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Evaluation of Potential Artificial Recharge of the Shallow Plio-Plistiocen Aquifer System Case Study Al-Auja

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Evaluation of Potential Artificial Recharge of the Shallow Plio-Plistiocen Aquifer System

Case Study Al-Auja

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Dedication

To my mother and father who put me on the road of success from the beginning of my life and I made them proud of me as I promised

To my mother and Father in law who believed on me as if I were their real daughter

To my husband, my soul mate “Ghassan” who supported me in each step to complete this work.

To my brothers and sisters with love

To my dear friends Amal and Nihal the bright sunlight in this life which is full of dark

To my beloved and home country “ Palestine “

Kayan Manasra

Declaration:

I Certify that this thesis submitted for the degree of Master is the results of my own research, except where otherwise acknowledged, and that this thesis (or any part of the same) has been not submitted for a higher degree to any other university or institution.

Name: Kayan Sabri Rashad Manasra

Signature: 

Date: 18/4/2015

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Abstract

Al Uja area locates in the Lower Jordan Valley/West Bank, which is a part of shallow lower eastern aquifer located at an elevation of -220 m in the west to -280 m (b.s.l). The availability of ground water, fertile soil, and warm climate during winter months make it remarkable for its agricultural activities where 600 hectares are under irrigation.

There are two sources of water available at Al Uja area ; these are Al Uja Karstic spring that drain water from the Mountain carbonate aquifer system with a discharge rate between 0.5 and 8 MCM/a , and nine groundwater boreholes that tape water from the shallow Plio-Plistocene aquifer system, with an annual abstraction of 0.7 MCM/a .

The south-north fault system of the Jordan Rift Valley separates the two aquifer system. The shallow aquifer system locates to the east of the fault, where the Mountain aquifer system locates to the west. The Mountain aquifer consists of high fractured and karstified limestone and dolomite of Upper Cretaceous age, and the shallow aquifer system consists of gravel, sand, silt, and clay layers of the Dead Sea group.

Groundwater flows from the Mountain aquifer in the west to the Shallow aquifer in the east through the major fault system. 15% of the Al Uja spring discharge infiltrated into the Upper Mountain aquifer system and indirect to the shallow system.

The permeability of the Mountain carbonate layers is $2.49*10^{-1}$ m/min and decrease to $1.6*10^{-2}$ m/min in the layers of the Shallow aquifer system, this decrease of Kf-value east wards cause a semi-barrier for groundwater flow regime, also water salinity increase from 1500 µS/cm in Mountain aquifer to 3000 few hundred m to the east of the fault and rise to 6000 µS/cm in the eastern part.

Lowering of water table and increasing salinity in addition to the presence of water pollution are major obstacles facing the economical development of this region. Due to the

limitation of natural recharge, and over pumping from shallow aquifer system, water salinity increase and caused a major shift in cropping pattern during the last 30 years, where more salinity tolerance vegetables and trees are becoming dominant crops.

The main goal of this study is to investigated and estimated different artificial recharge technique at the area, which are infiltration surface pond, and borehole direct injection.

The surface pond consists of soft material of Lisan formation that consists of 22% sand, 23% clay, and 45 % silt.

The geo-electrical investigations inside the pond show that the wet front reach a depth of 2.5 m depth after 3 days and the infiltrated water velocity is about $9.6 * 10^{-4}$ cm/s. according to this infiltrated water can reach the groundwater table after 50 days of filtration.

Different volumes of water were injected in the selected borehole, the static water table raised from 37 m to 34 meter below the ground after five min from the injection. After one and half hour the static water table fall to the original static level after stop the injection. The groundwater salinity of the borehole was decreased from 6000µS/cm to less than 550 µS/cm. The decrease of Ec –value through the well after injection test was cause of the Calcite precipitation.

Our investigation recommended Borehole injection method is the best option for direct artificial recharge in Al Uja area within the boundary of the Plio-Plistocene shallow aquifer system and possible to use the available nine boreholes as injection boreholes. And artificial recharge using surface infiltration pond is not recommended.

تقييم الحقل الاصطناعي منطقة حوض (بلاي –بليوستوسين) حالة دراسية: العوجا

إعداد: كيان مناصرة.

إشراف: د. عامر مرعي.

الملخص

تقع العوجا في منطقة وادي الاردن / الضفة الغربية ، وهي جزء من الحوض الشرقي ، حيث تقع ما بين احداثيين –220 متر و – 280 متر، تمتاز بخصوبة تربتها ووفرة المياه الجوفية فيها . العاملان جعلاها مثالية للنشاطات الزراعية.

هناك مصدران للمياه: اولهما نبع العوجا والذي يقع في بطن الجبال من الجهة الغربية للمنطقة ، بمعدل تدفق للمياه يتراوح ما بين 0.5 الى 8 مليون متر مكعب سنويا من الصخور الكربونية . والمصدر الاخر هومياه تسعة ابار جوفية في الحوض بلاي –بليوستوسين . ومعدل السحب من هذه الابار هو 0.7 مليون متر مكعب سنويا

نظام الصدع الشمالي الجنوبي من نهر الاردن يفصل النظامين الكربوني وحوض بلاي–بليوستوسين . حيث يقع حوض بلاي –بليوستوسين الى الجهة الشرقية من الصدع و الحوض الكربوني الى الجهة الغربية من الصدع . يتكون الحوض الكربوني في معظمه من الصخر الجيري ولدولومايت ، اما الحوض بلاي – بليوستوسين فهو مكون من طبقات الجرفل الطين والرمل .
تجري المياه من الحوض الجبلي الكربوني باتجاه الحوض بلاي – بليوستوسين مرورا بالصدع . 15 % من كمية المياه المتدفقة من النبعة في منطقة الحوض الجبلي الكربوني تغذي منطقة الحوض بلاي – بليوستوسين .

نفاذية طبقات الحوض الكربوني الجبلي $2.49*10^{-1}$متر / دقيقة ، تقل الى $1.6*10^{-2}$ باتجاه اوض بلاي – بليوستوسين. وايضا ملوحة المياه تزداد من 1500 ميكروسيمنز / سم في في الحوض

الكربوني حتى تصل الى 3000 ميكروسيمنز / سم على بعد مترات الى الشرق من الصدع .و من ثم تزداد حتى 6000 ميكروسيمنز / سم الى الجهة الشرقية.
انخفاض مستوى المياه في الابار في حوض بلاي – بلايستوسين وزيادة ملوحة المياه وبالاضافة لوجود ملوثات جانبية في المنطقة ، تعتبر تحديات رئيسية تواجه القطاع الزراعي في المنطقة.

ان الهدف الرئيسي في لهذه الدراسة التحقق وطرح توقعات لاستخدام تقنية الحق الاصطناعي في المنطقة ، بطريقتين الاولى استخدام البرك السطحة ، والثانية بالحقن المياه المباشر للابار.

اظهرت دراسة الحق الاصطناعي للبرك السطحية انها تتكون من طبقات اللسان في المعظم والتي تحتوي على 22% من الرمل، 23% من الطين و 45% من السلت. واظهرت القياسات الجيوفيزيائية ان المياه تصل الى 2.5 متر بعد ثلاثة ايام من تركها داخل البركة وهذا يدل على ان سرعى المياه في هذه الطبقات تساوي 9.6 $*10^{-4}$ سم/ثانية . وهذا يدل على ان وصلو المياه الى مستوى المياه الجوفية في المنطقة يحتاج الى 50 يوميا.

اما حقن المياه المباشر للابار فقد تم حقن بئر بكميات مختلفة من المياه ومراقبة الاختلاف في مستوى المياه للبئر فقد كان يرتفع في 5 دقائق الى اكثر من 3 امتار ، حيث ارتفع من 37 متر تحت الارض الى 34 متر تحت الارض، وبعد ساعة ونصف من اغلاق مياه الحقن كان يعود لوضعه الطبيعي . بمراقبة ملوحة المياه داخل البئر وجدنا بانها تنخفض من 6000 ميكروسيمنز/سم الى اقل من 550ميكروسيمنز/سم. السبب الرئيسي للانخفاض في ملوحة المياه خلال عمود البئر بعد الحقن يعود لترسيب الكلسايت .
في نهاية البحث نوصي بعمل حقن اصطناعي بالطريقة الثانية وهي الحقن المباشر للمياه داخل الابار التسعة الموجودة في حوض بلاي – بلايستوسين وان طريقة الحقن بواسطة البرك السطحية غير موصى بها .

List of Abbreviations:

Abbreviation	Full Name
b.s.l	Below sea level
a.s.l	Above f sea level
MCM	Million cubic meter
m	Meter
mm	Mile-meter
C°	Celsius
m/sec	Meter per second
m^3/s	Cubic meter per second
Km^2	Kilometer square
Km	Kilometer
MCM/ a	Million cubic meter annually
mS/cm	Milli-siemens per centimeter square
MCM/yr	Million cubic meter yearly
ppm	Part per million
EC	Electrical Conductivity
Ca^{+2}	Calcium
Mg^{+2}	Magnesium
Na^+	Sodium
K^+	Potassium
Cl^-	Chloride
NO_3^-	Nitrate
m^3	Cubic meter
HCO_3^-	Bicarbonate
TDS	Total Dissolved Solid
MAR	managedaquifer-recharge
PWA	Palestinian water Authority
GIS	Geographic Information system
Mg/l	milligram per litter
WERL	Water and Environmental Research Laboratory

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Chapter one:

Introduction:

1.1. Introduction

Water is the most important natural resources for human life, where the lack of reliable water supply is the most serious barrier for human life.

In West Bank, Palestine, the groundwater is the main water resources. The amount of these fresh groundwater resources is approximately estimated to be 669 MCM/yr and runoff water of about 215MCM (Oslo2, 1995).

The total amount of water that used by the Palestinian in the West Bank is about 148 MCM, that distributed for 50 MCM used for agricultural purpose, 98 MCM are for domestic and industrial use, from this volume 54 MCM are purchased from the Israeli National Water Company (Meckerot).Average water loses is 30% from the 148 MCM (Isaac -ARIJ, 2009).

Available water resources in the Jordan Valley are springs water and boreholes groundwater that taped from the shallow Plio-Plestocene aquifer system (Marie, 2005). Additional potential sources are flooding water, and treated wastewater; both sources are still not in use.

Our research will focus on Al Uja area that classified as agricultural area, where the agricultural sectors consume about 60% of water sources. Lowering of water table and increasing salinity in addition to the presence of water pollution are major obstacles facing the economical development of this region. Due to the limitation of natural recharge, and over pumping from shallow aquifer system, water salinity increase and caused a major shift in cropping pattern during the last 30 years, where more salinity tolerance vegetables and trees are becoming dominant crops, the major crop in the past are vegetables including melons, fruit trees (bananas, citrus, palm trees) and field crops are the main cultivated crop. The banana is good indicator for water consumption .Bananas have 72.6% of the fruit trees cultivated area in Jericho district and produce 79.8% of the total fruit production by weight (Thaher,2010) .The banana is a profitable crop, both in terms of production and net revenue, but it requires large amounts of water, up to 170,000 CM/yr/dunum (Jericho Agricultural Station,1994). The irrigation water consumed by banana trees is 6000CM/year/ durum. But now in the present dominant crop are the palm trees.

To avoid this change and to cover the increase in demand for water, we should lead to the implementation of high intensive water management measures to achieve efficient utilization of the limited available water supplies. The artificial groundwater recharge will be one of the proposed management options.

Artificial recharge is the process by which excess surface water moves through man-made systems from the surface of the earth to underground-bearing strata where it may be stored for future use.(NRC, 1994).For example in Kucuk Menderes River Basin in western Turkey has been facing continuous groundwater-level decline for decades. And the previous studies have suggested that artificial recharge structures should be constructed, to avoid aquifer depletion in the basin. (Peksezer Say it and Yazicigil, 2012) used SEEP/W software to set up two dimensional (2-D) groundwater model and deferent scenarios were simulated to observe the change in groundwater level and storage .Simulation results suggest that a significant increase in groundwater storage is achieved by applying surface artificial recharge methods. In addition to the recharge basins, to reinforce the effect of artificial recharge, simulations are repeated with underground dam construction at the downstream side of the basin.

1.2. Problem statement

The decrease and fluctuation of Al Uja spring discharge which depends mainly on rainfall during the last decades caused a big problem in the agricultural sector special during the early summer time. The behavior of the spring discharge directly affected by the climate change Fig 1.1, where the variation of the amount of rainfall from year to other will make the different of the discharge quantities (J.Guttman, 2007), relating to this the maximum discharge will appear after the rainiest months, and the rainiest months were, Dec, Jan, Feb and March (PWA, 2000).

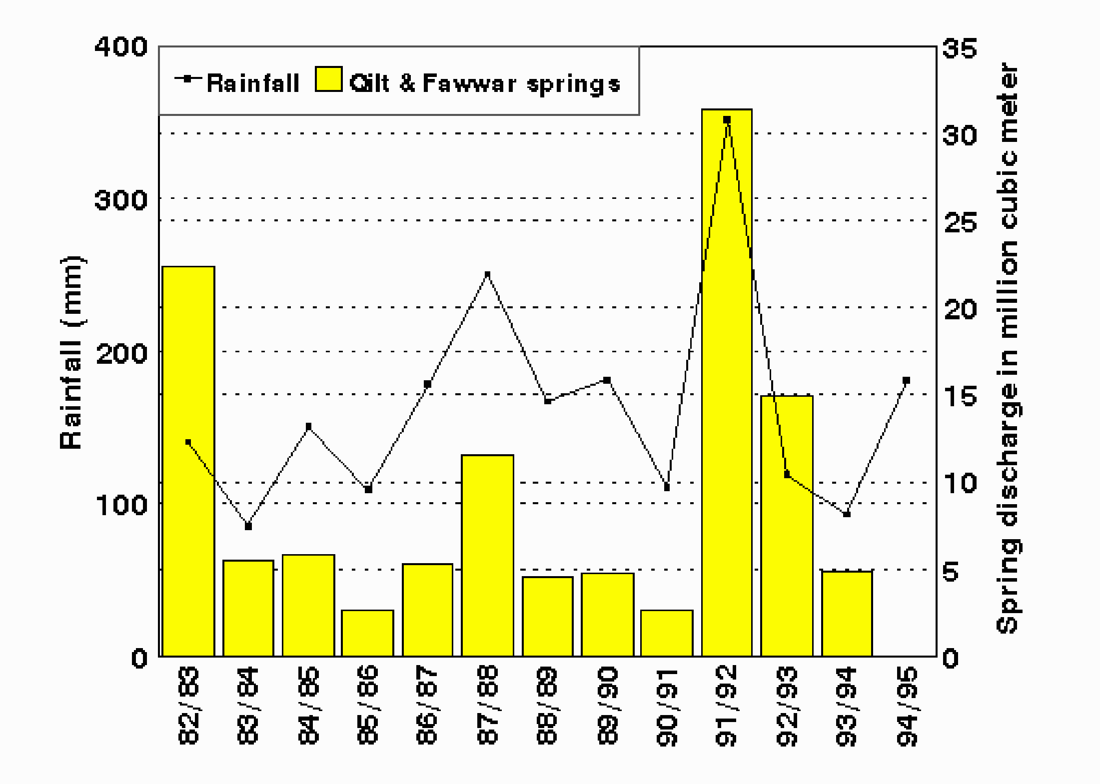
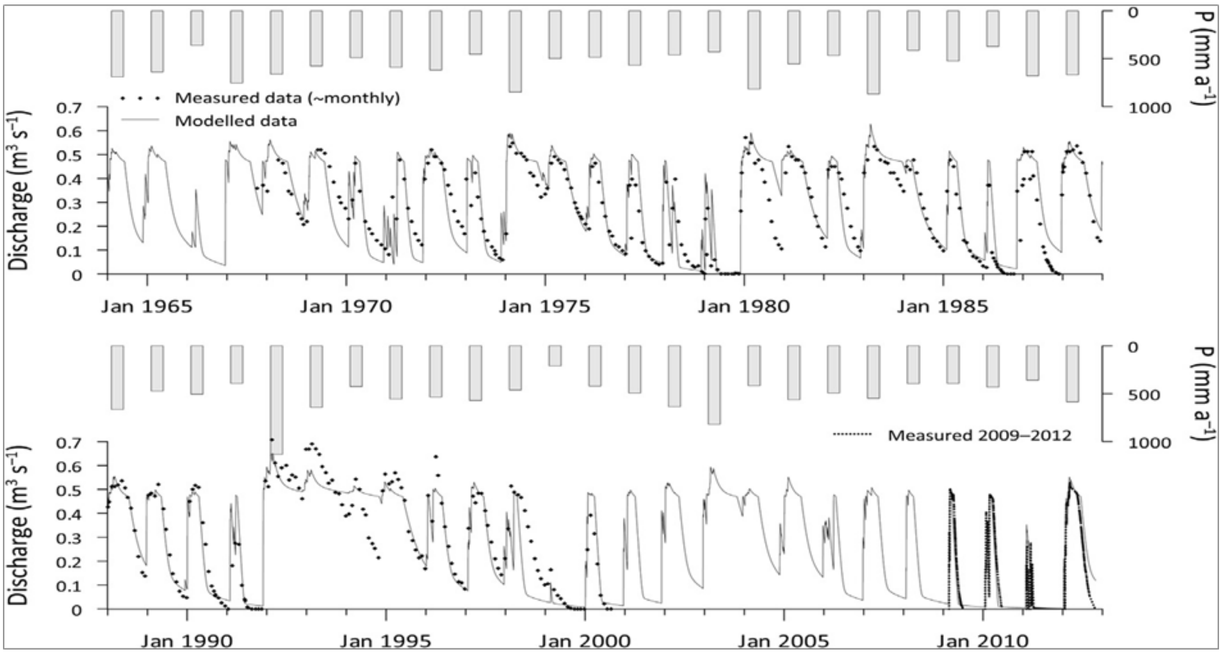


Figure 1.1: Discharge variation of the spring and rainfall distribution during the period of 1982/1983 until 1993/1994 (WBWD, 1994).

The Al Uja spring in wadi Al Uja with a mean discharge of 9.2 MCM/a (Period 1968-2000). In the period 1981-2000, the mean discharge was 9.5 MCM/a. The spring displays high discharge fluctuations.

In the last few years the discharge from the Al Uja spring was to observed decrease that the spring is drying out during the summer and flows for only short durations, during the winter and spring seasons Fig 1.2. For example in 2009, the spring discharged was only 2.45 MCM in total, and2010 only 3.25 MCM, (Israeli Hydrological Service, 2011).

The minimum observed discharge occurred in 2011 with about 0.7 MCM/a, and the



maximum observed discharge in 1992 with 18 MCM/a.

Figure1.2: Comparison of measured and modeled spring discharge (discharge data 1967–2000: Schmidt,S 2014).

To avoiding the decrease of spring discharge and water table in lower part of Al Uja area, we will working on new technology called artificial recharge of groundwater that will achieved by putting surface water into the aquifer (Raju, 1994).

1.3. Objective:

The scope of this research is to evaluate the hydrogeological situation in the Lower Al Uja area and to investigate different artificial recharge methods that can be applied to improve the water resources in term of quality and quantity.

Where the specific objectives are:

1. Hydrogeological evaluation of the natural recharge zones of the shallow aquifer system.
2. Hydrogeological evaluation of the lower part of the carbonate aquifer system and its connection with the shallow aquifer.
3. Evaluations of two artificial recharge technique in the shallow aquifer system.

1.4. Hypothesis:

1. The natural recharge zones of the shallow aquifer are along the major fault system.
2. The Wadi section between Al Uja spring niche and the entrance of the canal could be considered as the recharge zone for the carbonate aquifer and the shallow aquifer.
3. Source of salinity in the shallow aquifer system related to deep settled brines from ancient Lisan Lake.
4. Groundwater injection well artificial recharge technique could be better than the infiltration bond within the shallow aquifer system.

Chapter Two:

Study area:

2.1. Study area:

Al Uja area which is a part of shallow lower eastern aquifer located at an elevation of -220 m in the west to -280 m (b.s.l) Fig 2.1 .With population less than 5,000 capita.

Al Uja has catchment area of 170 km². The climate of Al Uja is classified as arid which has hot summers and warm winters with very rare frosts incidents, the average maximum temperatures during January (coldest month) and August (hottest month) are around 19C°and 38C° respectively, during spring, the maximum wind speed is measured at 15 m/sec, often reaching to 20m/sec from west to northwest, the maximum wind speed through the rest of the year reaches to 12 m/sec. (Kafermalek station, 2008). Al Ujacatchment receives direct rainfall of about 156 mm annually (PWA, Jericho station, 2001-2008).

Ein Al Uja located at an elevation of 20 m (a.s.l). It has a catchment area of 170 km² and received an average rainfall of about 769 mm (Al Bireh station, 2003) and 360mm annually (Kafermalek station, 2008).

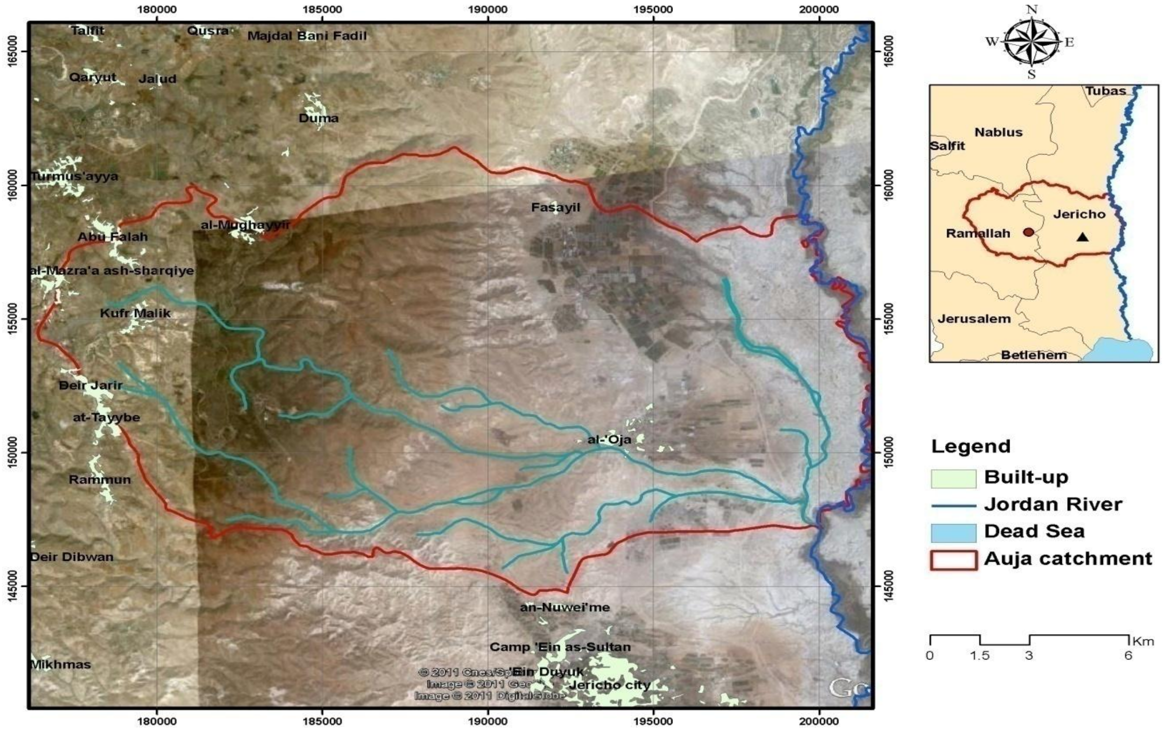


Fig 2.1: Surface catchment area of Wadi Al Uja2013-2014 (Al Quds University GIS lab)

2.2. Geology:

Al Uja is a part of the lower Jordan valley, where the geology of this area included of many geological formations that divided into three groups: Ramallah group on the eastern part of the slope, Abu dies formation outcropped and the Dead Sea group which cover the largest part of Al Uja area (Begin, 1974). (Figure 2.2).

