FINAL REPORT

PROJECT : DSR –AR - 68

"Natural Purification by Sediments of Wadi Hanifah Water System, Riyadh – KSA"

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شكر وتقدير

يتقدم الفريق البحثي بالشكر والإمتنان لعماده البحث العلمي بجامعة الملك سعود على دعمهم المشروع البحثي التطبيقي **DSR-AR-68** والتي نأمل أن تفي نتائج هذا المشروع بالغرض المنشود.

ولايفوتنا كذلك أن نتقدم بالشكر والعرفان للأستاذ الطاهر عثمان إدريس مستشار المشروع وطالب الدراسات العليا بقسم الجيولوجيا عبد العزيز العسبلي على ما بذلاه من جهود مميزه في تحليل المعلومات الجيوفيزيائية. الشكر موصول للدكتور أمين برزنجي (الباحث الرئيس للمشروع سابقاً) على مساهمته في إنجاز المرحلة الأولى من المشروع.

وفي الختام نشكر الهيئة العليا لتطوير مدينة الرياض وشركة المشرق وشركة بيركفيلد فلتر السعودية على تزويد المشروع بالمعلومات المائية وكذلك كل من ساهم بأي مجهود ولم يرد ذكر إسمه .

LIST OF TABLE

LIST OF FIGURES

الملخص

يناقش التقرير النهائي الخصائص الكيميائية والبكتيرية للمياه الجارية والمياه الجوفية والرسوبيات داخل وخارج مجرى وادي حنيفة. تم استخدام تقنيات جيوفيزيائية متكاملة وهي الانكسار السيزمي وصور المقاومية والسبر الكهربي العمودي (VES). توجد مناطق تجمع المياه في خزانين جوفيين، الأول مياه سطحية ملوثة على عمق ١٠ أمتر في الرسوبيات الطميية والثاني خزان مياه عذبة على عمق ١٠٠ متر في صخور الحجر الجيري المتشققة. الحد الفاصل بين المياه الملوثة والمياه العذبة تم تحديده أفقياً على مسافة ١٠٠ متر من القناة الرئيسية وعمودياً على عمق ٢٠ متر.

تشير النتائج الكيميائية أن مجرى الوادي يحتوي على تركيز نسبي قليل من عناصر الأثر (التتبع) ولكن بها كميه كبيرة غير مقبولة من التلوث البكتيري وهذا يرجع إلى حقيقة أن التدفقات المغذية للمجرى أساسا ناتجة عن النشاط السكاني.نظراً لأن تركيز الفوسفات وعناصر التتبع في مياه المجرى والرسوبيات مرتبط بصورة كبيرة بتركيزه في الرسوبيات، فقد تم تعريف الرسوبيات كأحواض لتلك العناصر. تعتبر محطات معالجة مياه الصرف هي المصدر الأعظم للفوسفات وأيضاً لإنخفاض تركيز الفوسفات في مياه المجرى كلما ابتعدنا عن محطات المعالجة. ويرجع هذا التحسن في جودة المياه إلى الدرجة العالية للتنقية الذاتية الناتجة عن مجموعة من البرك وعمليات التنقية الطبيعية. بالرغم من ارتفاع نسبة الTDS في عينات المياه الجوفية وان جودة العينات كانت عموما جيدة، وجدت معادن ثقيلة بنسب صغيرة جداً وكانت أيضاً العينات خالية من الفوسفات. على أية حال، المياه الجوفية في وادي حنيفة لها مشاكل بسبب الكميات الكبيرة من مياه الصرف التي تنفذ إلى الأرض. معظم المنازل في مدينة الرياض مازالت تستخدم خزانات تسبب التعفن والتي تسمح لمياه الصرف بتسريبها مباشرة إلى المياه الجوفية.عموماً، فإن مياه وادي حنيفة في الوقت الحالي لا تناسب أي استخدام تجاري أو تطويري. وإذا أردنا أن نستخدم وادي حنيفة كمصدر للمياه والري، فانه يجب إدخال تحسينات معينة كاستخدام الإشعاع الشمسي لتنقية المياه واستخدام الأراضي الرطبة التي تدار خصيصاً لتعمل كمرشحات طبيعية لتنقية المياه.

ABSTRACT

This report investigates the chemical and bacterial characteristics of stream water, groundwater and the sediments both within and outside of Wadi Hanifah course.

An integrated geophysical techniques, seismic refraction, resistivity image, and VES were carried out. Water bearing-zones occur in two aquifers, shallow contaminated water at 10 m depth in alluvial deposits and the deep of fresh water aquifer at depth of about 100 m in fractured limestone. The interface between the contaminated water (sanitary water) and fresh water marked out horizontally at 100 m distance from the main channel and vertically at 20 m depth.

Chemical results indicate that the wadi stream contains relatively low concentrations of the trace elements, but has unacceptable high bacteriological pollution, due to the fact that effluents feeding the stream are mainly residential. Sediments were identified as a sinks for phosphate and trace elements as their concentrations in stream water and sediments were significantly correlated.

A sewage treatment plant provides the dominant point source input for phosphate and also a reduction in phosphate concentrations along the wadi stream, away from the plant. This improvement in water quality is due to the high degree of self-purification resulting from a combination of ponds and natural purification processes.

Although groundwater samples were high in TDS, and the quality of samples was found to be generally good. Heavy metals were present in very low percentages and the samples were also free of phosphates. However, groundwater in Wadi Hanifah has problems caused by the high volumes of sewage water percolating into the ground. Most dwellings in Riyadh city are still using septic tanks, which allow sewage water to be recharged directly into the groundwater.

Generally speaking, at the present the water in Wadi Hanifah is unsuitable for any commercial or developmental use. If the Wadi Hanifah is to be used as a source of water supply and irrigation, then specific improvements will have to be made, such the utilization of solar radiation for water purification and the creation of wetlands specially managed to act as natural filters for water purification.

INTRODUCTION

In compliance with terms and conditions of this project, preparation along the lines allowing for the accomplishment of the goals of this project identified as : "to study the geological and hydrogeological conditions pertinent to changes to Water quality and to examine their nature and causative sources in order to formulate regimes for abstraction from wells at distances and places which produces ultimate qualities**".**

In this endeavor data and literature survey was carried out, as well as assessment of available chemical and hydrogeological studies, the selection of an area for the purpose of this study, equipment acquisition and setting, site visits and finally trial survey. Results from previous chemical analysis show the stream to contain relatively low concentration of trace elements, but has unacceptable high bacteriological and other chemical pollutants as consequence to a direct discharge of effluent discharge and de-watering plants from the city. This man-made river (Fig. 1.1) has developed a unique environmental challenge.

The final objective as perused in this study is to observe the gradual changes in water quality both chemically, and if possible bacteriologically, downstream which accompanies more noticeable changes in wells at varying distances from the course of the river.

1-1 Objectives:

The main aim of the present study is to examine the changing levels of stream and groundwater contamination, at a selected sites, this include:

- To determine the chemical characteristics of the stream water, the sediments both within and outside of Wadi Hanifah course, and the groundwater quality.
- To investigate how natural processes modify the gross chemical composites of the stream water with distance along the course and the sides of Wadi Hanifah.
- To carry out geophysical imaging in order to draw, where possible the relationship between variations in water chemistry and conductivity as an indicator of quality changes.
- To examine practical measures for the efficient management of the stream as a whole.

Wadi Hanifah

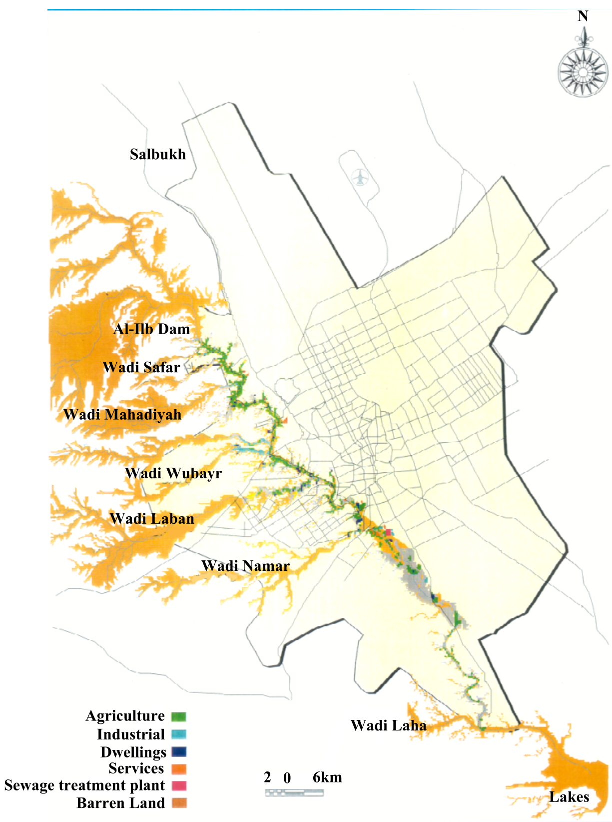


Fig.1.1 Man-made river of Wadi Hanifah.

1-2 Statement of the Problem

Scientific evidence is not widely available in Saudi Arabia to promote a greater understanding of the side effects of water pollution. These observations have prompted the present work to examine the levels of Wadi Hanifah stream and groundwater contamination in one of the most populated areas, Riyadh City. The chemical compositions of contaminants in the surface and groundwater is to be examined, imaged and assessed to determine level of natural purification of water and contributing parameters, their extend and role in the process of purification.

It is hoped that scientific data obtained from this investigation will act as a model to enable the public (in particular the farming community living in the area) best utilization approach of the stream and to formulate effective guidelines for managing wastewater and controlling groundwater contamination in this site and in similar environment throughout Saudi Arabia.

1-3 Literature Review

Wadi Hanifah had attracted a large number of research work and interest. Most of these studies were directed towards assessing this man-made river in order to utilize it for consumption and agricultural use (ADA, 1990; Al-Fayzi, and Al-Fateh, 1996; Al-Jaloud, 1994; Jaloud, et al 1993). Other studies were more direct in determining re-use of the treated sewage of Riyadh city (Al-Dhowalia, 1986) or its specific use in irrigation (Ali, 1987). The threshold levels of trace elements for crop production has been studied extensively (Pettygrove and Asano,1988). Locally similar work was also carried out (Jaloud, et al.1995) as well as an examination of the degree of pollution of different elements in drinking water and groundwater (Al-abdula'aly, 1997; 1998).

Interest in Wadi Hanifah stream emerges largely due the fact that over 400,000 m^3 of wastewater is discharged daily, increasing cost of desalinization and the growing need for water in this fast expanding city (RSA 1998; Al-Ibrahim, 1991; Hussain, and Saati, 1999). Although the issue of using re-cycled water has cultural and religious stigma, this matter has been addressed in a religious decree (Fatwa) in which it was proclaimed as a rational and an acceptable measure for water conservation and that " Wastewater is considered clean enough for human use(not necessarily as drinking water) and meeting the relevant health standards, could be used for all rituals of Islam concerning cleanliness"(Fatwa, 1979). A part from the waste of this very precious commodity, further degradation is inflicted through contamination of both soil and to the near surface and deep groundwater(Ellis et al. 1989; Lloyd 1991). Water crisis world wide is further compounded by climatic changes and the World Health Organization (WHO, 2001) has highlighted the implications of these changes and its consequences specifically to arid regions .

Recent study by Al-Othman (2002) has shown changes in chemical composition in 22 wells with varying changes in TDS, hardness, Alkaline, Chloride, calcium and magnesium attributed to interactions between the infiltrated water and the stream sediments and the embankment sediments. Changes in the Wadi stream vary for certain constituents from levels acceptable under international standards (Chapmen and Kimistach, 1996) to levels of high measurable risk and health hazards. The concentration of trace elements was found to be also linked with the position of the wells and in general they were very low at distant wells. Phosphate is linked to waste water and to some degree to intensive farming. The variation in phosphate also relates to the position of the wells or the location of the sampling stations on the stream and their proximity to discharging sources of treatment plats. A sample taken at the outlet of sewage treatment shows a level ten times greater than samples taken at a short distance upstream. This proves that the major source of reactive phosphate is attributed to the sewage and domestic activities (Al-Othman 2002). Such high levels are related to the norm of sub-standard treatment in these plants while lower levels are attributed to improved "tertiary" treatment (RSA 1999 , cited in Al-Othman 2002). On a self purification assessment, changes of reactive phosphate were noticed with distance downstream. This was incorporated into a regression formula: -Y= - 0.1814x + 11.992 with R^2= 0.87 (where Y is phosphate concentration and x is distance away downstream). Analysis of sediments from the Wadi Hanifah stream indicated a strong correlation of level of adsorption and changes in the water chemical composition.

II. GEOLOGIC SETTING

2-1 Geology of Riyadh

The following account of the geology of Riyadh city has been taken mainly from a comprehensive study carried out by the Arriyadh (Al-Riyadh) Development Authority (1990) to which the reader is referred for further details. This study shows the extent, thickness, ages and characters of the various geological units underlying Riyadh City.

The geology of Riyadh City is shown in Figure 2.1. A typical cross-section, summarizing the structural and lithological aspects of the region is illustrated in Figure 2.2. The hydrogeological units and stratigraphy units are shown in Table 2.1.

Surface deposits: For present study, the surface deposits are the most relevant, covering as they do about 30 percent of the city, concentrated in the Centre and the East. They include deposits which can be attributed to a fluvial or aeolian origin, including clay, silt, sand and gravel deposits, but not from residual soils which cover a substantial area of the city. Thick surface deposits also appear within Wadi Hanifah and its tributaries west of the city centre. The sediments contain fluvial and lacustrine deposits overlain by variable amounts of windblown sand. The wind action has a considerable effect on the susceptible and undeveloped areas. Alluvial deposits are well displayed in the numerous Wadi channels to the west of Wadi Hanifah that dissect the Jubaila Formation. However, there are two major distinct alluvial deposits in the city, the Central Alluvium and the Eastern Alluvium;

a) Central Alluvium.- The city centre area is developed on a site with a variable thickness of gravel clay, clayey gravel and silty sand. Two different alluvial types can be identified:

The Wadi Batha system: This is the most important type of alluvium which occurs within the centre of Riyadh City and consists of clays and inter bedded silts and gravel. A dynamic deposition regime, typical of flash flood conditions, is indicated by sharp breaks between sediment soil types. Along the city centre, underlying the alluvial deposits, is a gravel horizon of variable thickness and overlying highly weathered bedrock.

- The second alluvial type is a more recent deposit comprising of silty sands generally with a small gravel fraction. In general, alluvial deposits cover a large part of the city centre area. It appears that this is a conflux of numerous Wadi channels entering from the west and north. The lithology changes both laterally and vertically in the Wadi channels, thus indicating that the channel courses were often subject to change over time.

b) Eastern Alluvium: This is apparent in the east of Riyadh city and is considered to be the largest of the alluvial deposits. The sediments were deposited during the late Tertiary and Quaternary "wet" periods when watercourses flowed across the broad valley at the base of the Hith escarpment. This fluvial activity eroded the Kharj Formation and thus deposited a thick sequence of silt, sand and sandy silt, inter-bedded with gravel horizons.

2-2 Geomorphology of Riyadh City

The Riyadh region covers approximately 108,000 km^2. The city is located in the plateau region of the sedimentary Najd and was originally established on the alluvial plain of Wadi Batha, a tributary of Wadi Hanifah. As a result of the rapid expansion of the urban area, it now covers portions of the drainage basins of both Wadi Hanifah, including the tributaries Wadi Batha and Wadi Al-Aysan, and Wadi As-Sulaiy.

West of Wadi Hanifah the ground dips east following the leveled dip slope of the resistant outcrop in the Jubaila Formation limestone. This sloping surface extends westward to the Jabal Tuwayq where erosion of broad valleys has caused abrupt cliffs and scree slopes to develop parallel to the strike of the strata. Drainage across the limestone outcrop has developed along joints and fracture zones, which exhibit a strong west-east orientation. Wadi Hanifah and its tributaries have eroded broad steep sided valleys. These valleys may exceed 100 m in depth and are partially filled with coarse-grained alluvial deposits up to 50 m thick in places.

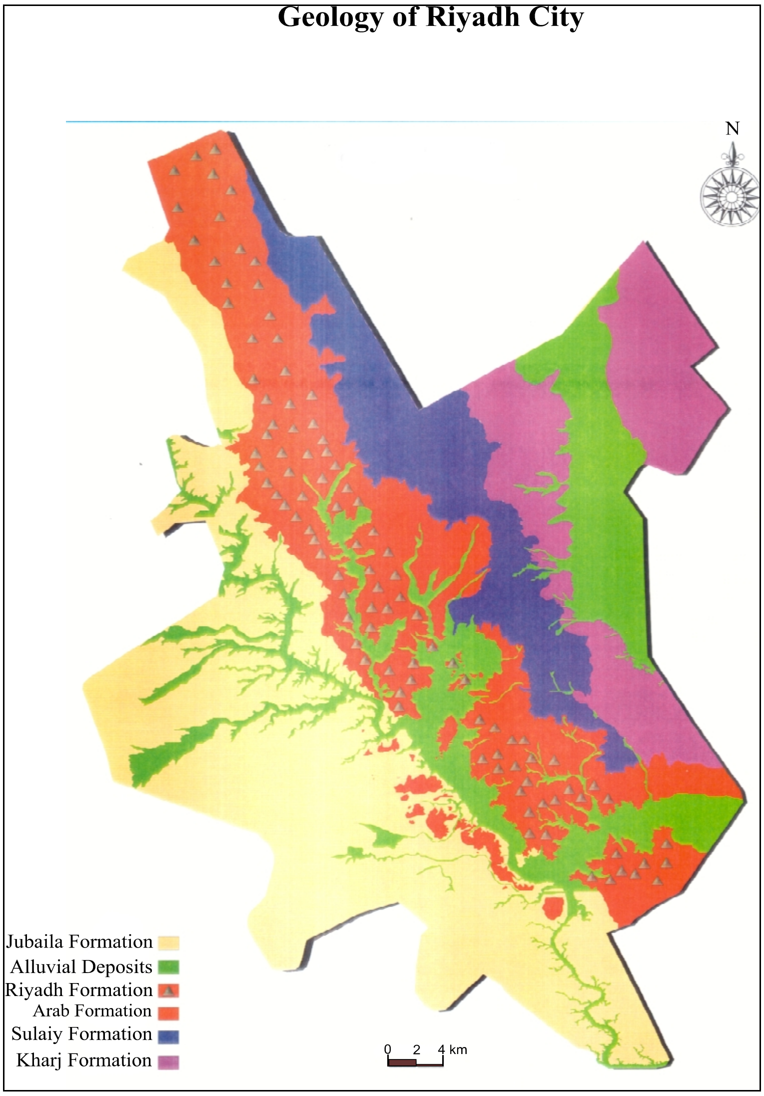


Figure 2.1 Geology of Riyadh Area

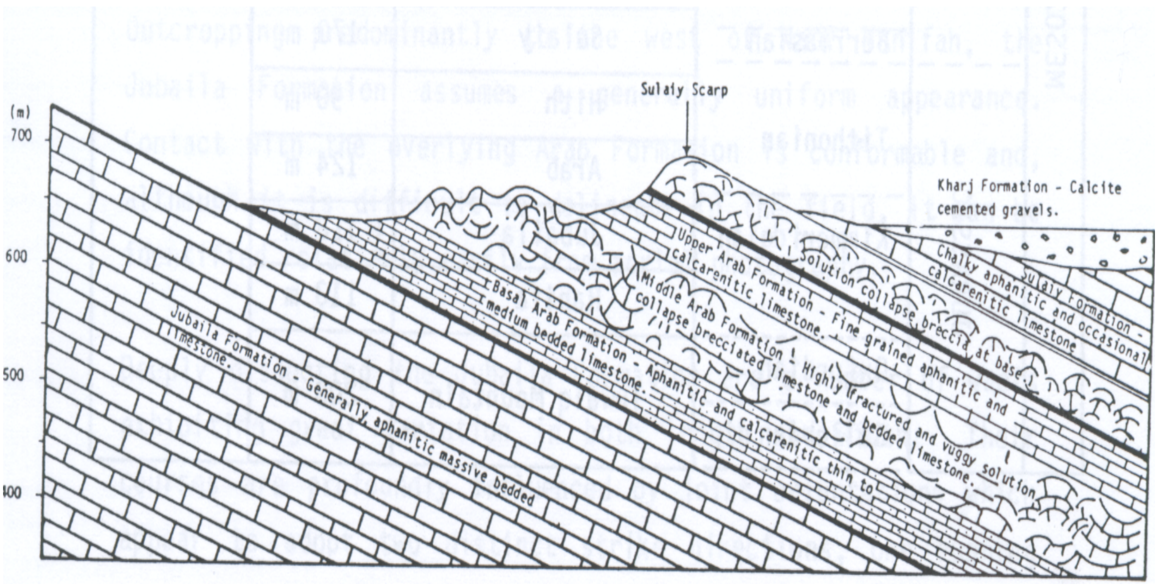


Figure 2.2. Representative geological cross section of Riyadh City (ADA, 1990).

