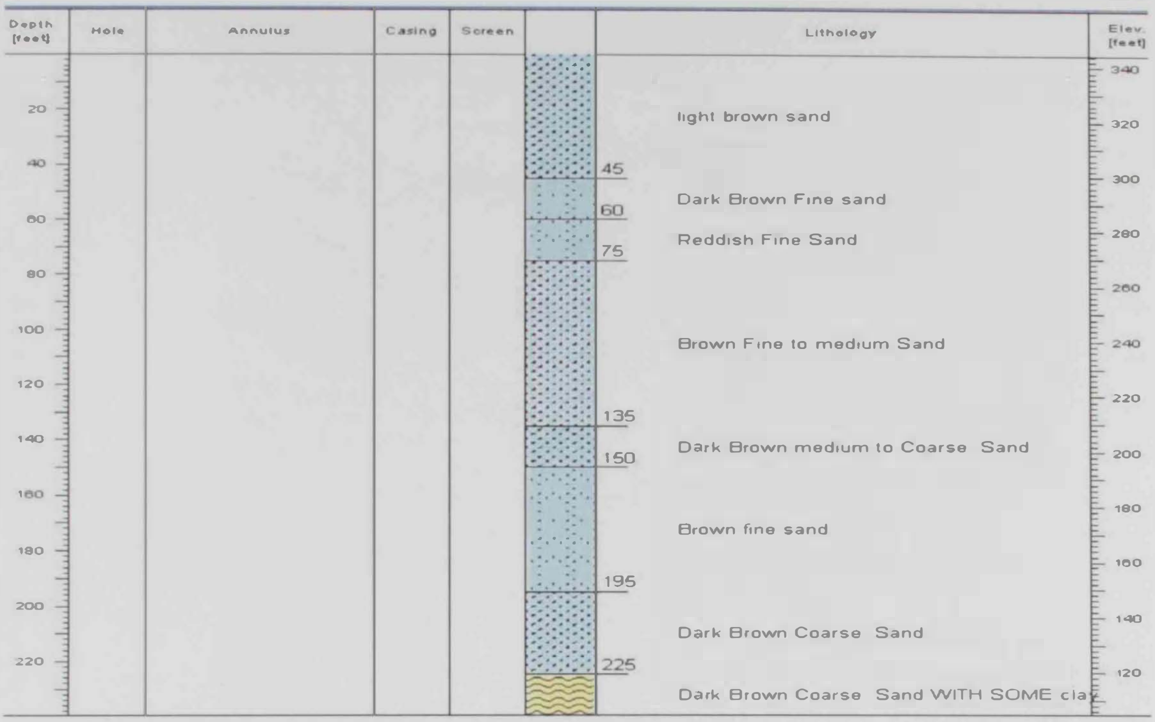

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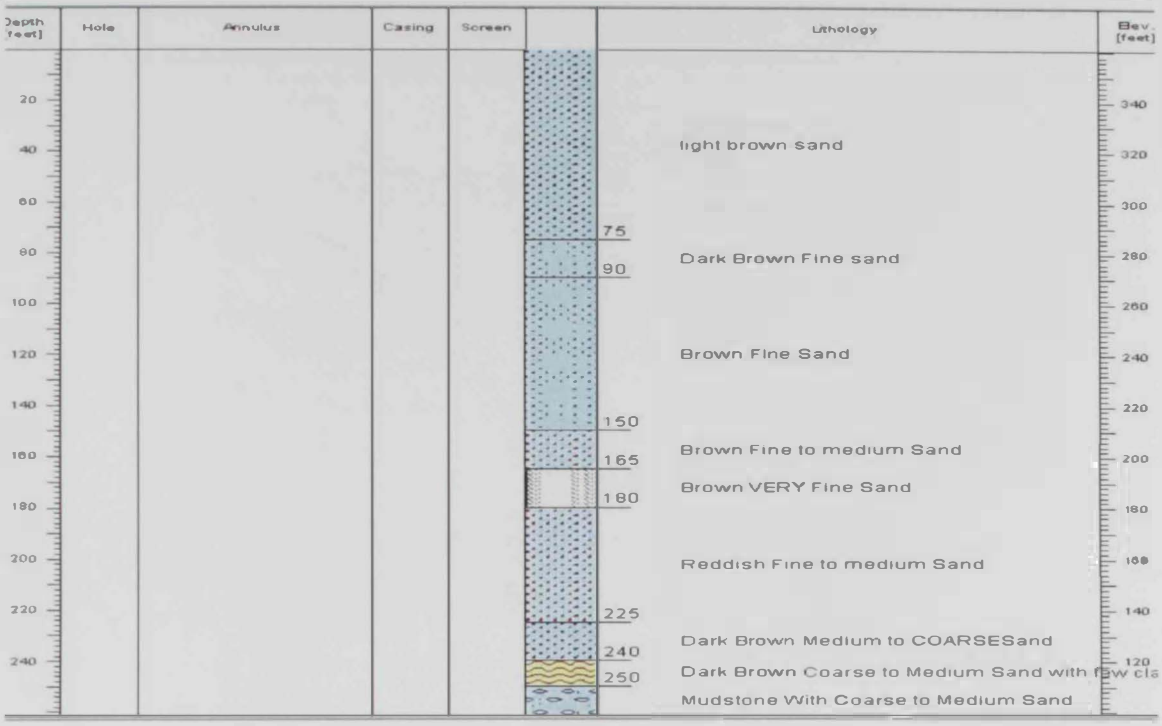

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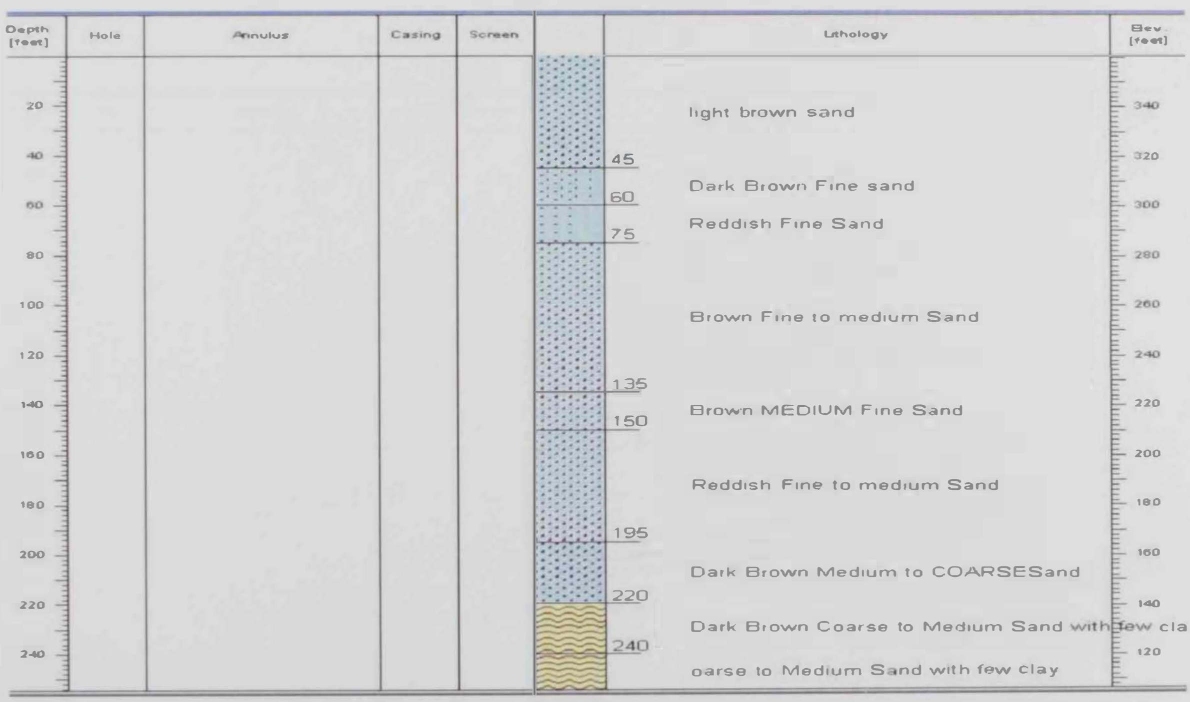