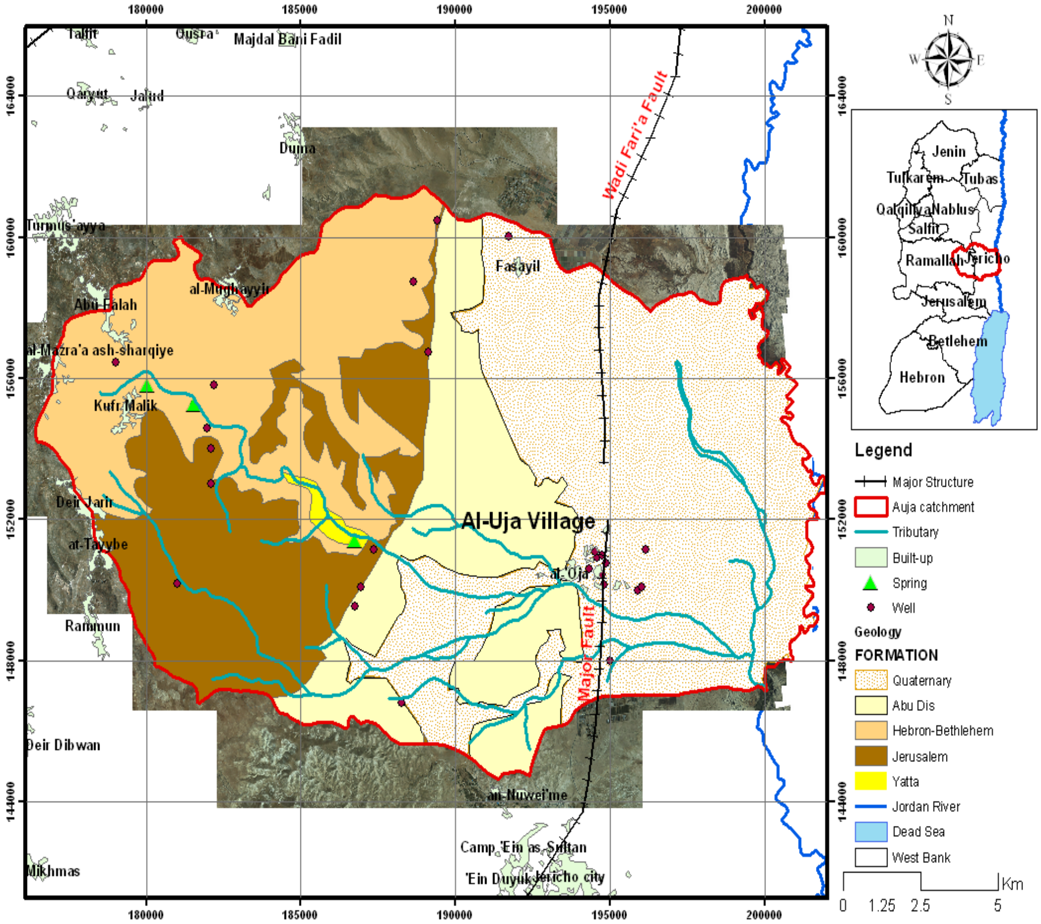


Figure 2.2 Geological map of the study area (AQU GIS lab).

2.2.1. Ramallah group:

2.2.1.1.Jerusalem Formations:

These formations consist of the Senonian Chert and Chalk deposits. The lower parts of this formation composed of limestone colored yellow, red or gray. At the base there are chalk and nodular limestone rich with Ostried. Poorly preserved ammonites were found in the lower parts and it is marks the upper Cenomainian age (Rofe and Roffty, 1963).

The middle parts of this formation consist of dark – gray dolomite. Ammonites were found and marked the lower Turonian age. The upper parts of this formation consists of limestone, dolomite, and marl with some charts. The age of this formation is Turonian – Cenomainian. Thickness of the formation ranging from 90 to 100 m (Wolfer, 1998).

2.2.2. Dead sea group:

2.2.2.1.Lisan&SamraFormatio:

Samra formation consists of conglomerates, Gravel Sandstones and silts and is subdivided into two members. Silt member: with average thickness of 20 m and It is composed of silt, sand, and clastic pebble lenses (Begin, 1974).

The coarse clastic member with average thickness of about 35 m, and it is composed of sand and unconsolidated materials chiefly (conglomerate and gravel). It is located near the ancient place called “Kherbet Al-Samra” to the north of Jericho city and also in the outlet of Wadi Al-Qilt (Begin, 1974).

Lisan formation is exposed in the eastern part of the Jericho area and covered thelarge part of the Jordan rift valley and the Wadis. This formation consists of laminated aragonite-chalk, gypsum and clay with some sandstone and pebble beds. The consecutive thin layers of clay and gypsum make it highly distinguishable.

The inter fingers between Lisan formation with conglomerates and silt beds occur above Samra formation. Where these dimentation of the Lisan formation started 60,000 years ago (Kaufman, 1971).

2.2.3.2. Alluvium Formation:

Alluvium formation covers the area adjacent to the Jordan Valley. It is bounded structurally by the Jordan rift regional fault in the east and another fault of 12 km long in the west.

Ten thousand years ago during the Holocene age, alluvium deposits started to sediment on both sides of the area's streams. It is located all over the area mixing with the sub and top soils; the thickness of this formation is ranging between 5 to 12 m (Begin, 1974).

2.3. Hydrogeology:

The Pli-Plis to ceneground water aquifer system consists of three formations:

2.3.1. Pleistocene aquifer (Lisan – Samra Formation):

Pleistocene Lisan includes three members which are Samra coarse clastic, Samra silt and Lisan. Pleistocene Samraa quifer is side along succession from terrestrial or fluvial, to deltic and limnic were it is brackish lake environment, and they reflect the Plio-Pleistocene depositional conditions of the Lisan Lake. Theunit of marl, gypsum and silt of Lisan were generally considered an aquiclude.

Samra formation consists of two members: Silt member interfingering with Lisan and a coarse clastic member that present more to the west and cosiest of gravel, interbedded with clay, sand and marl horizons layers (Khayat, 2005).

2.3.2. Holocene aquifer (Alluvialand Gravel fans):

Sub- recent alluvial aquifer distributed mainly in the Jordan Valley and neighboring areas.It is built up of sub-recent terrigenous deposits formed along main wadis. The alluvium is, generally, unconsolidated in theRift Valley where it is formed of laminated marls with occasional sands. And the gravel fans are widely distributed in the Jordan valley and have the capability oftransferring groundwater from the limestone aquifers.

Alluvial deposit still under accumulation after major flooding and consist of debris from all surrounding- litho logy. The maximum total thickness near the rift margins can reach up to high values. The thin layers are found out towards the center of the rift basin. The alluvial aquifer overlies the Pleistocene gravel aquifer and by that is hydraulically interconnected with this aquifer (Wolfer, 1998).

2.4.Hydro-meteorological characteristics:

The basic requirement for the success of any artificial recharge project is the availability of water sources. The source of water for artificial recharge could be surplus surface water such as streams, groundwater from another aquifer and non potable water such as wastewater treatment plants effluent, storm runoff, irrigation return flow, and surface (canal) supplies from large reservoirs (Pyne, 1995). The source of water in the Al Uja catchment is limited to the surplus from storm runoff and spring flow.

2.4.1.Rainfall:

The rainfall in the West Bank increase with elevation and from the south to the north and from the east to the west. Relating to that the annual average rainfall in EinSamia area during the period (1952-2004) is estimated as 350 mm, where the maximum monthly rainfall occurs in January and sometimes in December (PNAMO, 2004). And the average annual rainfall in Ein Al Uja is 360mm (Kafer malek station, 2008).(Fig 2.3) show the distribution of the rainfall mm at Al Uja Catachment area. The mean monthly potential evaporation rate in summer in Jericho area including Al Uja area 285 mm and 70.9 mm in winter (Arij, 1995).

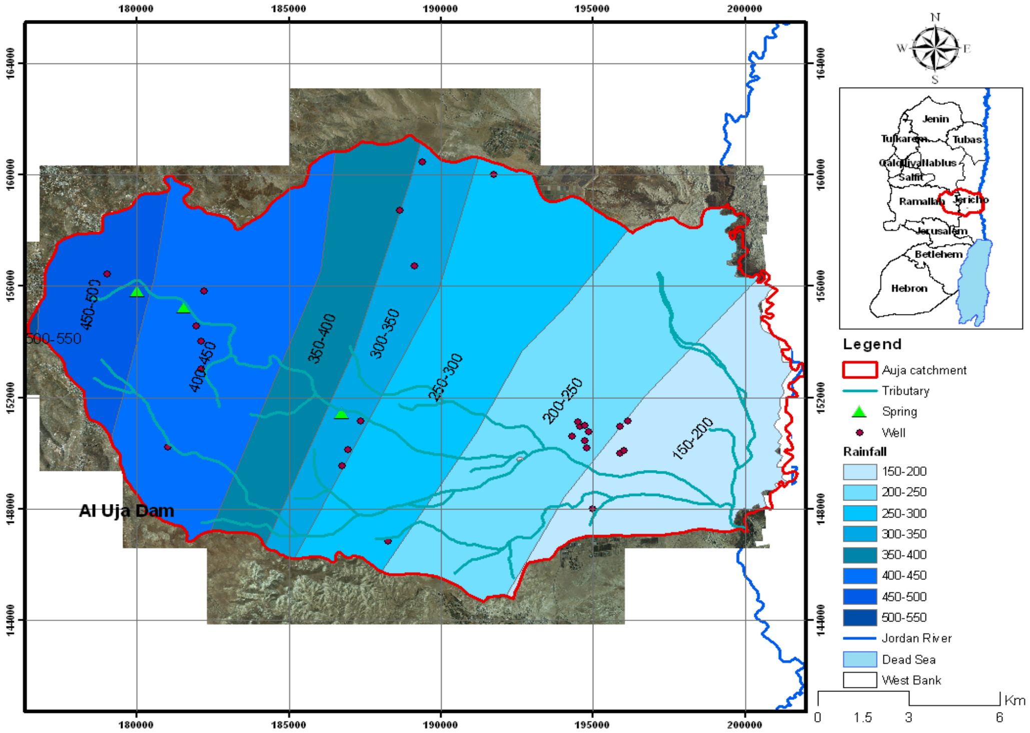


Figure 2.3Rainfall distribution map for Al Uja catchment area (AQU GIS lab).

2.5 Water Resources

Water resources at Al Uja area are including three types of resources:

2.5.1. Surface water:

Surface water resources in Al Uja are classified as winter flooding wades and discharge of Al Uja spring. In 2011/2012 the discharge of Al Uja spring was 10 m^3/s with surface runoff approximately 0.36 MCM, while the discharge in 2012/2013 was 5.5 m^3/s with 0.38 MCM of surface runoff (Ries, 2013).

2.5.2. Spring system:

Al Uja spring catchment geographically extends from the water divide running long to the Ramallah anticlinal axis in the west to the Jordan River in the east, and from the WadiFri'a in the north to the WadiQilt in the south Fig 2.4, (PWA, 2000).

The location of Al Uja spring has different formation from the lower Cretaceous age to young formations of the Holocene age. During Cretaceous age the limestone layer is the mainly composed along Ramallah anticlinal axis (J.Guttman, 2007).

Al Uja spring a mean discharge of 9.2 MCM/a (Period 1968-2000). In the period 1981-2000, the mean discharge was 9.MCM/a. The minimum observed discharge occurred in 2011 with about 0.7 MCM/a, and maximum observed discharge in 1992 with 18 MCM/a (Sebastian 2012).

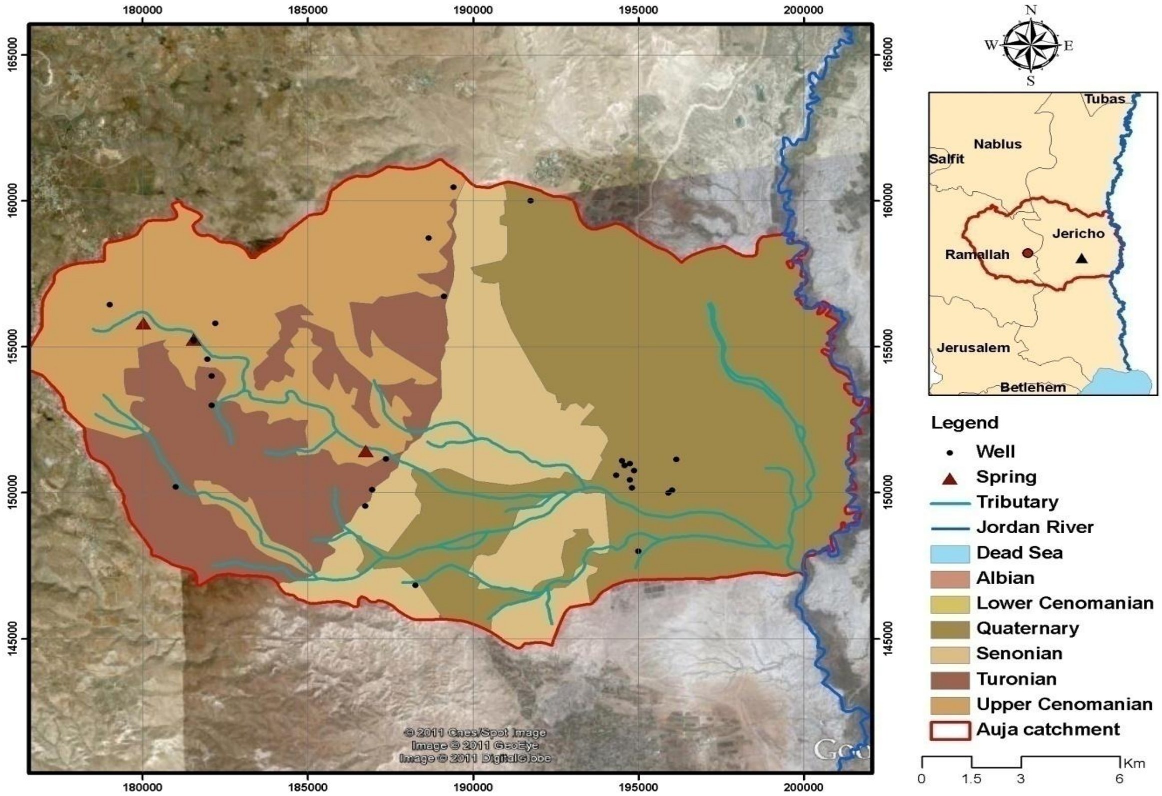


Figure 2.4: Wells and springs distribution overlaying the geological formations of Al Uja catchment.

2.5.3. Ground water wells:

In Al Uja area two groups of wells present. First group tap from the Upper Cenomanian-Turonian aquifer system including (Meckerot 1, Meckerot 2 and Meckerot3 wells). Second group tap from the Pli - Pleistocene shallow aquifer systems. While,these wells is suffer from large fluctuations in the quantintity. There are twelve wells in AlUja area(Table2.1), three wells around Al Uja spring, and nine in Al UjaTahtaarea with depth range between 40 and 108 m, the mean of the total abstraction from the carbonate aquifer 1981-2010 are 2,8 MCM /a and average yearly abstraction from the nine wells (Shallow system)will be about 0.7 MCM/a (Sebastian, 2012).

Table 2.1: Ground water wells in Al Uja area (Carbonate and Shallow systems)

Well name	Well ID	Depth (m)	Ground Elevation (m)	Water table (m)	EC mS/cm	Aquifer
Meckerot 1	18-14/001	-	62			**Carbonate Aquifer System**
Meckerot 2	18-15/011	615	-20	-170		
Meckerot 3	18-15/012	738				
AbdMoateQotop	19-15/011	95	-251	-315	3	**Shallow Aquifer System**
SobheDojane	19-15/007	105	-250	-315	3	
Sayedah	19-15/19	92	-274	-311	7	
Shlash	111	90	-260	-310		
JawadAldawode	19-15/005	108	-242	-308	4	
Abd Kareem Njoom	19-15/008	103	-283		7	
ElyasMkrkr	19-14/01	59	-268		7	
Njoom	19-15/028	93	-274	-310	6	
El Amad	19-13/028	95	-246	-315	4	

Chapter Three:

Literature review:

Jamil, 2006: was made an attempt in the Faria catchment to relate the runoff coefficient to rainfall lintensity in order to estimate runoff volumes for extreme rainfall eventsusing the Nash model. Analyzing the efficiency of constructing theretention dams for different return periods, the study concluded thatabout 90% of the storm water runoff could be used for artificial recharge for a return period of 2 years.

Vandenbohede, Houtte and Lebbe, 2008: the tertiary treated wastewater was used artificially recharged thorough two infiltration ponds in the dunes of the Belgian western coastal plain. This has formed a lens of artificially recharged water in the dunes fresh water lens. Recharged water was recovered by extraction wells located around the ponds. Hydraulic aspects of artificial recharge and extraction are described using fled observation such as geophysical borehole loggings and tracer test. Borehole logs indicate recharge water up 20 m below surface whereas the tracer test gives filed data about the residence time of recharge water. Furthermore, a detailed solute transport model was made of the area surrounding the ponds. Groundwater flow, capture zone residence times and volume of recharged water in the aquifer are calculated. This shows that the residence time varies between 30 days and 5 years due to the complex flow pattern.

Saleh, 2009: was focused on the assist in the establishment of the effect of recharge by floodwater on the groundwater system made up of alluvial andconsolidated sediments and karstic limestone in the Faria catchment. All hydrological and hydro geological properties of the area under study were identified. The results were that about 36 MCM is the natural recharge in the upper parts of the catchment against a total catchment recharge of 60.3 MCM. The man made artificial recharge in the upper catchment can contribute about 3.2 MCM. And he used the Weighted Index Overlay Method (WIOA) to determine the most proper locations for artificial recharge structures based on infiltration capacity, slope, and type of aquifer to be recharged and the existence of fractures. The results show that 14% of the total area is very suitable for artificial groundwater recharge.

Al-Assa'd and Abdulla, 2009: Artificial groundwater recharge was investigated at Wadi Mujib aquifer as one of the important options to face water scarcity and to improve groundwater storage in the aquifer. A groundwater model based on the MODFLOW program, calibrated under both steady- and unsteady-state conditions. The scenarios include variations of abstraction levels combined with different artificial groundwater recharge quantities. The possibilities of artificial groundwater recharge from existing and proposed dams as well as reclaimed municipal wastewater were investigated. Artificial recharge options considered in this study are mainly through injecting water directly to the aquifer and through infiltration from reservoir. Three scenarios were performed to predict the aquifer system response under different artificial recharge options (low, moderate, and high) which then compared with no action (recharge) scenario. The best scenario that provides a good recovery for the groundwater table and that can be feasible is founded to be by reducing current abstraction rates by 20% and implementing the moderate artificial recharge rates of 26million(M)m^3/year. The model constructed in this study helps decision makers and planners in selecting optimum management schemes suitable for such arid and semi-arid regions.

Thaher, 2010: was estimated the physical properties of the Plio-Pleistocene aquifer in Al Uja area and investigated the possible artificial recharge.By investigated and understand the hydro geological setting at the area. Field geological investigation in additional to 34 geo-electrical resistivity measuring points distributed and conducted by Schlumberger method, also water samples were collected from the wells. The investigated recommend artificial recharge pond in the east of the southern part. And new boreholes could be drilled around the pond with direct injection water in these boreholes is good to substitute the water shortage at area.

Al-Amoush,2012:was studied the potential for artificial groundwater recharge of Wadi Al-Butum catchments area—Jordan, using geoelectrical resistivity surveys and hydro geochemical methods with the aim of storing some of surface water during flood events times to be recharged in the groundwater as an essential part of integrated water resources management. The results of geoelectrical surveys show the existence of potential zones of alluvial deposits to store and re-charge the groundwater aquifers. The hydro-geochemical modelling results show an overall upgrading of the original groundwater quality could be expected.

Sayit and Yazicigil, 2012: was set up a two-dimensional (2-D) groundwater model by using SEEP/W software. To assess artificialaquifer recharge potential in one of the sub basins to avoid aquifer depletion in the basinat the Kucuk Menderes river basin in western Turkey. Various scenarios were simulated to observe the change in groundwater level and storage with respect to different exceedance probabilities. Simulation results suggest that a significant increase in groundwater storage is achieved by applying surface artificialrecharge methods. In addition to the recharge basins, to reinforce the effect of artificial recharge, simulations are repeated with underground dam construction at the downstream side of the basin. This shown that the groundwater storage is increased with the addition of the dam.

Rahman and Wiegand, 2013: In Dhaka City, Bangladesh a preliminary feasibility assessment of managedaquifer-recharge (MAR) techniques was undertaken, considering the top impermeable-layer (TIL) thickness and the land-use classification,four primaryMAR techniques have been suggested: (1) soilaquifertreatment (SAT) for TIL thickness 0–8m, (2)cascade-type recharge trenches/pits for TIL thickness 9–30m, (3) aquifer storage, transfer and recovery (ASR/ASTR)for TIL thickness 31–52m, and (4) use of natural wetlands to recharge water collected from open spaces. The study suggests that recharge trenches and pits will be the most appropriate MAR techniques, which can be implemented in most parts of the recharge area (277 km^2).

Our research will focusing to used the MAR techniques by estimate the potential artificial recharge of the shallow Plio-Plistiocen Aquifer System by using two different methods, that are surface infiltration pond and injection borehole.

Chapter Four:

Methodology:

Different methods, parameters, measurements and software were used to design the investigation approach in the study area of Carbonate and shallow Systems aquifer.

4.1 Geological Cross- Section

The structural and geological setting data was carried to determine the connection between Carbonate and shallow, to understand the regional groundwater flow direction, locations of water table, impact of the fault on groundwater salinity distribution. WinLog 4.46 and WinFence 2.2,2000 programme used to achieve this point.

4.2 Meteorological Data

Most meteorological data (Rainfall (mm), wind speed (Km/hr), temperature (C^0), and evaporation (mm/yr) of Al Uja area were obtained from Al Uja station. The rainfall (mm) data have been used to explain potential recharge zones, surface runoff. Potential evaporation rate was adapted from PWA-report.

4.3 Salinity map

Salinity contour map for Al Uja area was interpreted by using Geographic Information System (GIS) to show the distribution of the groundwater salinity for area wells with distance from the fault system

4.4 Methods used to identify potential artificial recharge sites

Two different methods of artificial recharge were used in the investigation, and deferent analysis was applied for each methods.

4.4.1. Infiltration pond method:

The annual Al Uja spring discharge ranges between 0.5 and 8 MCM (smart 2010), where most of the spring outflow stored in 53 surface collection ponds (Figure 4.1). The storage capacity range between 1500 – 25000 m^3/pond (Figure 4.2). The total storage capacity of these ponds is about 10 MCM, so the storage capacity of these ponds exceeds the spring discharge during the high peak. Currently many of these ponds are out of operation. The depth of these ponds ranges between 3 – 5 meters, where upper radius surface area range between 295 – 12000 m^2. These ponds were dogged in the Marl of the Lisan formation. One pond was selected in order to investigate its infiltration capacity, which is useful to carry out any artificial recharge pilot project.

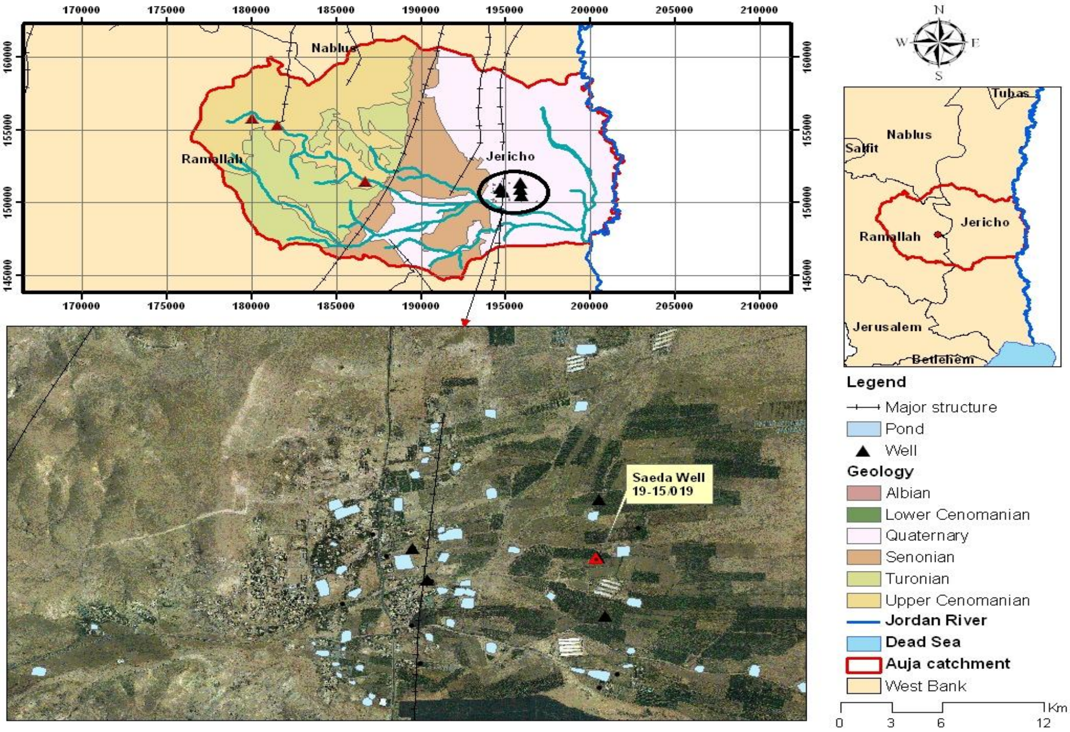


Figure 4.1: Distribution of surface collection ponds along Al Uja area

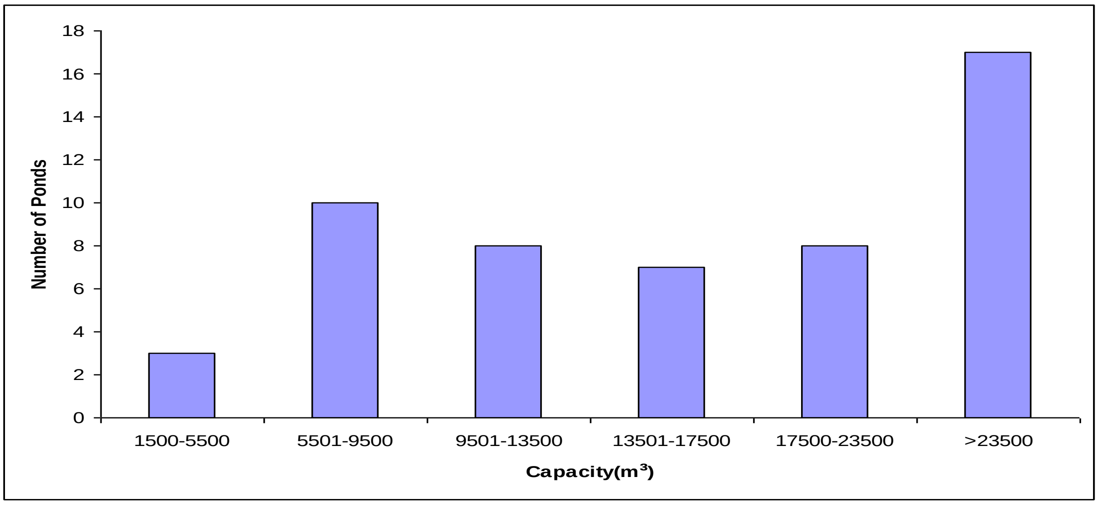


Figure 4.2.: Classification of collection ponds according to the storage capacity in Al Uja area

4.4.1.1.Infiltration Double rings methods in the Pond:

The Double Ring infiltrometer is a simple instrument used for determining the rate of infiltration of water into the soil. Consists of an inner and outer ring inserted into the groundfigure 4.3, 4.4 (ASTM, 2003)each ring is supplied with a constant head of water either manually. The rings are partially inserted into soil and filled with water,after which the speed of infiltration is measured (.

