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A VISIBILITY STUDY FOR CHOOSING THE DUG WELLS ALTERNATIVE VERSUS DEEP WELLS FOR WATER SUPPLY

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ABSTRACT: *While access to water remains an essential issue in arid and semi-arid regions, aquifers have the potential to help millions of people out of a reliable source of water. Boreholes are increasingly advocated as a safe and cost-effective substitute to mechanized drilling, as well as to traditional excavation methods. The main target of the present study is to evaluate and locate the possibilities of water resources occurrence in the proposed area, indicate whether to use a deep well or a shallow dug well. The study consists of three steps; the first step was drilling the dug well after data collection and allocates the suitable well location. The second step included a pumping test for the productive well lies at Nabq- Sharm El-Sheikh - South Sinai with a depth of 114 meters which was done. The third step included a water quality monitoring for the well, as the samples was taken each 12 hours for 3 days from the existing well. It is concluded that for the presented model of using large diameter wells instead of small diameter wells has shown insignificant improvement in the well yield in the study area. For the well under consideration, it is recommended to operate this well for a pumping rate of 50 m^3/hr (for 24 hours per day) to maintain the long-term drawdown at 3 meters in addition to the well losses which is less than 0.5 meter*.

KEYWORDS: Deep Well, Water Resources, Hydrogeology Study, Water Quality, Pumping Test, Development Area.

INTRODUCTION

Development of ground water resources frequently includes solving complex problems concerned with both extraction and replenishment. Examples of these problems include optimum design of well spacing, determination of safe yield, artificial recharge, water quality deterioration, or seawater intrusion in coastal aquifers. These problems can be solved by application of mathematical models. However, the results obtained depend upon use of accurate values of the hydraulic characteristics, and on properly assumed initial and boundary conditions. If they are not correcting, computation of ground water flow and transport will be erroneous.

The study area is located in South Nabaq Tourist Center in an integrally planned area for tourism development subject to a master plan covering the whole center aiming at ensuring harmony among the types of land uses, functions and activities. The project is located approx. 12 km away from Sharm El Sheikh City, inhabited by thousands of populations, which will offer work opportunities and support the local economy. External services may also be provided if necessary. The source of water mainly from the ground water aquifer used for "lagoon, gulf areas, and irrigation" groundwater is utilized after being processed through the desalination plants. They mainly use a deep well for water supply in the area and areas surrounding. The study suggests to use a deep well for the area near to the sea as a water sources instead of deep wells supply.

A pumping test is the most useful means of determining hydraulic properties of the well and the aquifer system. All formulas for analyzing pumping test data are based on assumptions and generalizations. In many cases when erroneous results are obtained, blame is placed on the incorrectness of the applied formula, while the actual cause of error is that field conditions did not satisfy the underlying assumptions, which apply to the equation.

In the present study, quantitative analyses of two step tests and one long duration pumping and recovery tests are performed to evaluate the aquifer hydraulic parameters and the well efficiency. The results from these field tests will assist in determining the aquifer hydraulic parameters, which include the aquifer hydraulic conductivity and storage coefficient, production-drawdown-well efficiency relationship. Having the hydraulic parameters, well efficiency, and the hydrogeologic boundaries located in the vicinity of the study area, the well field design could be performed to meet the sustainable water requirement in an economic matter.

The main target of the present study is to evaluate and locate the possibilities of water resources occurrence in the proposed area, and locate the suitable sites for drilling a borehole test and the production dug wells to verify the lithological section, the water bearing formations and the water quality of the available groundwater.

MATERIALS AND METHODS

Study Area and Study steps

The study area is located at the southeastern edge of Sinai Peninsula between Longitudes 34º 27' to 34º 15' and Latitudes 28º 07' to 28º 00', Figure (1). It is an extension of the Nabq resort study area.

This study consists of three steps; the first step was drilling the existing well after data collection and allocates the suitable well location.

The second step included a pumping test for the productive well lies at Nabq- Sharm El-Sheikh - South Sinai with a depth of 114 meters.

The third step included a water quality monitoring for the well, as the samples was taken each 12 hours for 3 days from the existing well. ***The Study Steps will be as follows:***

- Indicate the suitable dug well location
- Design the first proposed dug well
- Construction of the first dug well in the suggested location, and proposed design
- Pumping test operation, with continuous water quality monitoring.
- Data Analysis (water quality, and quantity).
- Visibility study for choose the dug wells alternative for supply water to Area I & II .

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Geomorphology and Geology

The geomorphologic features of the area are characterized by the presence of beach plains restricted between the Gulf of Aqaba and the mountainous area in the west, and slopes toward the Gulf. The beach plains slop moderately eastward to the Gulf of Aqaba.