Table 2.1. Mesozoic and Cenozoic Stratigraphy of Eastern Saudi Arabia
(After Powers et al, 1966)

Age				Formation	Thickness (Type or reference section)	Riyadh Occurrence
CAINOZOIC	QUARTERNARY			Surficial deposits		
CAINOZOIC	TERTIARY	Miocene and Pliocene		Kharj	28m	
CAINOZOIC	TERTIARY	Miocene and Pliocene		Hofuf	95m	Absent in Riyadh Area
CAINOZOIC	TERTIARY	Miocene and Pliocene		Dam	91m	
CAINOZOIC	TERTIARY	Miocene and Pliocene		Hadrukh	84m	
CAINOZOIC	TERTIARY	Eocene	Lutetian	Dammam	33m	
CAINOZOIC	TERTIARY	Eocene	Ypresian	Rus	56m	
CAINOZOIC	TERTIARY	Palaeocene	Thanetian Montian	Umm Er Radhuma	243m	
MESOZOIC	CRETACEOUS		Maestrichtian Campanian	Aruma	142m	
MESOZOIC	CRETACEOUS		Turonian Cenomanian	Wasia	42m	
MESOZOIC	CRETACEOUS		Aptian Barremian	Biyadh	425m	
MESOZOIC	CRETACEOUS		Hauterivian	Buwaib	18m	
MESOZOIC	CRETACEOUS		Valanginian	Yamaha	46m	
MESOZOIC	CRETACEOUS		Berriasian	Sulaiy	170m	
MESOZOIC	JURASSIC		Tithonian	Hith	90m	
MESOZOIC	JURASSIC		Tithonian	Arab	124m	
MESOZOIC	JURASSIC		Kimmeridgian	Jubaila	±118m	
MESOZOIC	JURASSIC		Kimmeridgian	Hanifah	113m	
MESOZOIC	JURASSIC		Oxfordian Callovian	Tuwaiq Mountain	203m	

*Reprint from Arriyadh Development Authority (ADA, 1990)

To the East of Wadi Hanifah, the topography is altered due to variations in geology. The resistant limestone of the West is replaced by more erodible limestone and the resultant landscape is made up of low conical hills in a slightly undulating land. The hills are outcrops of resistant limestone Breccia. A major geomorphic feature of Riyadh City is the Sulaiy Scarp, a line of steep hills of resistant limestone Breccia extending to the Northwest and Southeast. The scarp marks the divide between the catchment of Wadi Hanifah to the west and Wadi Sulaiy to the east. Its crest elevation is 685 m in the North and 620 m in the Southeast (ADA, 1990).

In the West of the scarp, the valleys of Wadi Al-Aysan and Wadi Batha have the same rock types filled with alluvium, containing sands, clays and some gravel. The topography in this area is one of low, conical hills in broad flat features. The hills are outcrops of resistant breccia, which diminish in elevation to the East where the breccia is overlaid by a weathered mantle of bedded limestone. In the North and South of the urban area, there are steep sided hills cut up by narrow scree - filled channels.

East of the Sulaiy scarp, the land surface grades evenly to the broad alluvial valley of Wadi Sulaiy. This valley is flat and contains indistinct surface drainage channels and East-West trending tributaries. Further to the East, the land rises sharply and forms a continuous escarpment which trends Northwest–Southeast, parallel to the strike. This is the Hith Escarpment and it marks not only the boundary of the Wadi Sulaiy catchment area, but is also the boundary of easterly groundwater flow in the shallow aquifer sequence.

To the South of the city Wadi Hanifah flows across a sequence of more erodible rocks of the Arab Formation and the stream morphology changes. The deep narrow gorge becomes a broad shallow valley filled with alluvium. The alluvial valleys of Wadi Al-Aysan, Wadi Batha, Wadi As-Sulaiy and Wadi Hanifah downstream of the Wadi Batha confluence, are broad flat features. The alluvial sediments have soils developed on them and they have historically been the areas of agricultural development. There are two major expanses of alluvium within the urban limits; the first is the Central Alluvium comprising of deposits of sands and clays up to 4.5 km wide, which were deposited by Wadi Batha and are located in the central part of the city. The second is the Eastern Alluvium which is composed of gravel sands and clays up to 6.5 km wide which were deposited by Wadi As-Sulaiy which occur in the outer eastern area of the city.

Further East is the Hith escarpment, which is located beyond the Eastern Alluvium. This is made up of the Kharj and Sulaiy formations. This is a steep-sided topographic feature which has resulted from solution and collapse of anhydrite layers within and between the Arab and

Sulaiy formations. It marks the edge of the Wadi As-Sulaiy catchment, and is an important feature with respect to groundwater flow. For a recent account of the aquifers of Saudi Arabia and their geological framework please see Edgell (1997).

2-3 Hydrogeology

In general, the Arabian Peninsula is an arid area where surface water resources are very scarce. The shortage of water is caused by the increasing demand of groundwater supply coupled with poor water management. Groundwater has played an important role in the development of the Riyadh area. Edgell (1997) showed groundwater at Wadi Hanifah has a relatively high tritium content and that there has been local rainfall recharge of groundwater.

Prior to the building of the desalination works in 1984, virtually all of the city's water came from aquifers. Deep aquifers supply potable water, whereas shallow aquifers are pumped for irrigation and industrial purposes. Shallow aquifers occur within 200 m of the surface and consequently, are highly affected by infiltrated wastewater, hence leading to rising water tables which influence the extension and development of groundwater. At the base of the sequence is the massive Jubaila limestone. This formation has played an important part in the development of Riyadh City. Water is being pumped from the Jubaila limestone through both shallow and hand-dug wells.

The hydrogeology of Riyadh is shown in Figure 2.3. The Jubaila limestone formation is a large unit of very low hydraulic conductivity, which outcrops mainly to the west of Wadi Hanifah. In the urbanised areas of the West of Wadi Hanifah, the water table is perched on top of massive Jubaila limestone. There are two prominent joint directions allowing erosion of Wadi Hanifah and its tributaries to produce deep valleys, which follow these joint directions. Due to stress relief resulting from this erosion, the rock at the base of, and adjacent to, these valleys is highly fractured. These fracture zones are combined with the overlying alluvial sands and gravel, thus creating a significant aquifer system.

Further Eastward of Riyadh City, beyond the urban limits, is the hydraulic barrier of the Hith Escarpment. This feature marks the edge of the collapses and fracturing associated with anhydrite dissolution, and it is reasonable to assume that it also marks the edge of Biyadh Aquifer (Edgell,1997). Groundwater can not flow across this barrier, so it is diverted parallel to it and flows to the south (ADA, 1990).

The reader is referred to (Othman, 1983; ADA, 1990; Edgell,1997) for further details of the aquifers of Riyadh region, however, the most significant aquifers include:

2.3.1. Biyadh Aquifer

The Biyadh aquifer is the most significant aquifer in the Riyadh region. It out crops east of Wadi Hanifah about 125 km north-northwest of Riyadh City. This aquifer contains very large amounts of groundwater estimated at several billion m3 in the Riyadh area alone (El-Khatib, 1980). It supplies raw water to Riyadh City and has a good yield and quality of groundwater.

2.3.2. Fracture zones

The Upper Arab-Sulaiy limestone typically has a low hydraulic conductivity; however, there are fracture zones with high hydraulic conductivity. These are more common in the Sulaiy Formation and generally appear as parallel linear features reflecting a prominent East-West joint orientation. The most significant area of fracturing appears to be beneath the broad Wadi As-Sulaiy Valley East of the city. Historically, this has been an important area for groundwater development. These fracture zones provide a hydraulic connection between the surface formations and the deep Biyadh Aquifer in the eastern part of the city.

2.3.3. Alluvial sediments

The recent alluvial deposits of Wadi Hanifah, Wadi Al-Aysan and Wadi Batha are a significant hydrogeological unit in Riyadh area. These comprise a sequence of poorly sorted carbonate and siliceous sands, carbonate gravel and rock fragments with silts and clays.

This aquifer system had been exploited by shallow hand dug wells prior to the extensive urban development of the city. Nowadays, this is the main supply for the agriculture along Wadi Hanifah and its tributaries. In the East of Riyadh City, there is a separate group of alluvial sediments which are deposited by high-energy streams flowing from the catchment of Wadi As-Sulaiy. The deposits are sands and silty sands, inter-bedded with gravel. This unit is largely unsaturated with water. Vertical drainage through these sediments has removed fine particles and partially dissolved calcium carbonate, resulting in the formation of honeycomb structure.

Groundwater within Wadi Hanifah has been found to have a modern age where wells in the Northern and Central of Riyadh produced groundwater aged between 1190 and 1532 years. In the South further away from the aquifer outcrop, the age was found to be 4060 years (Sogreah, 1967). The age of the groundwater in the Eastern part of Riyadh is 1829 years, indicating according to (ADA, 1990), that in this area vertical flow through the overlying fractured rock had been a dominating recharge process.

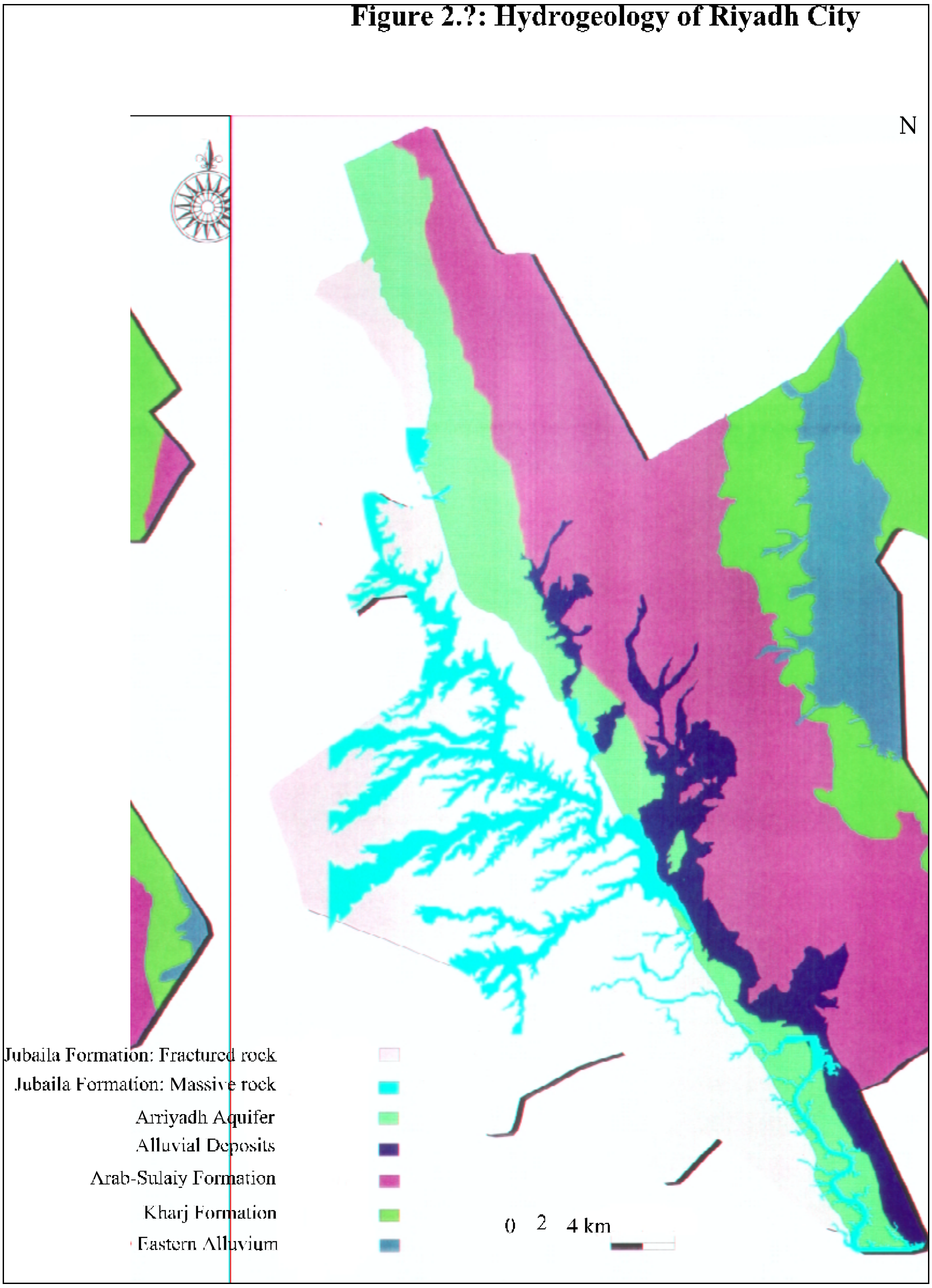


Figure 2.3 Hydrogeology of Riyadh Area

2.4. Climate and Rainfall

In order to assess the impact of the regional climate parameters such as, precipitation, temperature, evaporation etc., on the environment in the study area, the climatic characteristics will be presented for Saudi Arabia in general, and for Riyadh City in detail.

2.4.1. Riyadh City

The climate parameters of the area mainly depend on its geographic location and topography. Riyadh lies within the drainage basins of Wadi Hanifah and Wadi As-Sulaiy. The Wadi Hanifah catchment covers about 4400 km^2 extending from the Northwest to the Southeast having a length of about 150 Km and an average width of 30 Km. The drainage area of Wadi As-Sulaiy is about 1500 km^2 which is occupied by the eastern districts of Riyadh city. No records exist of any surface runoff in the channel of Wadi As-Sulaiy. However, it is a well-known fact that tremendous drainage problems occur in parts of the Naseem area during the rainy season.

Wadi Hanifah exists as the main drainage course and appears rather constricted to the north of the city while opening out into a wide flood plain to the south. Braided channels, composed predominantly of coarse gravel testify to the occurrence of violent flash floods with the energy to concentrate coarse material whilst removing the finer fraction downstream. For the purpose of monitoring the quality of stream water within the study area, it is necessary to outline the climatic parameters, which play a significant role in water stream quality, especially rainfall and evaporation. Rainfall can dilute the stream while evaporation contributes to the excess salinity of surface water. The climatic data for Riyadh City have been obtained by Ministry of Agriculture and Water and Ministry of Defense & Aviation (MEPA). The elevation of the climatic stations varies between 430 and 645 m above the sea level.

There is a great temporal variability of rainfall and a substantial variability of other climatic parameters due to the arid characteristics of the region. The long-term average annual precipitation, based on 35 years of record, is 94 mm with a standard deviation of 55 mm.

A study by the Sendil et al (1983) concerning the hydrological characteristics of Wadi Hanifah indicated that the intensities of maximum rainfalls around Riyadh range between 40-90 mm/hr for duration of 10 minutes. However, a recent study conducted by Alabdula'ay and Khan (2000) analysed the chemistry of rainwater in Riyadh. They showed the major cation and anion were calcium and sulphate, contributing 30.5% and 20.8% respectively, to the total dissolved solid. The dominant heavy metals ions were zinc, lead and aluminium. The first rain event contained higher concentrations of various ions than the later rain events.

Air temperature of Riyadh shows a definite periodicity, with July being the hottest month with an average of 34 °C whereas January the coldest month with an average of 14 °C over a period of 35 years. There is a decline in temperature from July through the autumn (September, October and November) and most of the winter (December and January). Then a gradual increase from February throughout the spring (March, April and May), reaching its maximum temperature in the summer season. The annual average air temperature was 25 °C. The absolute minimum air temperature, -6 °C, was recorded in January 1964 while the absolute maximum temperature reached 49 °C in July 1987.

Relative humidity displays variations within Riyadh, during the summer (June, July and August) the relative humidity is very low, with a mean monthly average being around 23 % whilst December and January are the months of maximum relative humidity (53%).

Sunshine duration is expressed in hours of sunshine and provides information on the length of the day and on cloudy periods when the intensity of solar radiation decreases below a certain level. The sunshine hours were highest in June (10.66) and lowest in December (7.14) with the annual average is 8.78 hour per day. The mean solar radiation values range from a minimum of 320 cal/cm^2/day recorded in December to maximum of 580 cal/cm^2/day in June. Both solar radiation and the number of sunshine hours are regarded as the important factors influencing evaporation.

In Riyadh City, the average wind speed lies somewhere between 3.48 and 5.83 km per hour. The general direction is south-west in winter and north-east and north-west in summer (Othman, 1983). Table 3 shows the monthly average wind speeds for the period 1968-1992. The records show that wind speed reached its average maximum in May (23.10 km/hr) and its minimum in October (14.79 Km/hr).

Meteorological factors which increase the evaporation rate include solar radiation, high wind speed, low relative humidity and high air temperature. The climatic station records evaporation by using the US Weather Bureau Class “A” pan. The highest rate of evaporation was in the month of July (380 mm) while the lowest was in January (101 mm). The total mean annual evaporation is about 2794 mm, with a monthly average of 235 mm. The dry climate of Riyadh leads to high evaporation losses. Potential evaporation in any month throughout the year is significantly larger than corresponding rainfall.

III FIELD WORK

The field work in the study area consists of both Geophysical and Geochemical surveyings. The chemical analysis can further provide information on the water quality and would provide correlation between the two approaches to formulate possible imaging results. Geophysical measurements, mainly Resistivity and Seismic Refraction were carried out to fully understand the subsurface hydrogeological picture.

The field work for the present study took a total of 3 months to cover the whole study area. Most of the surveys were concentrated in the areas of alluvial plain deposits adjacent to Wadi Hanifah. The area divided into two main localities (north and south of Wadi Hanifah). The geophysical investigations were carried out to achieve the objectives within the limits of the geophysical possibilities using seismic refraction and electrical resistivity measurements. The location of the all seismic and resistivity profiles were adjusted in the field by using the Global Positioning System (GPS) and the Landsat Image of the study area. Most of the survey profiles were constructed along the roads and irrigation canals. The locations of all geophysical profiles in the two areas are shown in Figs.3.1 and 3.2.