Within the bottom of the pond, three different sites were selected and investigated for its infiltration capacity.

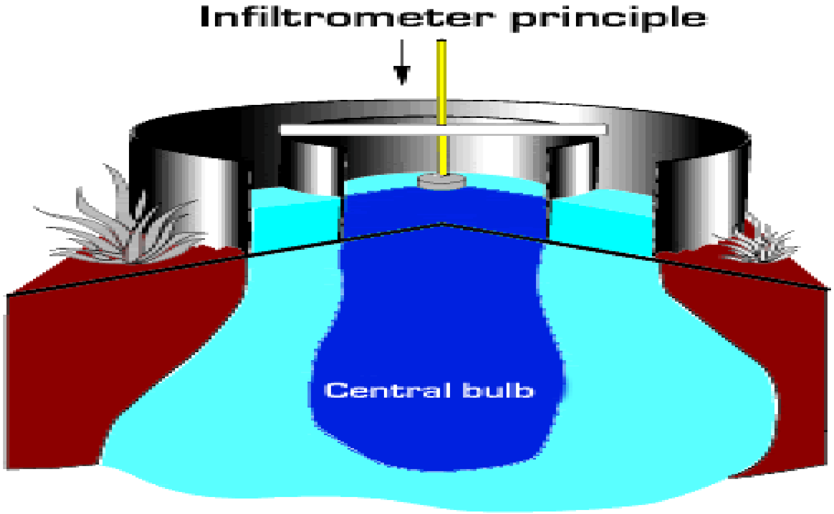


Figure 4.3: Sketch for double rings (infiltrometer)

Figure4.4: Shows Double rings apparatus.

4.4.1.2. Resistivity Method (Dipole – Dipole method):

The dipole-dipole array (figure 4.5), (4.6)is one member of a family of arrays using dipoles (closely spaced electrode pairs) to measure the curvature of the potential field. The separation between both pairs of electrodes is the same a, and the separation between the centers of the dipoles is restricted to a(n+1) (Loke, 2001). This method used to determine the depth of moister front , which could be consider as velocity of water within the Lisan formation.

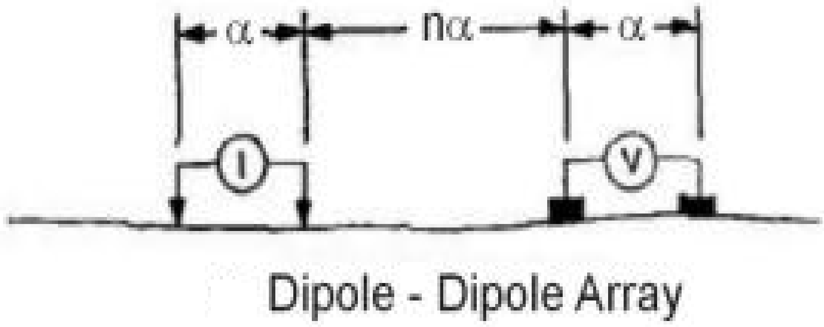


Figure4.5: Sketch for Dipole – Dipole array.

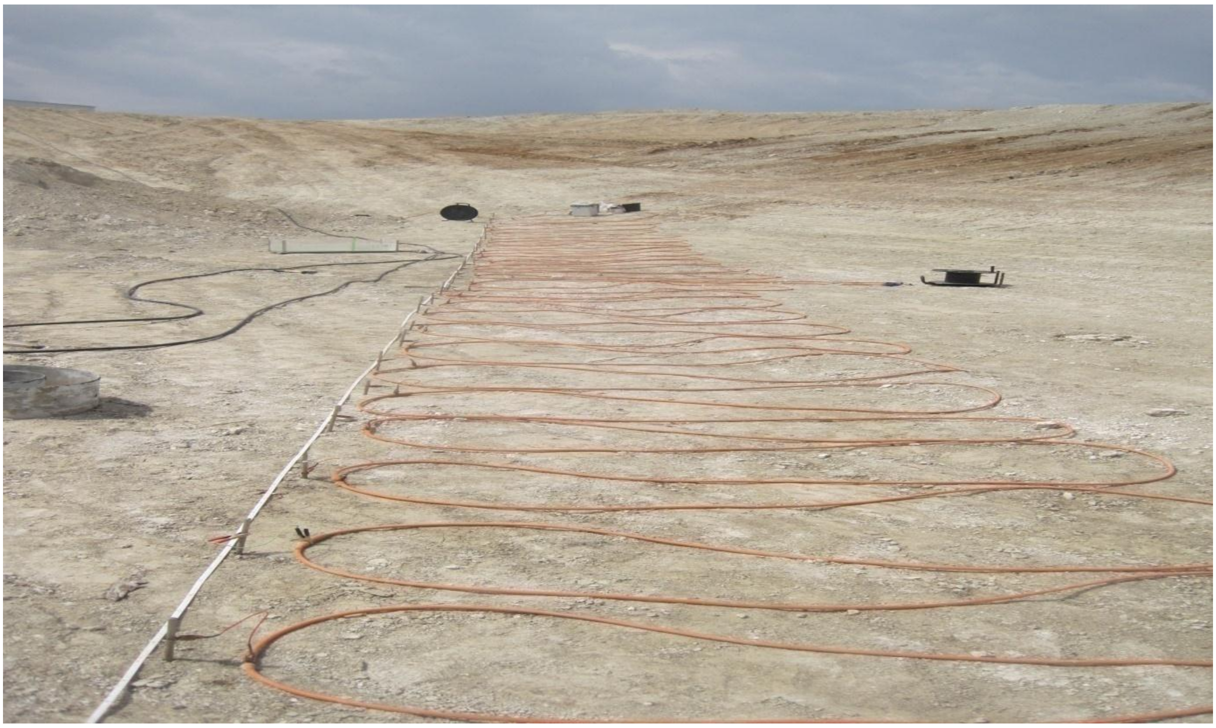


Fig (4.6):Shows Dipole – Dipole array in infiltrated pond.

4.4.1.3. Soil sieve analysis:

Four samples of soil from the pond was samples, all the samples was tacking at 40 cm depth from Lisan layer, the distance between sample sites are about 20 m. Sieve analysis was used to determined the texture of these soil samples and to calculated the permeability of the ponds material.

The weight of each soil samples is 500 gm. each sample was dried to the room temperature for one day. Sieve analysis using 11 sieve mesh size, starting with 2.00 mm, 1.600 mm, 1.00 mm, 0.710 mm, and 0.500 mm for the sand values. For the silt grain size the mesh size was starting with 0.250 mm and 0.200 mm. Less than 0.200 mm mesh size is consider as clay , the classification of clay are 0.160 mm, 0.090 mm, 0.075 mm and 0.065 mm. The samples placed at the machine and shake for up to 10 minutes, to separate the sample into fractions (Neven, 1997).

The grain size distribution curve is plotted on a semi logarithmic paper. The logarithmic scale of the grain size decreases from the left to right.

Uniformity coefficient used to calculate the permeability of the soil samples by the following equation:

$U = d_{60} / d_{10}$

Where:

- U is the uniformity coefficient.
- d_{60} is the sieve opening size (diameter) which allows 60 % of the sample by weight to pass and retaining 40 % of the sample.
- d_{10} is the sieve diameter which allows 10 % of the sample to pass and retaining 90 % of the sample.
  The permeability was calculated in reference to Hazen equation, that applicable for sediments with uniformity coefficient less than 5 ($U<5$) and effective grain size between 0.1 and 3 mm ($0.1mm < d_{10} < 3mm$).

4.4.2. Injection borehole method:

The objective of this experiment was to investigate possible artificial recharge through available production boreholes. For this purposes deferent test were applied, as following:

4.4.2.1. Filtration of injected water:

Al Uja Spring water was stored in an open surface pond of 8000 m 3 (Figure 4.7). Then water transfer through 6 inch underground pipeline to the experiment site at Al Uja Tehta area (well ID 19-15/019). On the borehole site the raw fresh water has to pass through a row of 16 filters to remove suspended material, and algae (Figure 4.8,9). These filters was built, and constructed from local materials. The opening pore space of the membrane filter is 120 meshes which is equivalent to 149 microns. Spring water must flow through these filters before interring the injection borehole. The different in elevation of about 50 m between the storage pond and the filter site cause a fluid pressure of 5 bar. Figure (4.10) summary the mechanisms.

Figure 4.7: surface storage pond for feeding the injection borehole

Figure 4.8: inflow, outflow with 16 filters.

Figure 4.9: 2 inch filter, and inertial material.

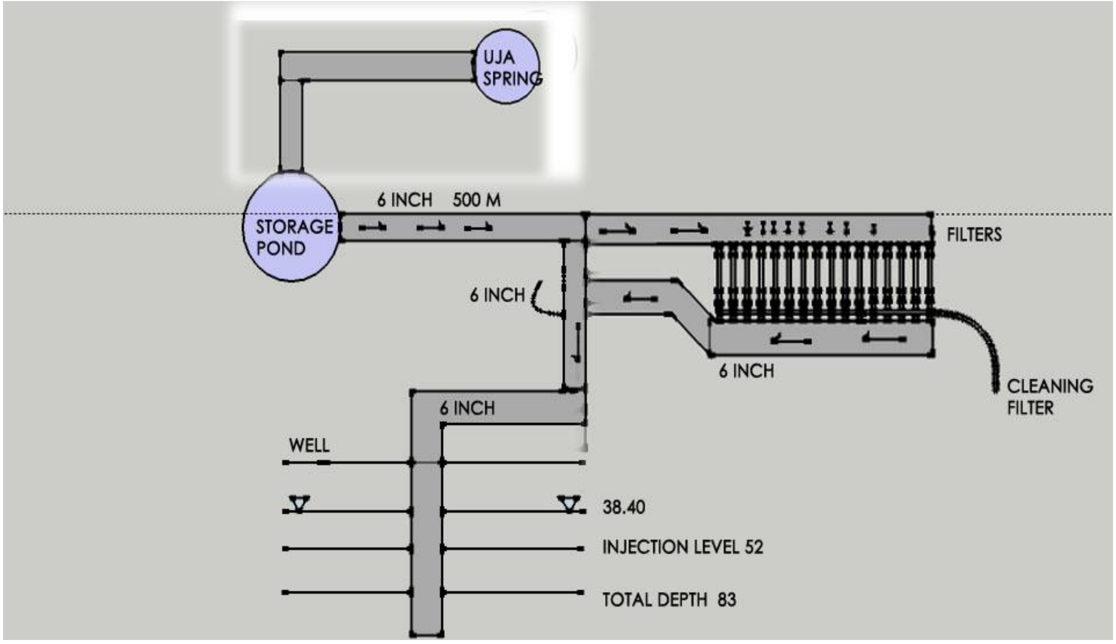


Figure 4.10: mechanisms of the injected water movement.

4.4.2.2. Static water table:

The static water table is the level of water in a well under normal, undisturbed, no-pumping conditions. Static water table can be influenced by climatic conditions and pumping of near wells. TLC-meter was used to gain information about how aquifers will react to climatic change and to the change of recharged period.

4.4.2.3. Ec and Temperature profile for the well:

The TLC-meter instrument was used to monitoring the changed of the Electrical conductivity and temperature of the water profile at well under experiment, the changed of these two factors will connected to the clime change that directly affected the amount of recharged water, time of measurements, amount of injected water, amount of water abstraction from the wells.

4.5. Aquifer physical parameters

Aquifer parameters (layers, average thickness of the layers, volume of ach layers, effective porosity of each layer, and the storage capacity) was calculated by Surfer 7, 1999 program, to explained the aquifer hydraulic potential of different layers with the average thickness.

4.6. Laboratory analysis:

Major and minor cation and anions (Ca^{2+}, Mg^{2+}, Na^{1+}, K^{1+}),(Cl^{-1}, HCO_3^- , NO_3^-, SO_4^{2-} ,PO_4-^{3})

PH, EC and water type was measured for Wells Groundwater a, Al Ujaspring and soilsamples.

Chapter Five:

Results and discussion:

5.1. Geology

Lithological cross section is constructed between upper mountain karsric aquifer to the shallow aquifer crossing fault system at Al Uja catchment Figure (5.1.a,b). Depending on it the water flow direction can be determined by comparing the formation between two aquifers and layers content water in carbonate aquifer and opposite layer in shallow aquifer. The gradient for this cross section approximately equal 0.01.

The type of formation in the Cross section modified /monocline at Carbonate aquifer are (Abu Dis, Jerusalem, Betlehem ,Hebron formation), all these formation locate to the west of the fault system, the opposite to these formation are 15 m lisan formation in the upper part of the profile, and Samra formation below the Lisan.

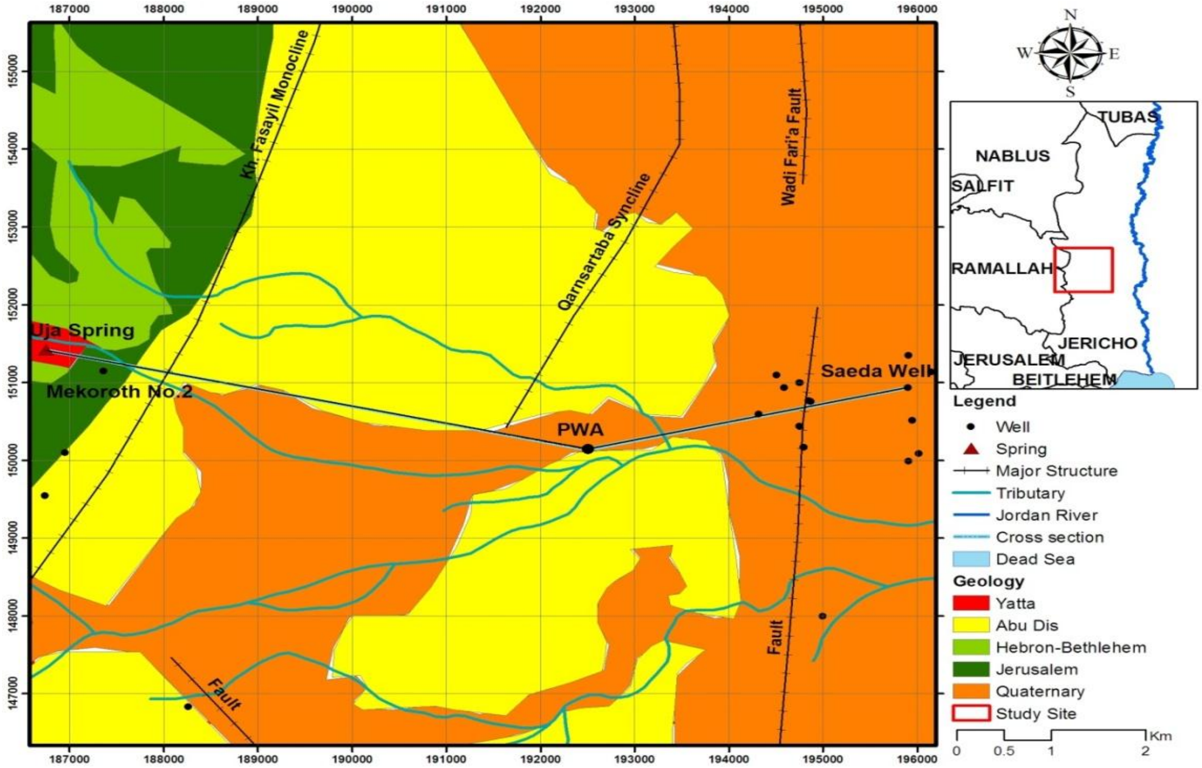


Figure 5.1.a: Geological map of Auja area showing different geological structure and fault system.

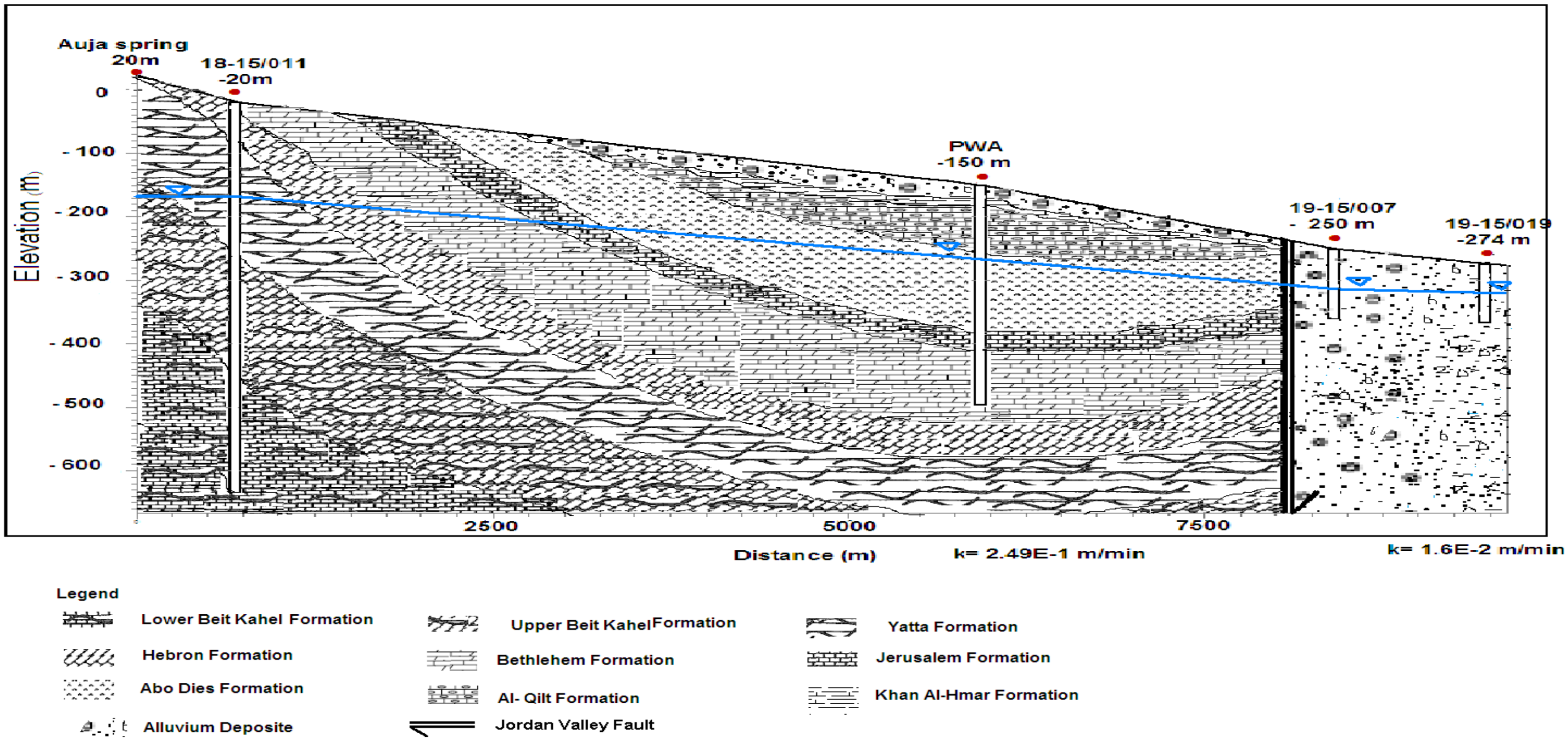


Figure 5.1.b:Hydro-geological cross section from west to east, showing the groundwater table and the connection between the two aquifer systems(Auja spring to well 19-15/019

As showing in table (5.1.a) the two wells in the carbonate aquifer taping water from different layers, the water table in Mekerot 2 well at (-170 b.g) which site in Yatta formation , where the well taping water from upper and lower BietKhael. And PWA well with water table at (-260) site in Abo Dies formation, taping water from Jerusalem and Bethlehem formation. At Shallow aquifer two wells in this cross section taping water from Alluvium deposit.

The changing in electrical conductivity is clearly shown from the carbonate aquifer to shallow aquifer that refer to the water taping layer and the present of fault system , this section will discuss in 5.2.

The water table in the mountain aquifer beneath Al Uja area (PWA wells), locate at a level of – 260 m (b.s.l), and for the shallow aquifer system to the east it reach to -311 m (b.s.l). Water gradient in both aquifer system is decline gently eastward across the fault system. This indicates that both aquifer system (mountain and shallow) are hydraulically connected with each other.

Table 5.1.a:litho logy formation of Carbonate aquifer wells

Aquifer	Well ID	Water table (m)	Electrical conductivity (µs/cm)	Depth (m)	Geological Formation
Carbonate Aquifer	Mekerot 2	-170	587	0 - 40	Bethlehem
				40 - 100	Hebron
				100 – 290	Yatta
				290 – 460	Upper BietKahel
				460 - 615	Lower BietKahel
	PWA	-260	1000	0 - 21	Alluvium
				21 - 35	Khan Al Hmar
				35 - 105	Al Qilt
				105 – 232	Abu Dies
				232 – 315	Jerusalem
				315 - 345	Bethlehem

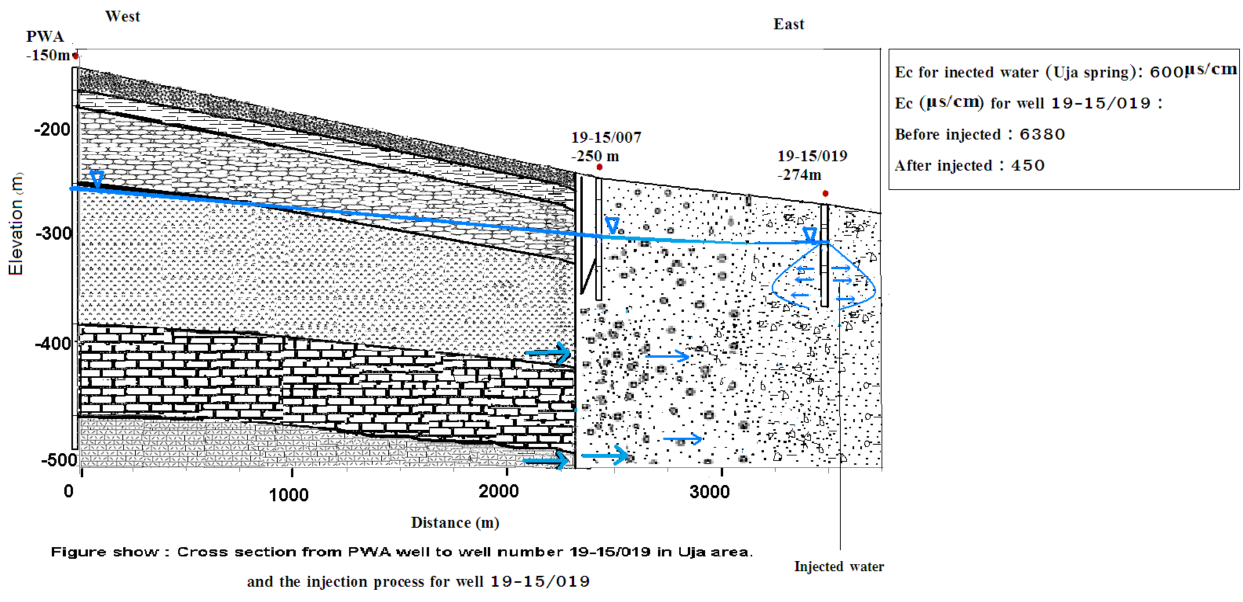
Table 5.1.b : litho logy formation of Shallow aquifer wells

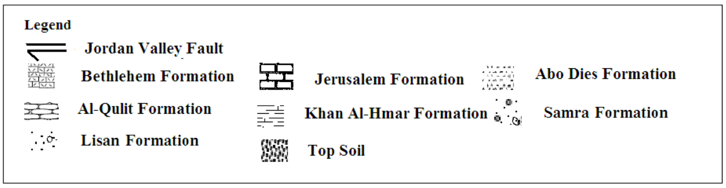
Aquifer	Well ID	Water table (m)	Electrical conductivity (µs/cm)	Depth (m)	Geological Formation

As water salinity increase from 1500 µS/cm in Mountain aquifer to 3000 few hundred m to the east of the fault and rise to 6000 µS/cm in the eastern part. The permeability of the Mountain carbonate layers at Mekerot 2 well is 1.3*10-3 m/min (WBWRP,2001) , deceased to 2.49*10-1 m/min close to the PWA well and decrease to 1.6*10 -2 m/min in the layers of the Shallow aquifer system, this decrease of K-value east wards is logical cause if the K-value is not higher than the shallow this mean that all water at the carbonate will drain to the shallow aquifer.