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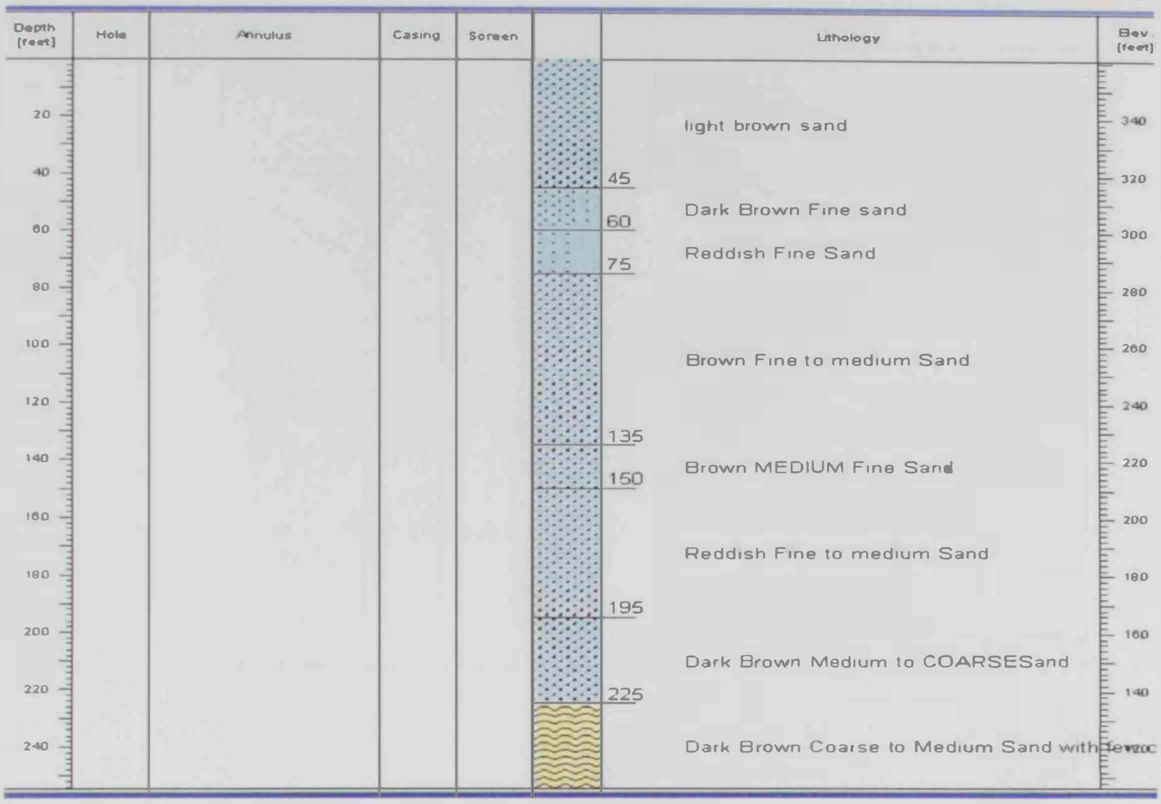

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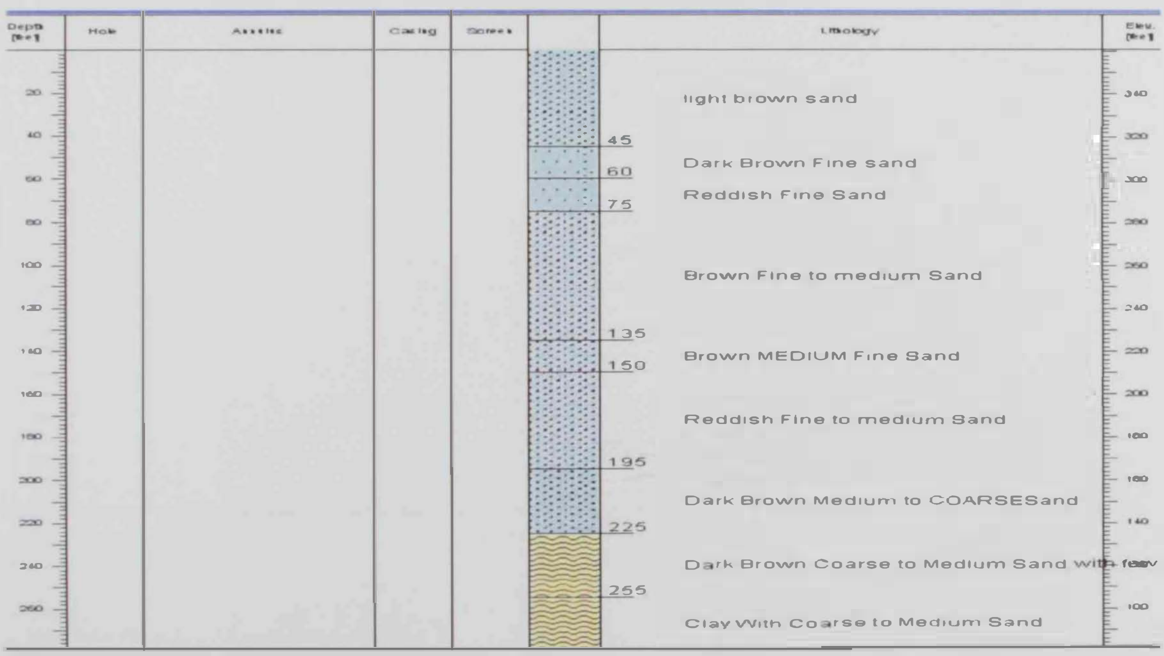

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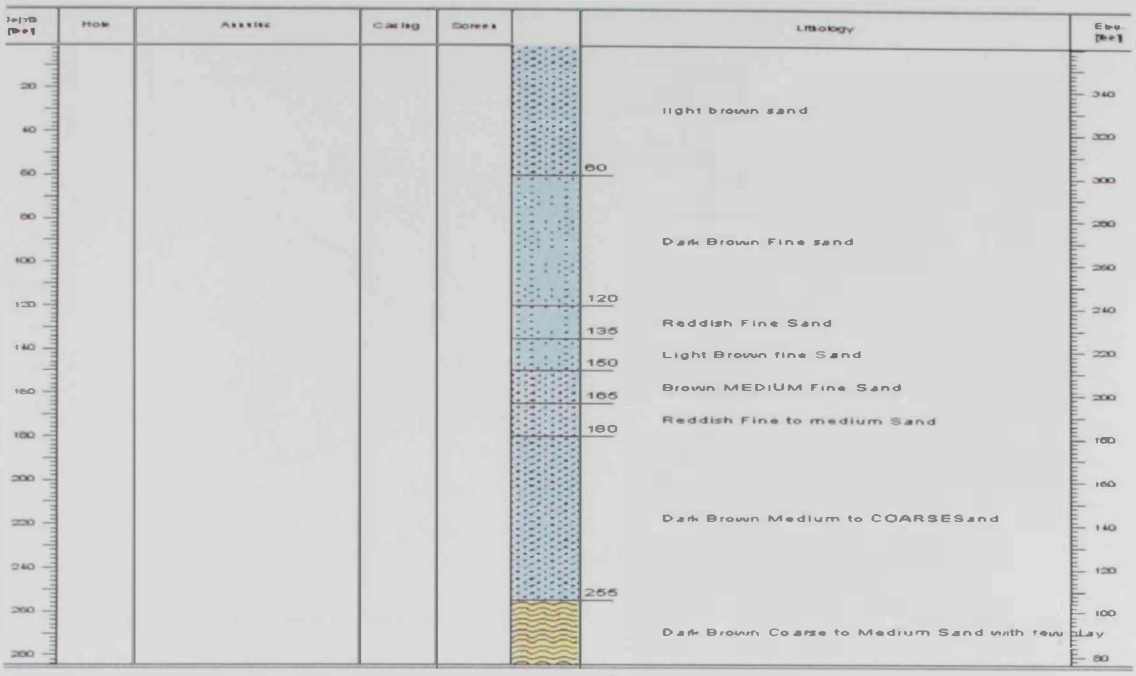