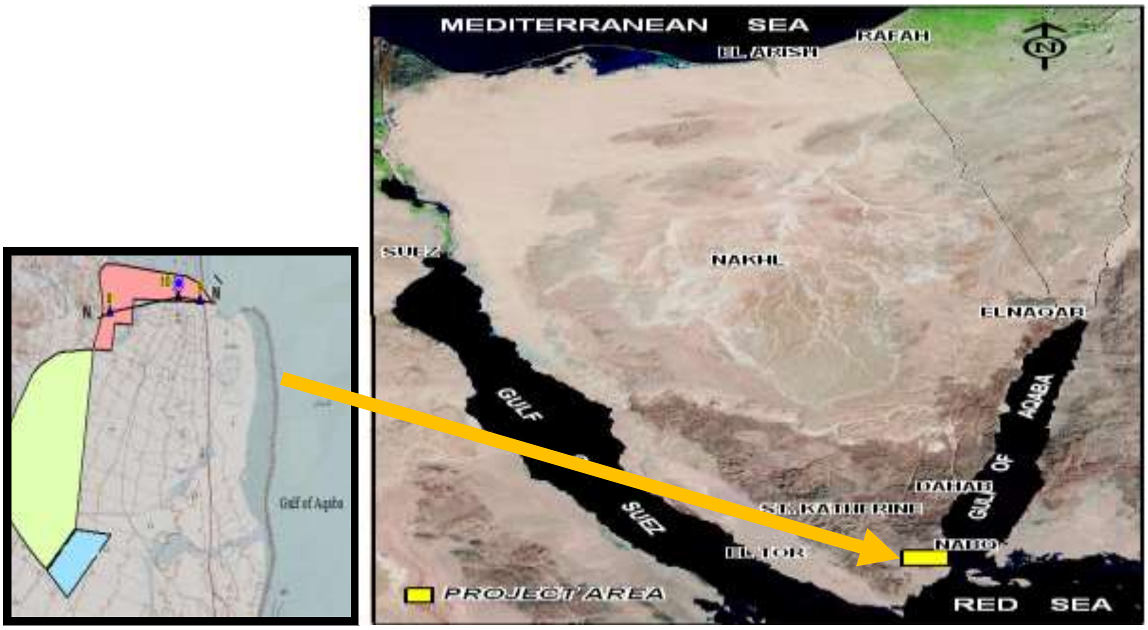

Figure (1) Location of the Study Area

The geologic setting of the study area is characterized by the existence of many mountains of different elevations. These mountains are composed of igneous and metamorphic rocks. The study area is subjected to strong tectonic movements and consequently some geological structures as faults, joints and others are formed. The geologic structures have direct or indirect affect on groundwater occurrence, movement and direction. The basement rocks are covered by the Quaternary deposits which composed of sand, gravel, rock fragments and limestone. The thickness of the sediments may decrease or increases in some parts because of transgression and regression of the sea. At some localities, clayey lenses of low permeability might exist. As shown in Figure (2), the study area is situated over the Wadi deposits which are considered a great potential of groundwater.

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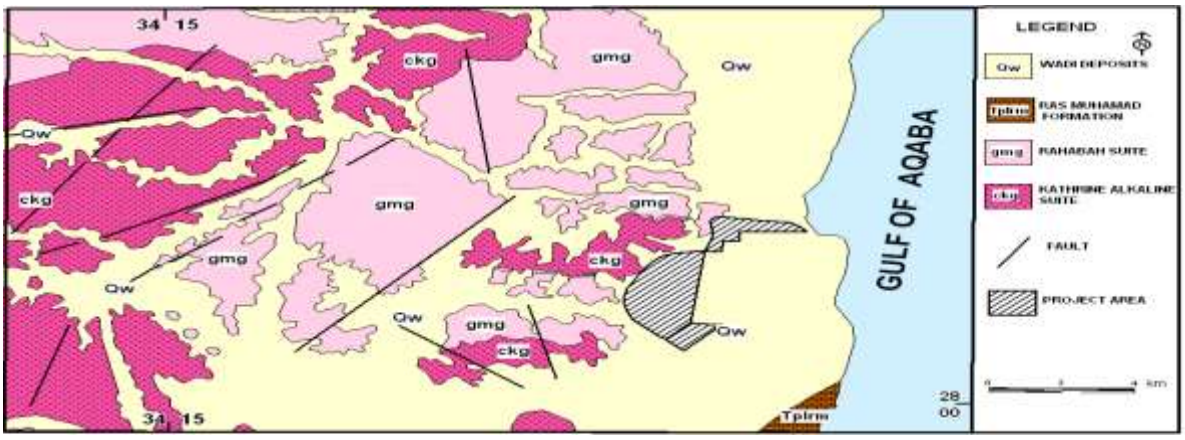

Figure (2): Geological Map of the Study Are

Hydrogeology

Groundwater data in the study area is scarce and limited to the available information obtained from the recently drilled wells located within the property of phase one of the study area.

Hydrogeological Units

The existing groundwater wells in the study area revealed that there is one main aquifer system classified as the Quaternary aquifer which is composed of gravel, sand and silt. The idealized hydrogeological columnar section around the study area is shown in Figure (3).

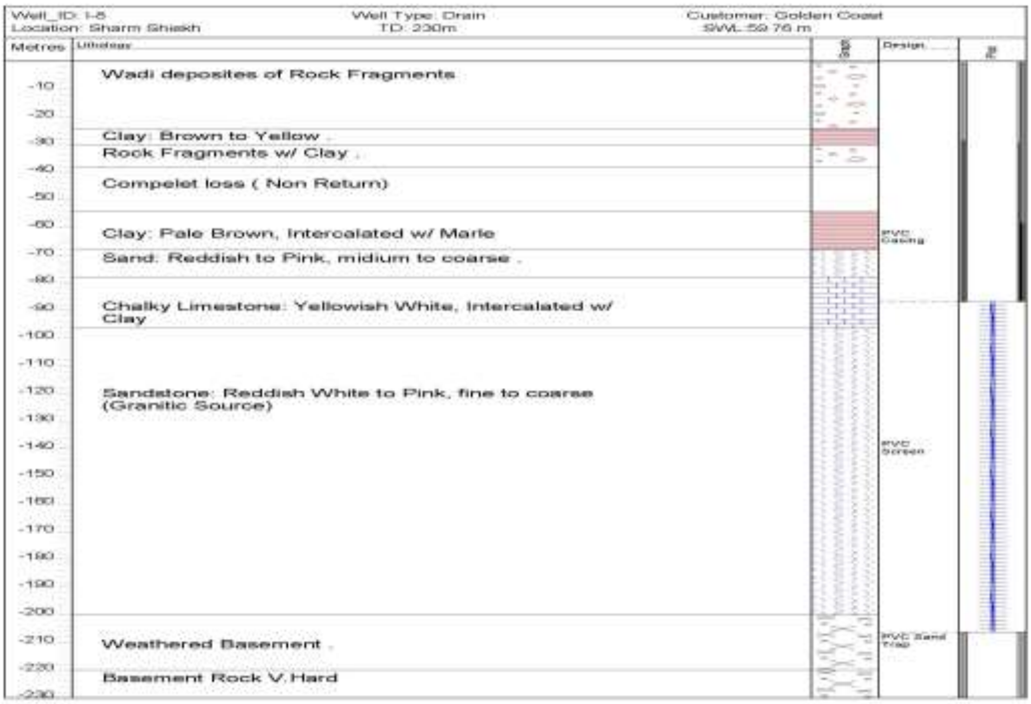

Figure (3): Lithologic columnar section of injection well located near the study area

a- The Basement Rock

The igneous and metamorphic basement rock crop out at the western part of the study area, where they represent the main catchment areas and watersheds. They are highly weathered and strongly fractured, jointed and faulted. Such structural features permit the accumulation and movement of the ground water. However, due to the limited rainfall in the study area, no occurrence of naturally flowing springs or hand dug wells.

b- Quaternary Aquifer

The Quaternary aquifer is formed of Detritus, sands, pebbles and rare boulders. This aquifer has variability in its thickness and is widely distributed in the area in the form of terraces or wadi deposits. The aquifer thickness of the sedimentary succession varies between 250 and 300 m with its maximum value closer to the coastline and decreases gradually towards the mountainous area,

2.3.1 Hydrogeological Characteristics of the Quaternary Aquifer

The static water level approximately coincides with the mean sea level which indicates the perfect hydraulic interaction between the groundwater and the sea water in the Gulf of Aqaba. Nevertheless, the depth to the groundwater level varies spatially according to the change in the topography. The measured water depths revealed that the depth to groundwater varies between 30 and 70 meters within the property of First Phase of the study area. The piezometric water levels indicate a general trend of groundwater movement toward the Gulf.