5.1.a. Shallow aquifer:

Lithological cross section was build from different well logs and from geo-physical profiles (Figure 5.4). The boundary of AlUja aquifer system is 1000 m length from north to south along the major fault system, and 3000 width (west to east) from the fault system to the Jordan River drainage system, where the saturated thickness of the aquifer is 120 m. The effective porosity of the aquifer is 27%, so the storage capacity of the aquifer system is about 97 MCM, we predict the available stored water of about 61 MCM. The groundwater gradient between the mountain aquifer and the shallow aquifer is 0.01. We found out that a lateral flow of 1.8 MCM/year from the mountain aquifer across the fault system into the shallow aquifer. The current abstraction from all boreholes is about 3 MCM/year, so there is a deficit in water budget of about 1.2 MCM/year, this cause lowering water table and an increase in salinity.





	PWA	19-15/019	19-15/007
Depth (m)	346	92	105
Water table (m)	-109	-37	-65
Ec (µs /cm)	1000	6380	3000
PH	--	7.09	7.07

Figure 5.2: Cross section for the study area, from PWA well at the mountain aquifer to injection borehole well at the shallow aquifer, showing the conceptual flow model from the mountain to the Dead Sea deposits aquifer, with the initial salinity from different wells.

5.2. Salinity of groundwater:

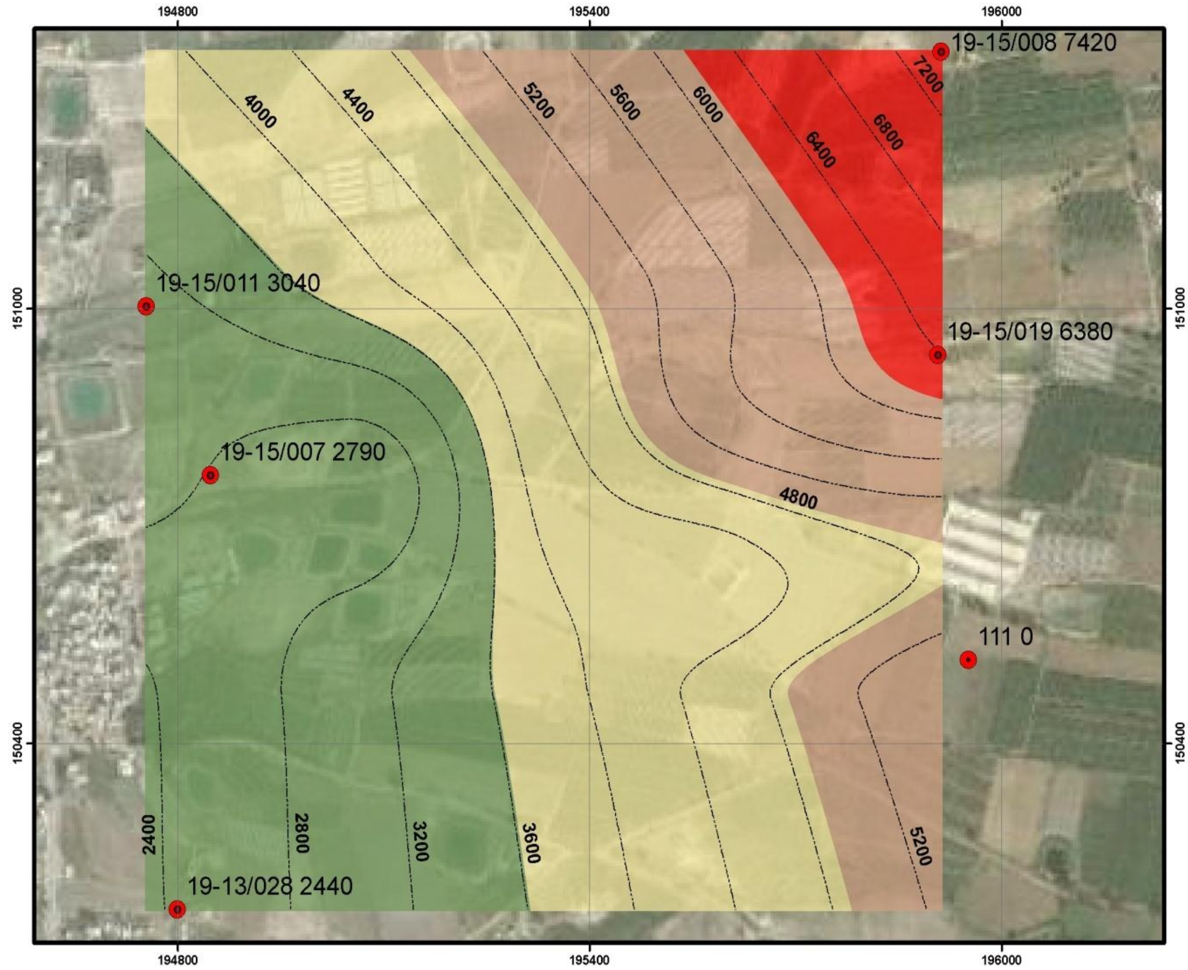


Figure 5.3: Salinity Contour Map for Al Uja wells at the shallow aquifer.

The contour map of electrical conductivity for the shallow aquifer shown in figure (5.3), explain the increased of EC – values from the south west to the north east. Where three wells with a salinity of about 2000 – 3000 µs/cm are located directly near the fault system. These wells tap water originated from the mountain aquifer that ascending upward through the fault system from the lower Jerusalem formation that confined with the overlying Abu-Dis formation. The other six wells have high water salinity 6000 – 7000µs/cm are locate further to the east of the fault system, and tapped water from a mixture between the freshwater in the mountain aquifer and that brackish water exist within the saline sediments. For example the electrical conductivity for well ID 19 -15 / 007 site in the south west equal 3000 µs/cm otherwise electrical conductivity for well 19 -15 / 019 equal 7000 µs/cm.

The changed of electrical conductivity refers to the distance of the well from the fault system. As shown in table (5.2) the distance for well ID 19 -15 / 007 from the fault system equal 60 m, but the well ID 19 – 15 /019 equal 1050This means that the water could be less salinity close to the fault, that the fault system controls the flow from the upper mountain aquifer to the Jordan Valley deposits aquifer. It's the recharge area of the shallow system.

Table 5.2: show the EcmS/cm Vs the distance from the fault for the shallow aquifer system

Well ID	Depth (m)	Ground Elevation (m)	Water table (m)	EC mS/cm	Distance from fault (m)	Aquifer
19-15/007	105	-250	-315	3	60	
19-15/19	92	-274	-311	7	1050	**Shallow**
111	90	-260	-310			
19-15/005	108	-242	-308	4	40	**Aquifer**
19-15/008	103	-283		7	490	
19-14/01	59	-268		7		
19-15/028	93	-274	-310	6		**System**
19-13/028	95	-246	-315	4	20	

5.3. Carbonate and shallow aquifer wells hydrochemistry

5.3.1. Water Type of Al Ujawells:

Four major groups of water type are identified: (Mg-Na-Cl water type group, Na-Ca-Cl group, Na-Cl group, Na-Mg-Clgroup) in more specific these water types are: Na-Ca-Mg-Cl-SO4, Mg-Na-Ca-Cl-SO4, Na-Mg-Cl-SO4, Na-Mg-Cl, Na-Mg-Ca-Cl-SO4 , Mg –Na-HCO_3-Cl, Mg-Na-Cl-HCO_3) fig (5.4).

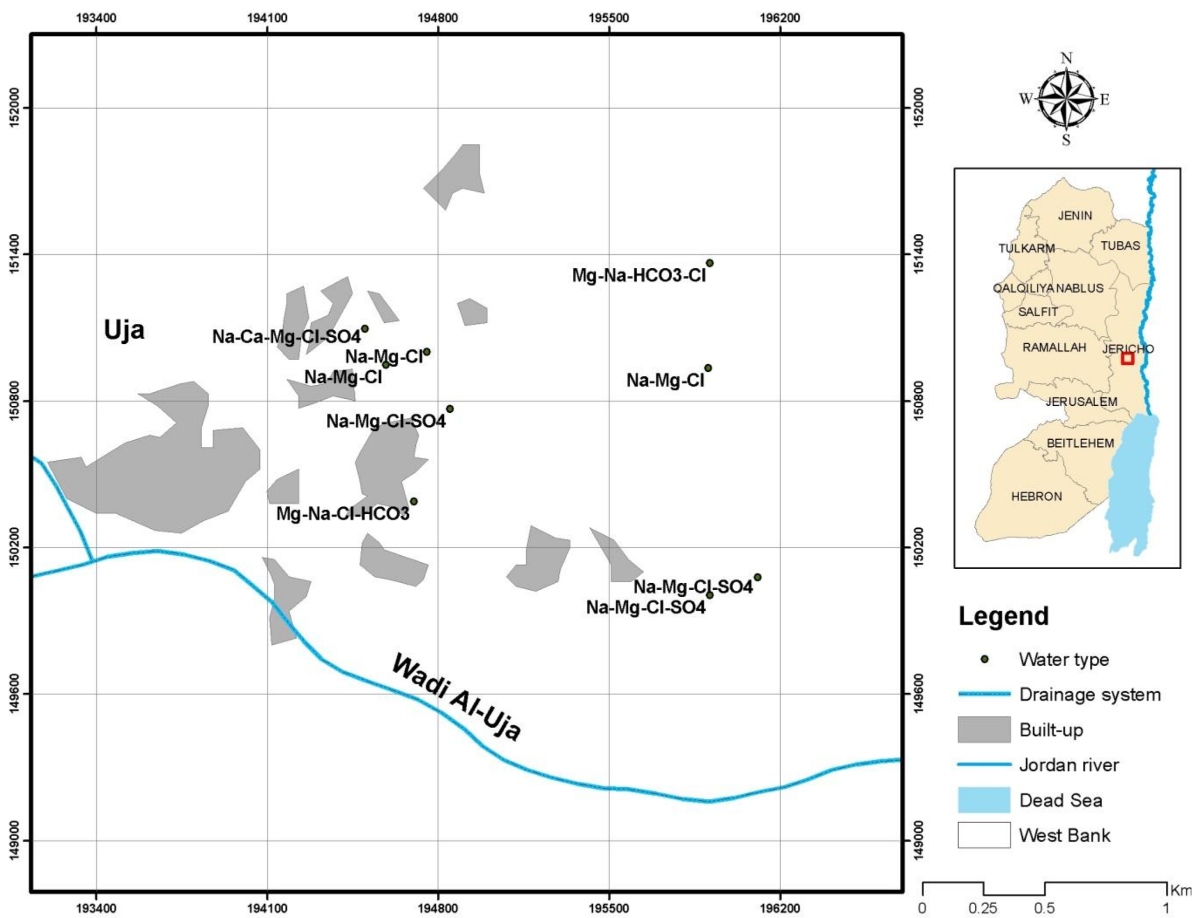


Figure 5.4: Water types classification of groundwater samples for carbonate and shallow aquifer.

5.4. Artificial recharge experiment

5.4.1. Carbonate aquifer:

5.4.1.1. Natural recharge wadi sediments:

Hydro geological measurements was applied to approve the knowledge about the connection between the mountain and the shallow aquifer, a salt tracer test was conducted to investigate the amount of surface spring water infiltrated into the mountain aquifer through wadi sediment through the section between spring niche and canal tunnel. This section consider as natural recharge zone for upper mountain and indirect to the shallow aquifer systems. Results of this test show that about 15% of the total spring discharge can consider as recharge downstream (WERL,2014). From the 8 MCM/year of average sprig discharge, it was calculated that an annual indirect recharge of about 1.2 MCM. Currently this volume flow eastwards and cross the fault system into the shallow system, and taped through the 9 wells. If the surface water retention cross the wadi and to the west of the spring niche can improve the recharge rate of both aquifer system significantly.

5.4.1.2. Infiltration Earth Dam:

In 2011, the Palestinian Ministry of Agriculture constructed Al Uja earth dam with a maximum storage capacity of 500 000 m³. The objective of this dam is to store surface water during flooding time and to use this water during water shortage period in summer. The dam was constructed to the west of the fault system where chalk and chert unit of Senonian age cropping out at the surface the dam has a catchment area of 50 km² figure (5.5). The chalk layer consider in the literature as impermeable layer. Our monitoring program during two hydrological years 2011/2012 and 2012/2013 show that 250 000 and 200 000 m³ were stored in the dam respectively. The storage duration of water was or 3.5 months/year. All water infiltrated before the end of June. This important result indicates that the chalk unit of Senonian age in this area do not consider as impermeable layer. In this case Al Uja earth dam can consider as artificial recharge dam.

Figure (5.5) : Satellite image for Al Uja dam area.

5.4.2.Shallow aquifer:

5.4.2.1. Infiltration pond:

5.4.2.1.1.Double rings methods:

Double rings measurement were applied in different site, we were used the cylinder - 30 cm in diameter drive 5 cm or more into soil surface or horizon, volume of Water Added was 50 L. Outer Rings are 50 cm in diameter. The accumulative infiltration for sample site one was 9 mm in 270 min, sire two was 55 mm in 270 min and for site three was 40 mm in 270 min.

The analysis measurement data for the infiltrometer data between accumulative infiltration rate with accumulative time shown in figure (5.6.a, b, and c), relating to the three curves 0.5 cm / hr was infiltrated. And as the thickness of Lisan formation equal 15 m , so the water need 3000 hr which equal 125 days to cross the Lisanlayer. But to reach to the ground water table which it is 37 m below the ground it need 308 days.

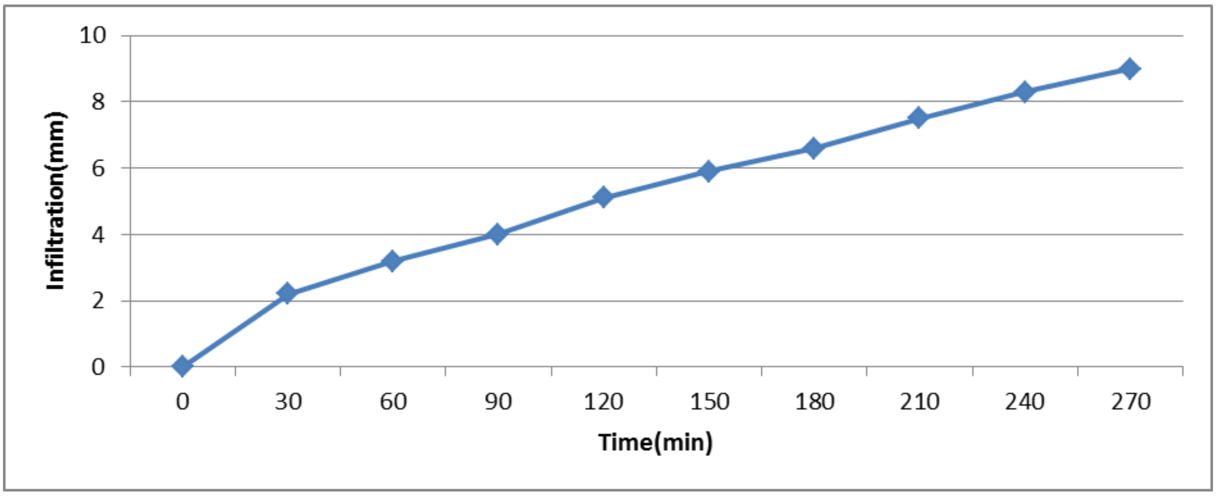


Figure (5.6.a) :Double rings analysis for site one .

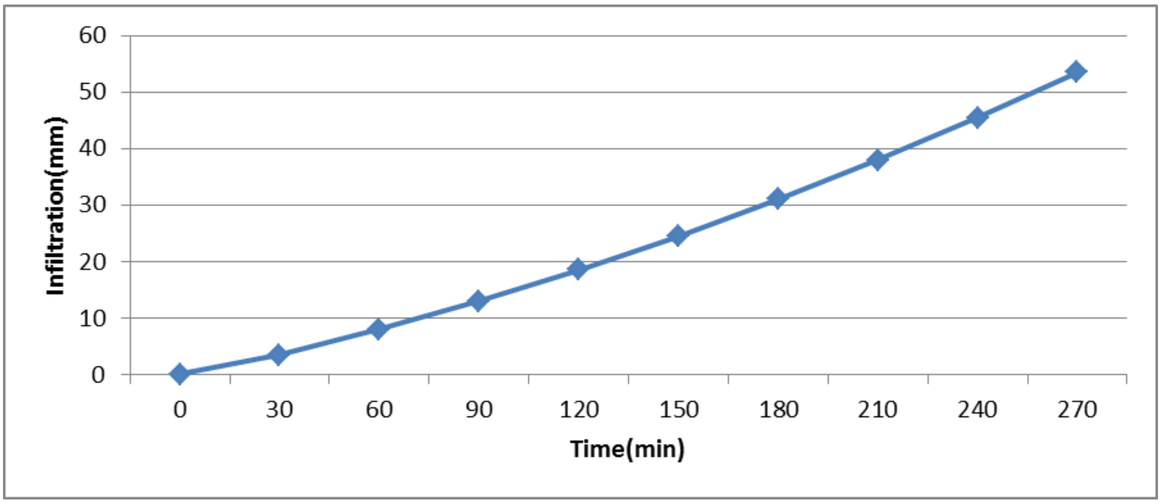


Figure (5.6.b) :Double rings analysis for site two .

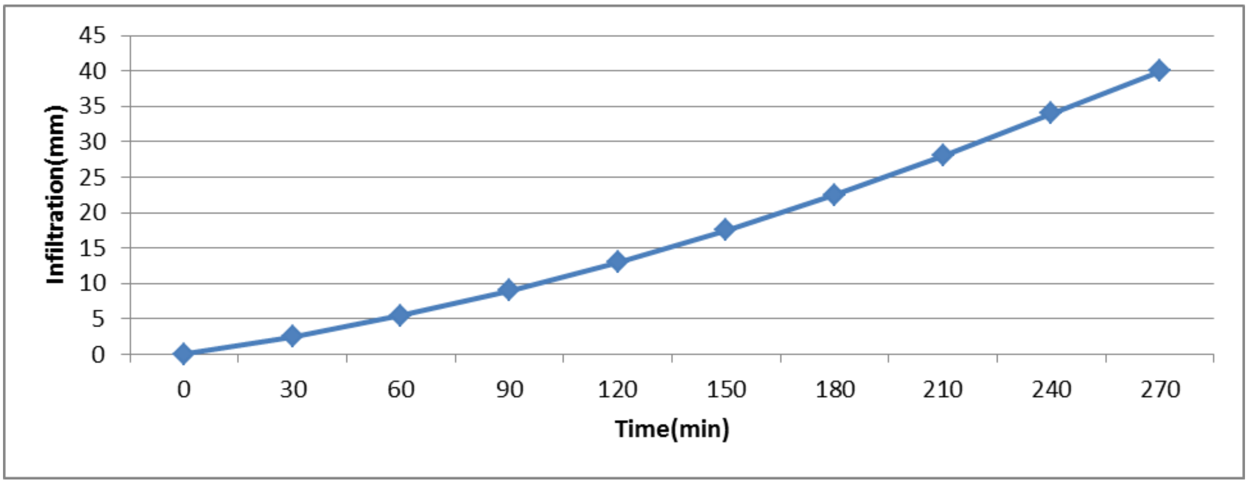


Figure (5.6.c) :Double rings analysis for site three .

Another test was applied on the pond to support our result from the double rings, as following 600 m3 of Al Uja spring flooding water was drain in the pond figure(5.6.d), and after seven days the water has been diapered figure (5.6.e) from the pond.

By using the above carves, 2.5 mm of water need 30 min to infiltrate and 10 mm need 120 min, this mean that 90 min will infiltrate 7.5 mm of water, which equal 0.08 mm/ min, and 4.8 mm/ hr. If it multiplied with the area of pond bottom which equal 600 m2, the result is 48 L / min. The amount we put was 600 m3, and according to the last result it needs 12500 min to infiltrate which equal 8.6 days. This means that the impact of evaporation reduces the volume of water by one day of infiltration.

Figure (5.6.d): 600m3 from Al Uja spring flooding were drain in the pond.

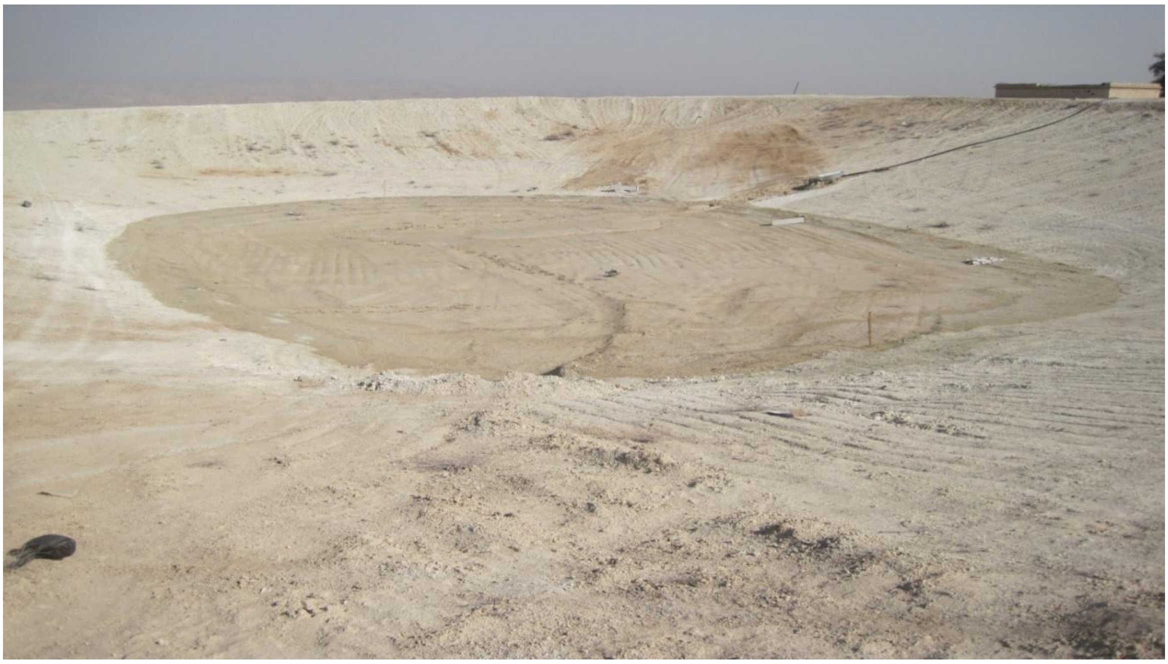


Figure (5.6.e): After 7 days (28-02-2012) the 600m^3 of pumped water was disappear.

5.4.2.1.2. Dipole – Dipole method:

This method was used to explain and explore the amount of infiltrated water, we were measured first profile in pond Figure (5.7.a) , after that we filled the pond by water with 20 cubic meter. After three days the second measurement was applied Figure (5.7.b). The analyzed data shows that water on that day infiltrated to a depth of about 2-3 m. Which means that the water need 15 days to cross the lisan Formation layer and 50 days to received to the water table in the area at 37 (b. g) .