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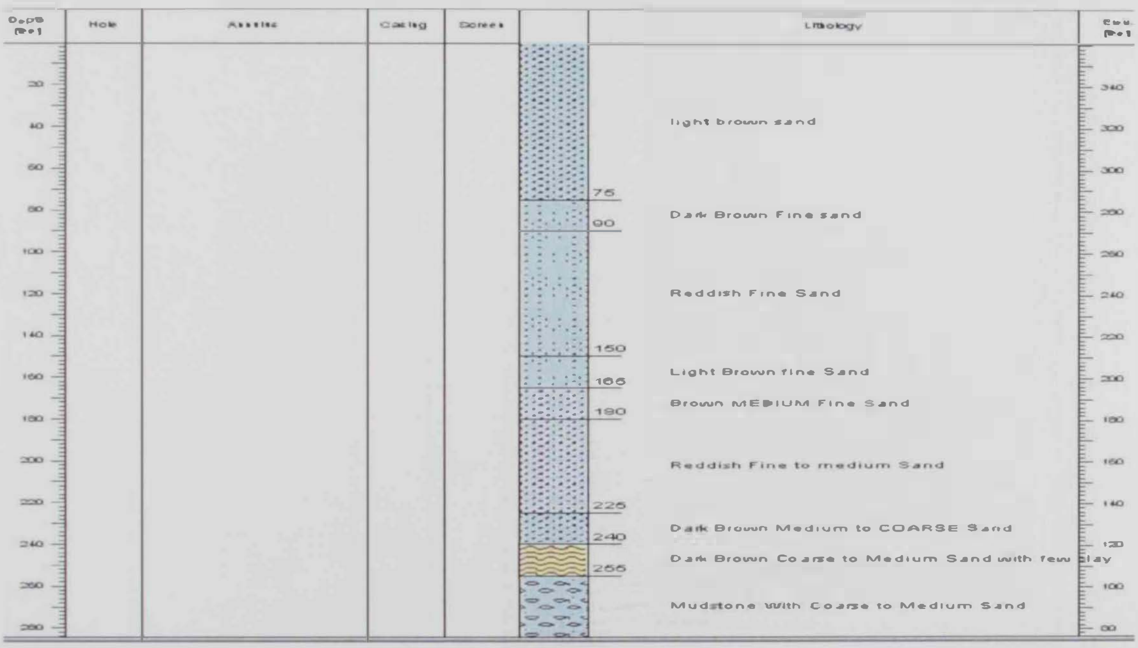

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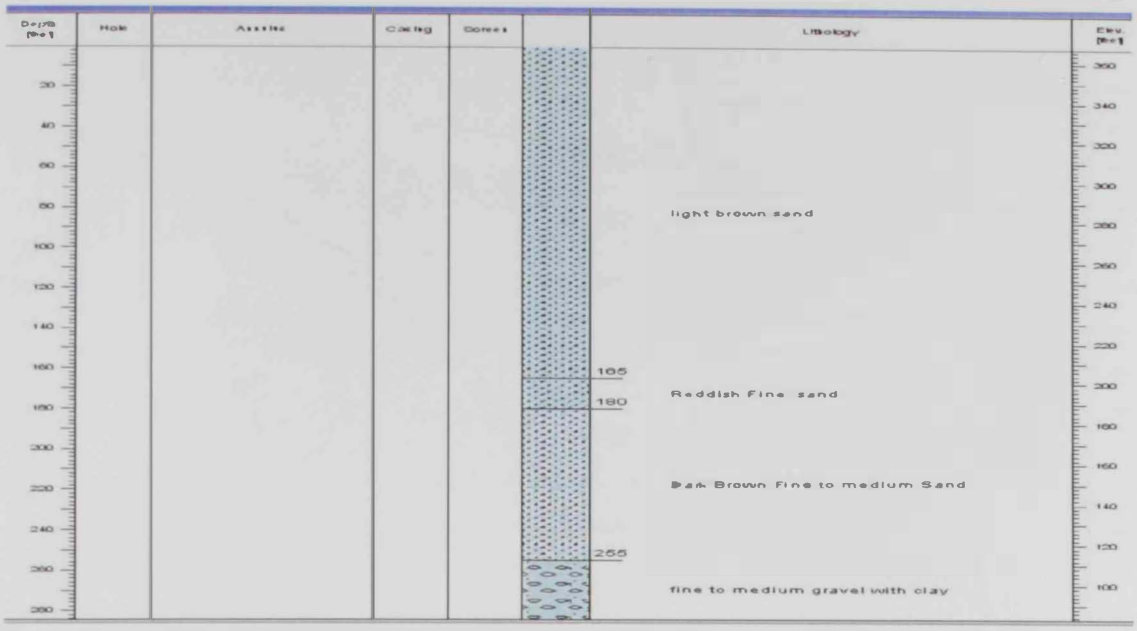

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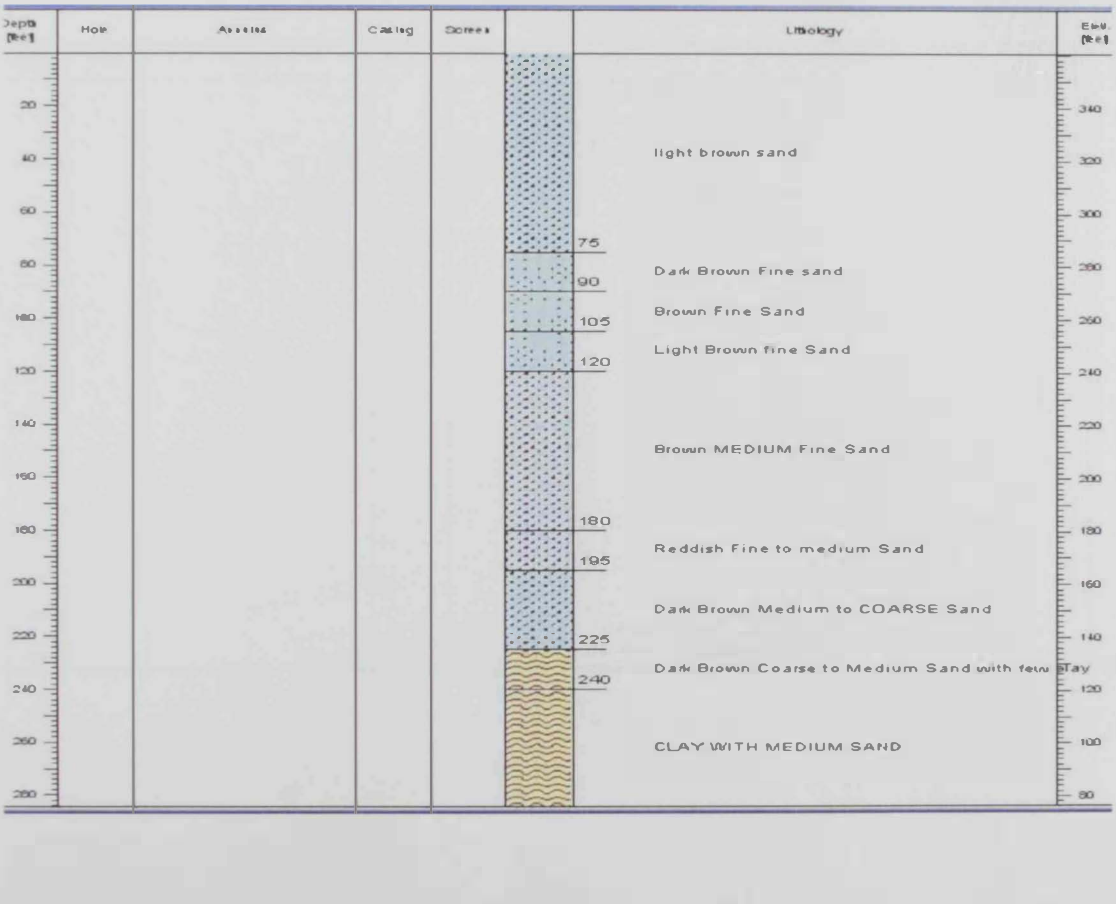