Groundwater is exploited from this aquifer through shallow wells. Water is very saline and this indicates the presence of original sea water without any effect of the fresh water flushing. The water salinity reaches to the same level of the sea water salinity which is 38,000 ppm.

Due to the deep groundwater levels and the high salinity, groundwater is not commonly used in the area. However, due to the intensified touristic development along the Gulf of Aqaba, groundwater is utilized after being processed through the desalination plants. The well productivity reaches varies between 70 and 90 m^3/hr with variable drawdown that reaches up to 4.3 meters. Furthermore, wastewater is injected in the Quaternary which might have environmental hazards with reported problems on the well clogging and sever reduction in the well efficiency. Table (1) , Fig.(4) shows the general data of the existing wells

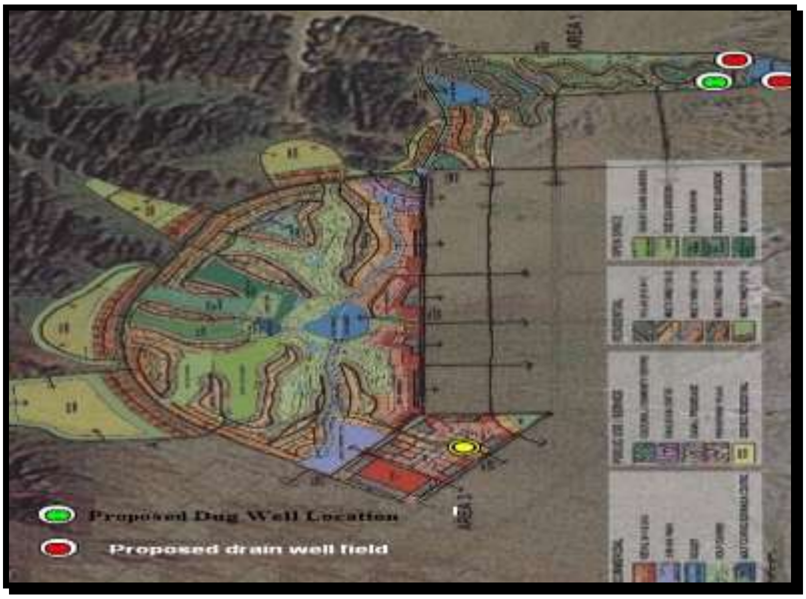

Figure (4) Wells locations in the study area

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Table (1) Existing Groundwater Wells Located within the Study Area

Well No.	Type of well	Total depth (m)	Blank casing (m)	Screen length (m)	Depth to Water (msl)	Dynamic Water level (m)	Discharge (m^3/h)	Salinity
P_1	Pumping	156	100.35	57	69.56	73.59	75	Sea Water
P_2	Pumping	145	89	57	67.37	71.61	77	Sea Water
P_3	Pumping	145	89	57	65.45	66.32	87	Sea Water
P_4	Pumping	153.8	92.2	62.6	63.48	63.98	85	Sea Water
P_5	Pumping	153.9	92.2	62.7	61.5	64.18	77	Sea Water
P_6	Pumping	153.9	97.9	57	60	61.25	75	Sea Water
P_7	Pumping	152.5	102.2	51.3	58.32	59.25	87	Sea Water
I_1	Injection	103	69.4	34.2	64.45	59.05	64	Sea Water
I_2	Injection	157	81.55	76.05	63.60	54.3	50	Sea Water
I_3	Injection	205.2	93.2	113	62.4	57.12	60	Sea Water
I_4	Injection	216.6	97.9	119.7	61.6	54.02	61	Sea Water
I_5	Injection	216.6	103.6	114	60.75	49.42	60	Sea Water
I_6	Injection	208.15	77.55	131.1	60.4	59.05	64	Sea Water
I_7	Injection	157	82.9	74.6	65.1	32.35	25	Sea Water

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Dug Well Design and Pumping Test

A large diameter well of 5 meters was drilled to a depth of 15 meters and the drilling results indicate that the depth to the static water level is about 5.5 meters below ground surface and the aquifer system can be idealized as a single layer aquifer with unconfined conditions Figure (5) shows the Designed Dug Well Elevation and cross section. The well casing is made of concrete with some openings at the bottom section of the casing. The groundwater flow towards the well is allowed through these openings. Four submersible pumps were installed at 10.5 meters from the ground surface to perform the step tests as well as the long duration tests. The capacity of these pumps is shown in Table (2). Figure (6) shows the well along with the four submersible pumps. Due to the turbulence of the flow regime inside the well, it is worth to mention that the measurements of the dynamic water level will be influenced by the relative position of the water level probe and the operating pump.

Table (2) Discharge rate of the four pumps

Pump Number	Pump Discharge m^3/hr
Pump-1	100
Pump-2	80
Pump-3	180
Pump-4	180

Three pumping tests were performed to evaluate the well and the aquifer characteristics. A long duration-pumping and recovery test is carried out to determine the hydraulic conductivity and to investigate the local hydrogeologic conditions. The second test is the step drawdown test, which is performed to determine the well parameters and the well efficiency according to the implemented design and the material used in the design. The following section describes the analysis of the pumping test data and hence the determination of the aquifer and well parameters.