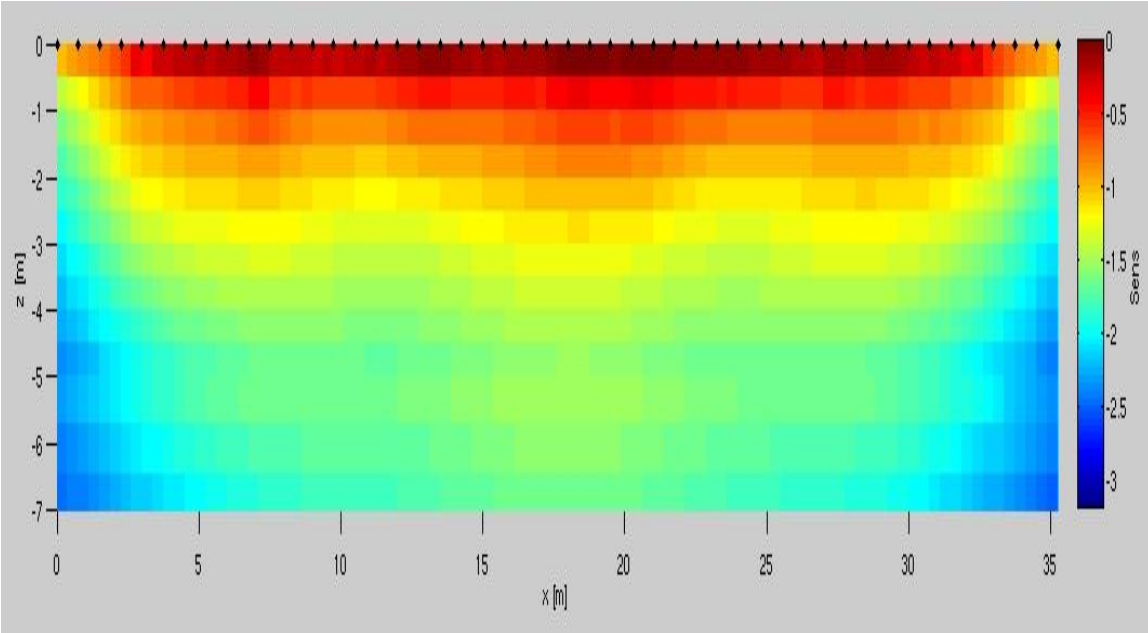


Figure (5.7.a): Vertical electrical sounding test for the first measurement.

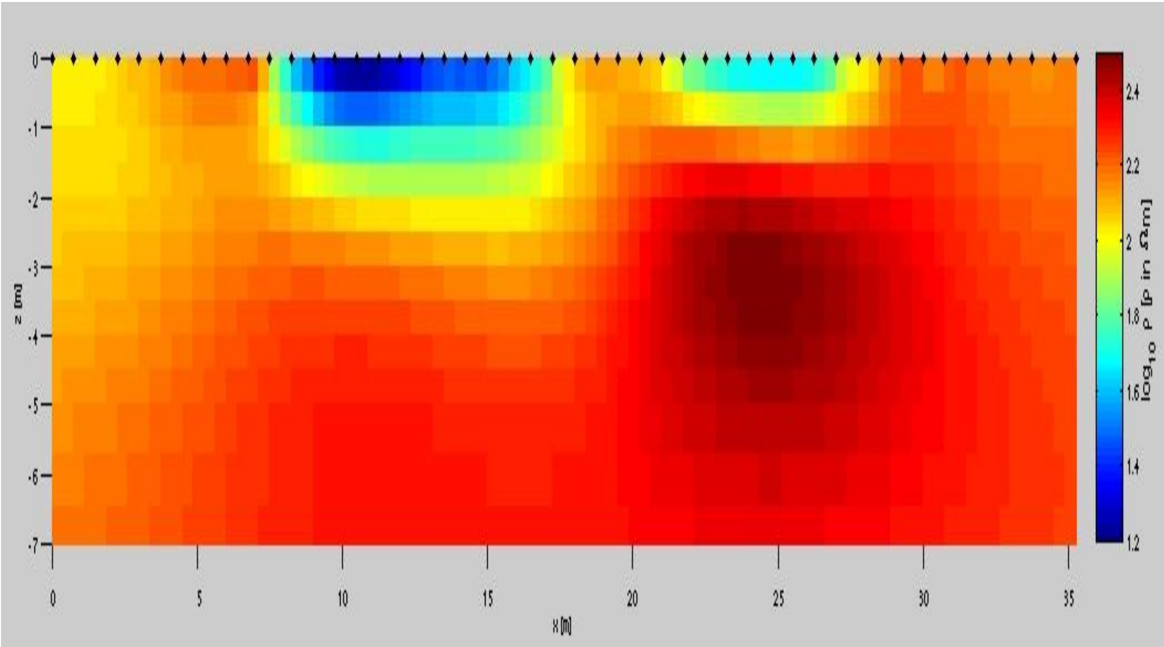


Figure (5.7.b): Vertical electrical sounding test for the first measurement.

5.4.2.1.3. Soil analysis:

The material of these ponds consists of soft material of Lisan formation that consists of 22% sand, 23% clay, and 45 % silt, table (5.3). The average hydraulic conductivity coefficient of the ponds material is $2.6*10^{-2}$ cm/second determined by Hazen equation. Results of additional geo-electrical investigations, show that the wet front reach a depth of

2.5 m depth after 3 days , so the infiltrated water velocity is about 9.6 * 10 E-4 cm/s. The depth to groundwater table is 37 m, so infiltrated water can reach the groundwater table after 50 days of filtration. According to this result, this method is not to recommend due to the high evaporation rate, and these ponds can use only for water management.

Table 5.3: Show soil sample percentage texture:

NO	sample No	Sand %	Clay %	Silt %	K
1	p1	36.6	22.25	39.65	7.21aE-6
2	p2	45.5	18.1	35.5	1.25E-5
3	p3	48.7	21.15	29.25	4.313E-5
4	p4	59.65	27.85	11.15	3.8E-4

From the above table the Average K is equal 2.66 * 10-3 m/ day.

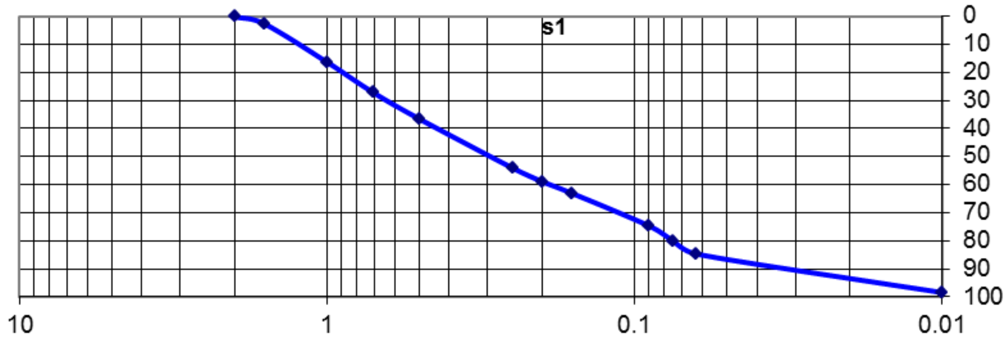


Figure 5.8.a: Grain size distribution curves for sample point 1 .

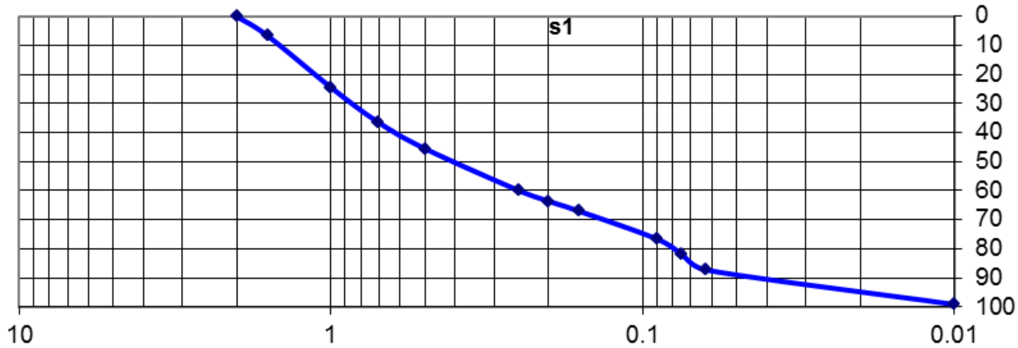


Figure 5.8.b: Grain size distribution curves for sample point 2 .

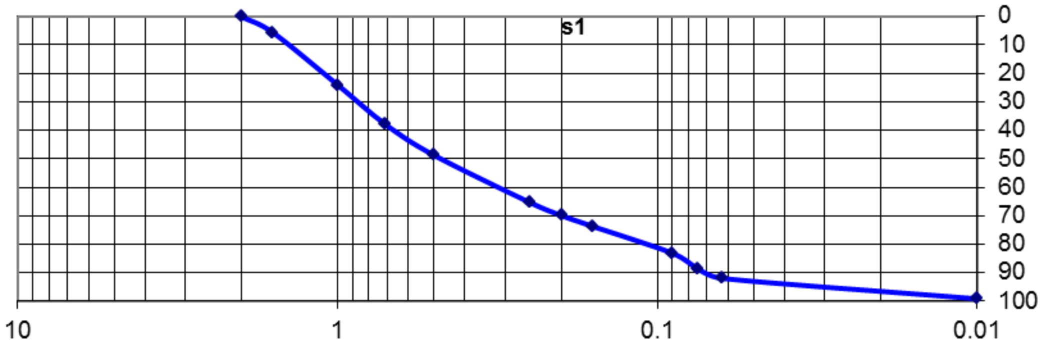


Figure 5.8.c: Grain size distribution curves for sample point 3 .

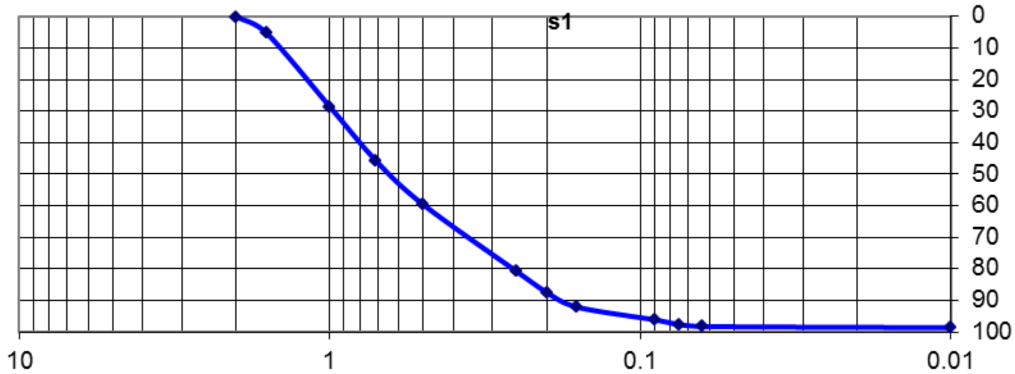


Figure 5.8.d: Grain size distribution curves for sample point 4 .

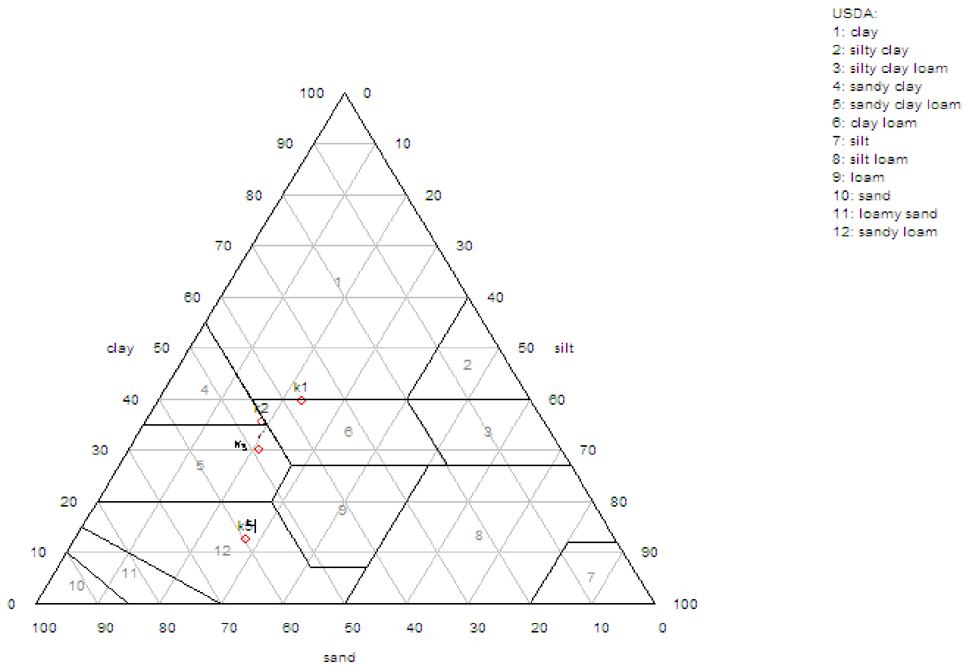


Figure 5.8.e : Soil texture triangle for four samples.

Table 5.4: Chemical analysis for soil samples (inside of pond)

Sample name	EC µs/cm	pH	Cl - mg/l	HCO3 mg/l	P mg/l	SO_4^{-2} mg/l	F- mg/l	Mg mg/l	PO_4^{-3} mg/l	P_2O_5 mg/l
P1	388	7.71	35.45	85.45	0.65	35	0.7	87.48	1.98	1.48
P2	356	7.78	35.45	97.63	0.21	8	0.9	79.98	0.64	0.47
P3	325	7.89	21.27	85.45	0.06	23	2.04	57.11	0.19	0.14
P4	327	7.73	28.36	85.45	0.17	14	2.08	68.04	0.52	0.39

5.4.2.2. Injection borehole:

5.4.2.2.1. Quality of the Static water at borehole:

Electrical conductivity and temperature measurement were carried out before starting the experiment. Figure (5.9.a) present the electrical conductivity of groundwater column. Water table located by 38.6 m below the ground and the electrical conductivity was 4.3 mS/cm by this depth, and with increasing the depth Ec raised through four steps: 1- increase to 6 mS/cm by a depth 46 m, 2- raised to 7.6 mS/cm by a depth of 52 and then reach 8.6 by a depth 82 meters. These values indicate that water within the aquifer system has different characteristics (Ec-values), which could be related to four groundwater stocks.

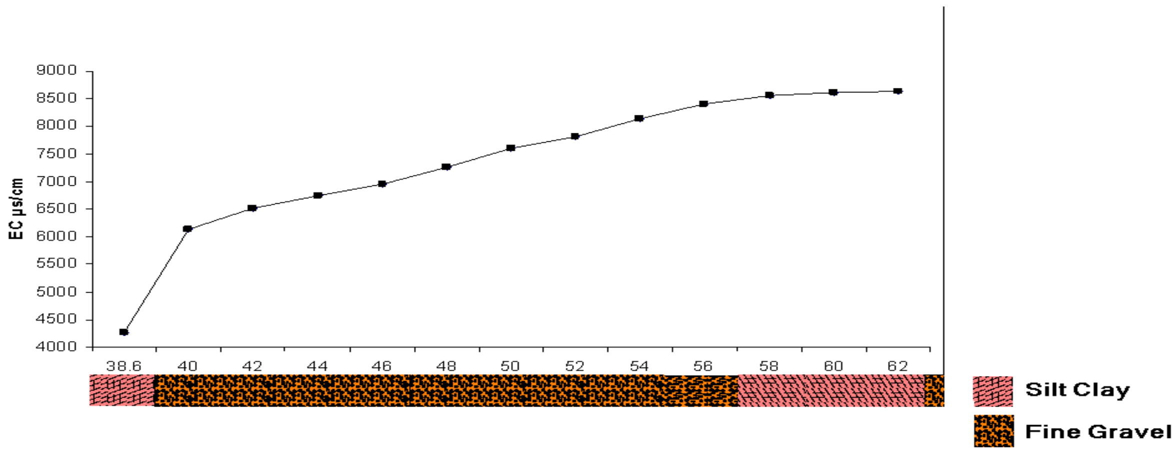


Figure 5.9.a: Electrical conductivity profile along the borehole water column (before injection).

The temperature of the water column profile ranged between 23.7 ºC to 26.5 ºC, and the temperature changes occurred also in four steps, first with 23.7 ºC in a depth of 42 m, second with 24.6 ºC by a depth of 50 m, third with 25.9 C by a depth of 56 m, and fourth with 26.5 ºC by a depth 82 m (see Figure 5.9.b).

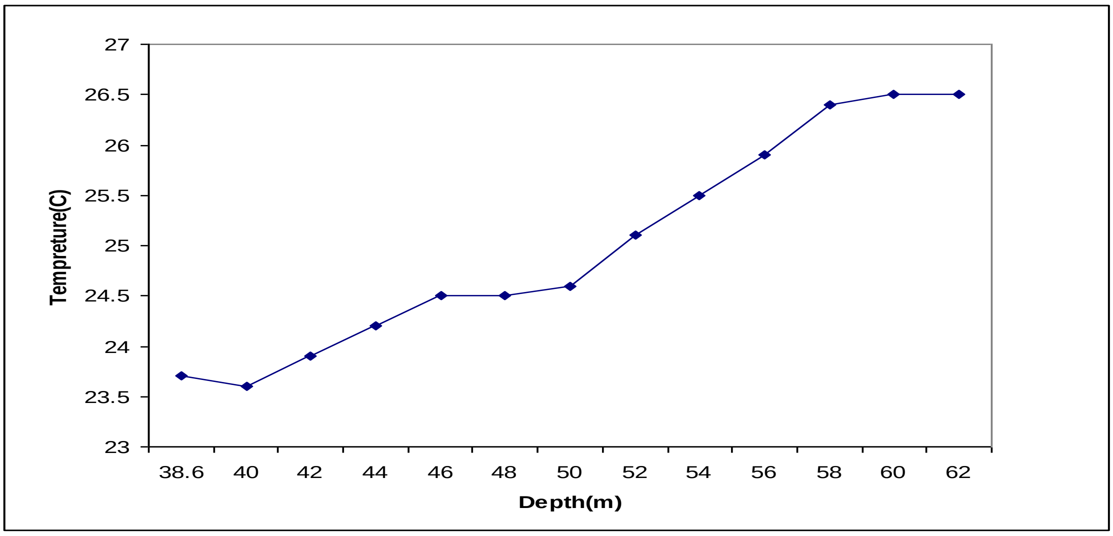


Figure 5.9.b: Temperature profile along the borehole water column (before injection).

5.4.2.2.2. Assessments of groundwater after borehole injection:

The experiment was carried out for four times during the period of 15/02/2012 to 6/4/2013. The water injected by a depth of 52 m .The first experiment was carried with different water flow and different duration time as following:

First test: 120 m^3/ 3 hours, 40 m^3/ 1 hour,215 m^3/3hours, and 200 m^3 /3 hours duration. During the injection processes, groundwater table raised from 38.6 m to 32.5 m below the ground level figure (5.9.c).

The static water table of the borehole located by 38.6 m below the ground, and after 5 minutes of running the experiment, water table raised to 34.0 m below the ground, and during the rest of experimental time, water table raised additional two meters. The raised of water table did not depends on the volume of injected water.

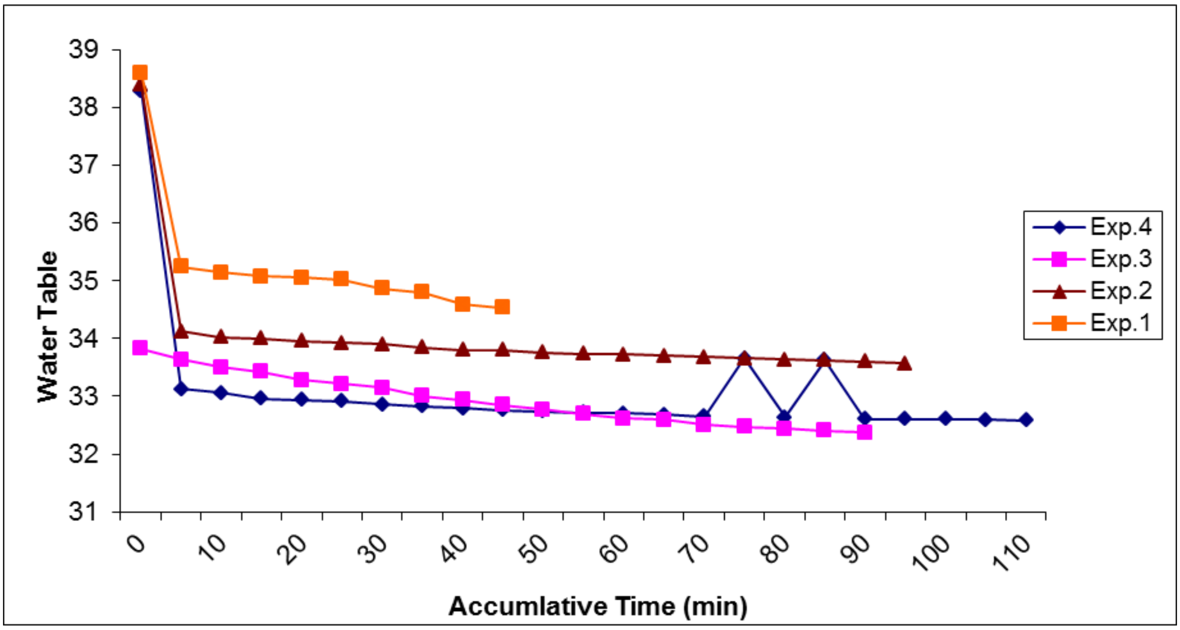


Figure 5.9.c: water table reaction during the four injection tests (120, 40, 215, and 200 m^3/h).

The electrical conductivity of the injected water 622 uS/cm. Figure (5,9,d,e) present the electrical conductivity of water column within the borehole profile. The measurements carried out after three hours for the first experiment. The Ec-values of the first 58 meter depth range between 1300 and 834 uS/cm, between 60 m depth 66 m , the Ec-values range between 3097 and 1420 uS/cm. From 68 to 78 m depth, the Ec-values range between 984 to 503 uS/cm. We noted that the Ec-values after a depth of 74 m, drop to less than the Ec-value of the injected water. And this well explains in other section.

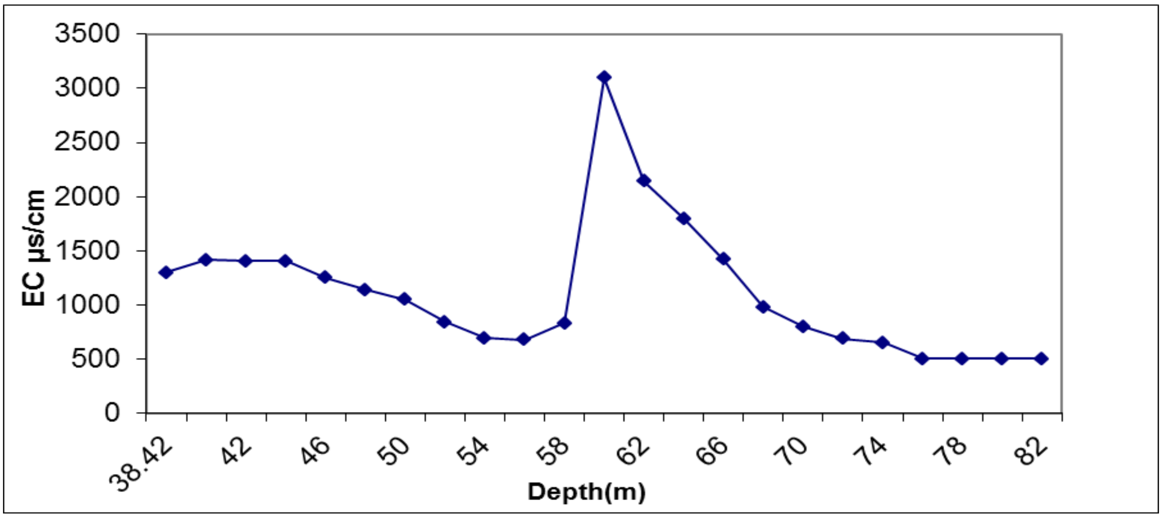


Figure 5.9.d : Ec-values after 3 hours, from the first experiment .

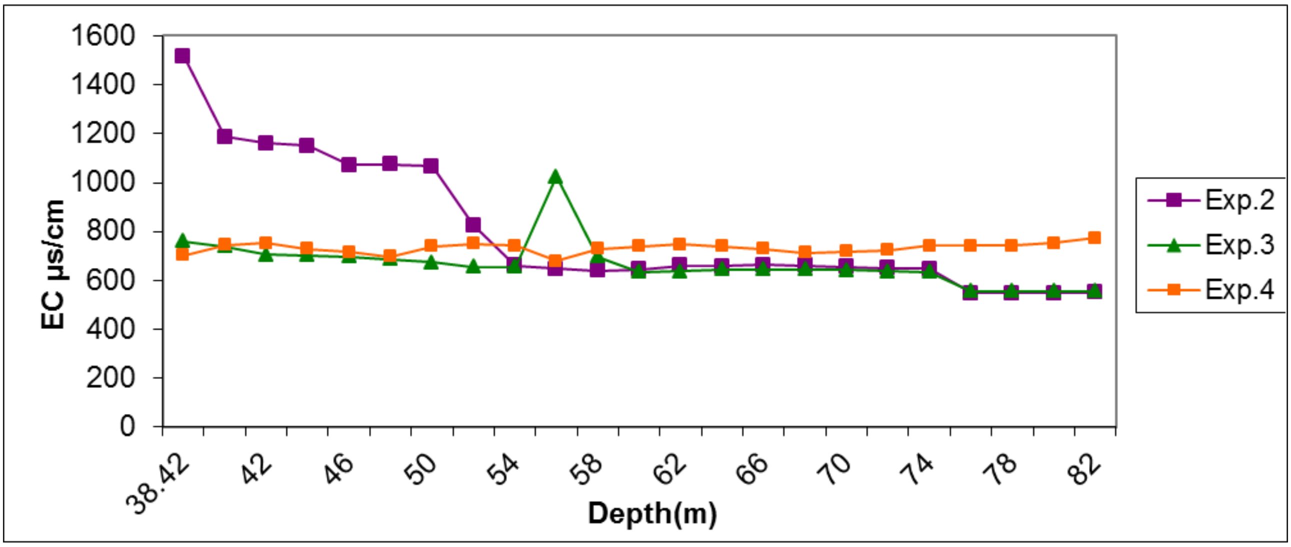


Figure 5.9.e: Ec-value after 3 hour form the 2, 3 and 4 injected flow of the first test.