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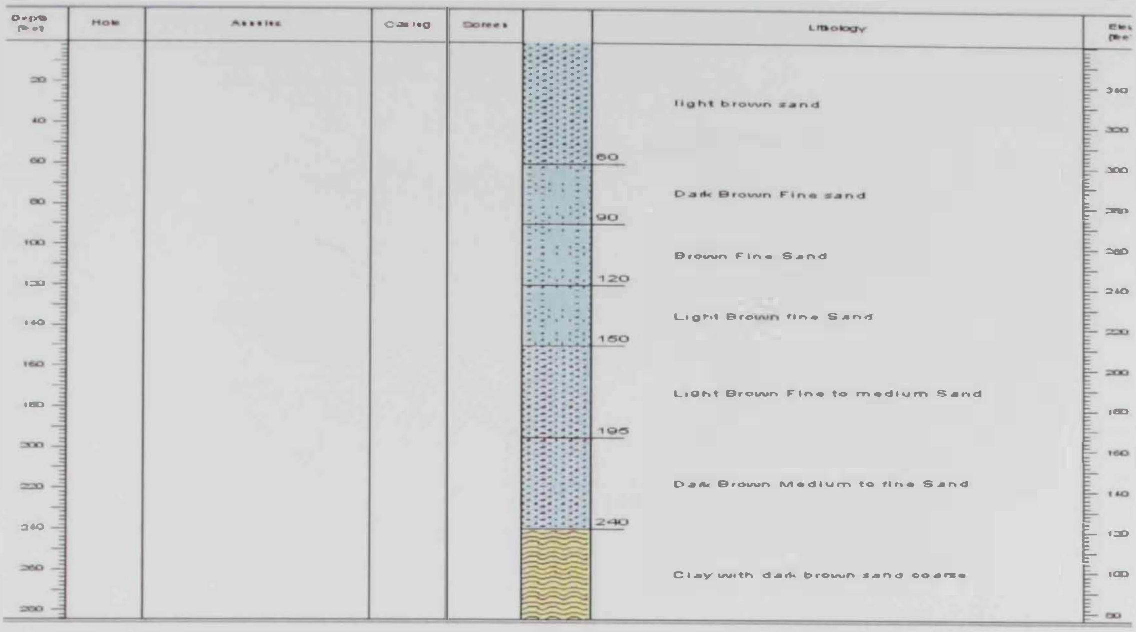

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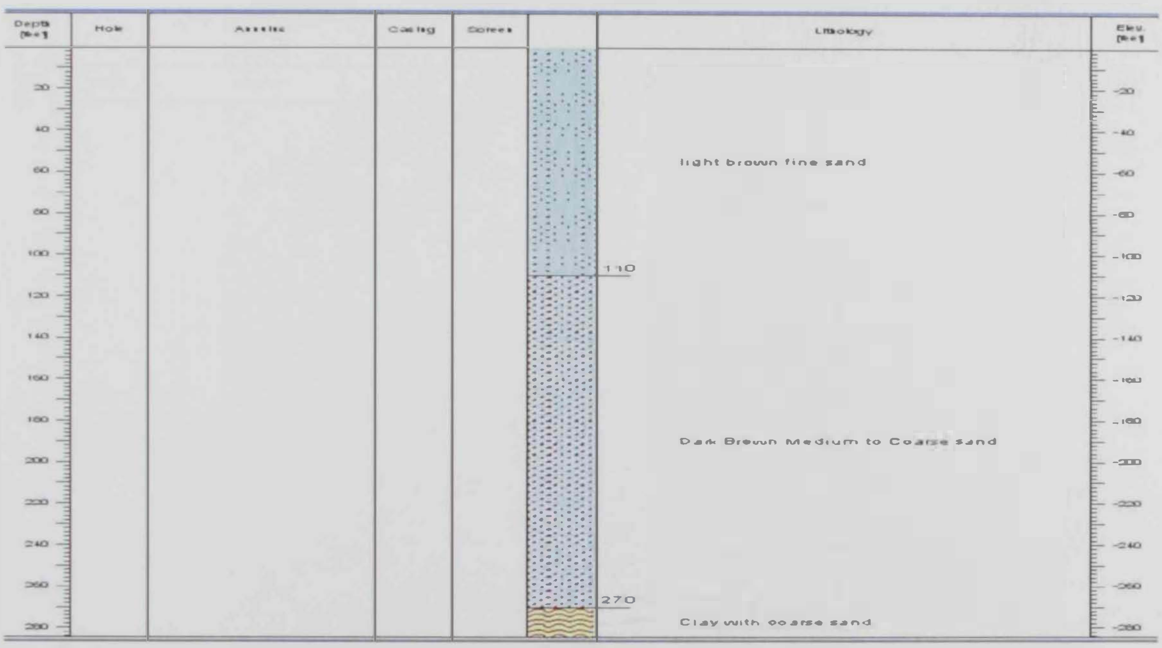

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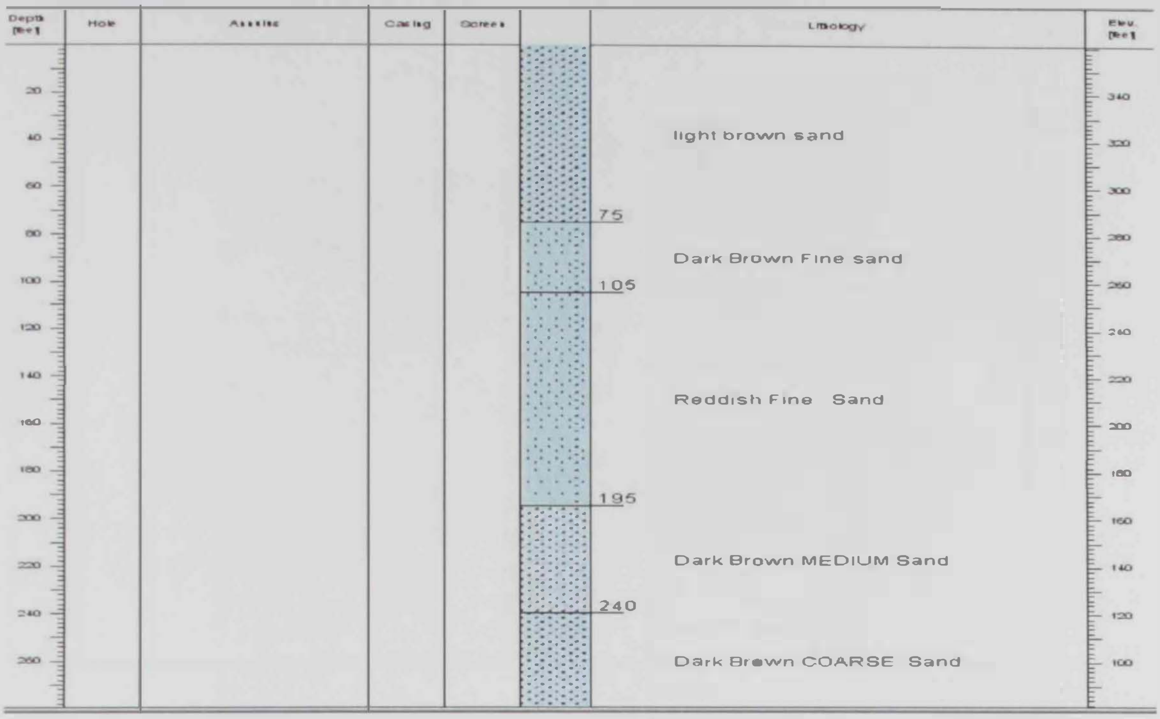