3.1 RESISTIVITY SURVEY:

Two basic types of field procedure were carried out in ground resistivity survey in the southern study area (Fig. 3.1). The first method is resistivity imaging survey and the second is vertical electrical sounding (VES). Two-dimensional (2-D) resistivity imaging surveys using automatic multielectrode resistivity meter system (Campus Geopulse) were carried out during the field work. The campus Geopulse Imaging System was used for data acquisition (Fig.3.3). A multicore cable of 25 electrodes was connected to the imager 25 module, and Geopulse was connected to a 12V external battery. In the survey the Imager cable is set out in straight line and electrodes connected at every take out. The laptop computer which is connected to Geopulse via the RS232 socket operates the control program and also processes and stores the data. The data acquisition process is completely controlled by the computer software (Imager25), which is also check all electrodes connection. A total of 8 2-D electrical imaging survey profiles and 10 vertical electrical soundings (VES) were carried out in the study area (Fig.3.1). A total of eight image profiles implemented on the western and eastern side of the main Wadi channel.

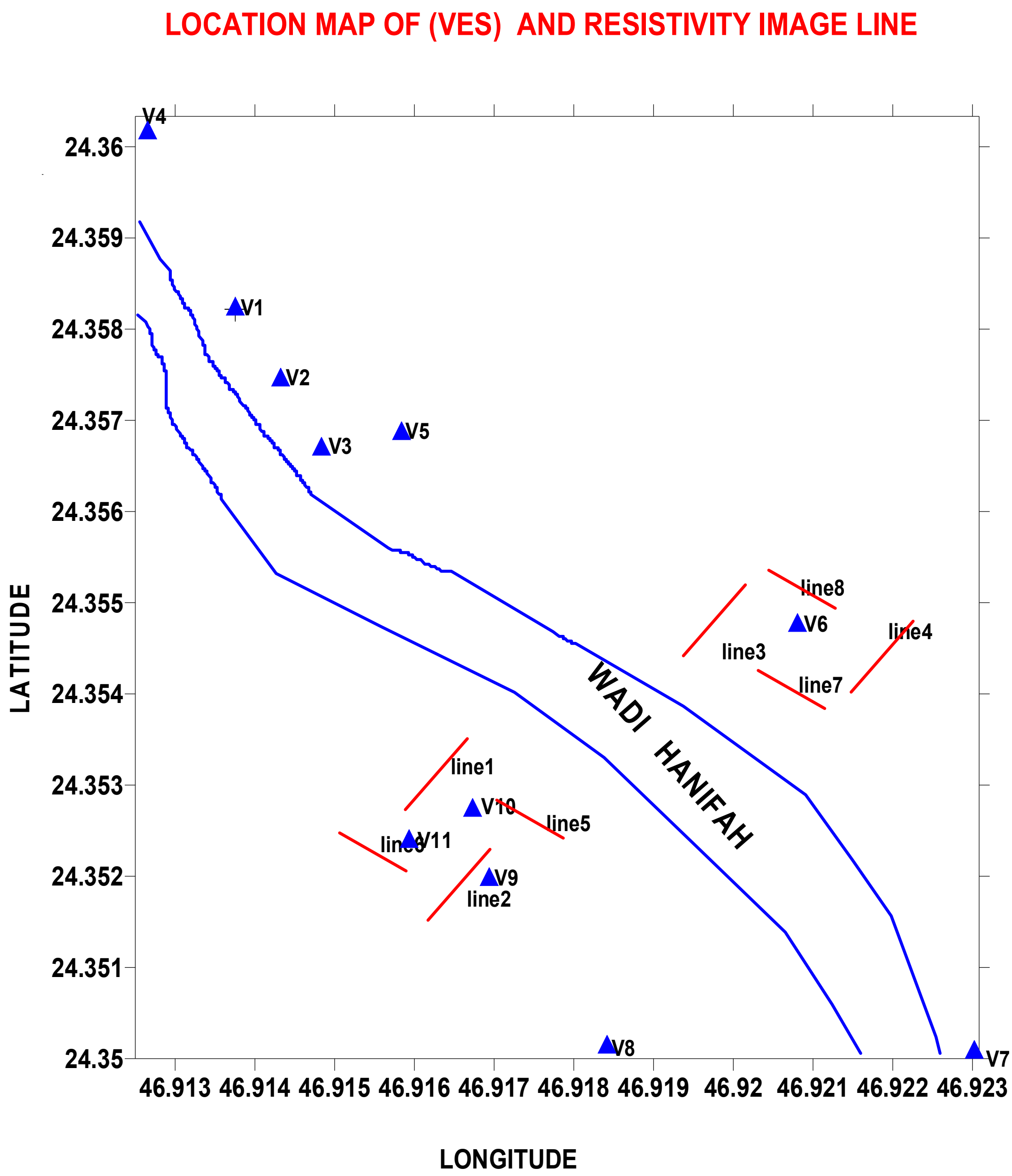


Fig.3.1 shows the locations of the Resistivity Image Lines inred color and Vertical electrical soundings (blue triangles).

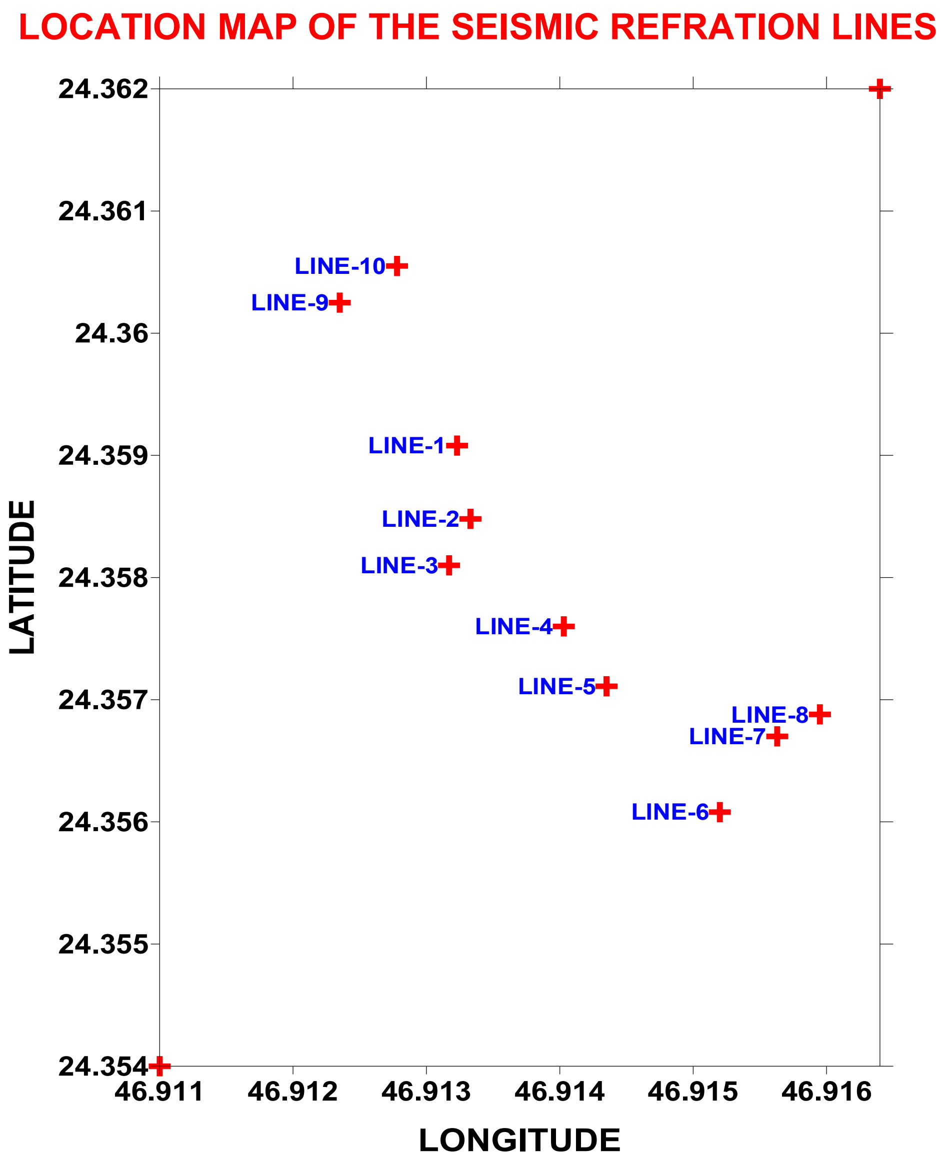


Fig. 3.2 shows the locations of Seismic Refraction Lines.

An ELREC-T instrument manufactured by BRGM, France was used to carry out the measurements of VES. The ELREC-T (Fig.3.3) is a high power electrical equipment designed for AC/DC electrical exploration and includes transmitter and receiver in one single unit. ELREC-T has internal batteries for the supply for its electronic circuits. The power source is a motor generator 220V –5 0 HZ supplied 1200 W AC/DC converter and the output voltages available on this converter are 50V, 100V, 200V, 400V, and 800V, and the maximum current available on each voltage is 2.5A. The measurement is made fully automatically through the control of a microprocessor, automatic self-potential correction, automatic ranging, and digital stacking for signal enhancement.

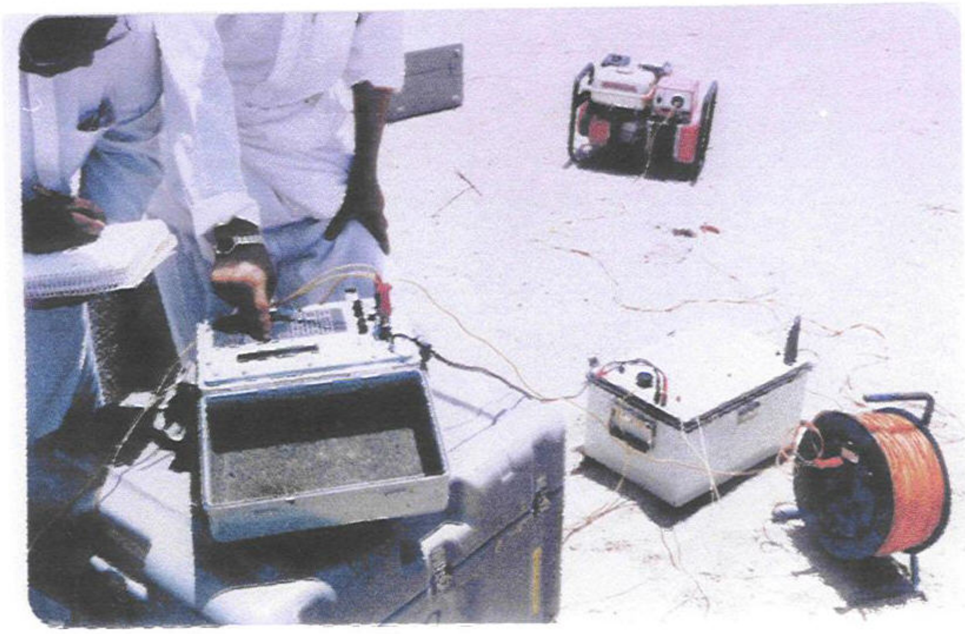


Fig. 3.3 ELREC-T Resistivity instrument.

3.2 SEISMIC SURVEY

A total of 10 seismic refraction survey profiles were carried out in the eastern side of the northern study area (Fig. 3.2). Five profiles located on the eastern side and five profiles located on the western side of the Wadi, parallel and perpendicular to the channel. The length of each profile is 65m with 5m geophone spacing. The recording instrument used in the seismic refraction survey was Geometric Seismograph Strata View. The Strata View seismograph is 24-channels seismic data acquisition system uses high-speed analog-to-digital (A/D) converters. The computer and software built into the seismograph are so powerful to select the sample at the optimum gain (i.e. Automatic Gain Control) and execute the other processing for the 24-channels record in less than 3 seconds. The energy source used for seismic survey is hammer drop. The seismogams were obtained for field inspection on the analog permanent wiggle-traces. The data for each shot point were recorded in the seismograph in separate file. These files were dumped to the computer for subsequent analysis and interpretation during a later phase for this project.

IV DATA ANALYSIS & INTERPRETATION

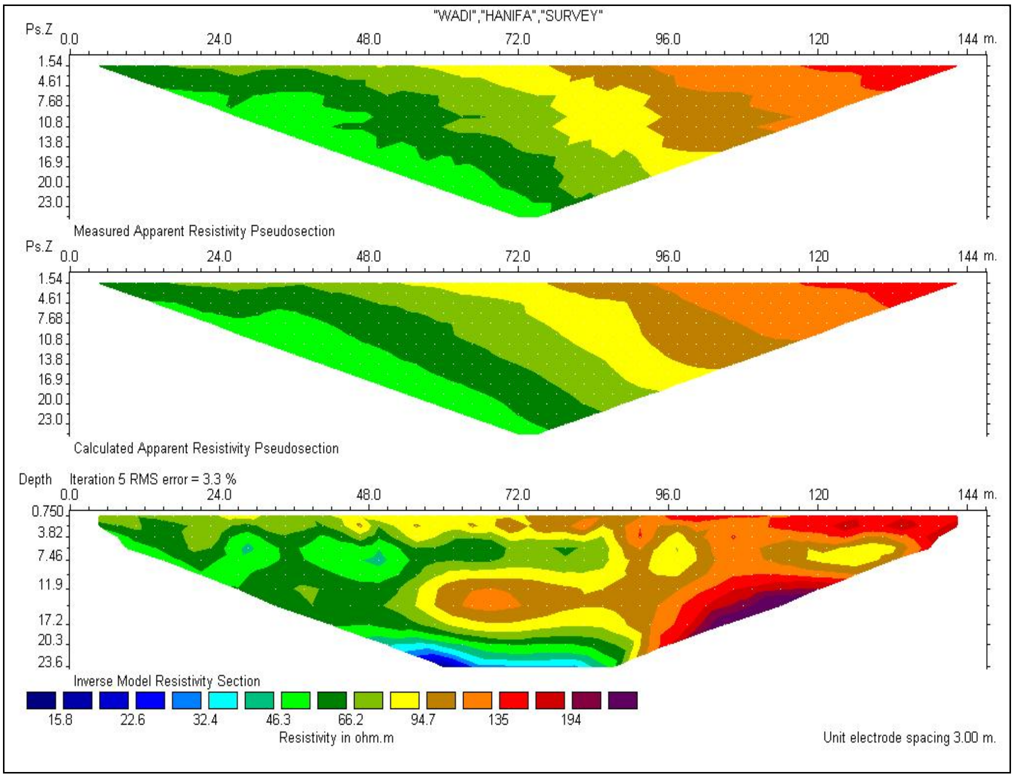
4.1 RESISTIVITY IMAGE:

The field data from the resistivity imager 2-D interpreted using RES2DINV program. The inversion model and apparent resistivity pseudosection displayed on the screen by using RES2DINV software. The RES2DINV program automatically divide the subsurface into a number of blocks and then it uses a smoothness-constrained least-squares method to determine the resistivity values of the blocks.

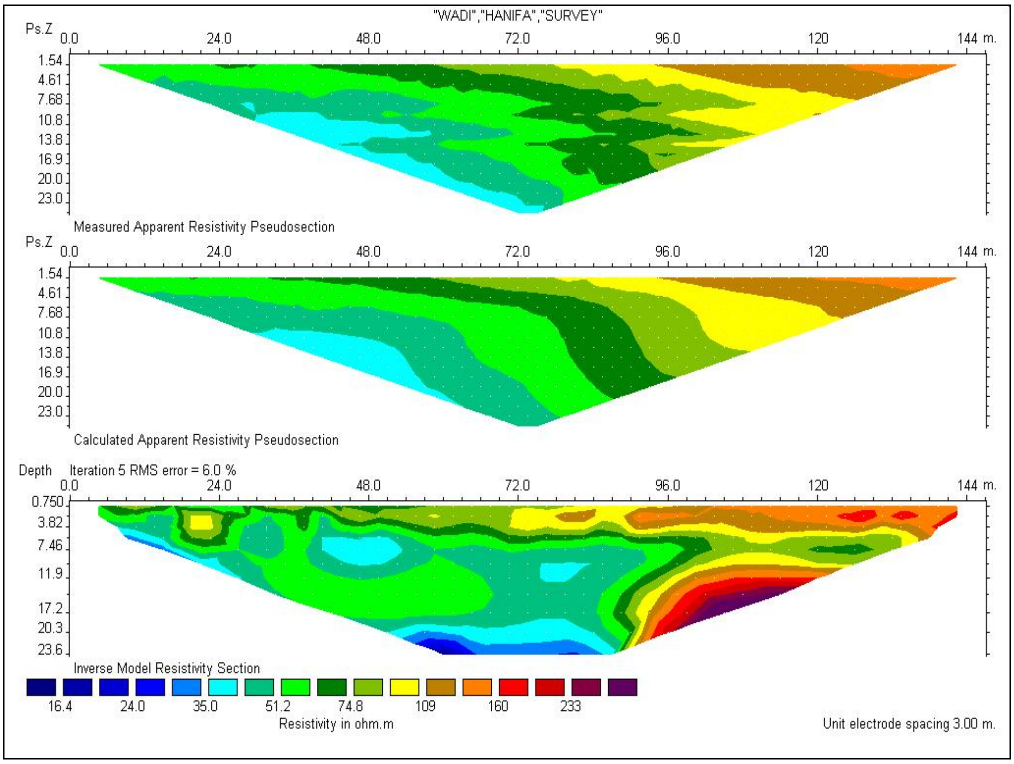
The inversion model and apparent resistivity pseudosection displayed on the screen by the program can be saved as PCX graphic files. In the interpretation of the model sections, the following sources of information were used: the general geology and hydrogeology of the survey area, results from boreholes, knowledge of typical resistivity values of rocks, soil, and groundwater. The anomalies in the resistivity profiles are correlated with the groundwater occurrence (in term of quality and quantity), the aquifer boundaries, and the fresh/contaminated groundwater interface respectively. The contaminated groundwater have lower resistivity values than fresh ground water due to the higher concentration of ions which reduces the resistivity. A detailed qualitative and quantitative interpretation of 2-D resistivity data is discussed .

<u>Profiles 1 and 2</u> :

These two profiles run perpendicular to the main channel on the eastern side and each one has a length of 144 m and about 20 m apart from the channel. The 2-D pseudosections model of the profiles 1 and 2 are shown in figure.4.1. The resistivity value gradually increases towards the end southwestern side indicating that the bed rock limestone is far from the main channel. The low resistivity (dark blue) at the northeastern end of the section near to the main channel is probably caused by contaminated (saline) ground water. The top layer is very thick and consists of sandy clay. The pseudosections model of the two profiles indicate that the bed rock in the western side of the main Wadi channel is more weathered and fractured, therefore the aquifer affected by the contaminated water from the channel. From the hydrogeological point of view this means that the sanitary water penetrates the aquifer in the western side up to 150 m from the main channel.