Water temperature was measured before and after the injection experiments. Figure (5.9.f) summarized the results. Water temperature before the experiment range between 23.7 and 26.5 C, and drop down between 21.9 and 18.1C, after carrying out the injection test, these values cope with the values ofinjected water, that originate from the spring and exposed to the local weather.

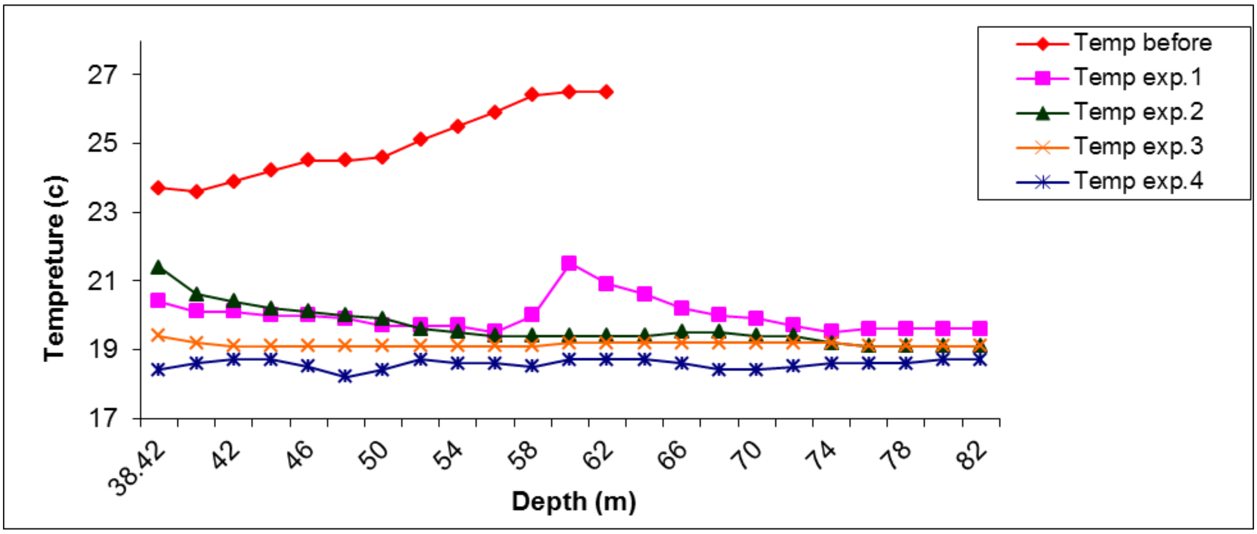


Figure 5.9.f: temperature of water profile before and after the tests.

Second test:

This test was occurred after three months from the first one.We note that the water table raised 1.2 meter to located by 36.40 m below the ground with electrical conductivity 589 µs /cm by this depth, and with increasing the depth Ec raised through steps: increase to 3600 µs /cm by a depth 60 m, raised to 5600 µs /cm by a depth of 68and then reach 6250 µs/cm by a depth 82 meters.

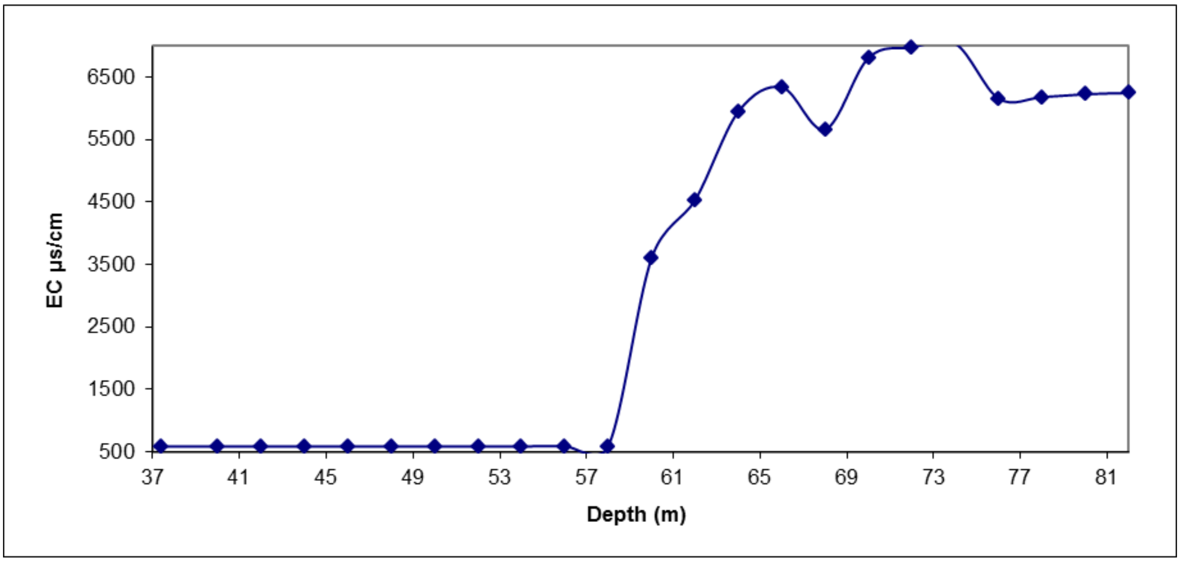


Figure 5.9.g: Electrical conductivity along the borehole water column after three months from the first test.

The temperature of the water column profile ranged between 23 ºC to 25.9 ºC, and the temperature changes occurred in three steps, first with 23 ºC in a depth of 58 m, second with 24.9 ºC by a depth of 64 m, and third with 25.9 C by a depth of 82 m.(see figure 5.9.h).

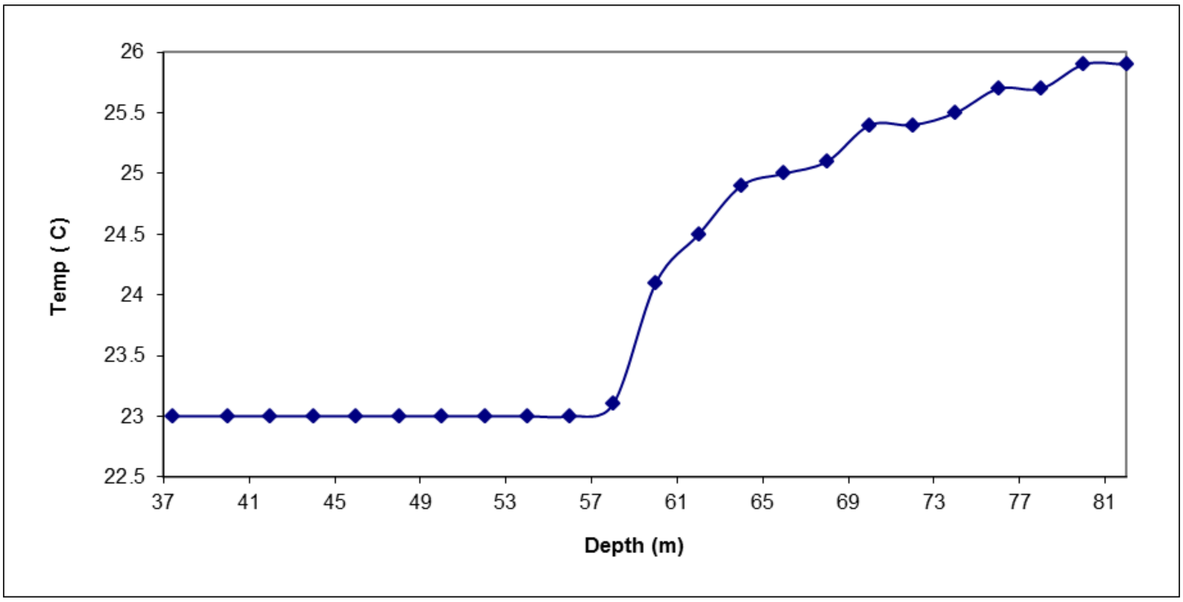


Figure 5.9.h: Temperature measurement along the borehole water column after three months from the first test.

The amount of injected water in the second test was 2600 m^3. With different flow and duration time as: 430 m^3/ 3 hours, 860 m^3/ 10 hours, 765 m^3/ 9 hours, and 630 m^3 /7 hours duration.

The groundwater table raised from 36.86 m to 26.35 m below the ground level, figure(5.9.i) .The static water table of the borehole located by 36.86 m below the ground, and after 15 minutes of running first and second injected water, water table raised to 32.4 m below the ground, and after 5minutes water table raised to 27.6 m in the their and fourth experiments.

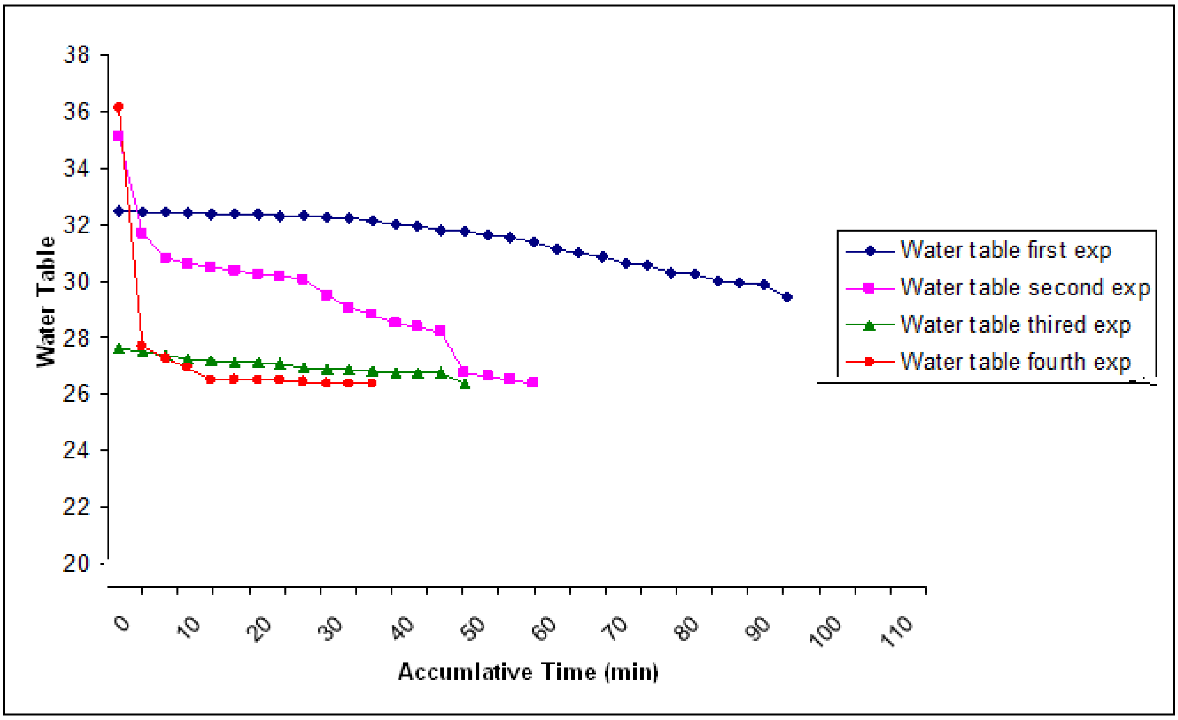


Figure 5.9.i: water table reaction during the four injection tests (430, 860, 765, and 630 m^3/h).

The electrical conductivity of the first 74 meter depth after injected 430 m3/h was 560uS/cm, and from 76 to 82 m depth Ec was 405uS/cm, figure (5.9.j)Ec- values at all after injected water through the borehole column less than theEc- values of the injected water.

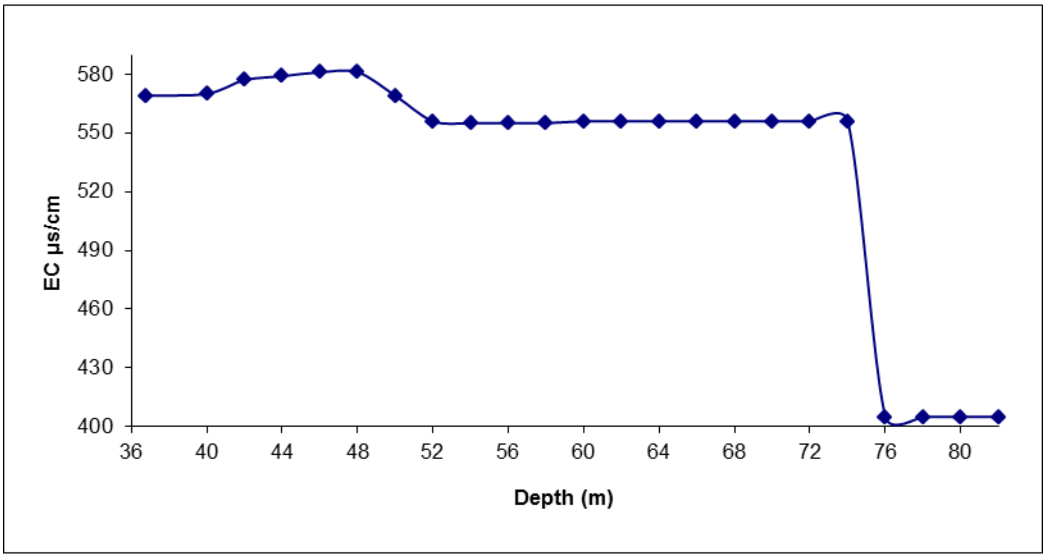


Figure 5.9.j: Ec- values after injected 430m3/h of spring water.

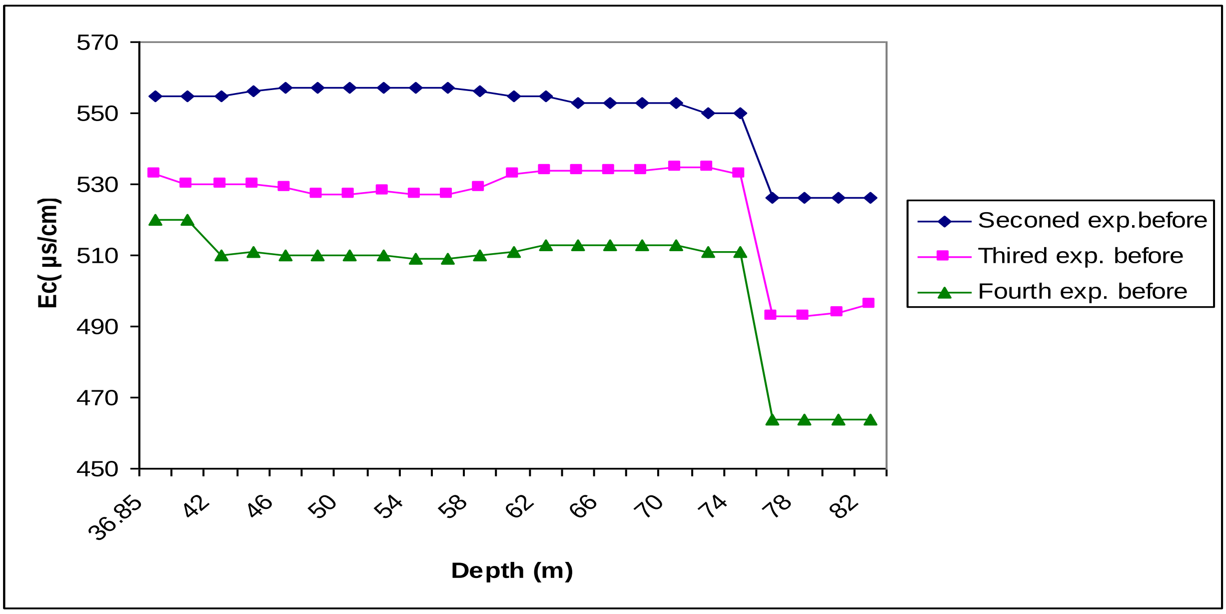


Figure 5.9.k: Ec- values after injected (860, 765, 630 m3/h).

There is a different in the Ec-values between the second and the third/fourth test for the first 54 meters, and then the three experiment show the same trend. After a depth of 74 m the Ec-values drop to 405 uS/cm.

Third test:

This test was occurred after ten months from the second test. We note that the water table decreased 0.7 meter to located by 37.42 m below the ground with electrical conductivity 7218 µs /cm by this depth. During the last ten months the weather was summer which mean that there is no spring flooding, the farmers pumped the water from the well, which support that the over pumping will reduced the amount of groundwater and will change the quality.

Figure (5.9.l) show that theEc-value increasing with depth from 7200µs/cm at depth 37.42 m below the ground to reached 12700 µs/cm by a depth 82 meters. The Temperature was 26.2 to 26.7 C. Figure (5.9.m)

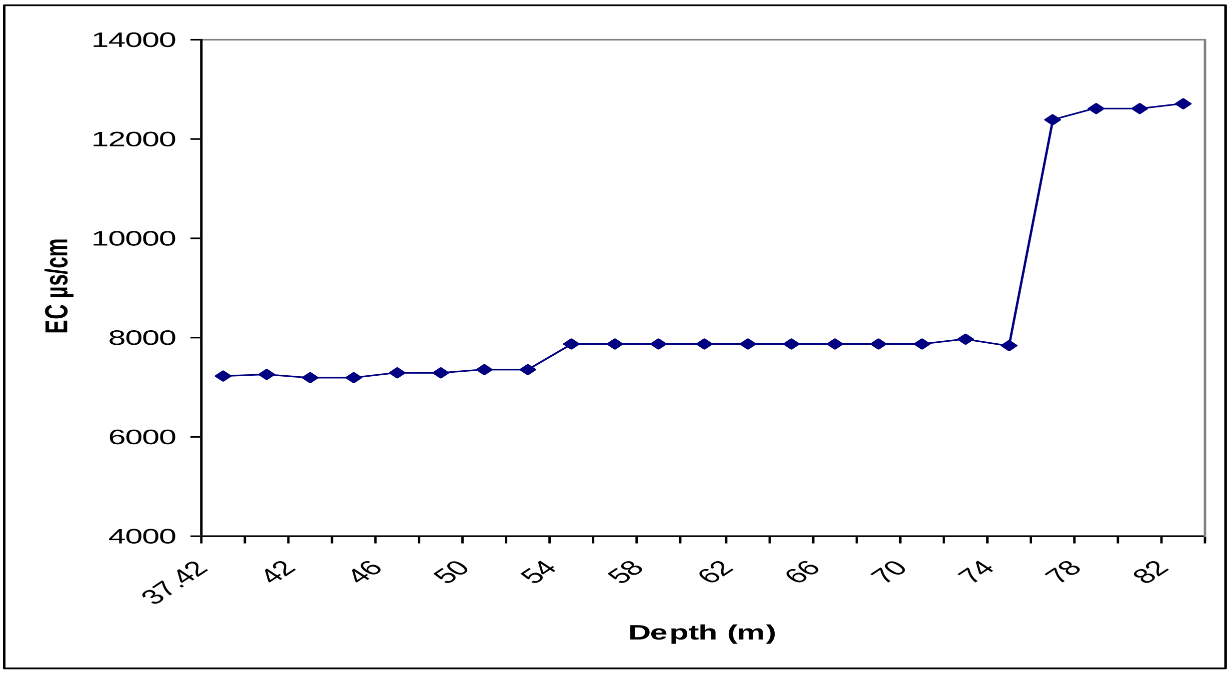


Figure 5.9.l: Ec- values after 10 months from the second test (during summer period)

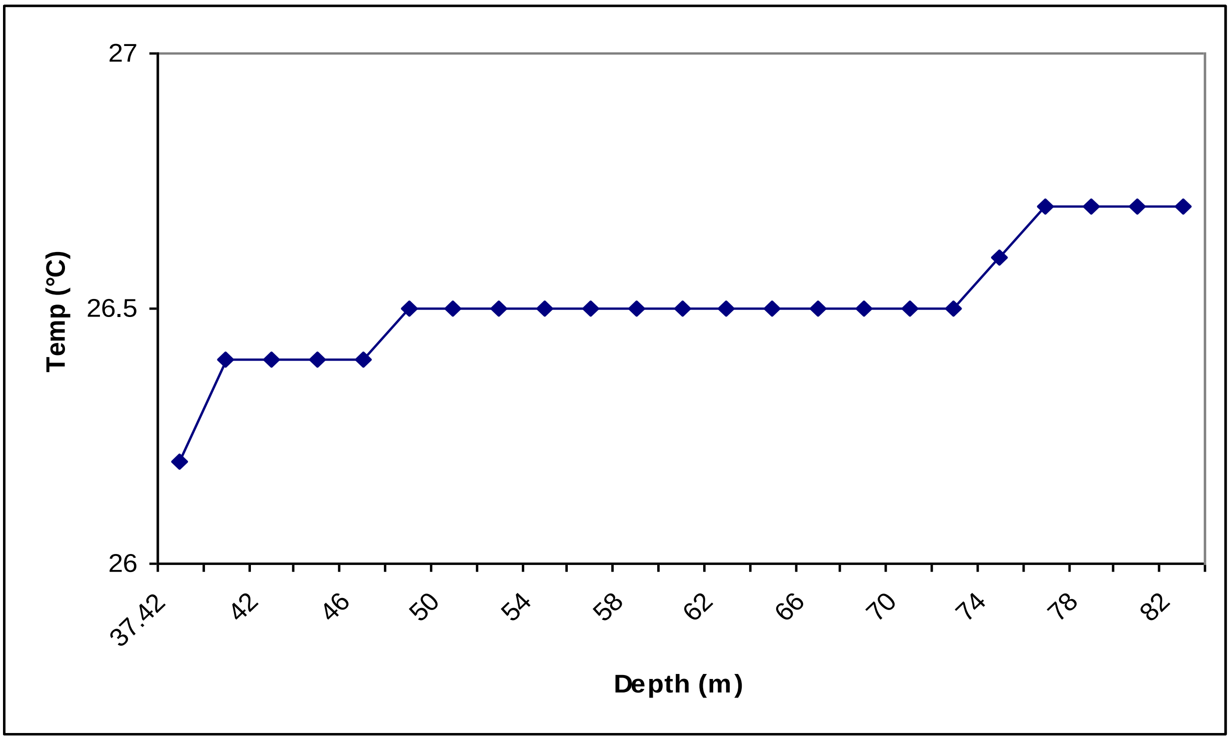


Figure 5.9.m: Temperature with depthafter 10 months from the second test (during summer period).

The amount of injected water in the third test was 1600 m^3 on 15 hours duration, in this test we note that after 5 min from start injected water the water table raised 3 meter to reach 34.07m below the ground. 1600 m3 / 15 hr increasing the water table one meter as shown in figure(5.9.n) the water table was 36.7 with Ec 533 µs/cm decreased to 513 µs/cm at depth 82m.

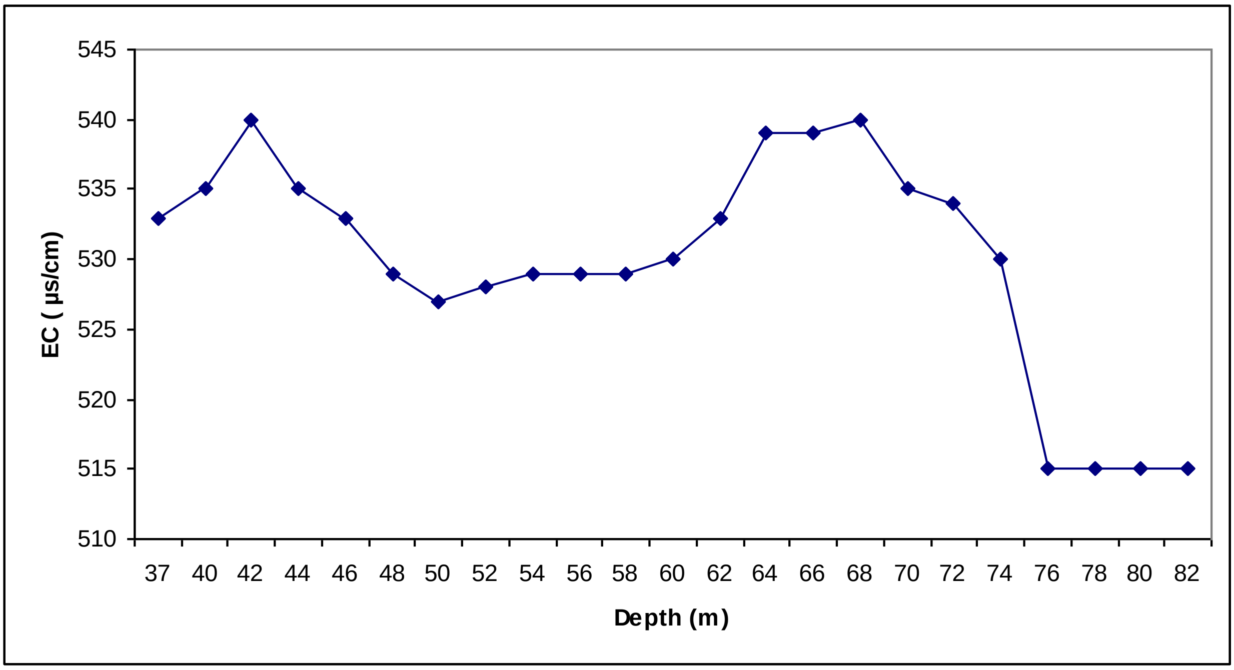


Figure 5.9.n: Ec-value with depth after injected 1600 m3 / 15 hr.