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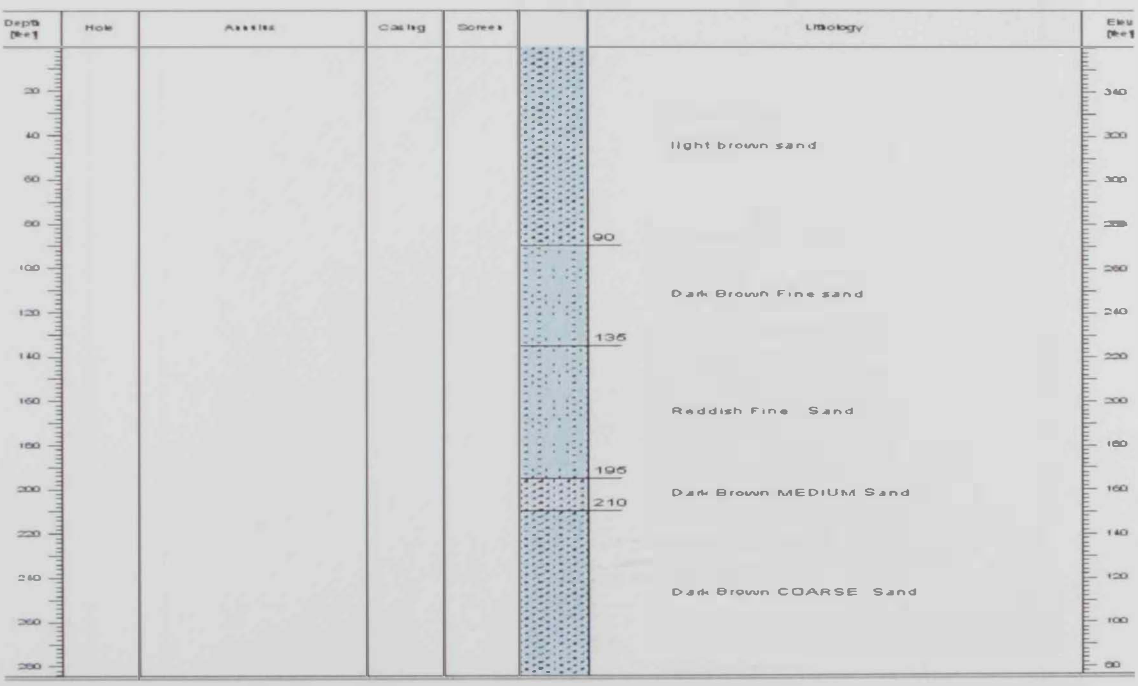

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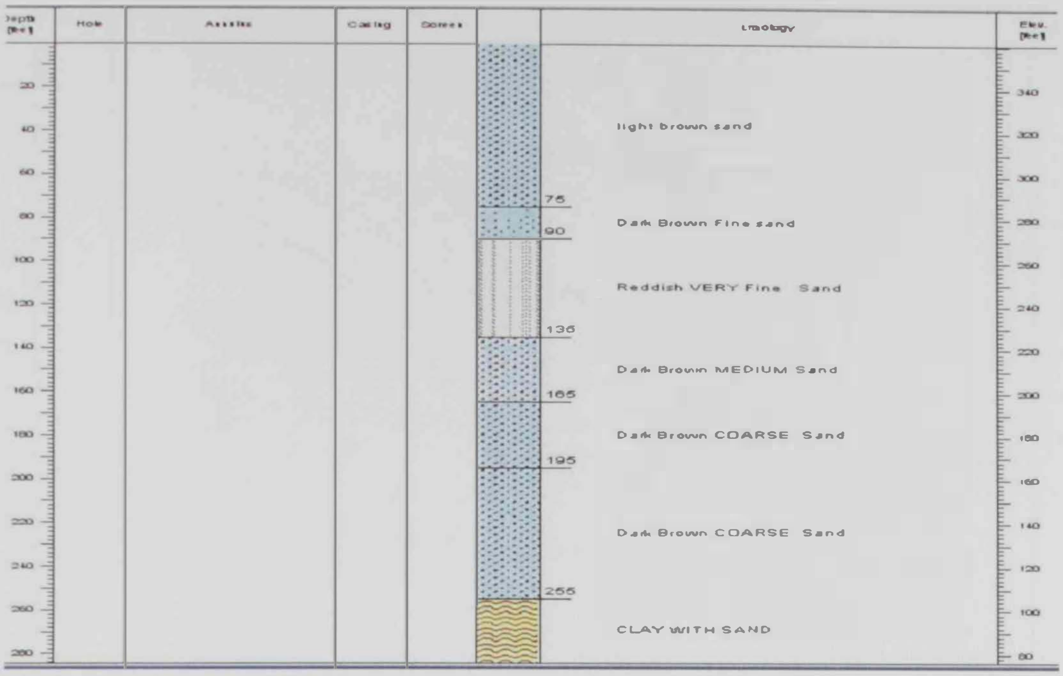

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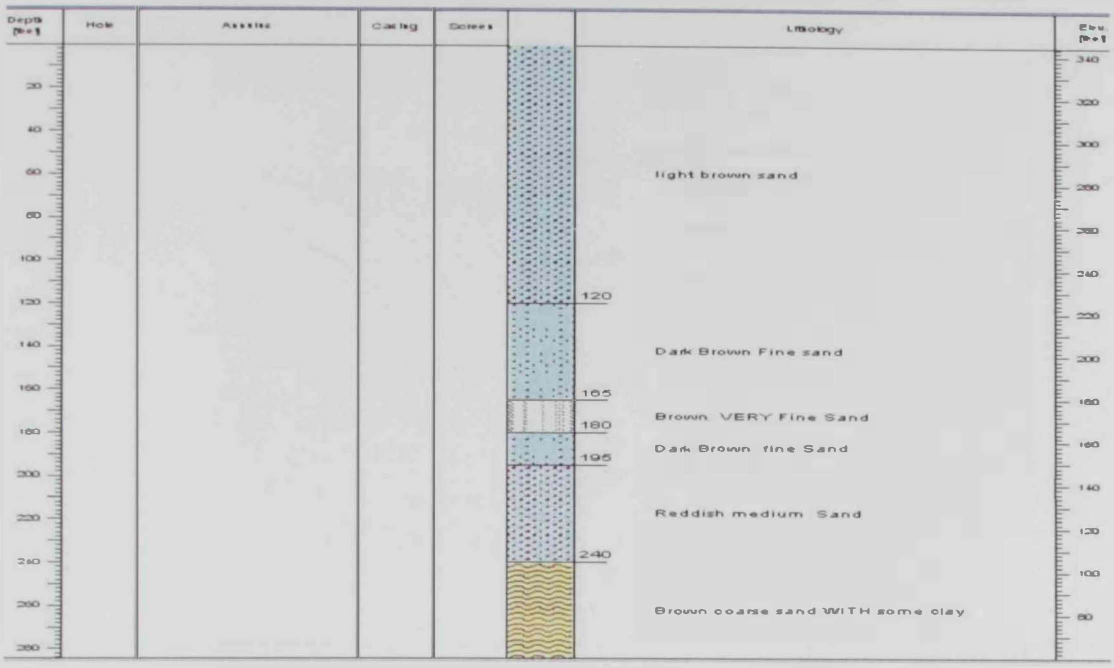

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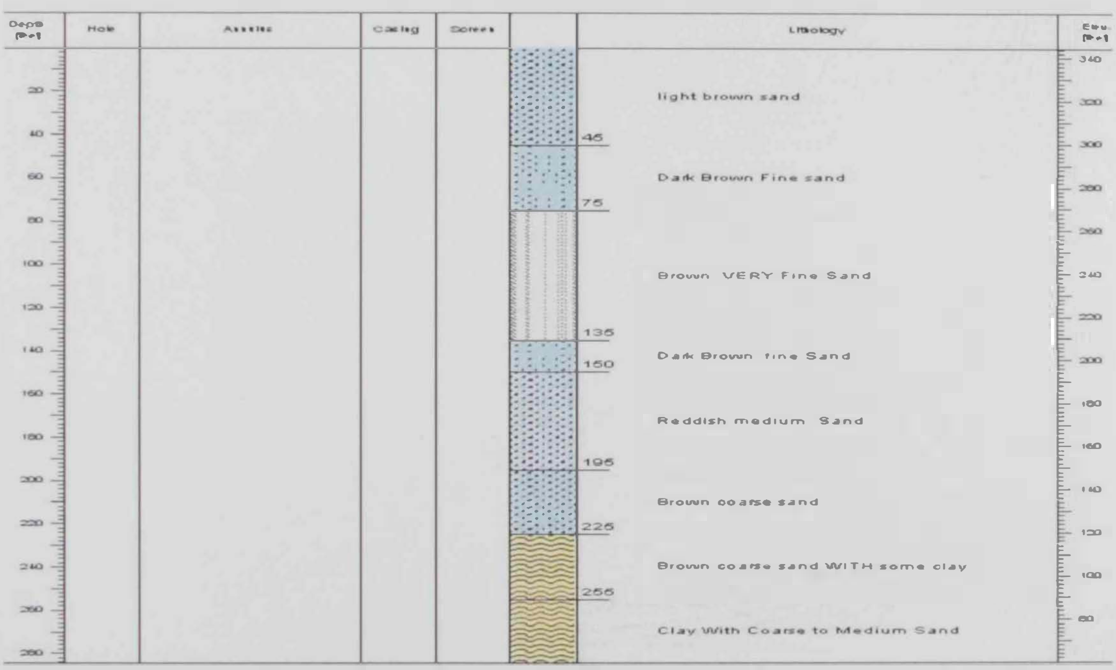