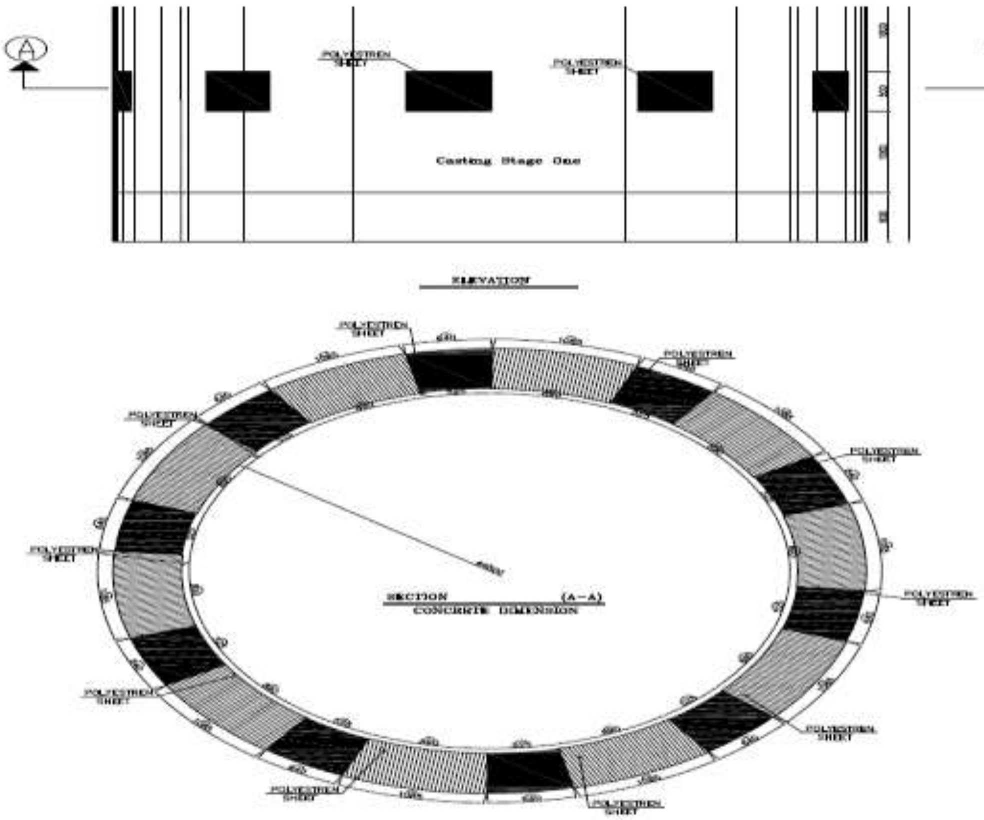

Figure (5): Designed Dug Well Elevation and cross section

Figure (6) A photograph of the large diameter well and the four submersible pumps.

Pumping Test Interpretation

Calculation of Well Parameters

Calculations of well characteristics are necessary to determine specific capacity and efficiency relationship. These relationships are used to help design production pumps, measure the degree of development, and determine well maintenance programs. Well parameters are found using variable rate pumping tests. Commonly called "step-drawdown" tests. Assuming that the well is fully developed and that no near-well turbulent flow losses occur, the drawdown in a pumping well satisfying these assumptions may be written as:

$$s_w = BQ + CQ^2 \qquad (1)$$

Where

s_w = drawdown in the pumping well [m],

Q = pumping rate [m^3/hr],

B = formation loss coefficient [hr/m^2]

C = well loss coefficient [hr^2/m^5]

Two step tests were performed. The first test was done on, March 6, 2016 and it was incomplete due to the sudden settlement of the well casing. The occurred failure is due to the land subsiding that was caused due to lowering the groundwater level to a critical level. This settlement caused a falling of the measuring equipment inside the well.

First Step Test-Sunday March 6, 2016

The first step test was performed on three stages. However, the test was not successfully completed. The following procedures are used to represent the measured data and to show the incompleteness in determining the aquifer and the well losses:

(1) Time-drawdown data for a three-step variable rate is shown in Figure (7).

(2) It is obvious from Figure (7) that the drawdown never reaches the steady state conditions during the three steps.

(3) Incremental drawdowns (Δs_i), occurring 45 minutes after the start of each step, are measured as the distance between the drawdown at the particular step and the extrapolated drawdown from the previous step. The total drawdown for each step s_m is obtained from $s_m = \sum_{i=1}^{m} \Delta s_i$. Specific drawdown is obtained by dividing total drawdown by the pumping rate for each step, as shown in Table (3). A plot of specific drawdown versus pumping rate is shown in Figure (8).

(4) A best-fit straight line for the measured data could not be constructed as shown in Figure (8). Therefore, the formation loss coefficient (B) and the well loss coefficient (C) are indeterminate and the test was repeated to overcome the problem.

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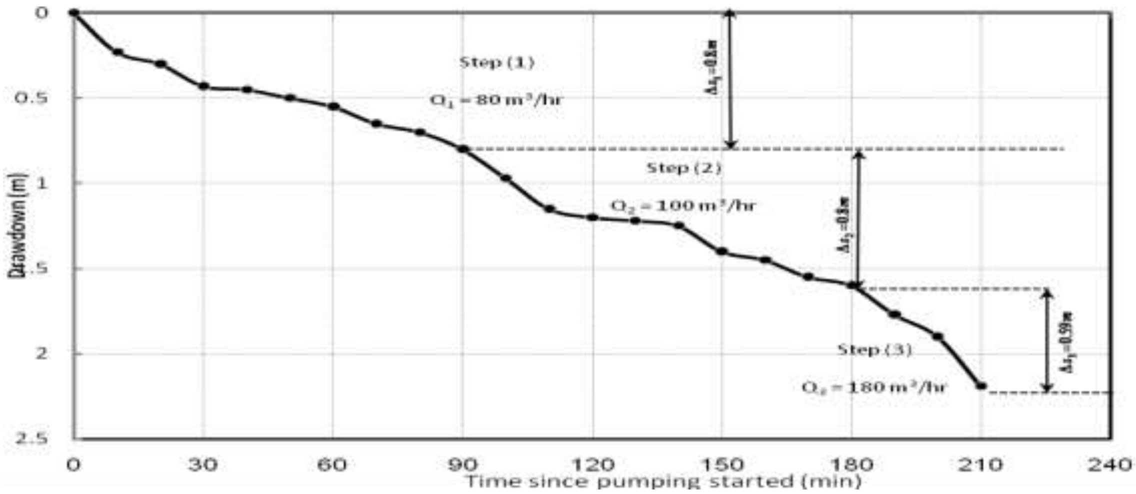

Figure (7) Time-Drawdown Data for the First Step test on March 6, 2016

Table (3) Summary of Step Test Data from Figure (7)

Step, n	Pumping Rate Q_n (m^3/hr)	Incremental Drawdown, Δs_i (m)	Total Drawdown s_n (m)	Specific Drawdown $(s/Q)_n$ (hr/m^2)
1	80	0.8	0.80	0.01
2	100	0.8	1.60	0.016
3	180	0.59	2.19	0.012167

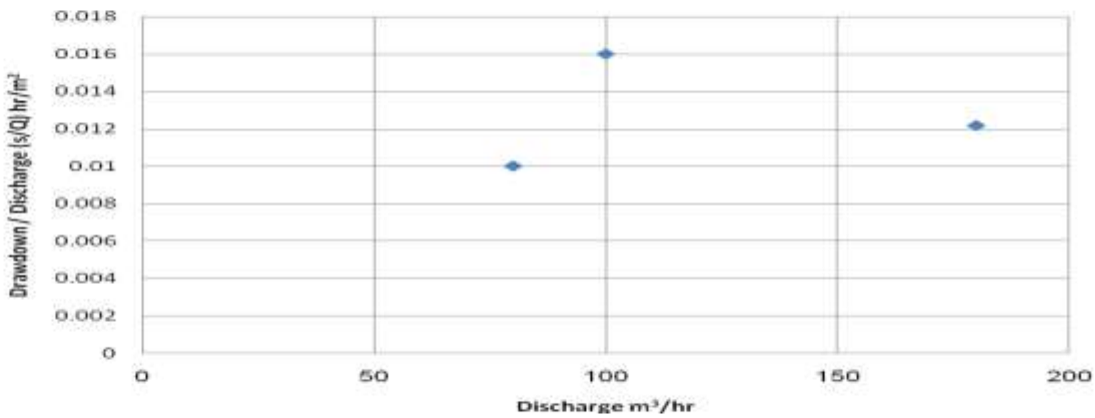

Figure (8) Specific Drawdown versus Discharge Rate

Second Step Test- March 7, 2016

The second step test was performed on four stages. Due to the high pumping rates which were applied in this test, a high turbulence was occurred inside the well and the fine sediments moved from the bottom of the well into the pumps causing a sever change in the water color and viscosity. Having said that, the following procedures are used to represent the measured data and to show the incompleteness in determining the aquifer and the well losses:

(1) Time-drawdown data for a three-step variable rate is shown in Figure (9).

(2) Incremental drawdowns (Δs_i), occurring 45 minutes after the start of each step, are measured as the distance between the drawdown at the particular step and the extrapolated drawdown from the previous step. The total drawdown for each step s_m is obtained from $s_m = \sum_{i=1}^{m} \Delta s_i$. Specific drawdown is obtained by dividing total drawdown by the pumping rate for each step, as shown in Table (4). A plot of specific drawdown versus pumping rate is shown in Figure (10).

(3) Once again, a best-fit straight line for the measured data indicates that the well loss (C) has a negative value which is not reasonable. This erroneous in the data indicates clearly that using more than one pump inside the pumping well has explicit complication in the well performance. Therefore, the formation loss coefficient (B) and the well loss coefficient (C) are indeterminate.

(4) The specific capacity diagram is constructed by substituting the values of B and C

(5) Well efficiency is plotted and calculated from the following equation:

$$E = \frac{100}{1 + CQ/B} \tag{2}$$

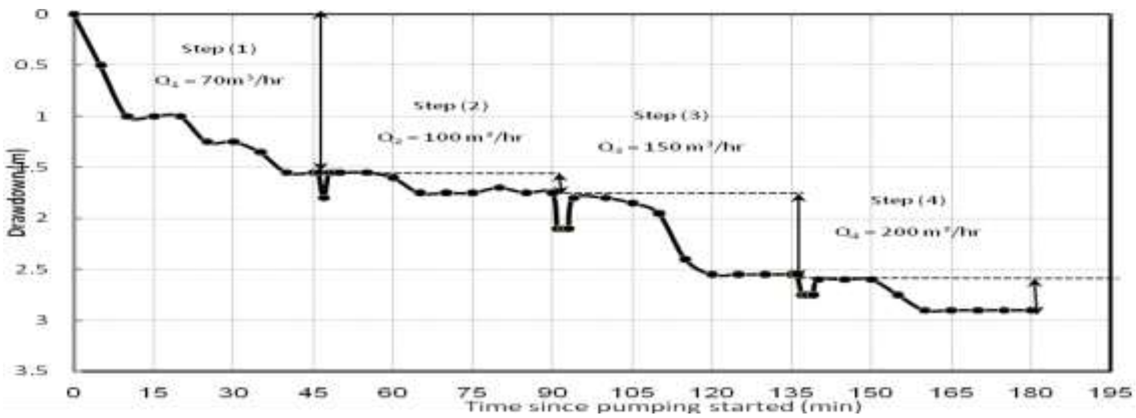

Figure (9) Time-Drawdown Data for the Second Step test on March 7, 2011

Table (4) Summary of Step Test Data from Figure (9)

Step, n	Pumping Rate Q_n (m^3/hr)	Incremental Drawdown, Δs_i (m)	Total Drawdown s_n (m)	Specific Drawdown $(s/Q)_n$ (hr/m^2)
1	70	1.55	1.55	0.0221
2	100	0.20	1.75	0.0175
3	150	0.80	2.55	0.0170
4	200	0.35	2.90	0.0145

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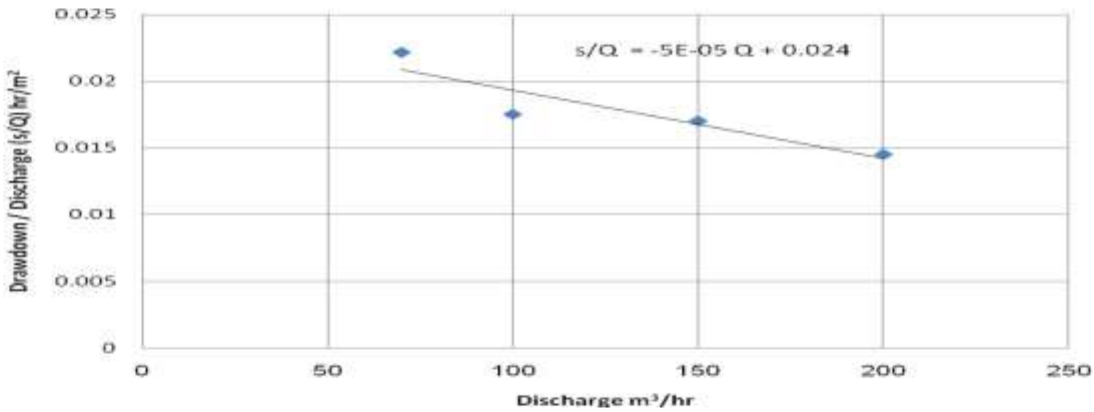

Figure (10) Specific Drawdown versus Discharge Rate

Third Step Test- March 9, 2016

The third step test was performed on five stages. Due to the high pumping rates which were applied in the fourth and fifth stages, a high turbulence was occurred inside the well and the fine sediments moved from the bottom of the well into the pumps causing a sever change in the water color and viscosity. Furthermore, the well went dry and the pumps completely stopped with a settlement of 5 cm in the well casing. The following procedures are used to represent the measured data and to show the incompleteness in determining the aquifer and the well losses:

(1) Time-drawdown data for a three-step variable rate is shown in Figure (11).

(2) Incremental drawdowns (Δs_i), occurring 120 minutes after the start of each step, are measured as the distance between the drawdown at the particular step and the extrapolated drawdown from the previous step. The total drawdown for each step s_m is obtained from $s_m = \sum_{i=1}^{m} \Delta s_i$. Specific drawdown is obtained by dividing total drawdown by the pumping rate for each step, as shown in Table (5). A plot of specific drawdown versus pumping rate is shown in Figure (12).

(3) Similarly, a best-fit straight line for the measured data indicates that the well loss (C) has a negative value which is not reasonable. This erroneous in the data indicates clearly that using more than one pump inside the pumping well has explicit complication in the well performance. Therefore, the formation loss coefficient (B) and the well loss coefficient (C) are indeterminate.

(4) Considering only the three first stages of the step test, the linear best fit for the relation between the specific drawdown and the pumping rate is shown in Figure (13).

(5) From this relationship, one could deduce the values of the formation loss coefficient (B) and the well loss coefficient (C) as 0.019 hr/m^2 and 5 × 10^{-5} hr^2/m^5 respectively.

(6) The well efficiency is calculated from the following equation and as represented in Figure (14):

$$E = \frac{100}{1 + CQ/B} \tag{2}$$

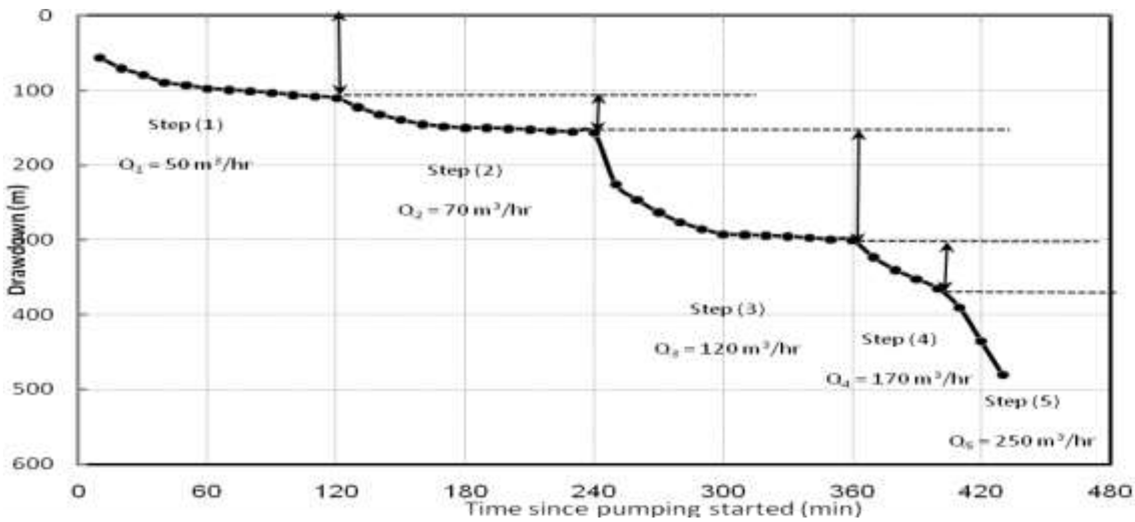

Figure (11) Time-Drawdown Data for the Third Step test on March 9, 2016

Table (5) Summary of Step Test Data from Figure (11)

Step, n	Pumping Rate Q_n (m^3/hr)	Incremental Drawdown, Δs_i (m)	Total Drawdown s_n (m)	Specific Drawdown $(s/Q)_n$ (hr/m^2)
1	70	1.1	1.1	0.0220
2	70	0.46	1.56	0.0223
3	120	1.44	3.0	0.0250
4	170	0.65	3.65	0.0215
5	250	1.15	4.8	0.0192

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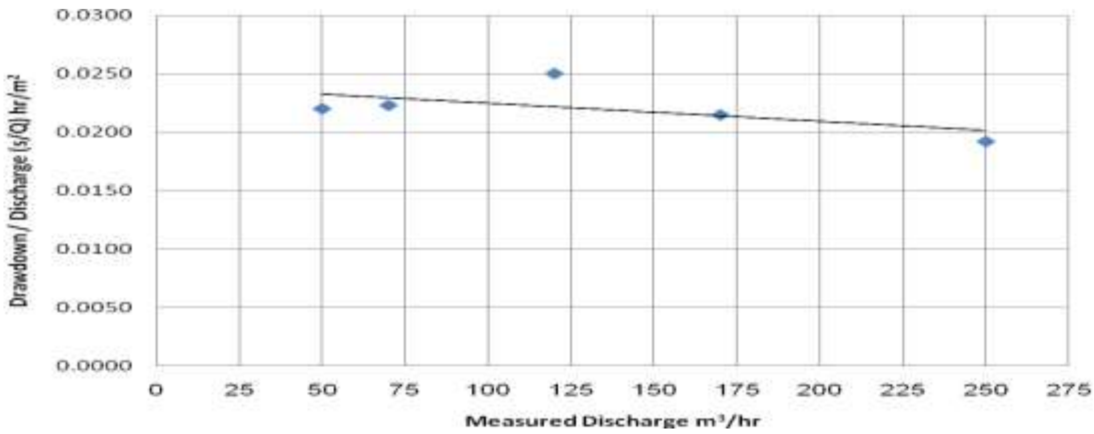

Figure (12) Specific Drawdown versus Discharge Rate

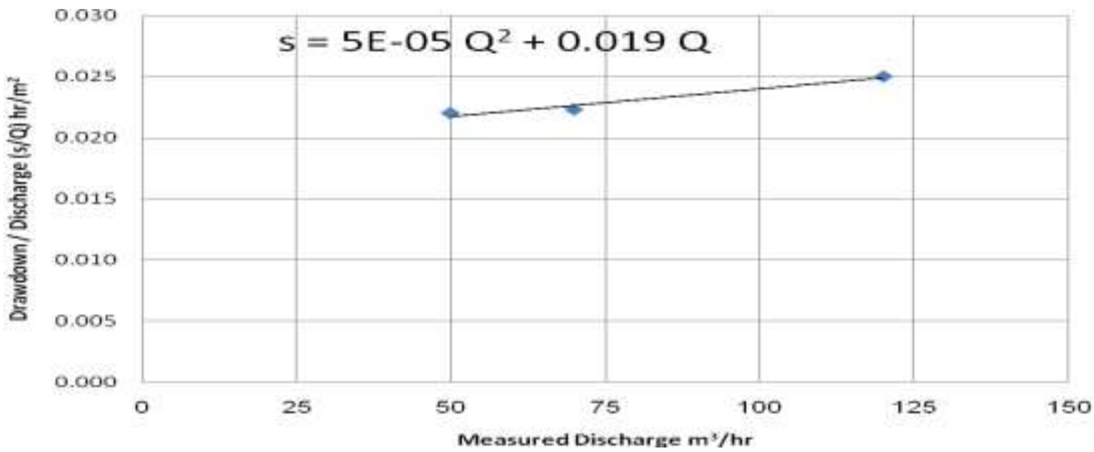

Figure (13) Specific Drawdown versus Discharge Rate for the first three stages

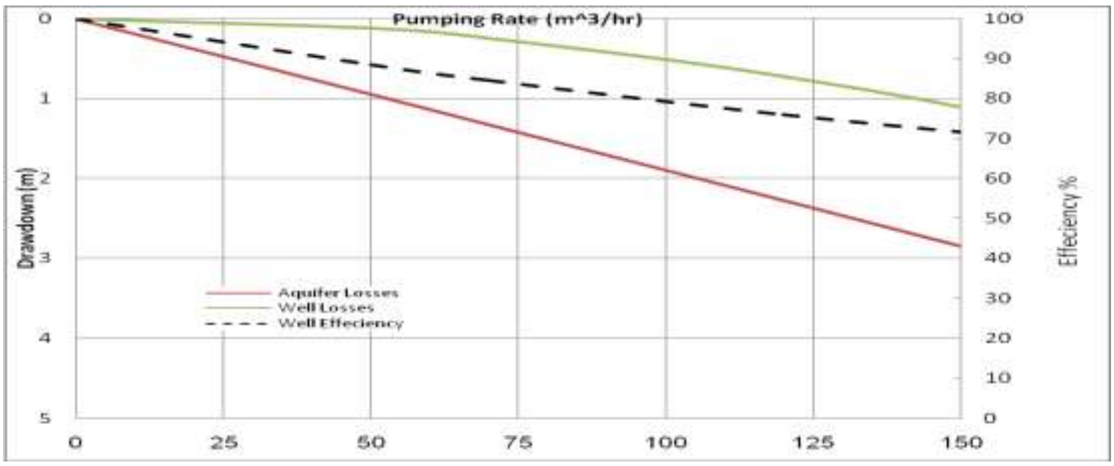

Figure (14) Specific Capacity and Efficiency Diagram for the Pumping Well

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Calculation of Aquifer Parameters using the long duration pumping test

The principle of a pumping test is that we pump water from a well and we measure the discharge of the well and the drawdown in the well and in piezometers at known distances from the well. Substituting these measurements into an appropriate well-flow equation we can calculate the hydraulic characteristics of the aquifer. In the present problem, the drawdown is measured only inside the large diameter pumping well. Using the long duration data, the aquifer transmissivity and storage coefficient are determined using the Papadopulos-Cooper's Method. Before going any further, we should admit that the measured drawdown in the pumping well is affected by the turbulent and linear and the non-linear well losses. Therefore, the calculated values of the aquifer transmissivity and storage coefficient are not accurate but could be reliable for planning purpose.

Time-Drawdown Data in the Pumping Well

When drawdown is measured in the pumping well at different time intervals, Papadopulos and Cooper (1967) devised a method to calculate the aquifer transmissivity that takes the storage capacity of the well into account. Figure (15) shows the Papadopulos-Cooper's type curves while Figure (16) shows the field data on log-log paper. The early time, almost straight portion of the field data corresponds to the period when most of the water is derived from storage within the well. These points do not adequately reflect the aquifer characteristics. The data was analyzed by matching the type curves and the field data such as:

r_w = 2.5 meters

Q = 2400 m^3/day

F (µ, B) = 6.5

1/µ = 2000

B = 0.01

t = 40 minute = 0.027778 day

s_w = 2 meters.

$$s_w = \frac{Q}{4\pi T} F(\mu_w, B)$$

Substituting the values of F (µ, B), s_w and Q in the above equation leads to the value of the aquifer transmissivity (T) as 620 m^2/d.

Using the following equation and substitute the values of t, r_w and the calculated T, we can estimate the value of the storage coefficient as = 5.5×10^{-3}

$$\mu_w = \frac{r_w^2 S}{4\,T\,t}$$

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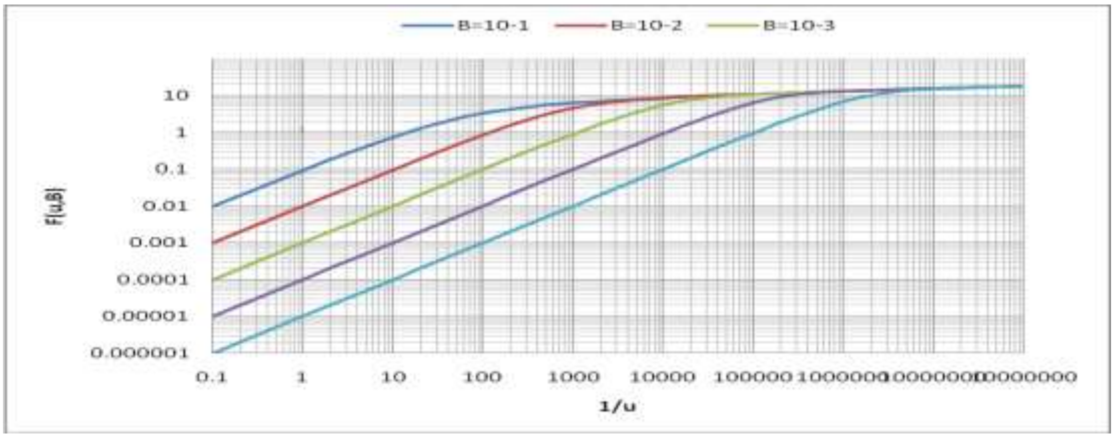

Figure (15) Papadopulos-Cooper's Type curves

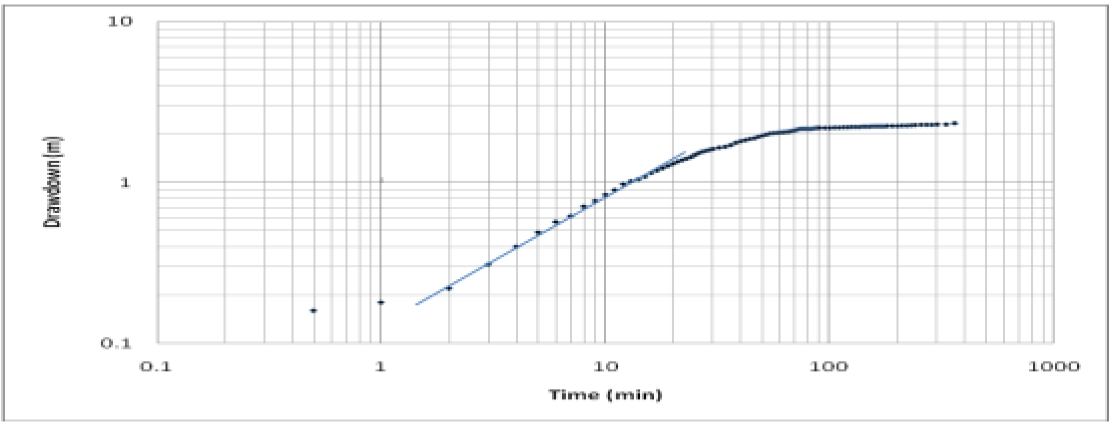

Figure (16) Pumping Test Analysis Using Papadopulos-Cooper's Method

Estimation of the drawdown with time

To calculate the drawdown in the aquifer which will be produced according to the continuous pumping from the well, the Papadopulos-Cooper's solution is used such as:

$$\mathbf{r_w = 2.5\ meters,\ Q = 2400\ m^3/day,\ T = 620\ m^2/day\ and\ S = 5.5\times10^{-3}}$$

Applying these values in the Papadopulos-Cooper's, the drawdown is calculated at different time periods as shown in Figure (17). Table (6) lists the values of the drawdown at 1, 5, 10, 15, 20, 25 and 30 years. It is obvious that the drawdown is increasing gradually during the first 5 years to reach a value of 6 meters approximately. Afterwards, the drawdown reaches to a steady state conditions. We should consider that the calculated drawdown accounts only for the drawdown in the aquifer. Hence, we should account for the additional drawdown that occurs due to the well losses which equals to one meter. Therefore, the pump should be set at the desired depth to avoid any pump failure.

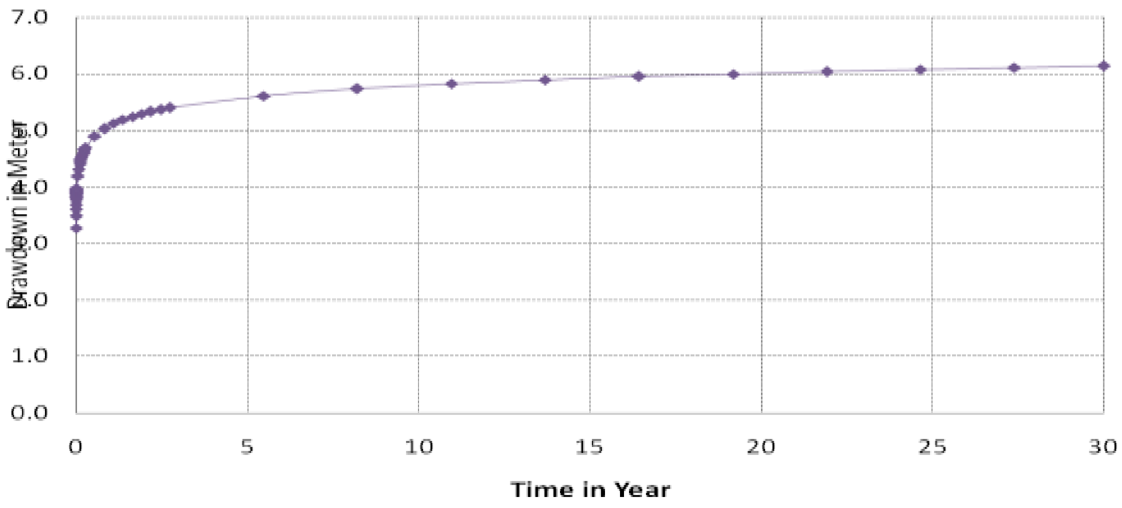

Figure (17) Time-Drawdown relationship inside the pumping well

Table (6) Drawdown values at the different time periods

Time (year)	0.5	1	5	10	15	20	25	30
Drawdown (m)	4.9	5.1	5.6	5.8	5.9	6.0	6.1	6.1

Comments on the Step Test

Following are some comments on the methodology that was used in performing the step test as well as a feedback on the results of the analysis:

1. The well efficiency depends on the size of the openings, well diameter, pump intake. The increase in the pumping rates through the operation of more than one pump would affect the well efficiency especially at the startup of the new pump.
2. The applied discharge rate exceeded the aquifer potential and the safe well yield.
3. The openings in the well casing are not enough to allow for the anticipated high discharge rate.
4. Deeper well casing with more openings would compensate for the desired discharge.
5. Large diameter wells slightly increase the permissible discharge. The governing factor is the area of the openings in the well casing. Long slotted screens of small diameter act equivalently to a large diameter casing with limited openings (surface area of the openings is a governing factor in the well yield).
6. The analysis of the step-test results proved that the well yield should not exceed 100 m^3/hr.

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7. The aquifer losses (BQ) is less than the well losses (CQ^2) for the discharges less than 100 m^3/hr. This indicates the limitation of the aquifer due to the small hydraulic conductivity as will be shown later.

CONCLUSION

The presented model of using large diameter wells instead of small diameter wells has shown insignificant improvement in the well yield in the study area.

For the well under consideration, it is recommended to operate this well for a pumping rate of 50 m^3/hr (for 24 hours per day) to maintain the long-term drawdown at 3 meters in addition to the well losses which is less than 0.5 meter.

The cost of digging the hand well is greater than the conventional well. However, the structural safety of the hand well requires permanent precautions to maintain this origin.

RECOMMENDATIONS

Critical Discharge and Recommended Production Rate:

Based on the pumping test results, a maximum safe pumping rate can be recommended. This long-term rate is generally the highest pumping rate at which equilibrium conditions can be maintained. When the equilibrium rate is exceeded, the dynamic water level continues to decline at a rate proportional to both well and aquifer parameters. When this decline is fairly rapid (several meters per minute), the well may dewater in a short period of time with the pump “breaking suction”. This latter condition is potentially serious and could result in casing collapse.

The discharge rate at which this rapid decline occurs is called the “critical discharge”. In areas of low transmissivity, and rapid dewatering of the well has been achieved quit easily.

According to this philosophy in defining the recommended discharge rate, the optimal design discharge rate for pumping wells within the study area should be less or equal 100 m^3/hr. This rate results in a total dynamic drawdown of 2.3 meters at steady state conditions as will be explained in the long duration pumping test analysis.

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