Fourth test: the last test that accrued after one month after the third, the water table was not changed in this period, its still 36.7m below the ground m but the big changed was happened on the Ec-value (1150 µs/cm) figure (5.9.o)and this mean that the last 1600 m3 that was injected in the third test still at the aquifer and decreased the salinity of water at borehole.

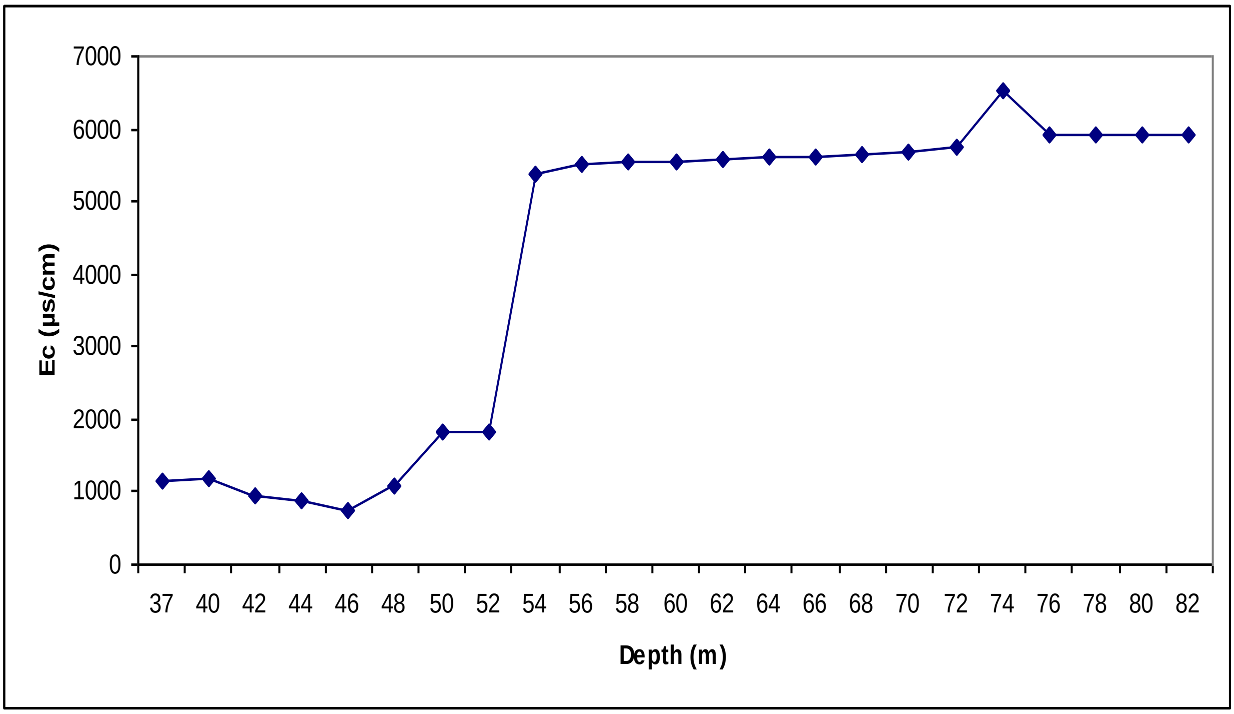


Figure 5.9.o: Ec-value with depth after one month from the injected 1600 m3 / 15 hr.

The amount of injected water in the fourth test was 2000 m^3 on 25 hours duration, we note that after 5 min from start injected water the water table raised 3 meter to reach 34.5 m below the ground. From figure (5.9.q) we can note that the Ec-value with depth after injected 2000 m^3reached to 545 µs/cm.

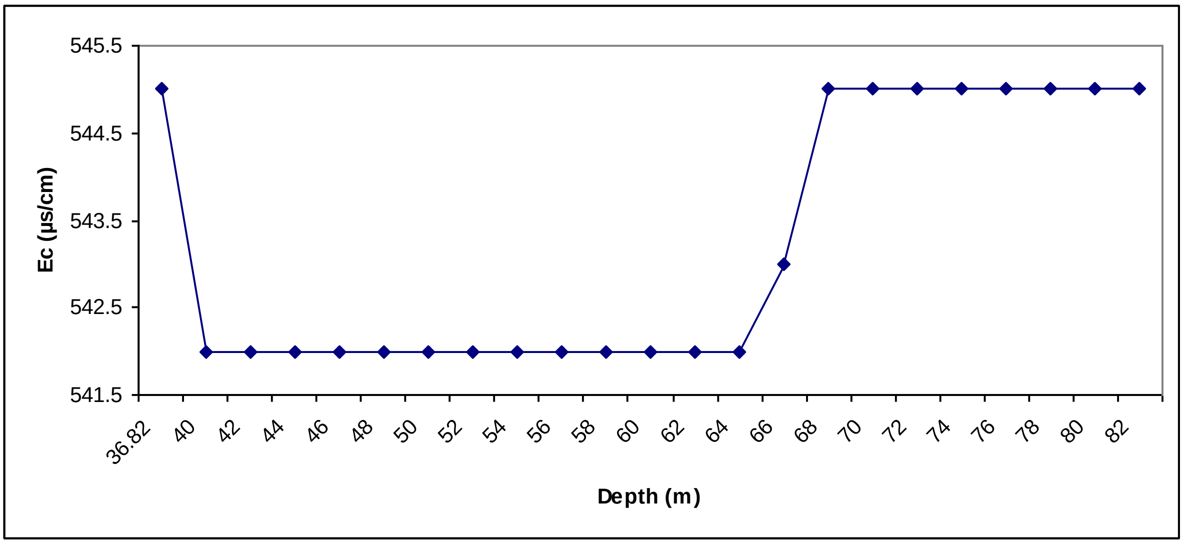


Figure 5.9.q: Ec-value with depth after injected 2000 m3 / 25 hr.

To understand the decreased of the Ec-value for the borehole profile, different test and analysis was applied to interpretation this changed**:**

First test: Calculated Conductivity:

The results of Ec-value in all tests show that after injected spring water with 622 uS/cm the Ec-value within depth changed to reached 500 uS/cm. This means that the Ec at water column is less that the injected Ec. So TDS mesurnemnt test was applied to analysis if our measurements are true:

The Conductivity is a good estimator of TDS because TDS in mg/l is proportional to the conductivity in micro-siemens.

TDS (mg/l) = A * conductivity (uS)

Where A : 0.62

Also the Conductivity (uS)= sum of anion (meq/l) * 100

By applied this equation:

EC = 126 * 100

Ec= 12600 (meq/l)

TDC = 12600 * 0.63

TDC = 7812 mg/l

From this result we can conclude that our measurements are corrected and the Ec electrode was fine.

Second test :Saturation indices (SI):

Saturation index are used to evaluate the degree of the equilibrium between water and mineral (Nwankwoala,H.O,2011).

Changing in saturation indices values or state are important to distinguish different stages of Hydro-chemical evolution and understand and identifying which of the geochemical reaction are important in controlling the water chemistry (Aghazadeh, N .,Mogaddam ,A 2010). The thermodynamic calculation of each saturation indices was calculated by using Aqua hemsoftware programme which based on the following equation:

$$SI= Log(K\ IAP/ Ksp)$$

Where K IAP is the ion activity product of the dissociated chemical species in solution whichequals the product of the measured activity and Ksp is the solubility product of the minerals.

An index of (SI) in case of KIAP <Ksp or saturation indices less than zero water is undersaturation with respect to the mineral phase which tent to dissolved more of the mineral ,(SI)values less than zero could reflect the chemical character of water in any lithologicalformation with insufficient amount of the mineral for the solution or short time in contactwater with the formation.

If (SI) greater than zero or KIAP >Ksp in this case water is over saturated with respect to themineral phase and for this reasons water in capable to dissolved more minerals and tent toprecipitation . (Aghazadeh,N .,Mogaddam ,A 2010). The following result Aquacem programpresent that the sample water from the selected borehole is over saturated with Calcite.

Phase	SI	log IAP	log Ksp	
Calcite	0.12	-8.36	-8.48	CaCO3

Third test: Calcium and Sulfateratio:

Calcium – Sulfate ratio for ground water samples was applied for the borehole water as following equation:

$$\mathbf{Ca^{+2} / (Ca^{+2} + SO_4^{-2})}$$

If the Ratio

= 0.5 Gypsum dissolution

<0.5 Calcium precipitate

>0.5 Calcium source other than gypsum – Carbonate or Silicate

After applied the equation for the water borehole before injection and for the recovery sample from the borehole table (5.5) the results show that there are Ca^{+2}removals, cause of Calcite precipitation. Figure (5.9.r)

Table 5.5: present the ratio between Ca^{+2} and SO_4^{-2}

Sample Name	SO4 meq/l	Cameq/l	Ca/(Ca+So4)
Well	17.0	13.3	0.4
R1	11.3	9	0.4
R2	9.4	5.9	0.4
R3	9.4	5.9	0.4
R4	12.0	8.1	0.4
R5	12.0	8.4	0.4
R6	12.0	8.3	0.4
R7	11.5	9	0.4
R8	9.4	7.6	0.4
R9	11.3	9.2	0.4
R10	10.4	7.3	0.4
R11	8.9	5.1	0.4
R12	8.3	4.6	0.4
R13	8.9	4.3	0.3
R14	9.9	2.9	0.2
R15	8.3	4.2	0.3
R16	10.4	8.4	0.4
R17	9.4	6.9	0.4

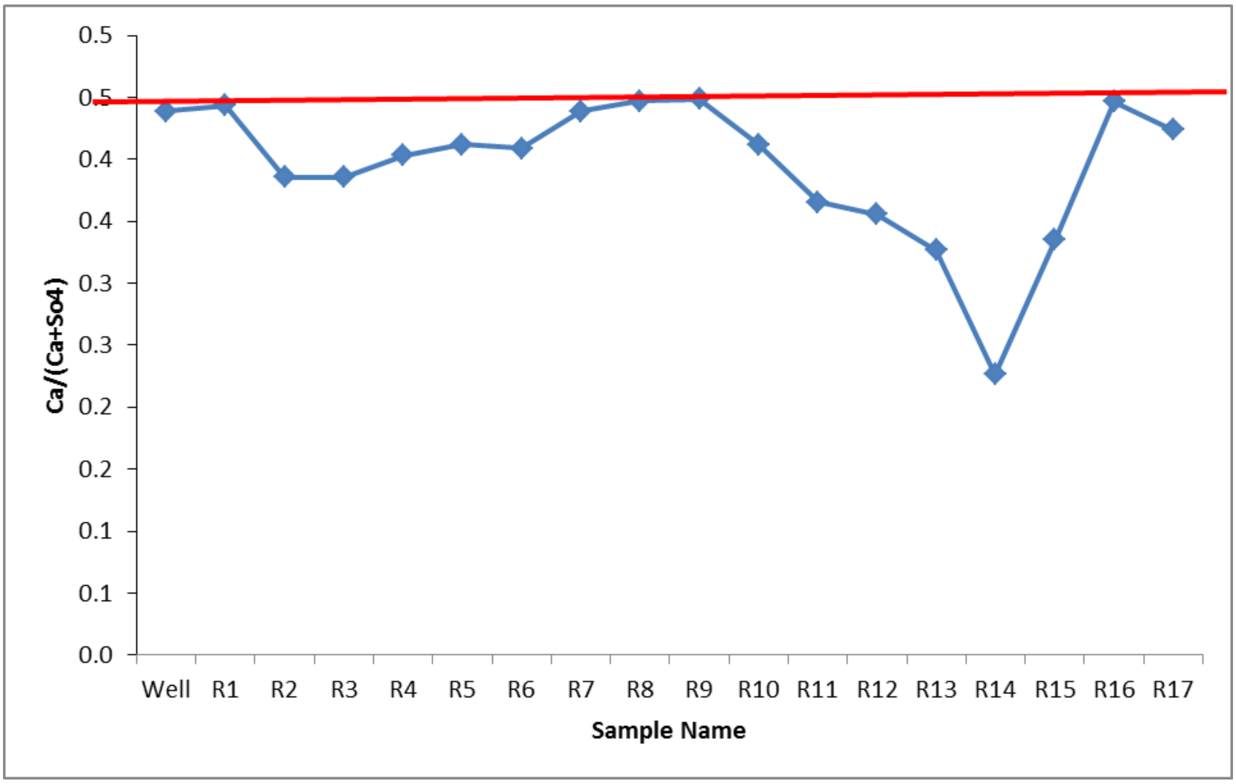


Figure 5.9.r: explain the ratio between Ca^{+2} and SO_4^{-2}

So the decreased in Ec-value within the depth after injection four test was related to the over saturation of Calcite, causer of calcite precipitate.

5.4.2.2.3. Water pumping recovery:

Recovery pumping test was applied on the borehole after first water injection test. With a rate of 70 m^3 /h for 8.5 hours duration. Ec-values and temperature were measures during the pumping test. Table 5 present the result of these measurements. It shows that after 8.5 hours the Ec-value reach 3800 uS/cm,taking into account that the original Ec-value of the water was 6500 uS/cm, also temperature increases with continuing of pumping. Figure (5.10.a.b) shows the relationship between accumulative pumping rate and temperature and electrical conductivity. Table 5.6 summarized the changes in water chemistry after three and 8 ½ hours from start pumping. Figure 10,c show that the Ec increase during the summer period were no spring flooding.

Table 5.6 : Ec-values and temperature measurement with time during the pumping.

Time	Ec µs/cm	Temperature °C
11:15	833	19.0
12:15	1257	19.4
1 :15	1742	20.5
2 :15	2219	20.6
3 :15	2698	21.2
4 :15	3118	21.9
5 :15	3526	22.0
6 :15	3878	22.2

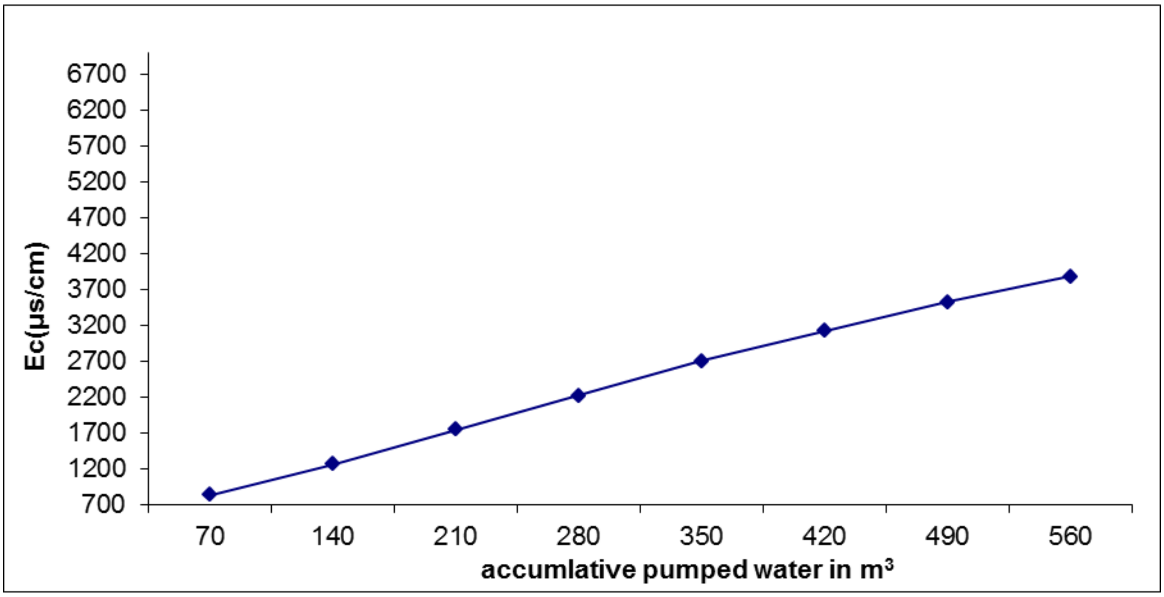


Figure 5.10.a: relationship between accumulative pumping rate and Ec-values.

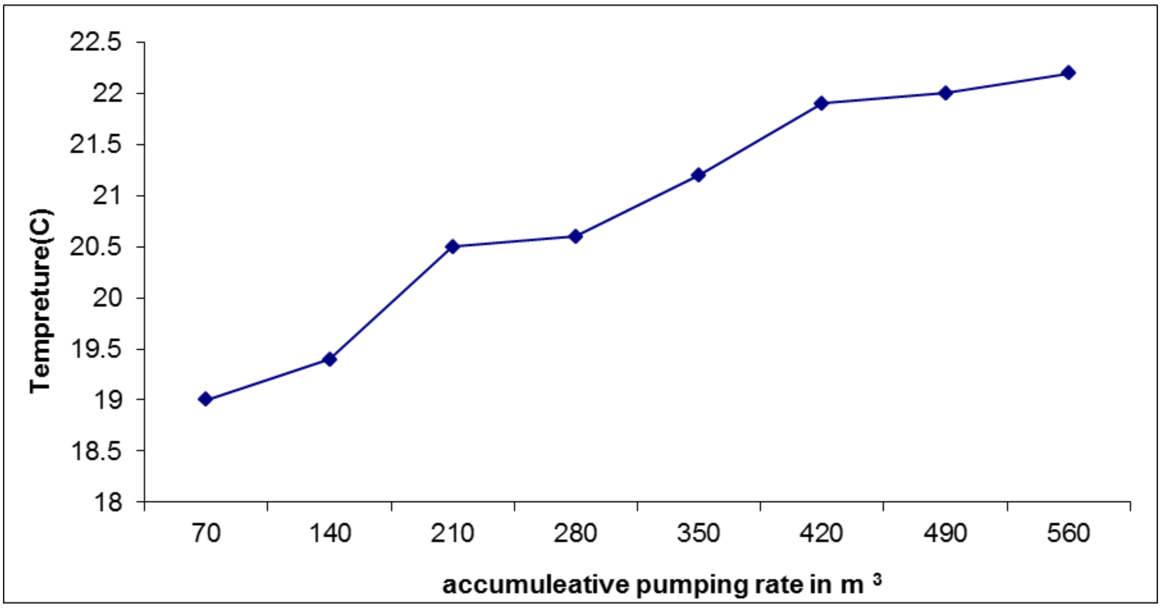


Figure 5.10.b: relationship between accumulative pumping rate and Temperature.

Table 5.7: chemical analysis for the pump water after 3 and 8:30 hours of pump:

Sample	PH	Ec µs/cm	Mg^{2+} mg/l	Ca^{2+} mg/l	K^{+} mg/l	Na^{+} mg/l	PO_4^{3-} mg/l	SO_4^{2-} mg/l	NO_3^{-} mg/l	F^{-} mg/l	Cl^{-} mg/l	HCO_3^{-} mg/l	NH_4^{+} mg/l
After 3 hours	7.7	**2135**	48.7	89.97	51.1	112.07	0.3	225	27.7	0.6	**443**	317.3	0.4
After 8:30 hours	7.6	**3927**	51.6	152.3	57.3	124.1	0.3	200	23.6	0.2	**1002**	414.9	0.2

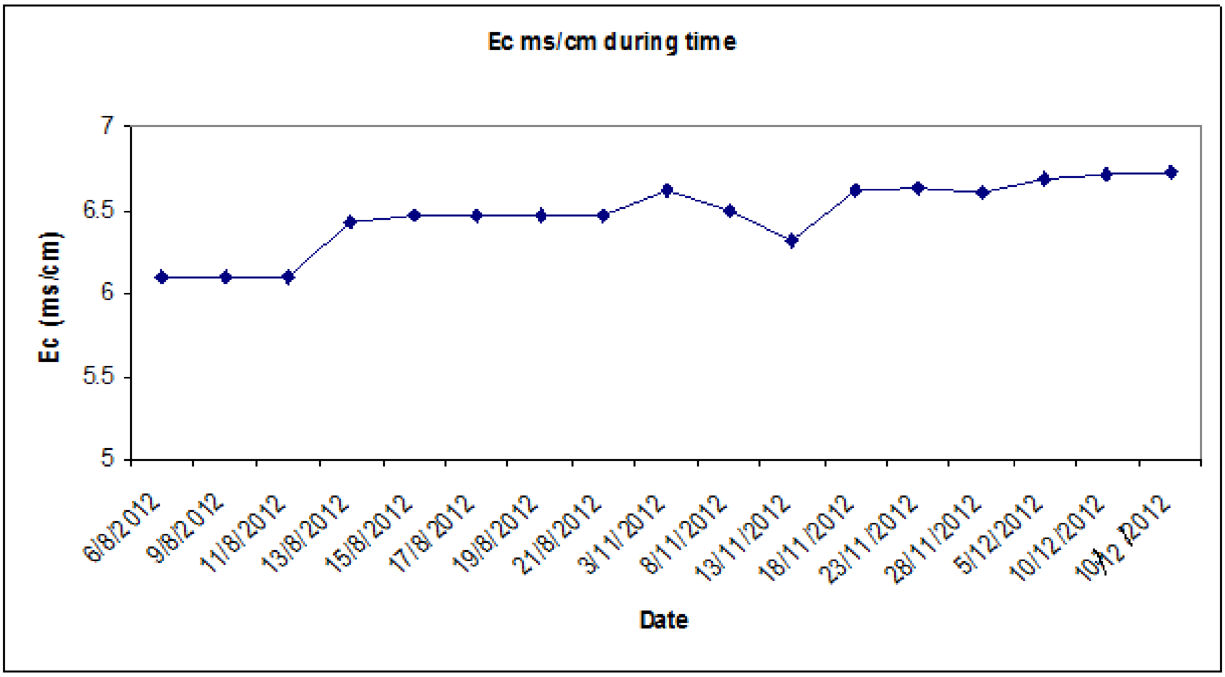


Figure 5.10.c:show the changed of Ec-value of the borehole with time.

5.5. Storage capacity of the aquifer

Shallow aquifer parameters are shown in table (5.7), where the hydraulic conductivity 800(m/day) for sand silt layer and 1900 (m/day) for gravel layer (Thaher, 2010). Transmissivityfor sand silt layer 70400 (m^3/day) and 13300 (m^3/day) for gravel layer. The layer thickness range between 6 – 75 m. The available total storage capacity was 332, 321, 5997 m3, calculated by the following equation:

Storage capacity =the volume of the potential aquifer (area of the aquifer x mean thickness) multiplied by the porosity ().Figure (5.11.a) show the 3D layers of shallow aquifer and figure (5.11.b) show the wells litho logy with electrical conductivity distribution.