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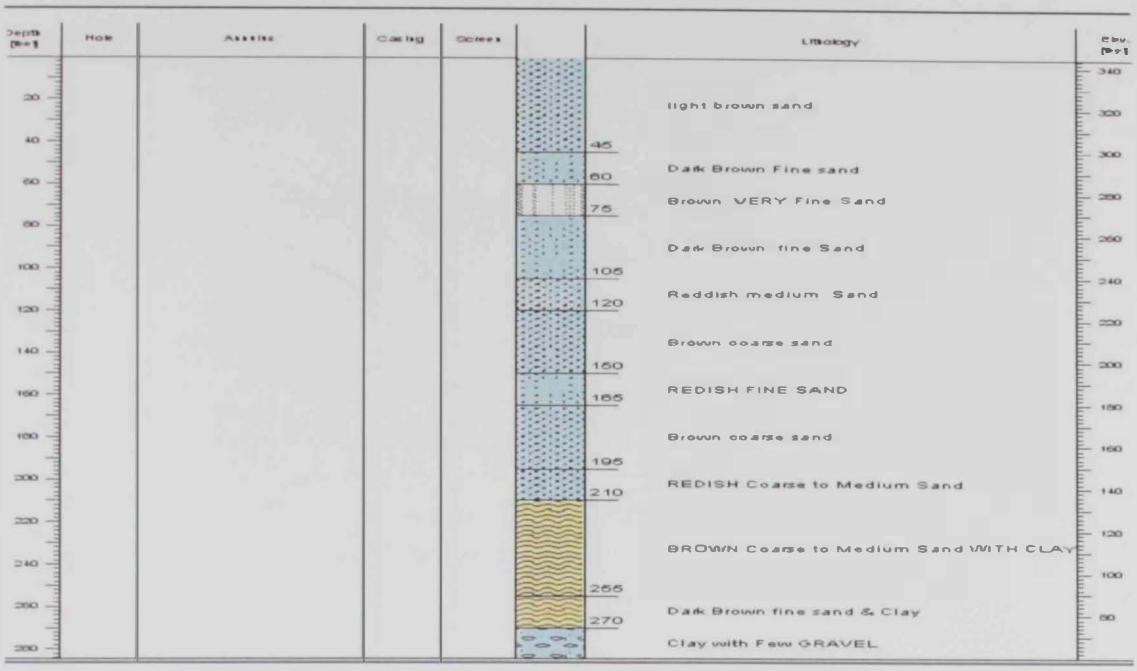

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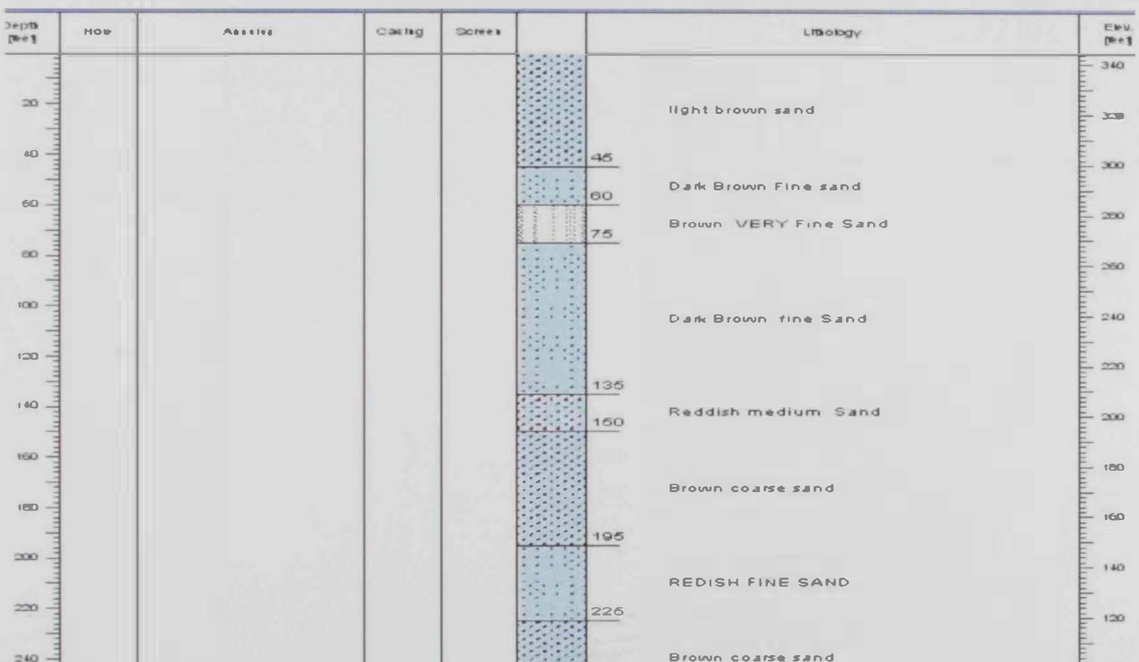

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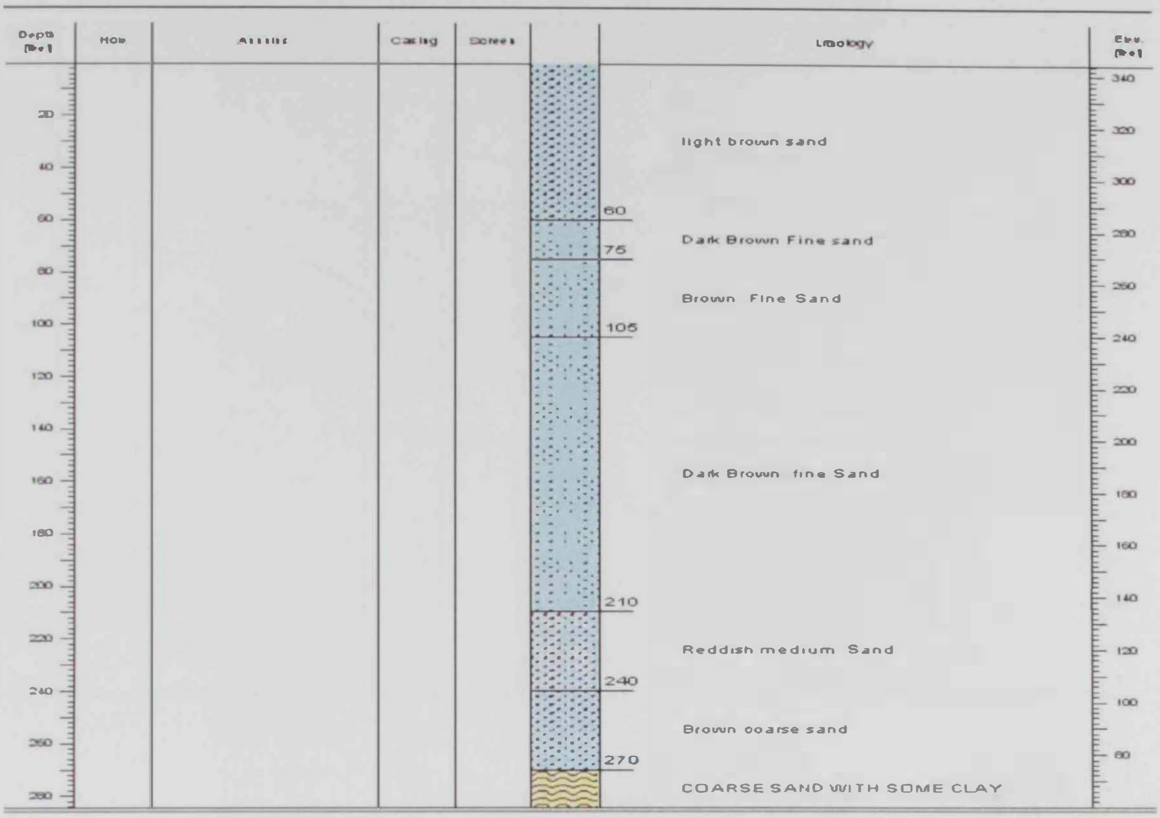

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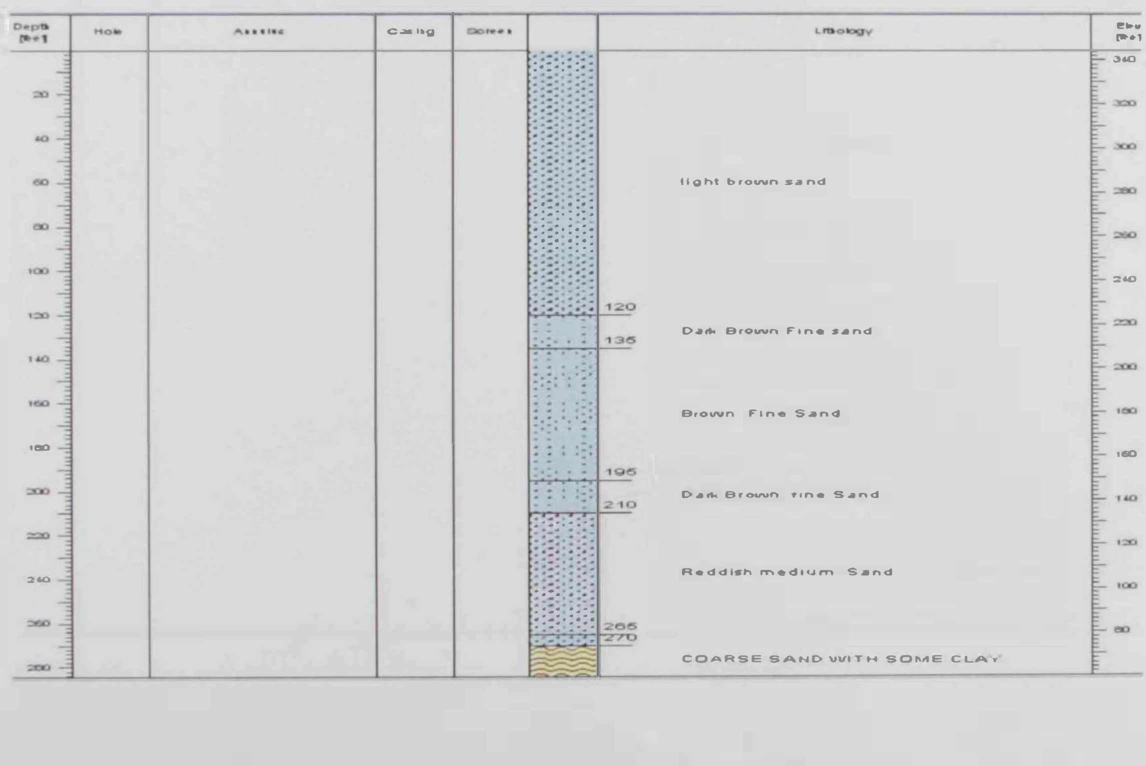

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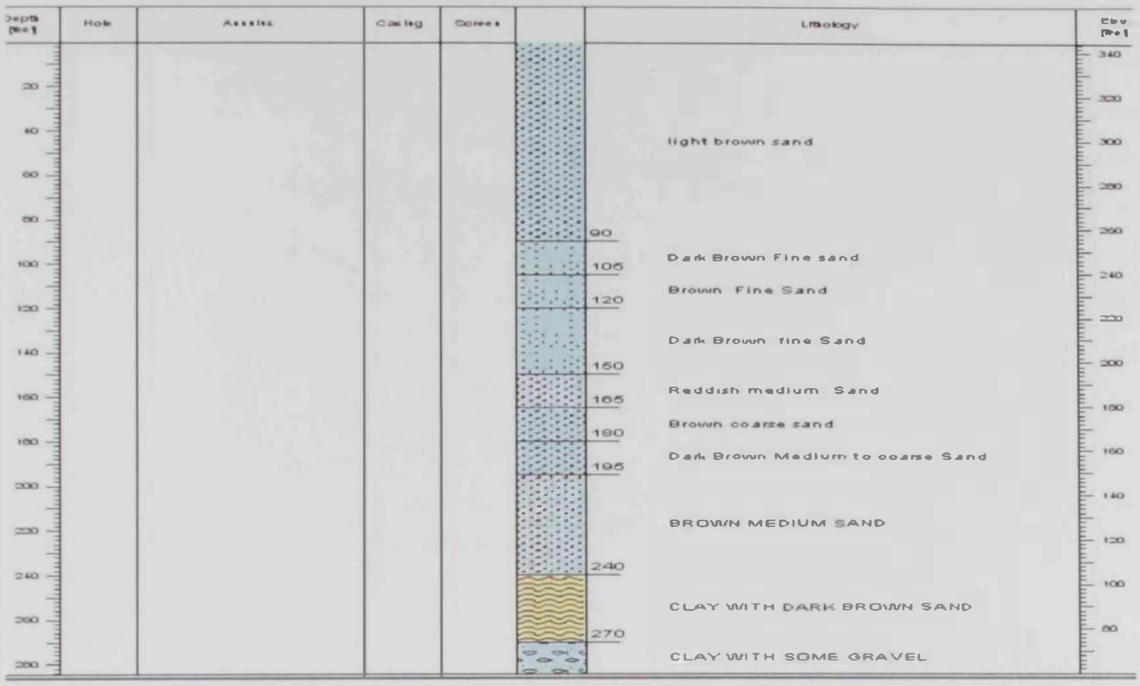

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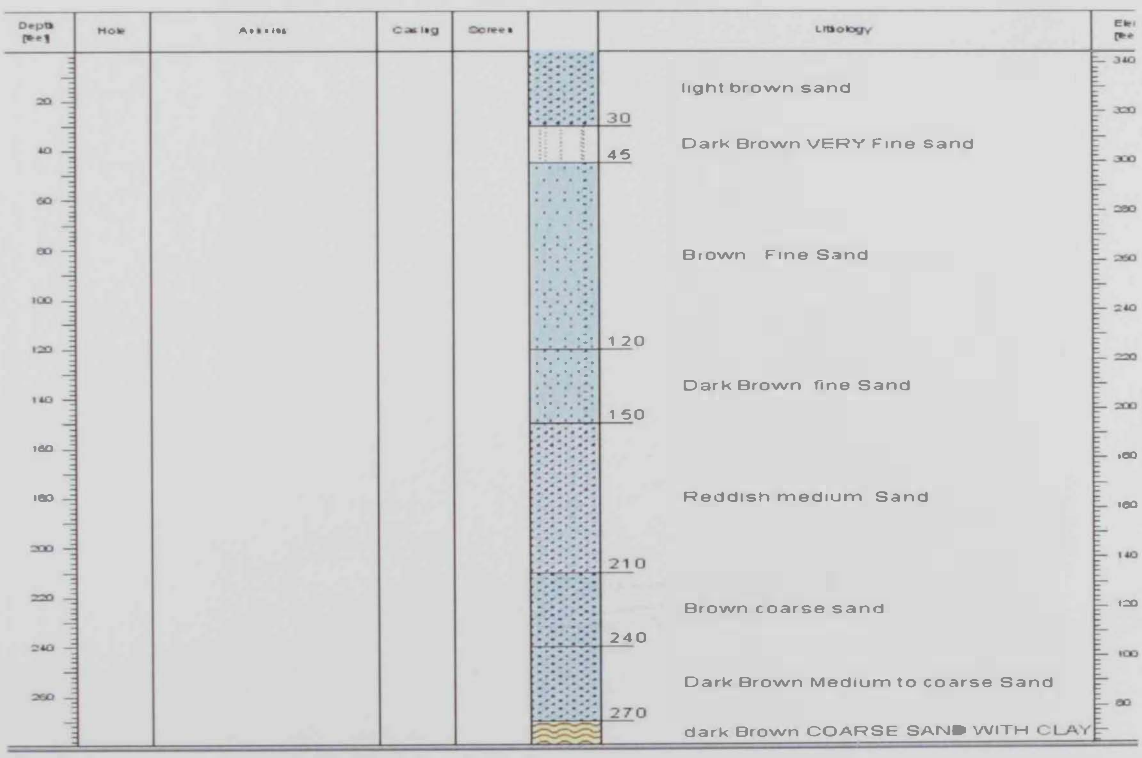

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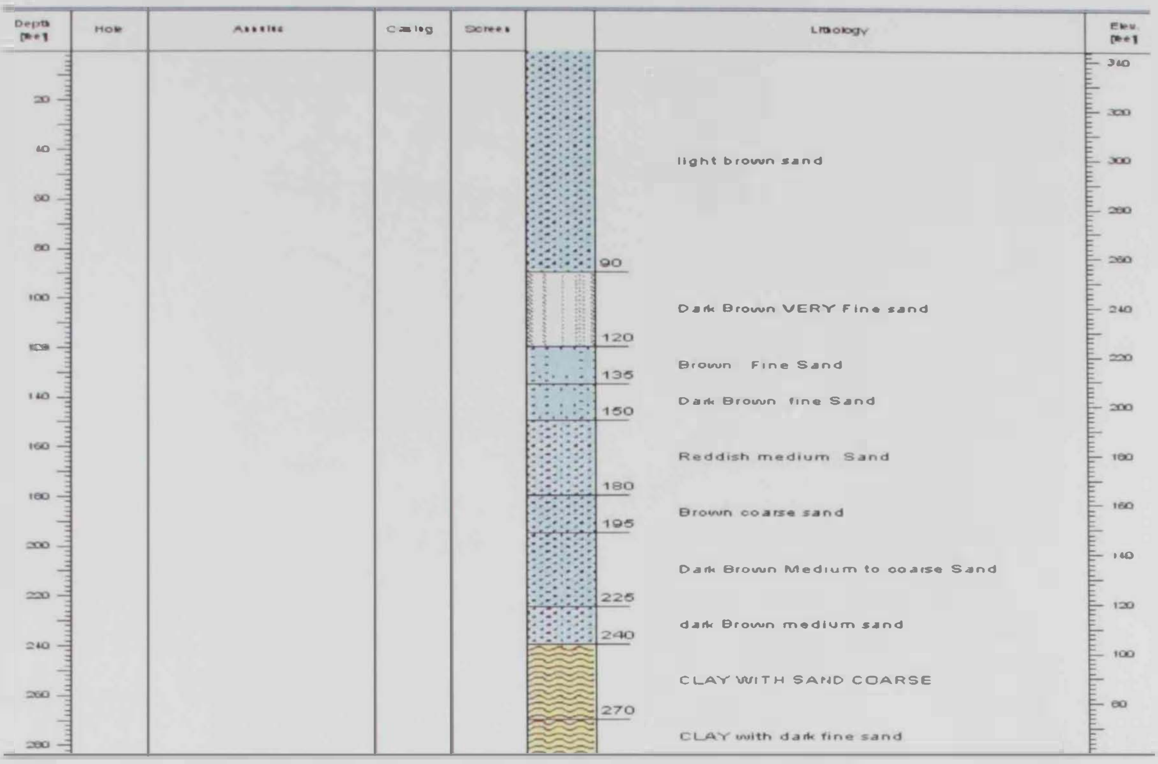

Hole
Screen
Lithology
light brown sand
90
Dark Brown VERY Fine sand
120
Brown Fine Sand
135
Dark Brown fine Sand
150
Reddish medium Sand
180
Brown coarse sand
195
Dark Brown Medium to coarse Sand
225
dark Brown medium sand
240
CLAY WITH SAND COARSE
270
CLAY with dark fine sand

خلاصة

انشاء قاعدة بيانات باستخدام نظم المعلومات الجغرافية لادارة المصادر المائية

بأمارة عجمان- الأمارات العربية المتحدة

نتيجة لسياسة تشجيع الاستثمارات المحلية والخارجية في مجالات الصناعة والتجارة والسياحة وغيرها التي تتبعها الحكومة الاتحادية والحكومات المحلية فقد زاد معدل النمو العمراني في مختلف المجالات حيث ظهرت مناطق تجارية وصناعية جديدة وتوسعات في الاحياء السكنية مما أدى بدورة لزيادة الطلب على الكهرباء والماء في الدولة عموما وفي إمارة عجمان بصورة خاصة. و عليه لتفادى مثل هذه المعضلات مستقبلا تسعى هذه الدراسة لتوفير قاعدة البيانات الاساسية للموارد المائية بالامارة معتمدة على تجميع البيانات الخاصة بعمليات إنتاج المياة و توزيعها حتى يمكن من عمل و إنشاء نظم معلوماتية تستطيع جهات إصدار القرار الرجوع اليها متى شاءت لمعالجة ومواجهة ما يمكن أن يتوقع مستقبلا.

تم خلال هذا البحث إنشاء و تكوين قاعدة بيانات لموارد المياة و هى المياه الجوفية و مياه التحلية بالأضافة إلى عمليات التوزيع.

بيانات المياه الجوفية تتضمن كميات المياه الجوفية المستخرجة، نوعيتها والتغير فى مستوى المخزون الجوفى. أما بيانات التحلية فتشمل كميات المياه المحلاة و نوعيه عمليات التحلية بالأضافة لعدد المحطات و مواقعها.

وعليه تم وضع هذه البيانات ضمن برنامج نظم المعلومات الجغرافية الذى يتميز بدقة عالية لتحميل أكبر كم من البيانات و التى من خلال البرنامج يمكن تحليلها و تصنيفها بعدة طرق للوصول إلى الحلول المثلى لكيفية التعامل مع الموارد المائية بالأمارة و وضع الخطط المستقبلة لتطويرو إدارة الموارد الهامة و إستدامتها و التى تساعد فى دفع عجلة التطور بالأمارة صناعيا و تجاريا و عمرانيا.

أهداف البحث:

يهدف هذا البحث إلى انشاء قاعدة بيانات أساسية للموارد المائية بامارة عجمان و ذلك من خلال وضعها ضمن برنامج نظم المعلومات الجغرافية كما يلى:

1- تجميع كل البيانات المتاحة و الخاصة بالموارد المائية بالأمارة

2- تحديث البيانات المتغيرة مع الزمن مثل كميات المياه المنتجة و نوعيتها بالاضافة الى الامطار و معدلات طلب الاحتياج ، مما قد يتطلب إجراء أعمال حقلية لتحديث هذه البيانات.

3- من خلال برنامج نظم المعلومات الجغرافية (Arc GIS) يمكن دراسة ومراجعة و تحليل و تصنيف البيانات بحيث يسهل التعامل معها.

4- من خلال النتائج المستخلصة من البرنامج يمكن وضع الخطط المستقبلة من خلال عدة سيناريوهات علمية و عملية تساعد على إدارة الموارد المائية بصورة مستديمة لتطور و رقى الأمارة.

و من خلال هذا البحث و النموذج الذى تم الوصول اليه يمكن تطبيقة على بقية الإمارات ليصبح أنموذج يتبع لإدارة و إستدامة الموارد المائية بالدولة.

جامعة الأمارات العربية المتحدة
عمادة الدراسات العليا

عنوان الرسالة:

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اسم الباحث :

محمد ريحان يوسف

المشرف :

أ.د. محسن شريف
أستاذ الموارد المائية
رئيس قسم الهندسة المدنية و البيئية
كلية الهندسة - جامعة الأمارات العربية المتحدة

المشرف المساعد:

د. علاء الدين محمد الحسن إدريس
منسق التخطيط و المتابعة
الإدارة العامة للمياه
هيئة كهرباء و مياه الشارقة

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رسالة ماجستير مقدمة الى

عمادة الدراسات العليا

جامعة الأمارات العربية المتحدة

لإستكمال متطلبات الحصول على درجة الماجستير

في

العلوم في موارد المياه

إعداد

محمد ريحان يوسف

جامعة الأمارات العربية المتحدة
يناير 2009

جامعة الأمارات العربية المتحدة
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