PROFILE-1

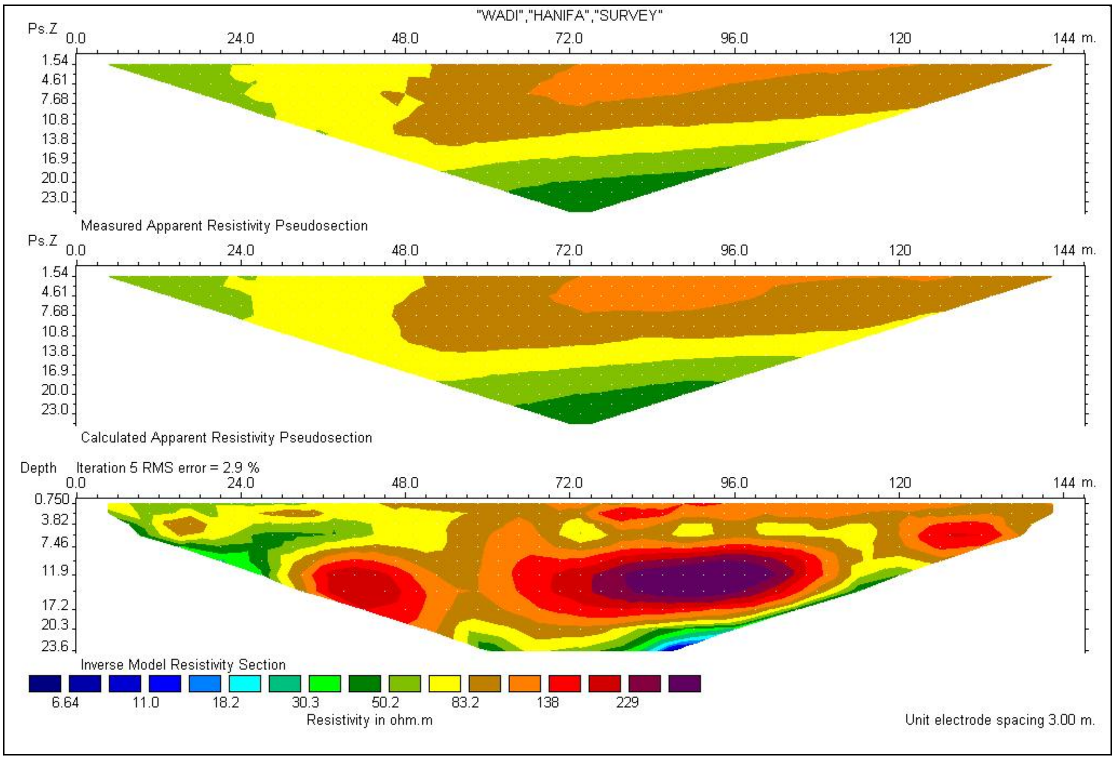


PROFILE-2

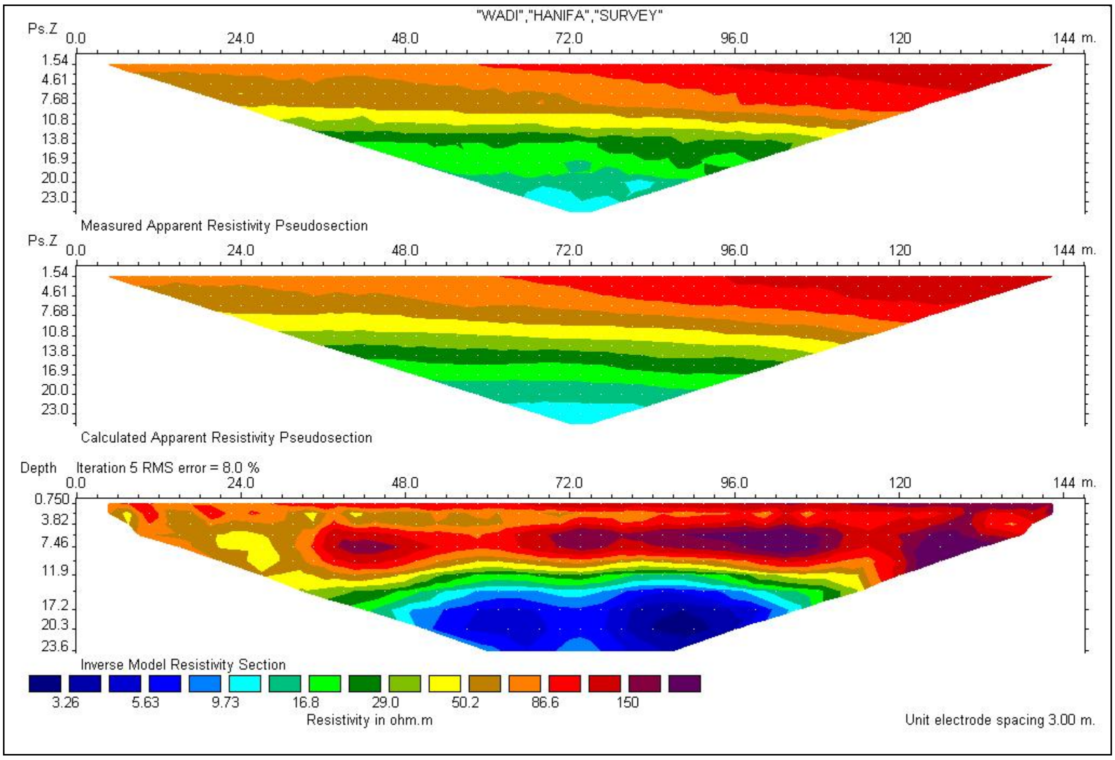
Fig. 4.1 indicates pseudosections models of profiles 1 and 2.

Profiles 3 and 4 :

These two profiles run perpendicular to the main channel on the eastern side, each one has a length of 144 m and about 20 m apart from the channel. The 2-D pseudosections model of the two profiles 3 and 4 are shown in Fig. 4.2. The higher resistivity value (red color) in the upper part of the section correspond to limestone rock and the increase of the resistivity forward the main channel indicates an occurrence of fresh ground water in this direction. The limestone bed rock in the eastern side of the channel is very thick compare with the western side. The low resistivity value (dark blue color) towards corresponding to a contaminated ground water zone. The interface between the fresh and contaminated ground water in the two model sections can be marked at 90 m from the main channel. The medium resistivity value (green color) corresponding to the fractured limestone.



PROFILE- 3.

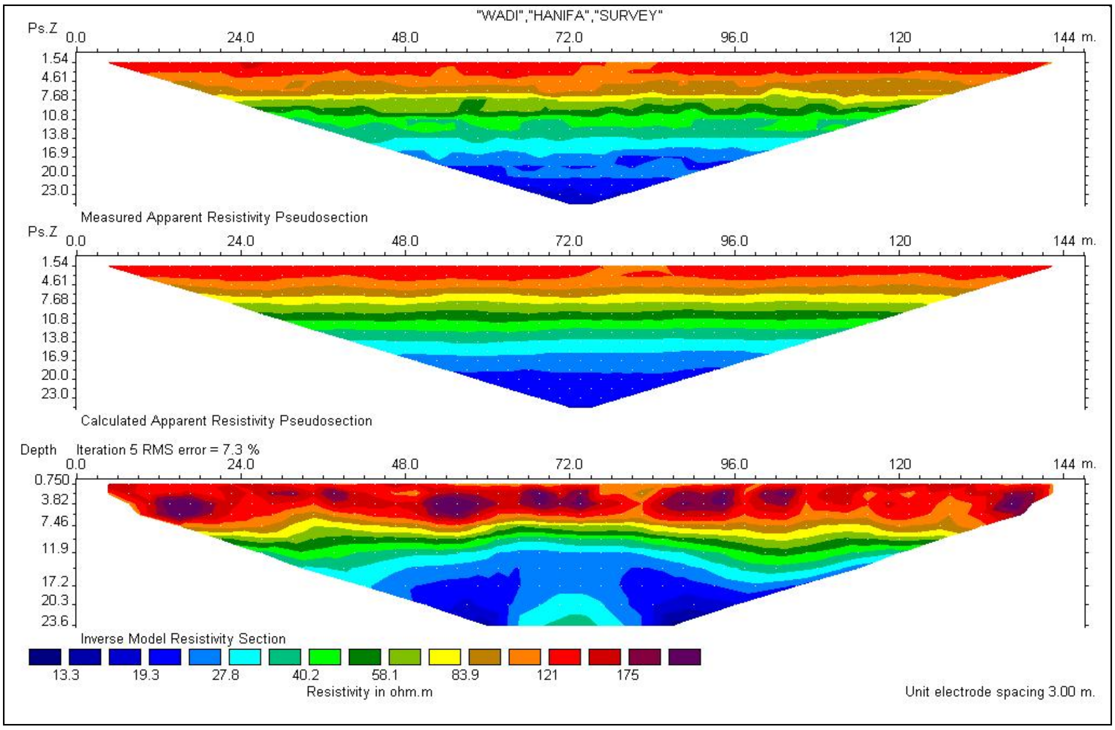


PROFILE-4

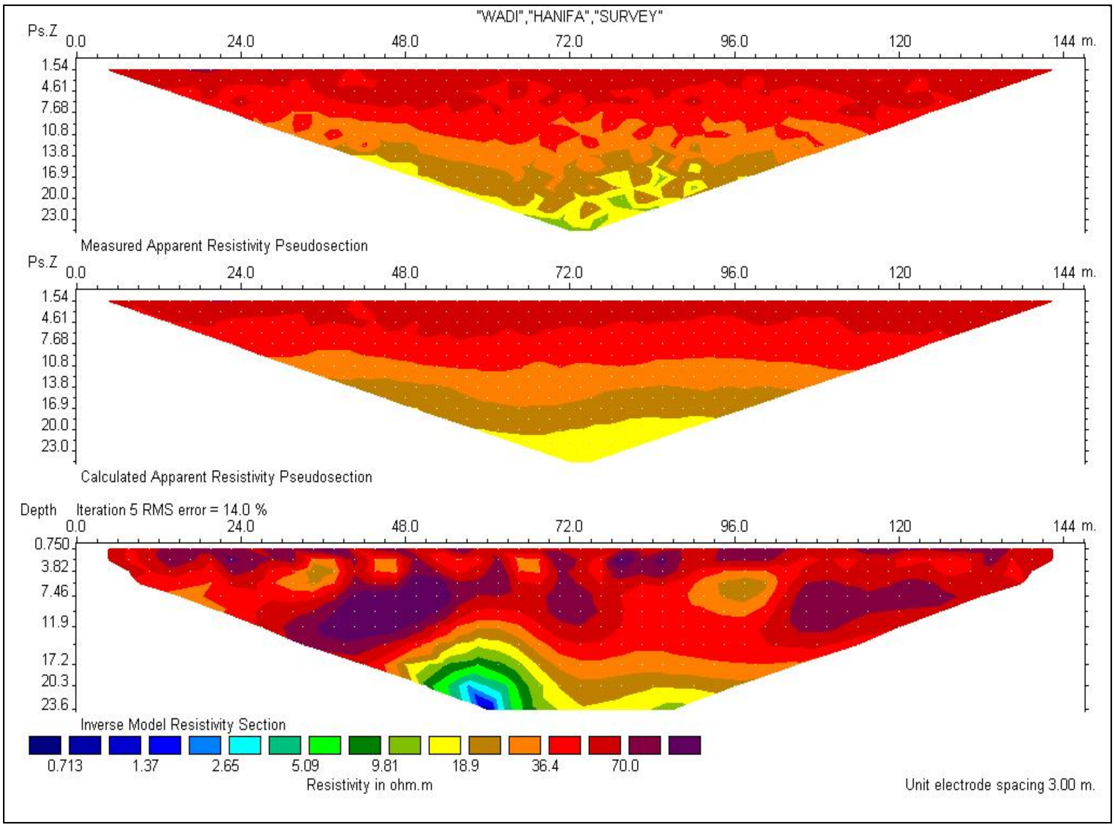
Fig.4.2 shows pseudosections models of profiles 3 and 4.

Profiles 5 and 6 :

Profile 5 and profile 6 are located on the western side of the Wadi channel running parallel to the Wadi. Each profile has a length of 144 m. The 2-D pseudosections model of the two profiles 5 and 6 are shown in Fig. 4.3. The general geology and interpretation of these two profiles are similar to profiles 1 and 2. The major feature is a low resistivity zone in Profile 5 corresponding to a contaminated ground water aquifer within the alluvial deposits at 8 m depth. The pseudosection model of profile 6 shows a very thick layer on the top with high resistivity underlained by fractured limestone layer.



PROFILE-5

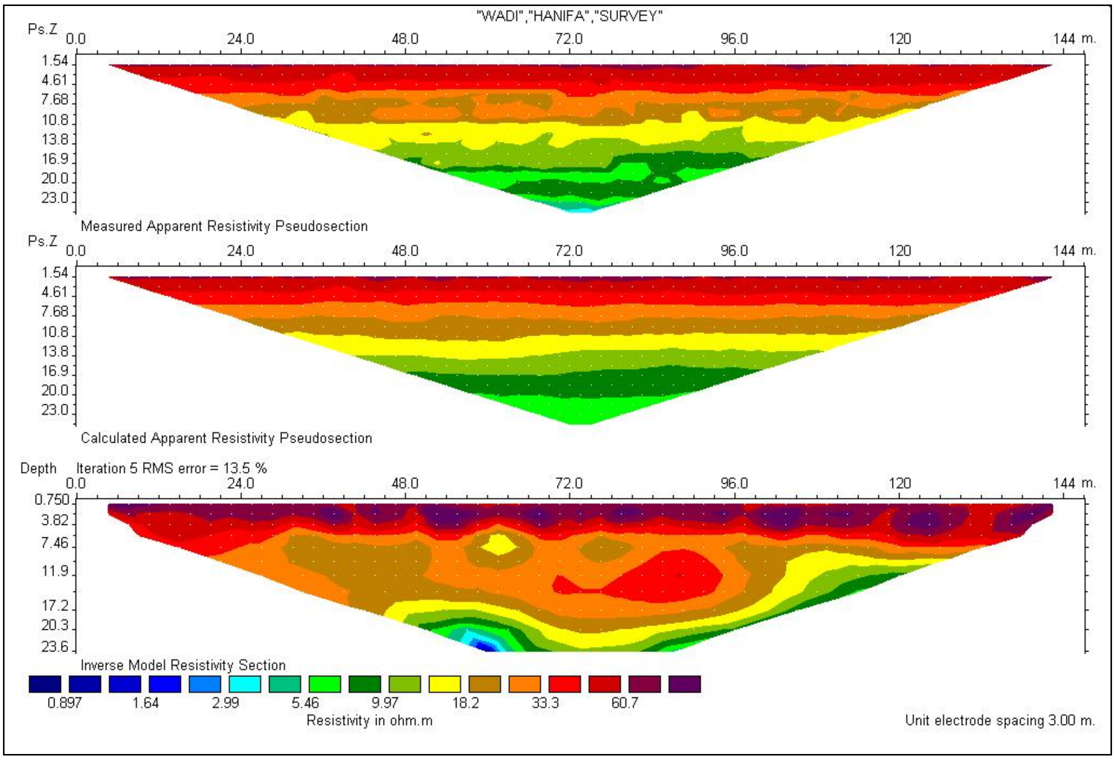


PROFILE-6

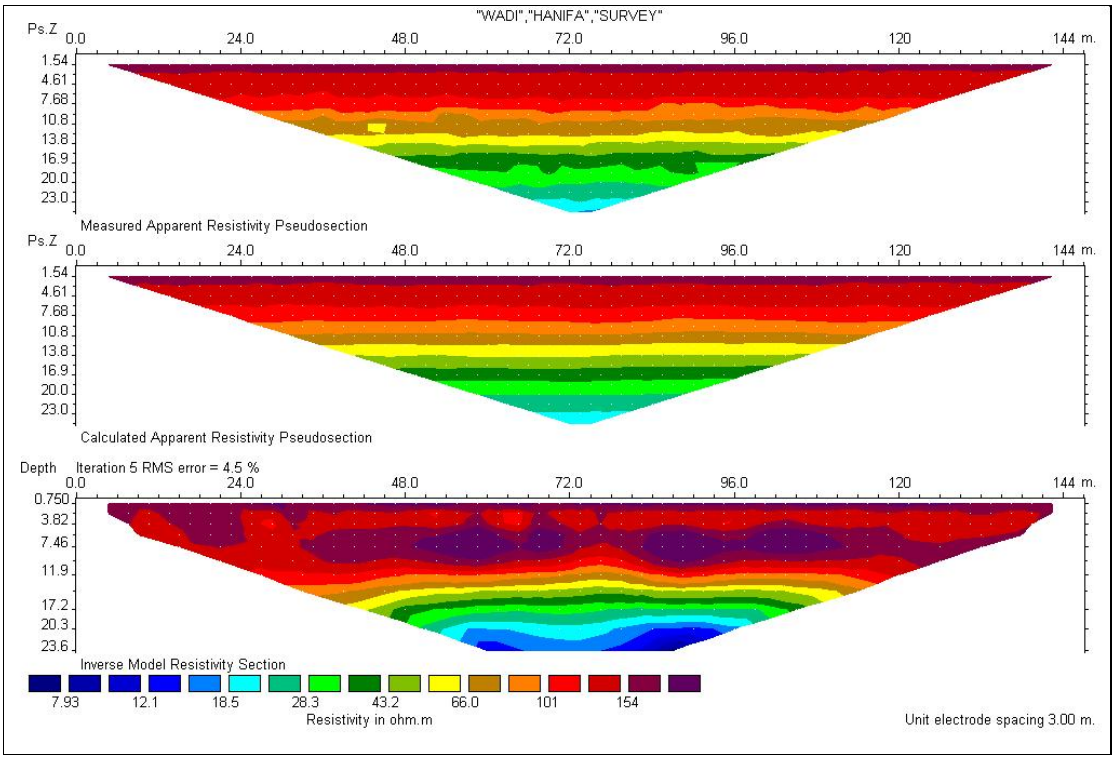
Fig. 4.3 indicates pseudosections models of profiles 5 and 6.

Profiles 7 and 8 :

These two profiles run parallel to the main channel on the eastern side, each one has a length of 144 m. Profile 8 is about 20 m apart from the channel and profile 8 about 50 m. The 2-D pseudosections model of the two profiles 7 and 8 are shown in Fig.4.4. The general geology and interpretation for these two profiles are similar to profiles 3 and 4. The higher resistivity values (red color) in the upper part of profile 8 correspond to limestone rock and the decrease of the resistivity towards the main channel indicates an occurrence of contaminated ground water in this direction.



PROFILE-7



PROFILE-8

Fig.4.4 shows pseudosections models of profiles 7 and 8.

4.2 VERTICAL ELECTRICAL SOUNDING (VES)

A total of 10 VES were carried out in the study area, seven soundings were made on the eastern side and 3 VES located on the western side of the Wadi. The VES were made along the bank and adjacent to the channel of Wadi Hanifah and sounding locations are shown in (Fig. 3.2). The main objective of the vertical electrical sounding is to deduce the variation of resistivity with depth and to correlate that with the geological information in order to infer the depths and resistivities of the layers present.

The vertical electrical sounding field data were then analyzed and interpreted using two computer programs. The first technique is RINVERT program developed by C Vision Pty Ltd, 1995. The second technique is IPI2Win software designed by Alexi A. Bobachev, Igor. N. Modin, Vladimir A. Shevnin (2002) and distributed by the Geoscan-M Ltd., Moscow, Russia. From the VES data thickness and resistivity values of the layers were determined and finally the interpretation of true resistivity for groundwater data and underground geological structures were concluded. VES curves were subjected to both techniques of sounding analysis. A multi-layered model and an absolute layering model corresponding to each sounding were then obtained. Interpreted parameters and depth model deduced from each profile using the previously mentioned programs are discussed in the following sections.

Geoelectrical Section-1 :

Section-1 lies in the eastern side parallel to the Wadi and shows the results of VES 4, 1, 2, and 3 (Fig. 4.5). The high resistivity values (>100 ohm.m) beneath VES 2 and 3 are associated with limestone at shallow depth and this in general agreement with that interpreted by seismic refraction in line-7. The sharp increase of resistivity may be due to a fault. The contour section reveals also the extent of thick alluvium layer beneath VES 4 and 6 which is associated with the lowest resistivity.

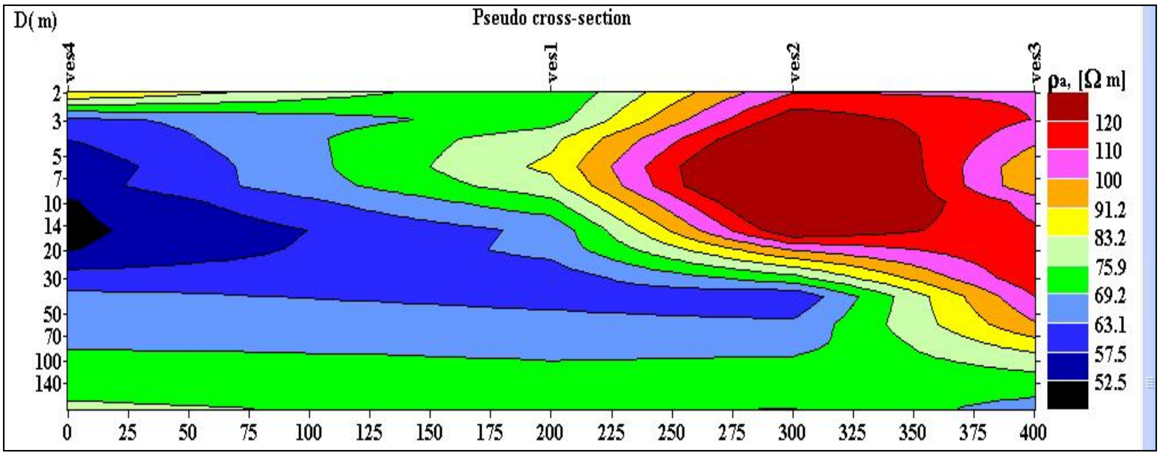


Fig.4.5. Geoelectrical section shows the interpreted subsurface

Geoelectrical Section-2 :

Section-2 lies perpendicular to the Wadi and shows the results of VES 3 and 5 (Fig.4.6). The high resistivity values (>100 ohm.m) beneath VES 5 are associated with limestone.The contour section reveals also the extent of thick alluvium layer beneath VES 3. The low resistivity values indicate water-bearing layer, beneath VES 3 contaminated water at depth 5 meter and the deep groundwater at 100 meter. The deep water-bearing layer extend beneath VES 5.

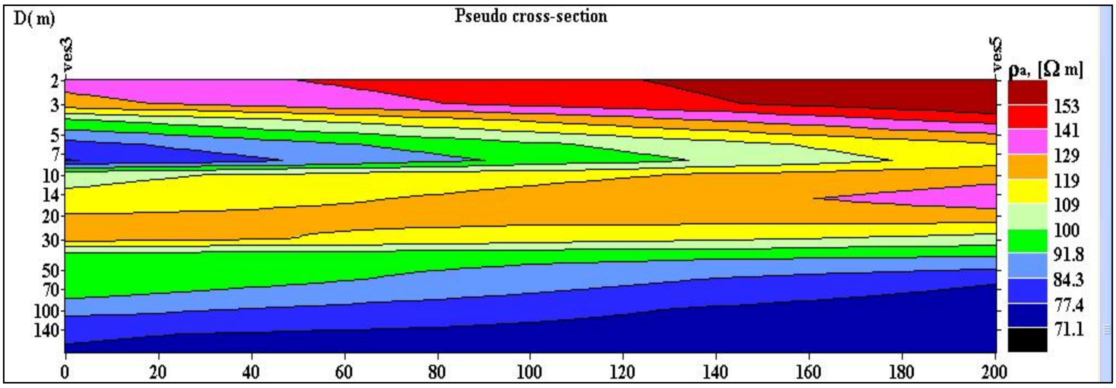


Fig. 4.6 Geoelectrical section indicates the interpreted subsurface

<u>Geoelectrical Section-3</u> :

Section-3 lies in the eastern side parallel to the Wadi and shows the results of VES 6 and 7 (Fig. 4.7). The high resistivity values (>100 ohm.m) associated with dry unconsolidated sediments at shallow depth .The contour section reveals also the extent of thick water-bearing layer beneath VES 7 which is associated with the lowest resistivity. The moderate resistive layer associated with a layer of weathered limestone.

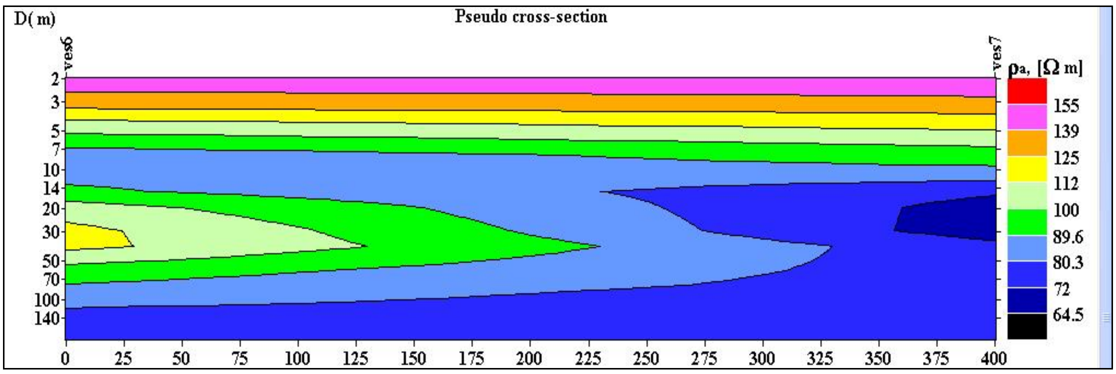


Fig.4.7 Geoelectrical section shows the interpreted subsurface

Geoelectrical Section-4 :

Section-4 lies in the western side parallel to the Wadi and shows the results of VES 8, 9, and 10 (Fig.4.8). The high resistivity values (>100 ohm.m) beneath VES 9 and 10 are associated with limestone .The contour section reveals also the extent of thick alluvium layer beneath VES 9. The low resistivity values indicate water-bearing layer, beneath VES 8 contaminated water at depth 5 meter and the deep groundwater at 100 meter. The deep water-bearing layer extend beneath VES 9, and 10. The moderate resistive layer associated with a layer of weathered limestone.

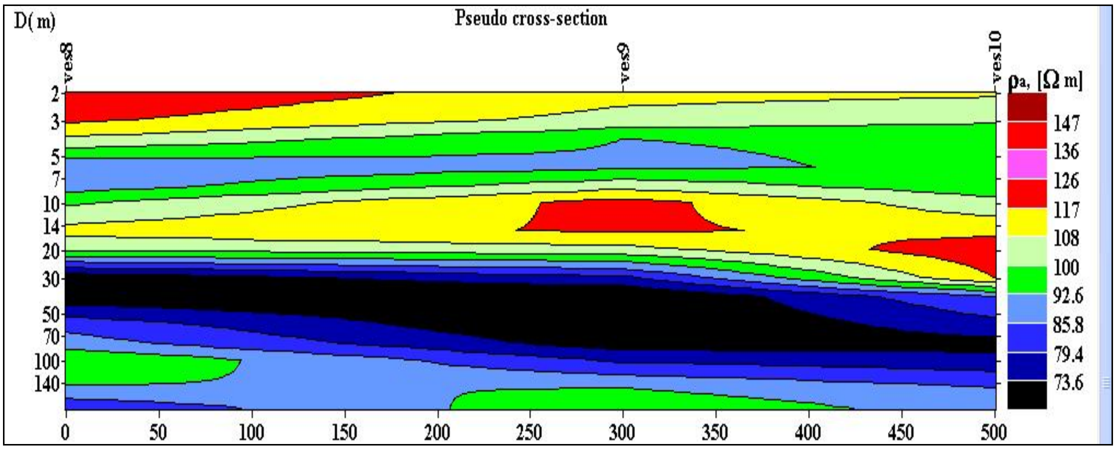


Fig. 4.8 Geoelectrical section shows the interpreted subsurface

4.3 SEISMIC REFRACTION:

SIP is a complete refraction interpretation software package designed by Rimrock Geophysics Inc. to run directly on Geometric Strata View exploration seismograph. The first arrival times were picked up the seisograms using BSIPIK program. SIPEDT program is used for editing the output data first arrivals, layer assignments, velocities, or other parameters. SIPT2 program is software for interpreting seismic refraction data using inverse modeling and iterative ray tracing techniques. Results, interpreted parameters and depth model deduced from each profile by using the previously mentioned programs are briefly described and discussed in the following section.

<u>Seismic Refraction Profile-1</u> :

Profile-1 is located on the western side upstream perpendicular to the Wadi and the first shot A located 5m from the channel bank. The interpretation of the seismic profile results for this profile reveals a depth model that has three layers with velocity contrast as shown in Fig. 4.9. The average velocity of the first layer is 725 m/s and varies in thickness between 2 to 3 meters. This layer is often dry wadi sediments, mainly silty sands. The average velocity of the second layer is 1431 m/s and thickness varies from 2 to 10m near to the channel. The velocity represents fractured limestone thicker near to the wadi and that may be due to fault along the wadi. The average velocity of the third layer is 2040 m/s represents the bed rock limestone.

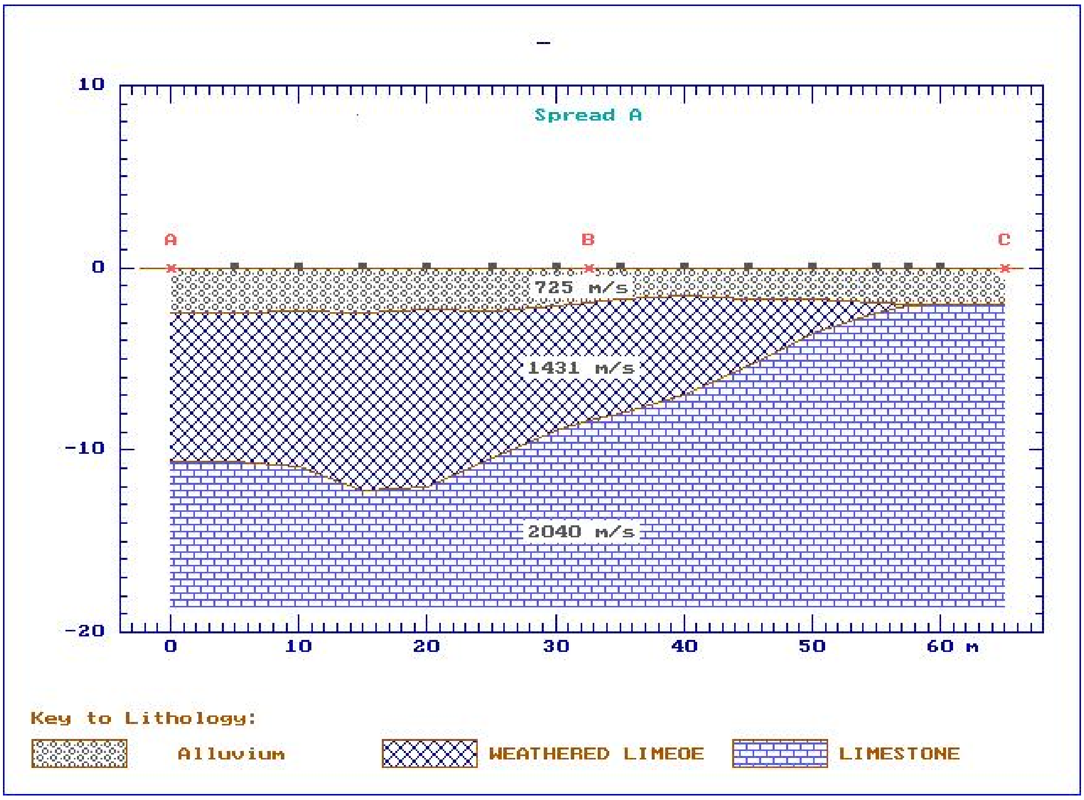


Fig. 4.9. Seismic Refraction Prpfile-1

Seismic Refraction Profile-2 :

Profile-2 is located on the western side parallel to the Wadi. The interpretation of the seismic profile reveals that has three layers with velocity contrast as shown in Fig. 4.10. The average velocity of the first layer is 728 m/s and varies in thickness between .5 to 3 meters. This layer is often dry wadi sediments, mainly silty sands. The average velocity of the second layer is 1372 m/s and thickness varies from 7 to 10 meters and represents weathered limestone. The average velocity of the third layer is 2108 m/s represents the bed rock limestone.

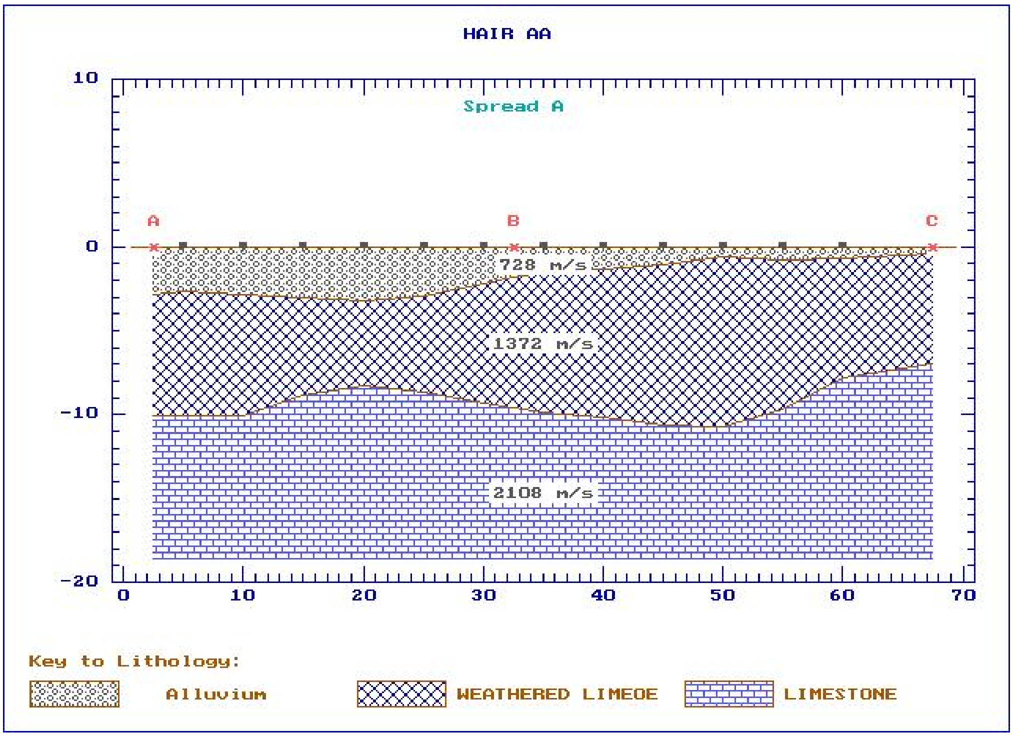


Fig. 4.10 Seismic Refraction Prpfile-2

Seismic Refraction Profile-3 :

Profile-3 is located on the western side parallel to the Wadi. The interpretation of the seismic profile results reveals a depth model that has three layers with velocity contrast as shown in Fig. 4.11. The average velocity of the first layer is 483 m/s and varies in thickness between 2 to 3 meters. This layer is wadi sediments, mainly silty clayey sands. The average velocity of the second layer is 1290 m/s and thickness varies from 8 to 12 meters and represents weathered limestone. The average velocity of the third layer is 2225 m/s represents the bed rock limestone.

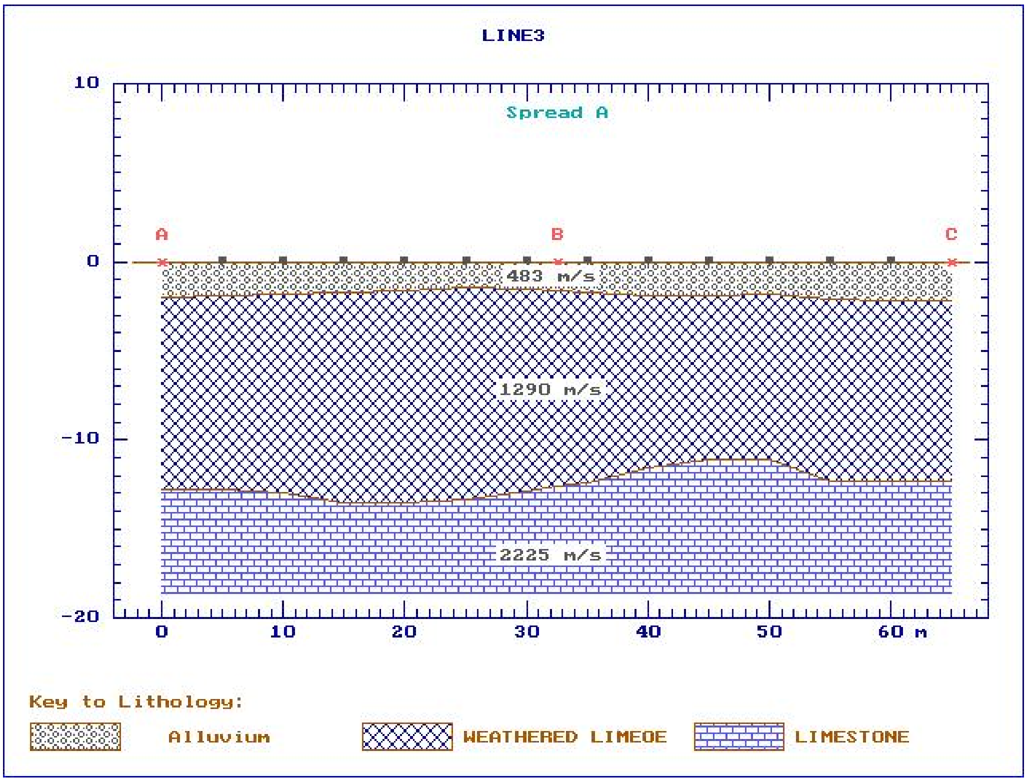


Fig. 4.11 Seismic Refraction Prpfile-3

Seismic Refraction Profile-4 :

Profile-4 is located on the western side downstream perpendicular to the Wadi and the last shot C located 5m from the channel bank. The interpretation of the seismic profile reveals a depth model that has two layers with velocity contrast as shown in Fig. 4.12. The average velocity of the first layer is 767 m/s and varies in thickness between 2 to 4 meters. This layer is often dry wadi sediments, mainly silty sands. The average velocity of the second layer is 1669 m/s and represents weathered limestone thicker near to the wadi. The bed rock limestone is deeper than 10 meters.

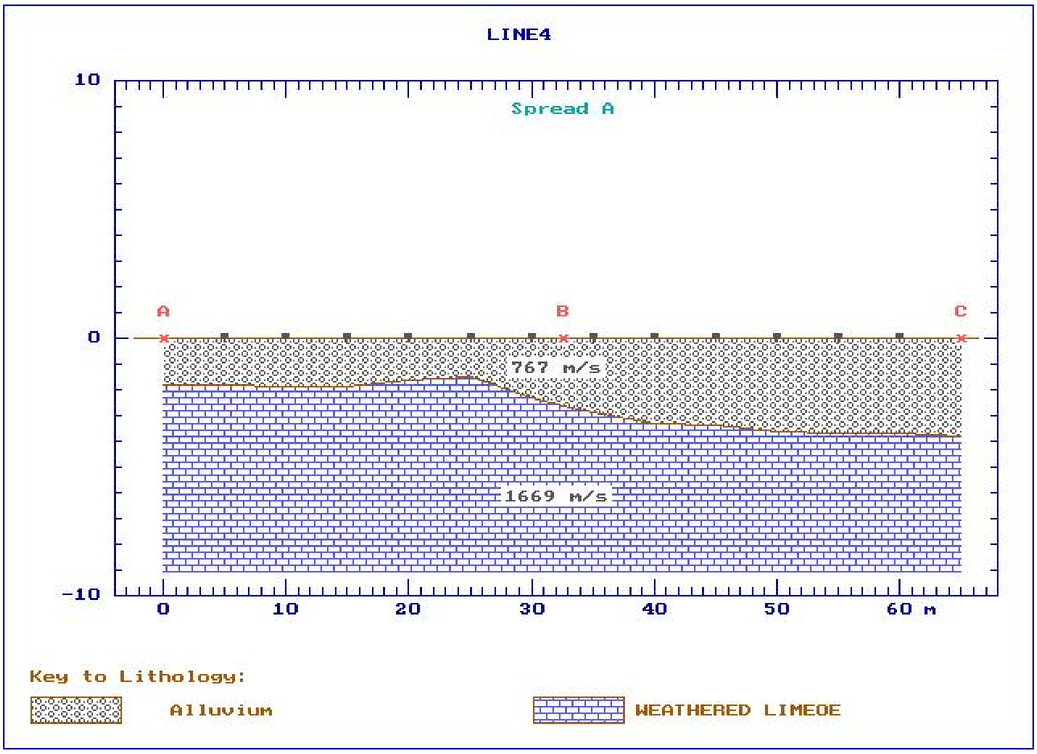


Fig. 4.12. Seismic Refraction Prpfile-4

Seismic Refraction Profile-5 :

Profile-5 is located on the western side downstream parallel to the Wadi. The interpretation of the seismic profile results reveals a depth model that has three layers with velocity contrast as shown in Fig. 4.13. The average velocity of the first layer is 601 m/s and varies in thickness between .5 to 2 meters. This layer is wadi sediments, mainly silty clayey sands. The average velocity of the second layer is 1148 m/s and thickness varies from 8 to 12 meters and represents weathered limestone. The average velocity of the third layer is 2110 m/s represents the bed rock limestone.

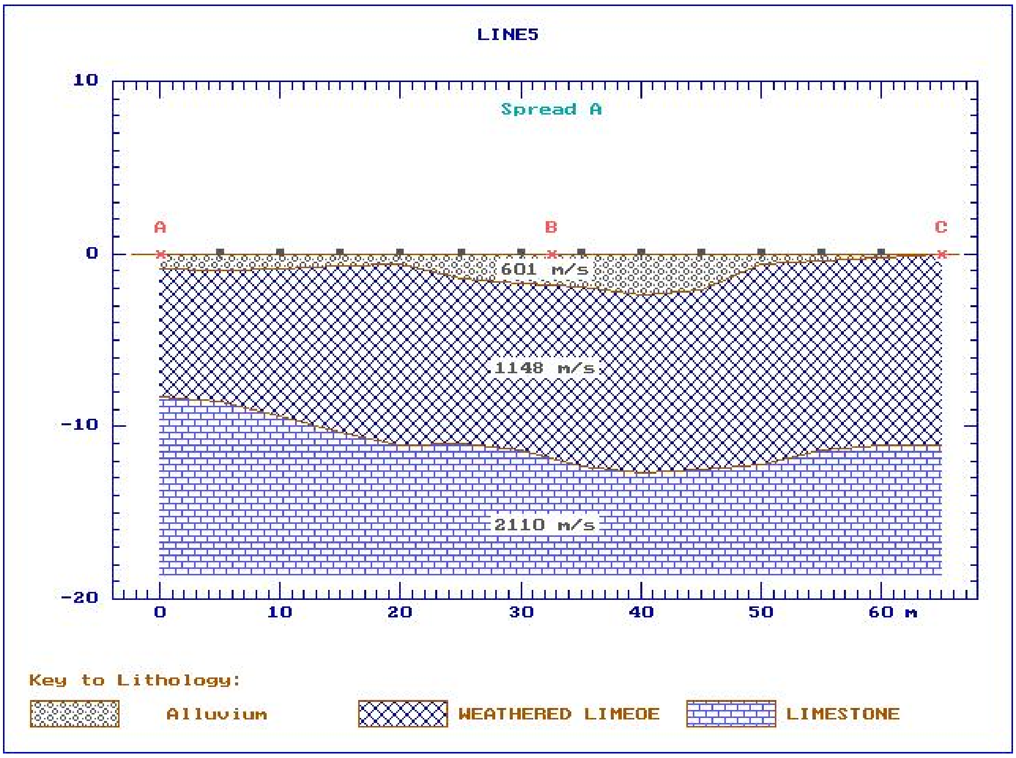


Fig. 4.13. Seismic Refraction Prpfile-5

<u>Seismic Refraction Profile-6</u> :

Profile-6 is located on the eastern side upstream perpendicular to the Wadi and the first shot A located 5m from the channel bank. The interpretation of the seismic profile results reveals a depth model that has three layers with velocity contrast as shown in Fig. 4.14. The average velocity of the first layer is 605 m/s and varies in thickness between 2 to 4 meters. This layer is often dry wadi sediments, mainly silty sands. The average velocity of the second layer is 1261 m/s and thickness varies from 2 to 10 m near to the channel. The velocity represents weathered limestone thicker near to the wadi and that may be due to fault along the wadi. Profile-6 located on the opposite side to profile-1 and same result was obtained.The average velocity of the third layer is 1977 m/s represents the bed rock limestone.

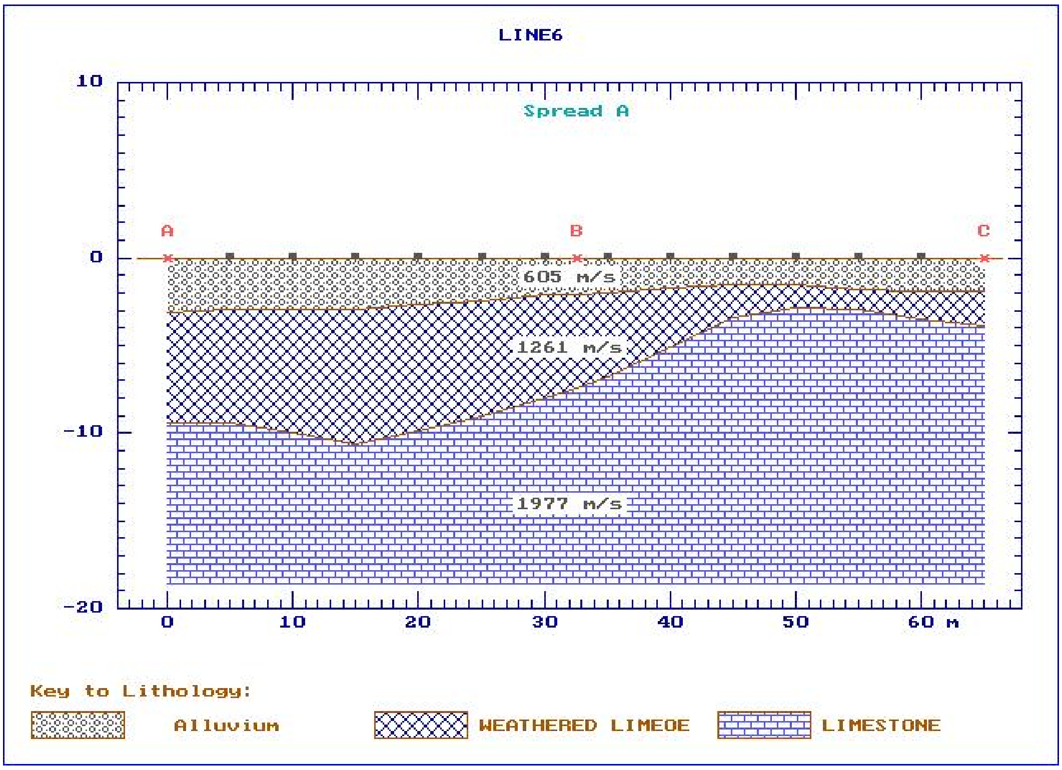


Fig. 4.14. Seismic Refraction Prpfile-6

Seismic Refraction Profile-7 :

Profile-7 is located on the eastern side parallel to the Wadi. The interpretation of the seismic profile results reveals a depth model that has three layers with velocity contrast as shown in Fig. 4.15. The average velocity of the first layer is 545 m/s and varies in thickness between 2 to 4 meters. This layer is wadi sediments, mainly silty clayey sands. The average velocity of the second layer is 1646 m/s and thickness about 15 meters represents weathered limestone. The average velocity of the third layer is 4502 m/s represents massive limestone near to surface at the end of the profile.

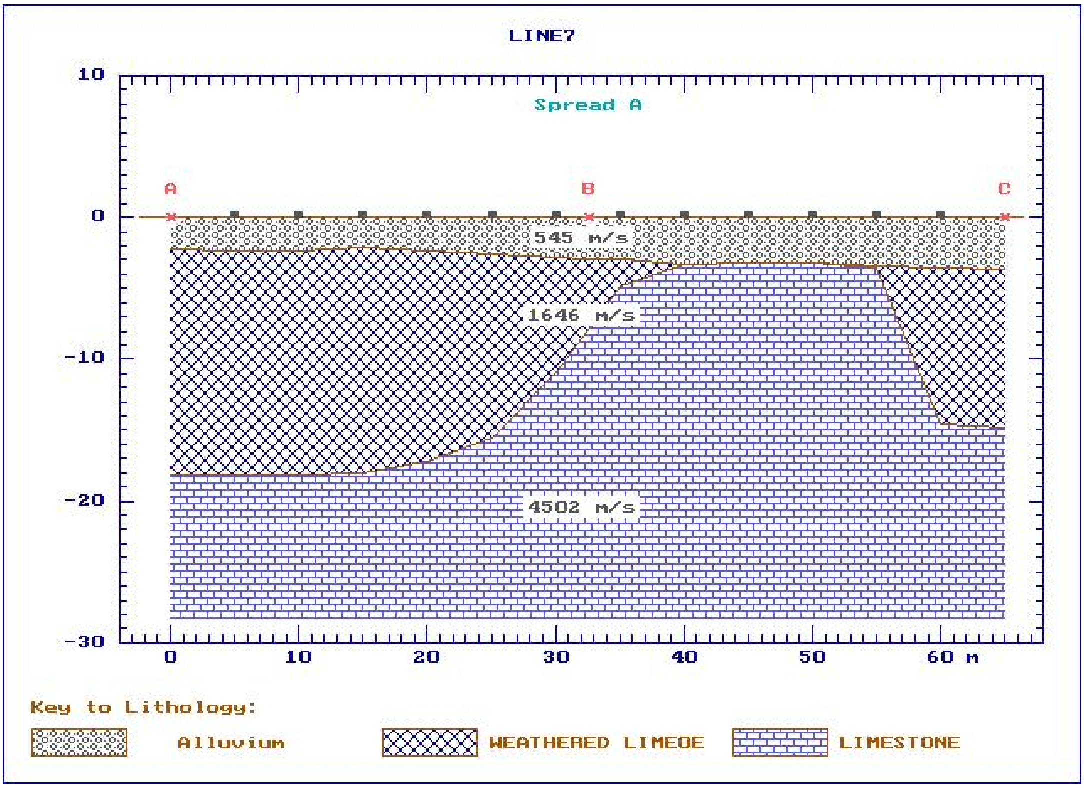


Fig. 4.15. Seismic Refraction Prpfile-7

Seismic Refraction Profile-8 :

Profile-8 is located on the eastern side parallel to the Wadi. The interpretation of the seismic profile results reveals a depth model that has three layers with velocity contrast as shown in Fig. 4.16. The average velocity of the first layer is 600 m/s and varies in thickness between .5 to 5 meters. This layer is wadi sediments, mainly silty clayey sands. The average velocity of the second layer is 1163 m/s and thickness about 12 meters represents weathered limestone. The average velocity of the third layer is 1988 m/s represents the bed rock limestone.

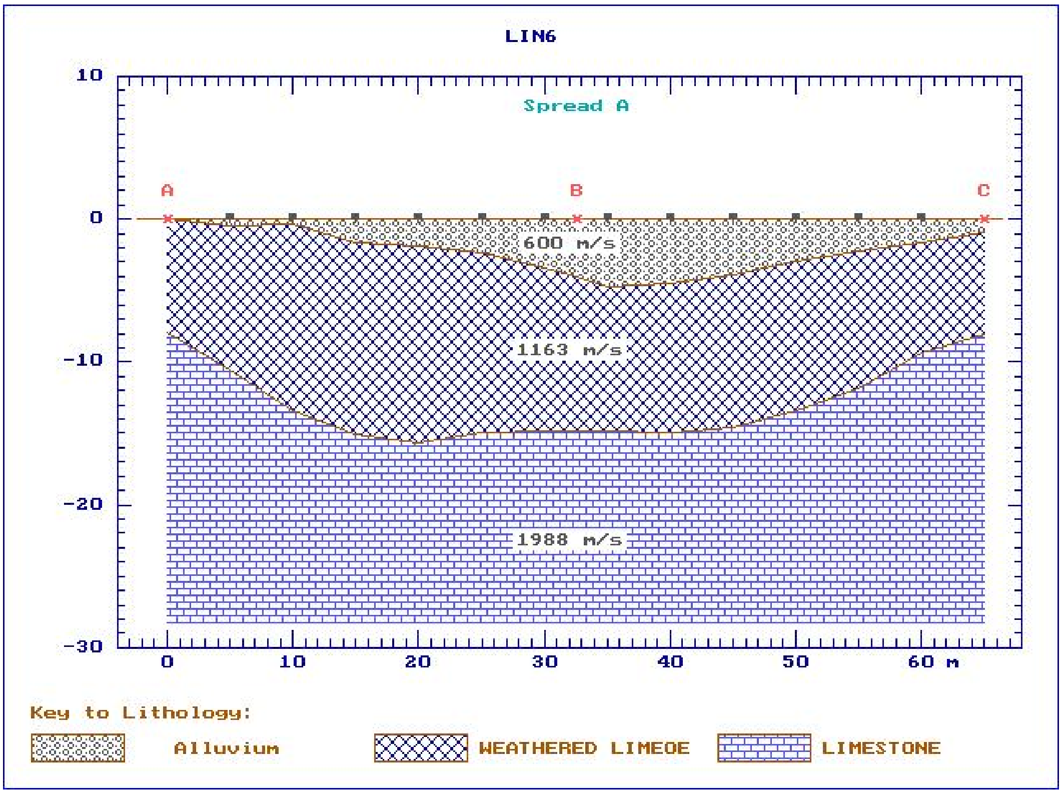


Fig. 4.16. Seismic Refraction Prpfile-8

Seismic Refraction Profile-9 :

Profile-9 is located on the eastern side downstream parallel to the Wadi. The interpretation of the seismic profile results reveals a depth model that has three layers with velocity contrast as shown in Fig. 4.17. The average velocity of the first layer is 519 m/s and varies in thickness between 2 to 3 meters. This layer is wadi sediments, mainly silty clayey sands. The average velocity of the second layer is 2009 m/s and thickness varies from 5 to 15 meters represents weathered limestone. The average velocity of the third layer is 2828 m/s represents the bed rock limestone.

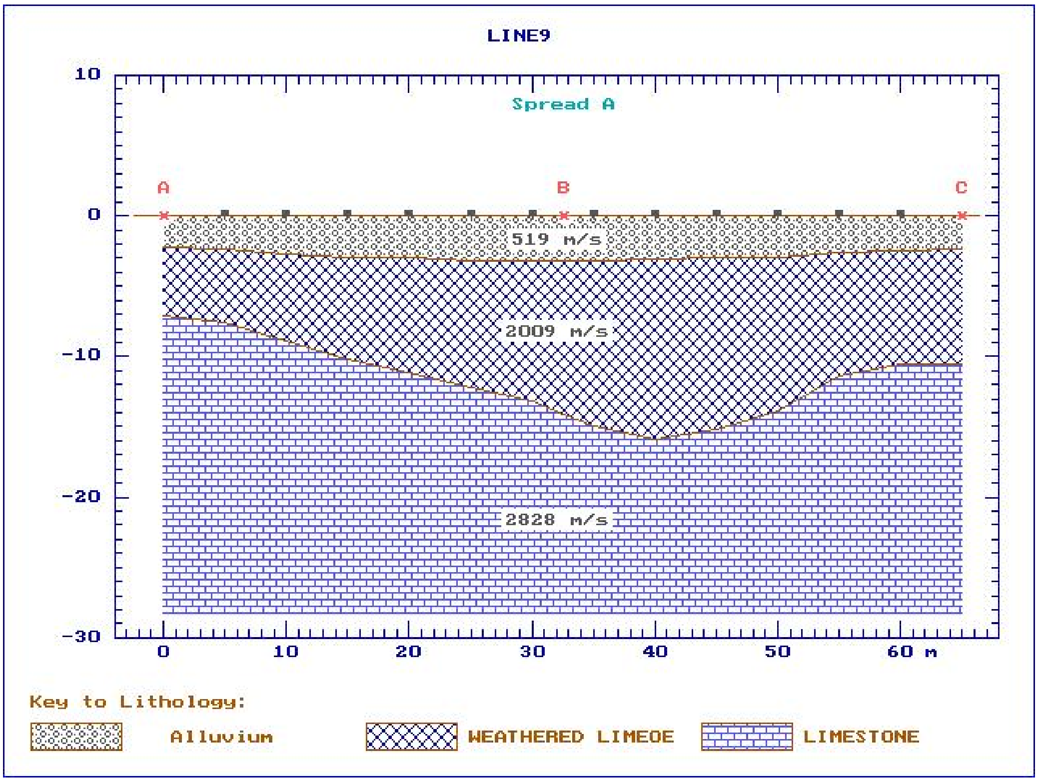


Fig. 4.17. Seismic Refraction Prpfile-9

Seismic Refraction Profile-10 :

Profile-10 is located on the western side downstream perpendicular to the Wadi and the first shot A located 5m from the channel bank. The interpretation of the seismic profile results reveals a depth model that has three layers with velocity contrast as shown in Fig. 4.18. The average velocity of the first layer is 786 m/s and varies in thickness between 1 to 4 meters. This layer is wadi sediments, mainly silty sands. The average velocity of the second layer is 1644 m/s and thickness varies from 8 to 16 meters thicker near to the wadi and represents weathered limestone. The average velocity of the third layer is 2980 m/s represents the bed rock limestone.

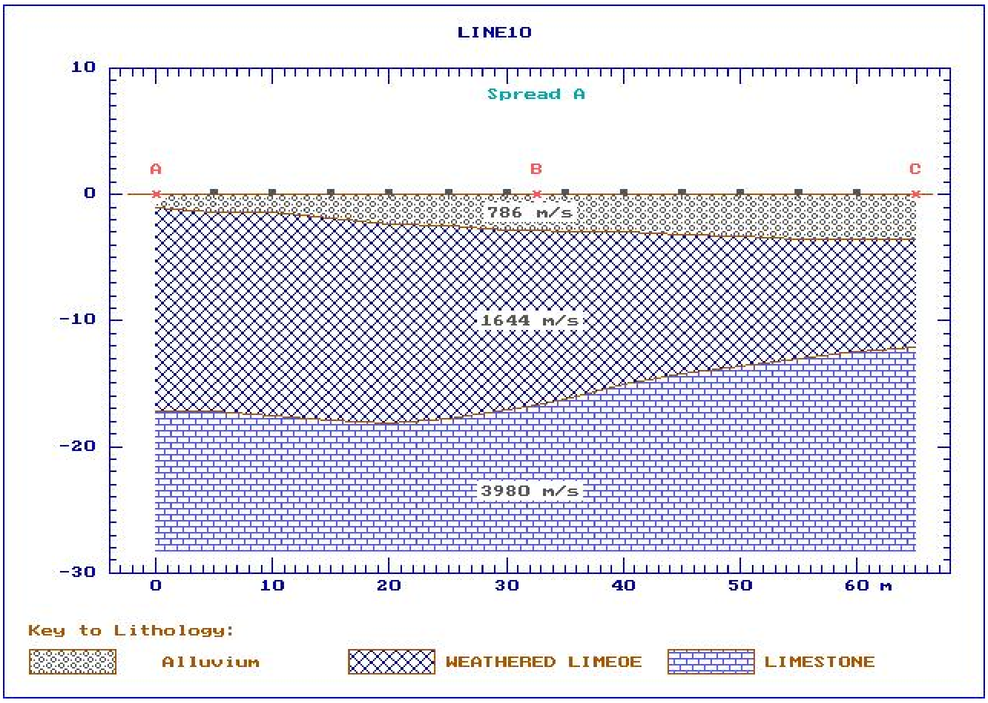


Fig. 4.18. Seismic Refraction Prpfile-10

4-4 WATER QUALITY

4-4-1 STREAM WATER

Surface water quality is most commonly associated with the discharge of effluents from sewer or sewage treatment plants and drains of wastewater. The disposal of wastewater from Riyadh City to Wadi Hanifah has caused serious environmental problems by bringing in considerable deterioration in the quality of water along the stream which creates swamps and marshes (Al-Fayzi and Al-Fateh, 1996). Ishaq (1992) studied the surface runoff and subsurface drainage of Riyadh City with respect to both qualitative and quantitative aspects of wastewater characteristics collected by the city drainage network and discharged into Wadi Hanifah through three main outlets. He observed that in an average year, the surface runoff discharged by the storm drainage network into Wadi Hanifah was approximately 2,190,000 m^3. Whereas, the volume of dry-weather flow discharged from the existing drainage systems in the city of Riyadh is approximately 53,400,000 m^3; i.e. some 26 times more. Since this is a perennial supply, a very high potential exists for the establishment of workable treatment schemes; thus, the quality of this drainage water is well within the possible concentrations suitable for reuse as well.

Assessment of stream water quality

Water quality is, generally, more important than water quantity and in Saudi Arabia this maxim is absolute. This is especially true for domestic and agricultural use. The quality of most natural waters is constantly changing. Water quality of the Wadi stream is influenced generally by dilution and various other physical, chemical, and biological processes. Table 4.1 summarises the results of the analyses of water samples collected from different stations along the Wadi River.

<u>pH of the water</u>

There is a little discernible regional variation for pH because site to site variations are small. The pH of the stream was slightly on the alkaline side, typical of a domestic sewage input (Arias et al, 2001). The pH level ranged from 7.35 to 8.38 within the range of natural waters (6.5 to 8.5) (Sarker et al., 1980; Antoine and Al-Saadi, 1982).

Hardness of the water

The stream water is generally very hard. The total dissolved solids (TDS) vary depending on the locations of water collection. The levels of TDS were between 1630 -4390 mg/L.

Electrical conductivity values were very high in the majority of stream samples (2226-5512 microsiemens/cm), reflecting the effect of effluent sources from residential and agricultural areas where large amounts of drainage water enter into the main Wadi steam, increasing its mineral load. High winds prevailing in the study area may be another source for increasing minerals into the Wadi. These winds coupled with high temperatures lead to higher evaporation rates, hence increasing the concentrations of salts in water.

Alkalinity

The total alkalinity was due only to the bicarbonate in the water. The total alkalinity was in the range of 180-500 mg/L. In general, there is a small variation in the alkalinity values of sampling stations along the Wadi River. The highest concentrations of alkalinity were found in site SW11a where watercourse creates swamps and marshes in this region of the Wadi stream.

Gross chemical composition

Chlorine is one of the substances that are usually present in the effluent discharged into the Wadi Hanifah stream. Under the hot climate of Riyadh, the water evaporates very quickly concentrating the chlorine so that the chloride has a large impact on the ecosystem. The concentrations of chloride (Cl^-) in the Wadi region varied between 300 and 1045 mg/L. The highest levels of chloride were detected in site SW11a where the stream flow is very low. Chloride shows some enhancement in the following sites by reduction in the concentration, which can be attributed to available dilution.

The nitrate concentrations (NO_3^-N) recorded in the region range between 0.29 and 7.96 mg/L. The stream of Wadi Hanifah contained a very low level of nitrates in this area where agricultural activities were less extensive. Bicarbonate concentrations (HCO_3^-) were found to be within the range of 216 - 600 mg/L. There is little changeable regional variation along the Wadi course except site SW11a.

Biochemical oxygen demand (BOD) was found to be in the range of 12 –148 mg oxygen/L. The majority of the BOD values along the Wadi stream indicated minor activity by microorganisms, hence the consumption of oxygen within five days is expected to be low. Nevertheless, at a few sites BOD values were exceedingly 'high', suggesting the presence of higher activity of microorganisms at these sites. The chemical oxygen demand (COD) indicates the presence of large amounts of organic matter in the water, due to the effluent of domestic sewage entering the stream. The stream water at various sites investigated can be classified into two categories based on the levels of COD concentrations ranging from 30 to 385 mg/L. The highest COD value of 385 mg/L coincided with that of highest BOD, due to the increase in organic matter for reasons explained previously. However, both high temperature and evaporation may act major factors in the variations of BOD and COD.

Trace elements

The results of the trace elements analysis are shown in Table 4.2. Trace metals concentrations tend to be below or near recommendations limits almost everywhere and were significant at only a few sites. Arsenic, Cadmium, chromium, lead, nickel and mercury concentrations in almost all water samples are non-detectable or at very low concentrations at most of the locations along the Wadi stream.

Phosphate in Wadi Stream

The main source of the total phosphates discharged into the drainage water is commonly from households where detergents are used in washing machines and industry (House and Denison, 1997). In addition, phosphates occur in significant concentrations in domestic sewage treatment work effluents as a result of their use in the treatment to prevent the formation of boiler scale and to decrease corrosion.

Phosphorus was found in wastewater/effluent in Wadi surface samples. The concentrations of total phosphate varied between 1.39 to 25.65 mg/L as analysed by ICP method. The analysis indicates that the amount of phosphate was significantly high. This is expected since sewage effluent is a major source of phosphate, thus the drainage water from Sewage Treatment Plants of Riyadh is usually discharged into the Wadi stream. In a typical sewage treatment plant the phosphorus removed into the sludge is 70-90% while in Riyadh sewage treatment plants the phosphorus removal is only about 30% (RSA, 1998).

Biological characteristics of stream water

The biological properties of the stream water samples collected at various stations along the Wadi region were analysed for the presence of coliform bacteria and fecal coliform counts. This bacteriological examination was intended to determine the quality of stream water and to evaluate its suitability for re-use. Table 4.3 shows the composite values of bacteriological analysis of Wadi stream water. Due to the fact that this water is contaminated by domestic waste, the presence of pathogenic organisms in the form of coliform group is to be expected. The results of the analysis show that water samples collected from all locations contain a high numbers of bacteria. Total coliform counts in Wadi stream were high at certain sites due to the disposal of untreated raw sewage from a district of Riyadh city and from the disposal of urban effluent from Riyadh city drainage network. The range of the total coliform varied between $1x10^4$ and $285x10^4$ in terms of the Most Probable Number per 100 millimetres (MPN/100 ml) and that of the fecal coliform was nil to $5x10^3$ (MPN/100 ml).

These values show a high level of bacterial activity in the waters of the Wadi. The concentration of fecal coliform fluctuates greatly between sampling sites. Downstream of the Wadi the concentration of bacteria in the water falls. This may be a result of natural purification within the stream system.

As a result of self-purification of wastewater, the fecal coliform bacterial counts decreased there after along the Wadi course. This Wadi course is covered by luxurious growths of reed plants and cattail plants. Schreijier et al. (1997) found that almost 95% of all coliform bacteria were removed from sewage treatment plant effluent in a constructed wetland system using two plant species. The climate in Saudi Arabia as a whole and Riyadh City in particular is characterised as being dry throughout of the year. This dry weather would help reduce the numbers of total coliform bacteria. This substantiates the findings of Green et al. (1997), who .maintained that a significant removal of total coliform was achieved in dry weather.

Table 4.1 The chemical composition for various locations along Wadi Hanifah stream

Well No.	PH	E.C.	TDS	B.O.D	C.O.D	Alkalinity	Biocarbonate	Calcium
SW9b	7.840	2359.714	1736.429	57.571	151.286	250.714	300.857	222.857
SW9a	7.836	2360.429	1737.571	58.000	152.714	245.000	294.000	266.429
SW15	7.854	2419.571	1784.857	56.143	147.571	256.429	307.714	238.571
SW10b	7.919	2455.571	1813.571	49.143	127.286	258.571	310.286	267.000
SW11a	7.929	4309.286	3367.714	66.143	175.286	348.571	418.286	436.714
SW11b	7.816	2398.429	1767.571	49.857	131.286	234.286	281.143	215.286
SW16	7.761	2417.429	1783.143	51.571	137.571	222.143	266.571	239.000

Well No.	Choloride	Magnesium	Nitrate	Potassium	Sodium	Sulphate	Ammonium	Phosphate
SW9b	345.000	48.957	2.959	15.769	236.969	567.143	30.588	17.876
SW9a	342.143	54.557	3.630	16.124	248.650	591.000	28.181	17.837
SW15	345.714	54.700	2.436	14.489	242.450	623.607	29.520	15.719
SW10b	342.857	53.314	2.470	14.536	259.126	619.000	29.166	15.387
SW11a	756.429	124.486	2.093	13.241	631.736	1232.536	3.301	4.621
SW11b	353.571	48.514	4.430	14.601	233.931	637.857	26.718	16.093
SW16	358.571	56.271	5.094	15.413	242.190	627.250	19.189	14.023

Table 4.2 Trace element concentration of Wadi stream at various locations along Wadi Hanifah

Well No.	Copper	Borron	Iron	Lead	Zinc	Mang-anese	Aesenic	Cadmium	Chromium	Cyanide	Mercury	Nickel
SW9b	1.059	1.234	0.123	0.000	0.065	0.026	0.006	0.000	0.001	0.022	0.000	0.008
SW9a	1.148	0.800	0.121	0.000	0.060	0.032	0.001	0.000	0.001	0.027	0.000	0.008
SW15	1.239	0.714	0.132	0.000	0.059	0.026	0.006	0.000	0.001	0.016	0.000	0.010
SW10b	1.202	0.771	0.119	0.001	0.063	0.035	0.006	0.000	0.001	0.015	0.000	0.007
SW11a	1.935	0.943	0.078	0.001	0.064	0.057	0.003	0.000	0.001	0.010	0.000	0.116
SW11b	1.135	0.657	0.108	0.000	0.040	0.037	0.006	0.000	0.001	0.012	0.000	0.011
SW16	1.118	0.543	0.097	0.000	0.035	0.034	0.001	0.000	0.001	0.013	0.000	0.010

Table 4.3 Bacterial count analysis in Wadi stream

Well No.	Total Coilform	Fecal Coliform
SW9b	1057142.857	1557.429
SW9a	1091428.571	714.429
SW15	548571.429	1628.857
SW10b	598571.429	1343.000
SW11a	260000.000	1.000
SW11b	220000.000	1.000
SW16	140000.000	450.667

4-4-2 GROUNDWATER

The relationship between flow in Wadi Hanifah and the rising water table has been studied (ADA, 1990; Rushton and Al-Othman, 1994). Historically the Wadi has been a major source of recharge for the shallow aquifers that underlie Riyadh, particularly upstream of the city. However, since urbanisation, the impact of natural flows in the Wadi on groundwater levels in the city has been insignificant in comparison with other recharge components. The most notable interaction exists downstream of the city where water levels in the Wadi alluvium are now higher than in the adjacent aquifers due to the effect of drainage flows (ADA, 1990).

Assessment of groundwater quality

The results of the chemical analyses carried out on samples from 14 wells along the study area are presented. Organic and inorganic constituents of the water samples were examined for each of the 14 sample wells. The indicators studied include pH, electrical conductivity, alkalinity, nitrate, phosphate, and bacterial activity and trace metal concentrations. The values and variations of these water characteristics for the different wells are outlined and discussed below. It was decided that descriptions of the groundwater composition results would be related to their locations within the Wadi.

Physico-chemical properties of groundwater

Hydrogen ion (pH) of the groundwater samples ranged between 6.70 and 8.35. These values are within the pH values provided by the USA (6.5-8.5) for drinking water. The total alkalinity recorded in the range of 200 to 800 mg/L. In groundwater, the distribution of electric conductivity is influenced by several factors: historic climate fluctuation; interaction with other aquifers; and the quality of recharge water.

Electrical Conductivity (EC) was very high in all water samples collected in the wells. It varied from 3012 to 12470 microsiemens per centimetre. These high values of EC can be directly compared with values of calcium and magnesium.

Most of the groundwater in the Kingdom may be classified as brackish. The previous observations in groundwater compounded show a high level of salinity in groundwater around the Wadi stream. These observations are in agreement with other published studies (Alaa El-Din et al., 1994; Al-Jaloud and Hussain, 1993).

This high groundwater salinity may attributed to the groundwater flow into the

Wadi aquifers zone through the Jubaila formation and the Arab formation both of which contain fracture zones with higher conductivity formed as a result of dissolution of calcium sulphate (anhydrite) and calcium carbonate (calcite and limestone rock) (ADA, 1990).

A review of the chemical composition shows that the groundwater in Wadi Hanifah falls into the category of 'very high salinity' (C4) according to the USDA, Salinity Laboratory Classification of irrigation water (Al-abdula'aly, 1998) and thus requires careful use for crop production.

Chemical composition of groundwater

Inorganic parameters: The results obtained from the chemical analysis of water collected from 14 wells along Wadi Hanifah are presented in Table 4.4.

The most notable feature of Table 2 is the water composition of the two well sites (M16b and M16c) of the Wadi region. The water at these sites contains highest levels of all of the principal elements. These results obscure the general chemical characteristics of the water in the wells of the Wadi. Individual components show broad trends for groundwater composition throughout the study area. The concentrations of calcium and magnesium are in the range varying from 320 to 590 mg/L and from 30 to 276 mg/L, respectively. Variations in the calcium and magnesium levels are broadly parallel at most of the well sites.

Chloride values in the groundwater samples were very high for most of the well samples with an average of 886 mg/L with standard deviation of 746 mg/L. The highest concentration of chloride was 3500 mg/L and the lowest value (375 mg/L). The sources of high chloride contents in the study area are the brackish nature of groundwater in Saudi Arabia, and also agricultural activities.

Variations in the alkalinity of the groundwater in the study area of the Wadi are minor, higher concentrations of alkalinity (800 mg/L) are found in well M16b whilst lower concentrations (200 mg/L) are found in well BH19 downstream in the lower Wadi.

Parameters influence by organic matter: It should be noted that wells M16b and M16c do not show the extreme characteristics of organic abundance that were evident in the inorganic components. The level of nitrate in the groundwater varies greatly between wells. The nitrate levels recorded in the wells water range between 1.10 and 66.00 mg/L. Nitrate exhibits a general fall in levels down valley. Wells M19c and M19b have very low concentration of nitrate. The high nitrate values in groundwater is probably due to the application of fertilisers. Fresh groundwater is usually low of nitrate (Valiela, 1983), but agricultural and urban contributions may produce very high groundwater nitrate values. It is noted that in several wells located within the Riyadh area nitrate levels were recorded in higher levels i.e more than 50 mg/L (Al-abdula'aly, 1997). This clearly illustrates the impact of agricultural practices in these areas. All these wells are located within small farmsteads. Manure, which is high in nitrate is used as fertiliser, hence large amounts of nitrates find their way into groundwater, due to the sandy, unsaturated zones around the wells. On the other hand, some of the sampled sites contained nitrate in much lower levels. These are the deep wells in which leakage from surface water is minimized.

Like calcium and magnesium, bicarbonate also fluctuated from well to well falling in the range 240 277 mg/L – 960 277 mg/L. The biological oxygen demand (BOD) was found to be in the range of 26 to 74 mg/L, the BOD oscillates close to the mean and doesn't exhibit the variation that is evident in the wells of the study area along the Wadi.

Presence of phosphorus in groundwater.

The region of the Hanifah Wadi that is being investigated in this study is affected not only by urban wastewater and sewage disposal but also by the intense agricultural activity practised on the adjacent land. Phosphorus concentrations in the groundwater will reflect this inputs as a potential sources of pollution. The fourteen wells along the Wadi were assessed for phosphorus concentrations in three forms; total phosphorus, and total dissolved phosphorus.

A small amount of total phosphorus was detected in major of the wells whilst only three samples contained a detectable amount. The levels of total dissolved phosphorus were never above 0.58 mg/L. Although fewer sites contain total dissolved phosphorus at traceable levels, the concentrations at well M16c and BH46 are considerably high.

Phosphorus concentrations at all sites are considerably low. This may be attributed to two main factors. The first is that the geological structure of the area is deficient in phosphorus. The second is that most of the reactive upper layer of surface soils have adsorbed and retained available phosphorus. Thus, the low value of phosphorus in groundwater tends to achieve dynamic equilibrium with the solid phase of sediments through adsorption desperation reactions (Froelich, 1988). Takater et al. (1999) found that phosphorus concentrations in both shallow and deep groundwater in a regularly flooded area in the Rhine Plain (eastern France) were less than 62 to 76% of those found in surface water which related to the retention capacity of the clay colloids of soils.

Trace elements in groundwater

The concentration of trace elements in groundwater samples collected from 14 wells along Wadi Hanifah is shown in Table 4.5. Twelve trace elements were measured. This includes priority pollutant elements and secondary pollutant elements. The high-risk pollutant (priority) elements recorded in the groundwater samples of the Wadi are: arsenic, cadmium, chromium, copper, lead, and zinc. The trace element concentrations are found at very low levels. Arsenic and chromium were only detected in three samples (arsenic) and one sample (chromium) and below the detection limits in the remaining wells. Copper occurred in all wells at levels above 0.006 mg/L with the highest concentration of 1.4 mg/L with little variation between sites. Cadmium and lead both found in very low concentrations with a little variation between sites. All wells samples contained low concentrations of zinc, range from below the detected limit to 1.88 mg/L.

The secondary pollutant elements determined by ICP analysis include: boron, cyanide, iron, manganese, mercury and nickel. The concentrations of these elements were either insignificant or very low.

The results relating to the concentrations of trace elements show that these concentrations are very low. These results agree with those recently reported by Alabdula'aly (1998), who also investigated trace elements in groundwater and treatment plants production in Riyadh. The study area of Alabdula'aly (1998) was in and around Riyadh city. The present study involved wells along Wadi Hanifah. It should be noted that wells investigated in the present study all sampled shallow groundwater, whereas those studied by Alabdula'aly were deep, unconfined aquifers.

Bacteriological characteristics of groundwater

The locations of the wells within the catchment of urban areas and also agricultural areas may explain the impact of domestic sewage disposal into the groundwater along the Wadi Hanifah, some of which seems to have percolated into the wells. Al-Kharabsheh (1999) investigated the effect of urbanisation on spring water quality at Wadi Kufranja basin, Jordan. He found that the cesspools of houses not connected to the sewer system are the main cause of water pollution by fecal coliform bacteria. Thus, the implementation of well protection zones and groundwater monitoring network for the control of possible groundwater contamination from sewage effluent is necessary (Bernhart, 1973, El-Arabi, 1999).

In the groundwater (well samples), bacterial counts were made for coliform groups and found to be in the range of zero to high (Table 4.6). Since the surface water locations were positive with high counts of coliform and fecal coliform, the groundwater supplies which were located near the stream, along the Wadi, are expected to be contaminated with bacteria and pathogens.

The groundwater samples showed contamination with total coliform bacteria. The coliform counts were exceedingly high. While the analysis of fecal coliform bacteria in the wells of the study area showed less than one colonies per 100 ml.

The bacteriological results suggest that the groundwater in some areas is being polluted due to the insurgence of wastewater from some other sources. In this case the pollutant source could be the seepage of water from Wadi Hanifah main water stream flowing through the area which may cause problems if the well water is being used as a source of irrigation water. There is also the possibility of the effect of the radius of influence of the well at the time of pumping water that might have increased the seepage of flow from Wadi stream.

Table 4.4 The chemical Composition in Wadi Hanifah groundwater

	P^H Value	E.C.	TDS	B.O.D.	C.O.D.	Nitrate (NO3)	Ammonia	Total Phosphorus	Alkalinity
M19c	7.312	3547.167		43.000	114.167	1.657	5.292	3.148	286.667
M19b	7.382	3962.500		40.000	105.833	2.387	3.030	2.852	275.000
M19a	7.160	3254.333		34.000	90.333	25.459	1.398	2.850	255.833
M6a	7.390	4326.500		33.167	87.833	23.187	2.359	3.377	270.833
T6	7.427	4750.167		33.000	86.667	28.546	3.251	3.412	270.000
M15	7.387	5423.667		35.333	93.500	29.050	3.718	2.752	298.333
M11	7.323	4156.667		32.667	76.833	86.067	1.114	3.193	248.333
M16a	7.105	4317.167		36.333	91.333	50.928	1.532	2.517	396.667
M16b	6.938	11933.333		52.000	131.667	57.807	1.513	2.515	625.833
M16c	7.070	7050.667		56.333	139.000	10.259	15.921	4.090	610.000
M18a	7.337	4407.833		32.167	80.500	26.439	3.628	3.628	258.333
BH46	7.330	3129.000		33.000	88.833	21.347	1.282	3.770	198.333
BH28	7.318	3281.000		33.667	88.500	29.589	1.505	4.260	259.167
BH19	7.473	3087.333		32.500	86.000	27.681	1.125	3.023	189.167

	Bio-carboniate	Calcium	Chloride	Magnesium	Potassium	Sodium	Sulphate	Amm-onium	Phos-phate
M19c	344.000	352.333	520.833	140.600	14.588	368.502	1034.813	5.648	
M19b	330.000	430.167	570.167	143.500	18.703	336.192	1342.500	3.221	
M19a	307.000	409.167	436.667	94.600	11.560	274.943	1033.750	1.481	
M6a	325.000	474.500	632.500	144.467	12.885	488.205	1344.500	2.513	
T6	324.000	534.833	703.333	165.533	13.728	444.838	1655.417	3.452	
M15	358.000	561.833	999.167	199.500	15.983	560.747	1565.833	3.953	
M11	298.000	465.333	567.500	85.767	18.832	492.453	1256.250	1.178	
M16a	476.000	392.500	881.667	186.533	7.452	560.485	914.833	1.625	
M16b	751.000	516.000	3149.167	244.433	3.328	3396.810	1683.417	1.614	
M16c	732.000	526.500	1772.500	203.133	25.960	1244.967	1082.750	16.943	
M18a	310.000	527.167	635.000	134.550	17.562	422.545	1519.750	3.905	
BH46	238.000	380.333	408.333	78.950	14.762	263.030	1074.167	1.358	
BH28	311.000	419.667	386.667	91.233	10.197	210.295	1130.000	1.595	
BH19	227.000	355.167	434.167	74.550	11.942	239.665	1025.625	1.192	

Table 4.5 Trace elements concentration in Ground Water samples along Wadi Hanifah

	Borron	Mang-anese	Lead	Zinc	Iron	Copper	Arsenic	Chrom-ium	Cadm-ium	Cyanide	Mercury	Nickel
M19c	1.133	0.283	0.004	0.013	0.321	0.240	0.001	0.000	0.001	0.011	0.000	0.031
M19b	1.400	0.328	0.002	0.020	0.559	0.415	0.002	0.000	0.001	0.013	0.000	0.088
M19a	1.100	0.015	0.000	0.024	0.028	0.395	0.001	0.000	0.000	0.009	0.002	0.005
M6a	1.800	0.126	0.028	0.061	0.027	0.416	0.009	0.001	0.001	0.014	0.001	0.036
T6	1.383	0.133	0.025	0.350	0.025	0.389	0.009	0.001	0.001	0.013	0.001	0.021
M15	1.700	0.206	0.014	0.408	0.049	0.182	0.007	0.000	0.000	0.013	0.003	0.048
M11	1.333	0.165	0.011	0.149	0.027	0.376	0.014	0.000	0.000	0.015	0.001	0.017
M16a	1.700	0.187	0.022	0.059	0.067	0.307	0.013	0.001	0.001	0.013	0.001	0.026
M16b	1.783	1.515	0.004	0.604	0.068	0.285	0.005	0.008	0.000	0.015	0.001	0.097
M16c	1.150	1.863	0.002	0.616	0.501	0.483	0.006	0.001	0.000	0.008	0.000	0.125
M18a	1.350	0.322	0.014	0.316	0.176	0.156	0.003	0.000	0.000	0.013	0.001	0.058
BH46	0.850	0.269	0.024	0.077	0.060	0.311	0.011	0.001	0.001	0.020	0.001	0.013
BH28	1.533	0.092	0.008	0.122	0.535	0.356	0.011	0.000	0.000	0.006	0.002	0.014
BH19	0.917	0.114	0.008	0.054	0.034	0.368	0.007	0.000	0.001	0.010	0.002	0.013

Table 4.6 Bacterial count analysis in Wells Samples

	Total Coilform	Focal Coliform
M19c	311666.667	0.833
M19b	245000.000	0.833
M19a	380000.000	0.833
M6a	208333.333	0.833
T6	1101666.667	0.833
M15	448333.333	1.000
M11	421666.667	0.833
M16a	281666.667	0.833
M16b	850000.000	0.833
M16c	418333.333	0.833
M18a	605000.000	0.833
BH46	685000.000	0.833
BH28	550000.000	1.000
BH19	448333.333	0.833

CONCLUSIONS & RECOMMENDATIONS

CONCLUSIONS

This project investigates the physico-chemical and bacterial characteristics of stream water and groundwater to assess how this current condition has evolved.

Results showed that the Wadi stream contains low concentrations of trace elements, but has unacceptably high bacteriological pollution, due to the fact that effluents feeding the stream are mainly residential.

Wastewater disposal, along the course of Wadi Hanifah, has lead to general increases in the electrical conductivity of the stream water, and it has also introduced large amounts of organic matter into the water, which fits more into the high to very high level of contamination for water courses.

A sewage treatment plant provides the dominant point source input for phosphate and also a reduction in phosphate concentrations along the Wadi stream, away from the plant. This improvement in water quality is due to the high degree of self-purification resulting from a combination of ponds and natural purification processes.

In the Riyadh area, the amount of water necessary for the inhabitants has increased with the population growth of the city. Hence there has been an increased burden on groundwater supplies in the form of depletion and pollution.

The findings of the study related to the groundwater quality indicated a significant bacterial contamination in wells within the study area, suggesting a recharge from agricultural and urban areas. The concentrations of trace elements in groundwater are very low.

Additionally, the detailed geophysical investigation seismic refraction, resistivity image, and VES revealed that the study area consisting of three major layers. The uppermost layer has moderate resistivity and is composed of alluvial deposits mainly clay and sand with thickness varies from1 to 15 m. The middle layer has high resistivity values and is composed of limestone at depth varies from 15 to 80 m. The lower layer has low resistivity values and may represent fractured weathered limestone .

Water bearing-zones occur in two aquifers, shallow contaminated water at depth 10 m in alluvial deposits and the deep fresh water aquifer at depth of about 100 m in fractured limestone. The interface between the contaminated water (sanitary water) and fresh water marked out horizontally at 100 m distance from the main channel and vertically at 20 m depth. This means that the sanitary water flow down to a depth about 20 m direct in the alluvial deposits but since there is a fractured limestone the upper 30 m should be cased and sealed to prevent the sanitary water to mix the deep fresh water. Also the deep wells should be located far from the main channel about 100 m distance.

The combination of vertical electrical sounding (VES), resistivity image, and seismic refraction have made a valuable contribution to the identification of the interface between the contaminated and fresh water in the study area. Resistivity image and sounding in this area clearly identified the nature of the lithological depth and proved useful at identification water-bearing zones. Fresh groundwater was found in the study area at depth 100 m within the fractured limestone.

RECOMMENDATIONS

The present study suggests several recommendations for further investigations:

- ❖ Conducting systematic surveys of groundwater quality within Riyadh city to detect the presence of contaminates.
- ❖ Future studies should consider the mercury levels in the main stream.
- ❖ The limited data on toxic metal concentrations suggests that a national project for this purpose should be carried out to assess groundwater quality for human consumption and agricultural usage.
- ❖ Dwelling codes have to be established in Riyadh to ensure that sepatic tanks and cesspools are properly built and maintained to prevent wastewater overflows in order to protect groundwater from pollution.

REFERENCES

Alaa El-Din, M. N., Madany, I. M., Al-Tayaran, A. Al-Jubair, A.H., and Gomaa, A. (1994). Trends in water quality of some wells in Saudi Arabia, 1984-1989.

Abel, P.D. (1989). Water Pollution Biology. Ellis Horwood Limited Publishers, Chichester, UK.

ADA - Arriyadh Development Authority. (1990). Draft report of water resources management study. Wadi Hanifah Development Programme. High commission for development of Riyadh

Al-abdula'aly, A. (1997). Nitrate concentrations in Riyadh, Saudi Arabia drinkingwater supplies. Environmental Monitoring and Assessment.47, 315-324.

Al-abdula'aly, A. (1998). Trace metals in groundwater and treatment plant product water of the central region of Saudi Arabia, Desalination. 120,163-168

Al-Dhowalia, K.h.(1986. Reuse of Riyadh Wastewater for Irrigation. Project No. 18-1402, Final report. King Abdulaziz City for Science and Technology, Riyadh-Saudi Arabia

Al-Fayzi, S. A. and Al-Fateh, M.(1996). Program for Control high Groundwater Level in Riyadh. Proceedings of symposium on Wastewater Treatment Technology and Re-use, Riyadh, Saudi Arabia 19-20 November 1996, pp 185-204. College of Engineering. King Saud University and Riyadh Region Water and Sewage Authority, Riyadh, Saudi Arabia

Ali, I. (1987). Wastewater criteria irrigation in arid region, Journal of Irrigation and Drainage Engineering, 113, No. 2, 173-183.

Al-Ibrahim, A. (1990). Water Use in Saudi Arabia: Problems and Policy Implications.Journal of Water Resources Planing and Management, 116, No. 3, 375-388.

Al-Jaloud,A (1994). Effect of Irrigation with treated Municipil wastewater on Soil and Crops. Met., Environment Arid Land Agricultural Science, 5, 77-88.

Al-Jaloud, A., and Hussain, G. (1993). Waters quality of different aquifers in Saudi Arabia and its predictive effects on soil properties. *Arid Soil Research and Rehabilitation*, **7**, 85-101.

Al-Jaloud, A., Hussain, G., Al-Saati, A., and Karimullah, S. (1995) Effect of Wastewater Irrigation on Mineral Composition of Corn and Sorghum Plants in a Pot Experiment. *Journal of Plant Nutrition*, **18**(8), 1677-1692.

Al-Kharabsheh, A. A. (1999). Influence of urbanisation on water quality at Wadi Kufranja basin (Jordan). *Journal of Arid Environment*. **43**, 79-89.

Al-Othman,A.A.(2002). Environmental Study of Wadi Hanifah,Riyadh with special Reference to Wastewater and Quality of the stream Water, Groundwater and Sediments, Ph.D. Theses. Cardiff University, UK.

Antoine, S. E., and Al-Saadi, H. A. (1982). Limnological studies on the polluted Ashar Canal and Shatt al-Arab River at Basrah (Iraq). *Internatoinale Revue gesamten der Hydrobiologie*. **67**, 405-418.

Arias, C. A., Del Bubba, M. and Brix, H. (2001). Phosphorus removal by sands for use as media in subsurface flow constructed reed beds. *Water Research*. **35**, 1159-1168.

Arriyadh Development Authority (ADA). (1990). *The Rising Groundwater Management Program. Volume 1*. High Commission for Development of Arriyadh. Riyadh. Saudi Arabia.

Bernhart A. P. (1973). Protection of Water-supply Wells from Contamination by Wastewater. *Ground Water*. **11**(3), 9-15.

Bobachev, A. A., Modin, I. N., and. Shevnin, V. A., (2002). IPI2Win software program, Department of Geophysica, Geological Faculty, Moscow State University, Moscow, Russia.

Chapman, D. and Kimstach,K. (1996). The Selection of Water Quality Variables. In Deborah Chapman(ed) Water Quality Assessment: A Guide to the Use of Biota.Sediments and Water in Environmental Monitoring, pp. 59-125. Second edition Published on behalf of UNESCO, WHO,UNEP and E&FN SPON. An Imprint of Chapman &Hall. London.

Edgell, H. S. (1997). Aquifers of Saudi Arabia and their geological frameworks. *The Arabian Journal for Science and Engineering* **22**, 3-31.

El-Arabi, N. (1999). Problems of groundwater quality related to the urban environment in greater Cairo. In Bryan Ellis J. (ed) *Impact of urban growth on surface water and groundwater quality, proceedings of an international symposium held during IUGG 99, at Birmingham, UK 18-30 July 1999*, pp 29-38.

El-Khatib, A. B. (1980). Seven Gren Spikes. Water and Agricultural Development, 2nd edn. Riyadh, Kingdom of Saudi Arabia. Ministry of Agriculture and Water.

Ellis, K. V, White, G., Warn, A. E. (1989). *Surface Water Pollution and its Control*. pp 101, Macmillan presses Ltd, London. UK.

FAO, Water Quality for Agriculture (1985), Irrigation and drainage, paper 29 Rev., Edited by Ayers, R.S. and Westcot,D. W. Rome.

Fatwa (Religious ruling) on use of Recycled Wastewater for Religious Purposes (1979). In Mamdouh Shahin, A.A. (ed) Hydrology and Scarcity of Water Resources in Arab Region. Balkema Publishers, Netherlands. 1996.

Green, M. B., Griffin, P., Seabridge, J. K. and Dhobie, D. (1997). Removal of bacteria in subsurface flow wetlands. *Wat. Sci. Tech*. **35**(5), . 109-116.

House, W. A. and Denison, F. H. (1997). Nutrient dynamics in lowland stream impacted by sewage effluent: Great Ouse, England. *The Science of the Total Environment.* **205**, 25-49.

Hussain, G. and Saati, A.J(1999) wastewater quality and its reuse in agriculture in Saudi Arabia. Desalination, 123, 241-251

Ishaq, A. M. (1992). Surface and subsurface drainage of metropolitan city in arid zone. *Journal of Irrigation and Drainage Engineering*. ASCE. **118**(1), . 19-35

Lloyd, J. W. etal (1991)Urban and Industrial groundwater pollution . In Bowning, R.A. and Wilknson W.B. (eds),pp. 134-148. Groundwater Hydrology.

Meterology and Environment Protection Adminstration, MEPA (1999), cited in Al-Othman .A. 2002, Ph.D. Thesis.

Pettygrove,G. and Asano,T.(1988). Irrigation with Reclaimed Municiple Wastewater- A Guidline Manual. 3rd Edition, Michigan: Lewis.

Riyadh Area Water and Sewage Authority(RSA), Annual Report(1995).

Riyadh Area Water and Sewage Authority(RSA), Water Programme, water and Wells Department (1998). Water Consumption for Riyadh City. Cited in Al-Othman A, 2002).

Rushton, K. R. and Al-Othman, A. A. R. (1994). Control of rising groundwater levels in Riyadh, Saudi Arabia. In Wilkinson, W. B. (ed) *Groundwater problems in urban areas; proceedings of the international conference*, pp. 299-309. Thomas Telford, London, United Kingdom.

Sarker, A. L., Al-Nasiri, S. K., and Hussein, S. A. (1980). Diurnal fluctuations in the physico-chemical conditions of the Shatt al Arab and the Ashar Canal. *Proc. Indian Acad. Sci. (Anim. Sci.)*. **89**, 171-181.

Schreijier, M., Kampf, R., Toet, S. and Verhoeven, J. (1997). The use of constructed wetlands to upgrade treated sewage effluents before discharge to natural surface water in Texel Island, the Netherlands – Pilot study. *Water Science Technology.* **35**(5), 231-237.

Sendil, U. Salih, A. M. and Alvi. S. H. (1983). Hydrological Characteristic of Wadi Hanifah. In: *Water Resources in Saudi Arabia*, **1**, pp. 1-14. Symposium, 17-20 April 1983. Riyadh, Saudi Arabia.

SOGREAH (1967). *Water and Agricultural Development Studies, Area V*. Final Report for Ministry of Agriculture and Water, Riyadh, Saudi Arabia.

Takater, N., SanchezPerez, JM. and Tremolieres, M. (1999). Spatial and temporal variations of nutrient concentration in the groundwater of a floodplain: effect of hydrology, vegetation and substrate. *Hydrological Processes*. **13**(10), 1511-1526.

Valiela, I. (1983). Nitrogen in salt marsh ecosystems. In Carpenter, E. J. and Capone, D.G., (eds) *Nitrogen in the Marine Environment,* pp. 649-678 Academic Press, New York.

Wallingford, Froelich, P. N. (1988). Kinetic control of dissolved phosphate in natural rivers and estuaries: a primer on the phosphate buffer mechanism. *Limnology and Oceanography* **33**, 649-668.