Table 5.8: Calculated aquifer parameters of Al Uja shallow aquifer

Layer	Avg. Thickness of layer(m)	Specific yield (EffectivePorosity	Hydraulic conductivity (m/day)	Transmissivity (m3/day	Volume of each layer	Storage capacity(m^3)
Tope soil	6	-	-	-	3269727	3269727
Sand silt	46	16%	800	70400	47646245	762339920
Gravel	75	25%	1900	13300	102304254	2557606350
Total					153220226	3323215997

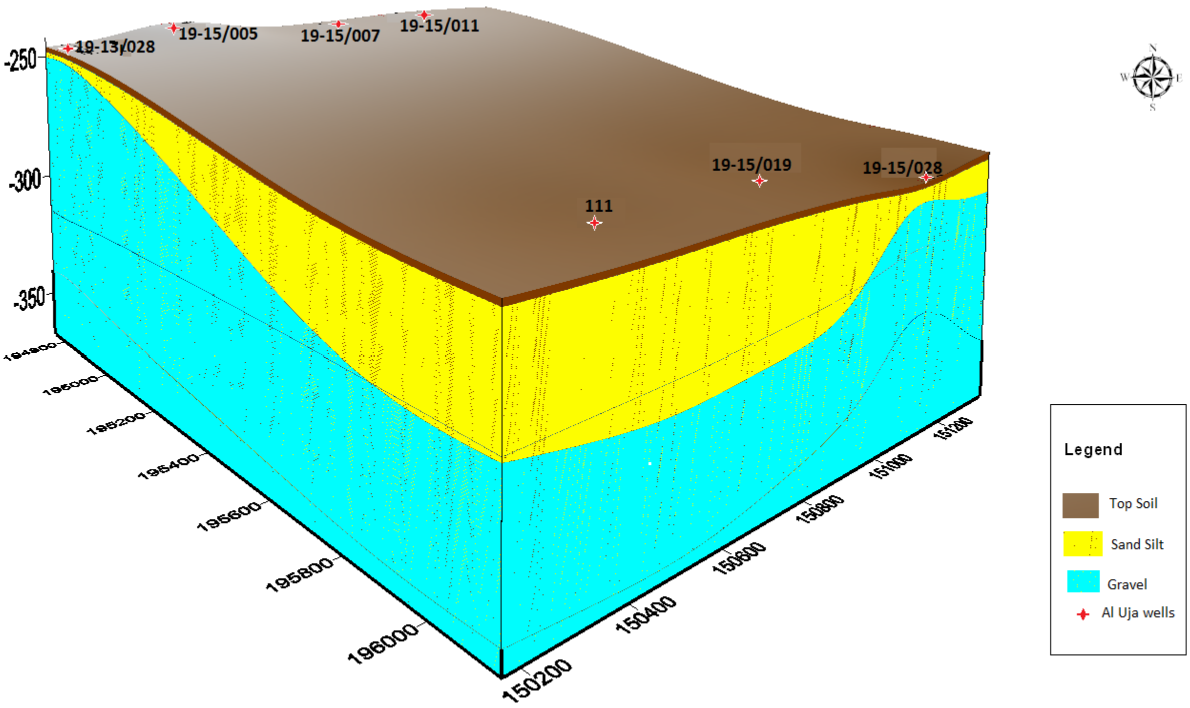


Figure (5.11.a) show the 3D layers of shallow aquifer

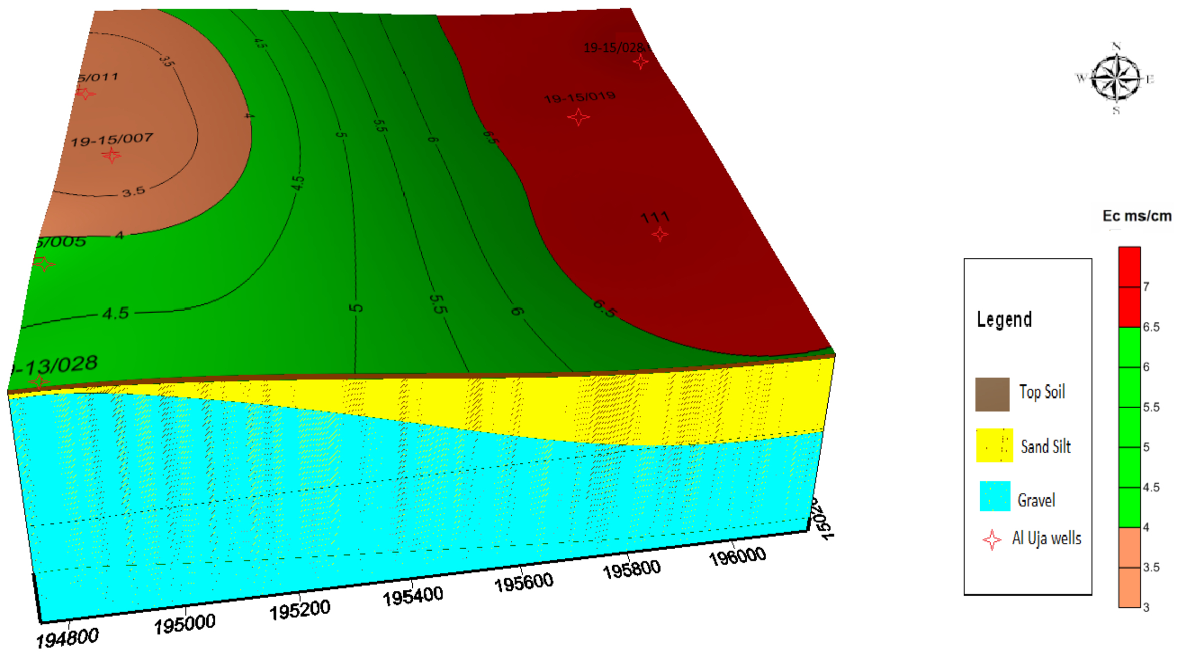


Figure (5.11.b) show the wells litho logy with electrical conductivity.

Chapter Six:

Conclusions and Recommendations:

6.1. Conclusions

The mountain and the shallow aquifer system are hydraulically connected, where underground lateral flow from west to east crossing the major fault system, where 1.8 MCM/year flow in this direction. And the groundwater boreholes locates close to the fault system have low salinity (3000 uS/cm) than that locates eastwards, so salinity increase when passing the fault from 1500 uS/cm due to the change in formation to reached to 6000 uS/cm eastwards.

15% of the Al Uja spring discharge infiltrated into the Upper Mountain aquifer system and indirect to the shallow system. Retention walls cross the wadi will increase the recharge rate.

The Chalky layer of Senonian age do not consider as impermeable rock where stored water infiltrate in relatively short period into the underground, additional earth dams for collecting flood water can improve the recharge rate as well as the quality of groundwater.
Two different artificial recharge techniques were estimated at the shallow aquifer, that are infiltration surface pond, and borehole direct injection.

The surface pond consists of soft material of Lisan formation that consists of 22% sand, 23% clay, and 45 % silt.

The geo-electrical investigations inside the pond show that the wet front reach a depth of 2.5 m depth after 3 days and the infiltrated water velocity is about 9.6 * 10-4 cm/s. according to this infiltrated water can reach the groundwater table after 50 days of filtration.

Different volumes of water were injected in the selected borehole, the static water table raised from 37 m to 34 meter below the ground after five min from the injection. After one and half hour the static water table fall to the original static level after stop the injection. The groundwater salinity of the borehole was decreased from 6000µS/cm to less than 550 µS/cm. The decrease of Ec –value through the well after injection test was cause of the Calcite precipitation.

Borehole injection is the best option for artificial recharge practices within the boundary of the Plio-Plistocene shallow aquifer system. And by carrying out an artificial recharge through these boreholes it will be possible to store 900 m^3/h from the spring overflow or from other sources which meet the slandered of injected water. Where recharge through surface ponds is not recommended.

6.2. Recommendation

1. Borehole injection method is the best option for direct artificial recharge in Al Uja area within the boundary of the Plio-Plistocene shallow aquifer system.
2. Artificial recharge using surface infiltration ponds is not recommended.
3. Abstraction from the Mountain aquifer system west of the fault will influence the recharge of the shallow aquifer system east to the fault, so managements of both aquifer systems is needed.
4. Increase hydrological study at Al Uja area should be carried out in order to predict the agricultural and hydrological situation in the future.
5. Increases awareness for the stakeholder environment for the Management Aquifer Recharge.

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Appendices:

Appendix I: Measured Rainfall quantities in the catchment area(2008)

Abu falah	Taybeh	Kafermalek	Date
16	16.8	16.8	**Dec.2007**
97.4	127.8	156.8	**jan.2008**
53.8	98.6	103.2	**feb.2008**
2	7.4	0.2	**Mar.2008**
0.2	0	0	**Apr.2008**
0.6	0.4	0.6	**May.2008**
0	0	0	**Jun.2008**
0	0	0	**July2008**
0	0	0	**Aug.2008**
2.8	5	2	**Sep.2008**
6.2	7.8	13.2	**Oct.2008**
7.4	11	6.4	**Nov.2008**
47.8	51.6	61.2	**Dec.2008**
234.2	326.4	360.4	**Total**

Historical water table data of Uja area Wells (PWA 2007)

DGR_MSL	DGR_Reading	PN_Name_E	PMD_Z	PMD_Y	PMD_X	DGR_Date	PMD_Code
-251.6000061	313.6000061	Na'ran No.4	62	149550	186740	09/03/2003	**18-14/001**
-305	37	IlyasMkarkar	-268	149990	195910	06/04/2003	**19-14/001**
-309.1400146	67.09999847	JawadDawudi	-242.0399933	150440	194750	14/02/2000	**19-15/005**
-307.9899902	65.94999695	JawadDawudi	-242.0399933	150440	194750	16/04/2000	**19-15/005**
-309.7099915	67.66999817	JawadDawudi	-242.0399933	150440	194750	20/06/2000	**19-15/005**
-310.2600098	68.22000122	JawadDawudi	-242.0399933	150440	194750	15/08/2000	**19-15/005**
-311.7600098	69.72000122	JawadDawudi	-242.0399933	150440	194750	22/10/2002	**19-15/005**
-311.4299927	69.38999939	JawadDawudi	-242.0399933	150440	194750	13/01/2003	**19-15/005**
-309.2600098	67.22000122	JawadDawudi	-242.0399933	150440	194750	08/03/2003	**19-15/005**
-307.2399902	65.19999695	JawadDawudi	-242.0399933	150440	194750	25/05/2003	**19-15/005**
-306.9700012	64.93000031	JawadDawudi	-242.0399933	150440	194750	06/09/2003	**19-15/005**
-307.0700073	65.02999878	JawadDawudi	-242.0399933	150440	194750	14/02/2004	**19-15/005**
-308.2799988	66.23999786	JawadDawudi	-242.0399933	150440	194750	10/04/2004	**19-15/005**
-308.9899902	66.94999695	JawadDawudi	-242.0399933	150440	194750	02/06/2004	**19-15/005**
-309.7399902	67.69999695	JawadDawudi	-242.0399933	150440	194750	08/08/2004	**19-15/005**
-310.7900085	68.75	JawadDawudi	-242.0399933	150440	194750	12/10/2004	**19-15/005**
-308.2900085	66.25	JawadDawudi	-242.0399933	150440	194750	13/12/2004	**19-15/005**

-309.2900085	67.25	JawadDawudi	-242.0399933	150440	194750	03/02/2005	**19-15/005**
-308.269989	66.23000336	JawadDawudi	-242.0399933	150440	194750	16/04/2005	**19-15/005**
-308.6700134	66.62999725	JawadDawudi	-242.0399933	150440	194750	15/08/2005	**19-15/005**
-309.5599976	67.51999664	JawadDawudi	-242.0399933	150440	194750	15/10/2005	**19-15/005**
-308.7399902	66.69999695	JawadDawudi	-242.0399933	150440	194750	06/12/2005	**19-15/005**
-308.3900146	66.34999847	JawadDawudi	-242.0399933	150440	194750	12/02/2006	**19-15/005**
-308.6000061	66.55999756	JawadDawudi	-242.0399933	150440	194750	01/04/2006	**19-15/005**
-308.0399933	66	JawadDawudi	-242.0399933	150440	194750	04/03/2007	**19-15/005**
-308.7899933	66.75	JawadDawudi	-242.0399933	150440	194750	02/12/2007	**19-15/005**
-309.8399933	67.8	JawadDawudi	-242.0399933	150440	194750	08/12/2007	**19-15/005**
-316.6000061	68.59999847	'Abed Al Mu'ti Al Qutub	-248	150940	194590	14/03/2004	**19-15/012**
-303.9500122	26.14999962	'Abed Al Ra'ufNusaibah	-277.7999878	151140	196150	14/02/2000	**19-15/015**
-302.2200012	24.42000008	'Abed Al Ra'ufNusaibah	-277.7999878	151140	196150	16/04/2000	**19-15/015**
-303.8399963	26.04000092	'Abed Al Ra'ufNusaibah	-277.7999878	151140	196150	19/06/2000	**19-15/015**
-304.3500061	26.54999924	'Abed Al Ra'ufNusaibah	-277.7999878	151140	196150	14/08/2000	**19-15/015**
-306.5	28.70000076	'Abed Al Ra'ufNusaibah	-277.7999878	151140	196150	22/10/2002	**19-15/015**
-307	29.20000076	'Abed Al Ra'ufNusaibah	-277.7999878	151140	196150	13/01/2003	**19-15/015**
-306.6400146	28.84000015	'Abed Al Ra'ufNusaibah	-277.7999878	151140	196150	08/03/2003	**19-15/015**
-305.4200134	27.62000084	'Abed Al Ra'ufNusaibah	-277.7999878	151140	196150	25/05/2003	**19-15/015**
-299.980011	22.18000031	'Abed Al Ra'ufNusaibah	-277.7999878	151140	196150	14/02/2004	**19-15/015**
-300	22.20000076	'Abed Al Ra'ufNusaibah	-277.7999878	151140	196150	10/04/2004	**19-15/015**
-300.019989	22.21999931	'Abed Al Ra'ufNusaibah	-277.7999878	151140	196150	02/06/2004	**19-15/015**
-300.2000122	22.39999962	'Abed Al Ra'ufNusaibah	-277.7999878	151140	196150	08/08/2004	**19-15/015**
-301.2999878	23.5	'Abed Al Ra'ufNusaibah	-277.7999878	151140	196150	12/10/2004	**19-15/015**
-300.7200012	22.92000008	'Abed Al Ra'ufNusaibah	-277.7999878	151140	196150	03/02/2005	**19-15/015**
-300.25	22.45000076	'Abed Al Ra'ufNusaibah	-277.7999878	151140	196150	16/04/2005	**19-15/015**
-299.5499878	21.75	'Abed Al Ra'ufNusaibah	-277.7999878	151140	196150	14/08/2005	**19-15/015**
-299.6499939	21.85000038	'Abed Al Ra'ufNusaibah	-277.7999878	151140	196150	13/10/2005	**19-15/015**
-300.3699951	22.56999969	'Abed Al Ra'ufNusaibah	-277.7999878	151140	196150	06/12/2005	**19-15/015**
-300.5499878	22.75	'Abed Al Ra'ufNusaibah	-277.7999878	151140	196150	12/02/2006	**19-15/015**

-300.0700073	22.27000046	'Abed Al Ra'ufNusaibah	-277.7999878	151140	196150	01/04/2006	**19-15/015**
-302.0499878	24.25	'Abed Al Ra'ufNusaibah	-277.7999878	151140	196150	04/03/2007	**19-15/015**
-303.7499878	25.95	'Abed Al Ra'ufNusaibah	-277.7999878	151140	196150	02/12/2007	**19-15/015**
-299.6499878	21.85	'Abed Al Ra'ufNusaibah	-277.7999878	151140	196150	08/12/2007	**19-15/015**
-305.7109985	32.5	SulaymanMkarkar	-273.2109985	150090	196020	14/02/2000	**19-15/023**
-306.1610107	32.95000076	SulaymanMkarkar	-273.2109985	150090	196020	18/06/2000	**19-15/023**
-306.9909973	33.77999878	SulaymanMkarkar	-273.2109985	150090	196020	15/08/2000	**19-15/023**
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-307.4110107	34.20000076	SulaymanMkarkar	-273.2109985	150090	196020	13/01/2003	**19-15/023**
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-300.92099	27.70999908	SulaymanMkarkar	-273.2109985	150090	196020	10/04/2004	**19-15/023**
-301.1210022	27.90999985	SulaymanMkarkar	-273.2109985	150090	196020	02/06/2004	**19-15/023**
-301.7810059	28.56999969	SulaymanMkarkar	-273.2109985	150090	196020	08/08/2004	**19-15/023**
-303.4110107	30.20000076	SulaymanMkarkar	-273.2109985	150090	196020	12/10/2004	**19-15/023**
-303.92099	30.70999908	SulaymanMkarkar	-273.2109985	150090	196020	13/12/2004	**19-15/023**
-302.2109985	29	SulaymanMkarkar	-273.2109985	150090	196020	03/02/2005	**19-15/023**
-300.4909973	27.28000069	SulaymanMkarkar	-273.2109985	150090	196020	16/04/2005	**19-15/023**
-301.401001	28.19000053	SulaymanMkarkar	-273.2109985	150090	196020	14/08/2005	**19-15/023**
-302.2109985	29	SulaymanMkarkar	-273.2109985	150090	196020	15/10/2005	**19-15/023**
-303.42099	30.20999908	SulaymanMkarkar	-273.2109985	150090	196020	06/12/2005	**19-15/023**
-302.8110046	29.60000038	SulaymanMkarkar	-273.2109985	150090	196020	12/02/2006	**19-15/023**
-301.6809998	28.46999931	SulaymanMkarkar	-273.2109985	150090	196020	01/04/2006	**19-15/023**
-303.9109985	30.7	SulaymanMkarkar	-273.2109985	150090	196020	04/03/2007	**19-15/023**
-305.3109985	32.1	SulaymanMkarkar	-273.2109985	150090	196020	02/12/2007	**19-15/023**
-302.5609985	29.35	SulaymanMkarkar	-273.2109985	150090	196020	13/08/2007	**19-15/023**

Appedix II: Geological scal-West Bank

Typical Thickness (m)	Jordanian Terminology	Israeli Terminology	Palestinian Terminology			Typical Lithology	Age	Period	
			Symbol	Formation	Group				
0-100	Alluvium	Alluvium	All	Alluvium		Alluvium, gravels, fan deposits, and surface crust (Nari).	**Halocene**	**Quaternary**	
Unknown	Lisan	Lisan/ Kurkar Group	Lis	Lisan		Thinly laminated marl with gypsum bands, and poorly sorted gravel and pebbles.	**Plestocene**		
± 200	Dana	Saqiya Group	Bei	Beida		Conglomerate, marl, chalk, clay, and limestone.	**Pliocene-Miocene**	**Tertiary**	
300-600	Rijam&Shallala	Avedat Group	Jen	Jenin		Numulitic limestone, reef limestone, bedded limestone, limestone with chalk, chalk with limestone (undifferentiated).	**Eocene**		
150		Taqiya	KhA	Khan Al Ahmar	**Gerzim**	Marl, clay, and chalk.	**Paleocene**		
55	Muwaqar	Ghareb				Chalk, marl, metamorphic rocks.	**Mastrichtian**	**Upper**	**Cretaceous**
50-75	Amman &Hisa	Mishash	Qil	Al Qilt		Phosphate, and chert	**Campanian**		
50-175	Ghudran	Minuha	ADi	Abu Dis		White chalk, Chalky limestone, chert, and phosphate	**Coniacian-Campanian**		
40-120	Wadi Sir	Bina	Jer	Jerusalem	**Ramallah**	Karstified limestone, and dolomite.	**Turonian**		
5-30	WadiShueib	Weradim	Ube	Upper Bethlehem		Limestone, dolomite, and marly limestone (karstic).	**Cenomanian**		
30-115		KefarSha'ul	Lbe	Lower Bethlehem		Limestone, marly limestone, chalky limestone, and dolomitic limestone.			
105-260	Hummar	Amminadav	Heb	Hebron		Karstic limestone, and dolomite.			
50-150	Fuhais	Moza	UYa	Upper Yatta		Marl, clay, and marly limestone.			
		Beit Meir	LYa	Lower Yatta		Limestone, chalky limestone, and dolomitic limestone.			
10-40	Na'uor	Kesalon	UBK 1	Upper BeitKahil 1		Reefal limestone interbedded with marl.	**Albian**	**Lower**	
50-150		BeitSoreq	UBK 2	Upper BeitKahil 2		Dolomite interbedded with marl.			
10-50		Giv'atYe'arim	LBK 1	Lower BeitKahil 1		Limestone, and dolomitic limestone.			
100-160		Kefira	LBK 2	Lower BeitKahil 2		Limestone, dolomitic and marly limestone.			
40-60		Qatana	Qat	Qatana		Marl, and clay.			
70-100		EinQinya	EQi	EinQinya		Marl, and marly limestone.			
50-90		Tammun	Tam	Tammun		Clay, and marl.	**Aptian**		
50-250	Kurnub	HathiraKurnub	Ram	Ramali		Multicoloured sandstone.	**Neocomian**		
100-200	Ramlah, Hamam, Mughaneieh	Zohar, Sherif, Mahmal	UMa	Upper Malih		Marl interbedded with chalky limestone.	**Callovian-Bajocian**	**Jurassic**	
50-100			LMa	Lower Malih		Karstified and jointed dolomitic limestone.			

Appedix III

sample	K	Ca	Mg	Na	Softening or reverse softening
Spring Ratio meq/l Percentage %	41 1.05 12.8	42 2.1 25.8	38 3.1 38.1	44 1.9 23.3	
Well before Ratio Percentage%	103.9 2.7 3.8	276.35 13.3 18.9	218.75 18.2 25.8	830.05 36.1 51.3	Reveres softening
R1 Ratio Percentage%	60 1.5 9.1	180 9 54.9	19.5 1.6 9.7	100 4.3 26.2	Reveres softening
R2 Ratio Percentage%	60 1.5 11.3	117 5.9 44.3	19.5 1.6 12	100 4.3 32.3	Reveres softening
R3 Ratio Percentage%	60 1.5 11.3	117 5.9 44.3	19.5 1.6 12	100 4.3 32.3	Reveres softening
R4 Ratio Percentage%	75 1.9 12	162 8.1 50.9	19.5 1.6 10.1	100 4.3 27	Reveres softening
R5 Ratio Percentage%	102 2.6 15.3	168 8.4 49.7	19.5 1.6 9.4	100 4.3 25.4	Reveres softening
R6 Ratio Percentage%	66 1.7 10.7	165 8.3 52.2	19.5 1.6 10.1	100 4.3 27	Reveres softening
R7 Ratio Percentage%	99 2.5 14	180 9 50.6	19.5 1.6 9	110 4.7 26.4	Reveres softening
R8 Ratio Percentage%	60 1.5 9.8	153 7.6 49.7	19.5 1.6 10.5	106 4.6 30	Reveres softening
R9 Ratio Percentage%	96 2.5 13.8	184 9.2 51.1	60 5 27.7	30 1.3 7	Reveres softening
R10 Ratio Percentage%	92 2.4 15	146 7.3 45.6	60 5 31.2	30 1.3 8.1	Reveres softening
R11 Ratio Percentage%	82 2.1 15.7	102 5.1 38.1	56 4.7 35.1	34 1.5 11.1	Reveres softening
R12	96	92	72	28	Reveres

Ratio Percentage%	2.5 17.5	4.6 32.1	6 42	1.2 8.4	softening
R13 Ratio Percentage%	90 2.3 17.8	86 4.3 33.3	57 4.8 37.2	34 1.5 11.6	Reveres softening
R14 Ratio Percentage%	84 2.2 19.8	58 2.9 26.2	57 4.8 43.3	28 1.2 10.8	Reveres softening
R15 Ratio Percentage%	86 2.2 17.3	84 4.2 33.1	58 4.8 37.8	36 1.5 11.8	Reveres softening
R16 Ratio Percentage%	98 2.5 14.7	168 8.4 49.4	58 4.8 28.2	30 1.3 7.6	Reveres softening
R17 Ratio Percentage%	98 2.5 16	138 6.9 44.2	58 4.8 30.7	32 1.4 8.9	Reveres softening

Appedix IV: Al Uja wells chemistry , 2013:

NO	Sampling	Sample	Well	Code	x_cord	y_ cord	z	pH	O.D	Temp	sal	EC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	HCO_3^-	PO_4^{3-}	Br-	No-3	F-	Pumpimg rate	Depth
*	Date	ID	Name	NO	pal	pal	(M)	*	(mg\l)	©		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/l	mg/L	mg/L	mg/L	mg/L	m3/h	Meter
1	25/5/2011	110328f58	Khader Zawahreh	111	195911	150933	-262	7.07		26.8	3.7	7	500.76	85.83	100	419.2	1808	850	708.8	0.07	*	8.50	0.68	50.00	70.00
2	25/5/2011	110525f66	Sleman Mkarkr	19-15/23	196107	150078	-269	7.32	1.63	25	1.1	2	50.8	39.4	100.2	109.4	433	*	536.9	0.8	*	21.10	0.63	50.00	41
3	25/5/2011	110525f65	Abd Moate Qotop	19-15/011	194754	151001	-236	7.45	1.62	26	1.6	3	63.2	36.6	140.3	170.1	872	*	323.4	2.4	*	5.30	0.61	50.00	95
4	25/5/2011	110525f64	Abd Moate Dojane	19-15/012	194587	150949	-231	7.41	1.53	24.4	1.2	3	44.9	29.8	60.12	170.1	645	*	341.7	9.3	*	6.00	0.90	100.00	103
5	25/5/2011	110525f69	Abd Karem Saed Njoom	19-15/10	194501	151095	-229	7.45	1.49	27	1.7	3	64.4	33.2	100.2	182.3	915	*	341.7	0.01	*	3.80	0.61	45.00	102
6	06/01/2011	110601f70	Jawad Aldawode	19-15/005	194700	150389	-251	7.41	*	24	*	4	41	24.8	80.2	133.7	454	*	366.12	127.3	*	10.90	0.41	60.00	108
7	06/01/2011	110601f71	Abd Kareem Njoom	19-15/008	195913	151364	-283	7.3	1.2	26.3	4	7	139.3	74.3	120.2	352.4	1801	*	427.1	1.16	*	25.20	0.93	60.00	103
8	13/3/2011	110313f33	Sobhe Dojane	19-15/007	194848	150768	-254	7.47	3.72	23.4	1.7	3	439	72.2	247.7	156.25	851	711.36	335.61	0.07	14.81	3.20	0.24	100.00	105
9	13/3/2011	110313f35	Yosef Njoom	19-15/19	195905	150935	-268	6.84	1.98	24.4	3.6	7	830.05	103.9	276.35	218.75	1737	547.24	457.65	0.1	28.80	*	0.46	55.00	90
10	13/3/2011	110313f36	Elyas Mkrkr	19-14-01	195912	150006	-281	7.35	*	23.4	*	2	408.75	82.15	158	118.75	425	712.4	524.77	0.09	8.79	*	0.31	50.00	60

Appedix V

Al Uja Borehole (19- 15/ 019) litho logical profile: