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OPTIMUM WATER WELLS DESIGN OF KHARTOUM BAHRI AREA, SUDAN

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ABSTRACT

Ground water is the most important resource in Sudan. Demand for groundwater in Khartoum area has recently increased considerably in order to meet the needs for domestic, irrigation and industrial purposes. The optimum design and construction of water wells is highly required in order to maximize the benefits from water wells. This paper discuses optimum design for the Khartoum Bahri area using well design procedure, hydrological and litholology information for the study area to produce a combination of longevity, performance, water good quality free from contamination and cost effectiveness.

KEYWORDS: water wells, optimum design, sieve analysis, Khartoum Bahri.

1. INTRODUCTION

Ground water is the largest source of fresh water accessible on earth which represents important resource in Sudan. And the most important aquifer in Sudan is the Nubian sandstone formation.

Due to the importance of groundwater in Sudan, proper design and construction of wells is very essential. Successful and proper design of wells generally provide an efficient well with a long service life, use techniques in drilling and well construction that take maximum advantage of the hydrogeologic conditions and apply the principles of hydraulics in a practical way to the analysis of wells and aquifer performance [1]. The design of the well or borehole must be chosen before drilling or manual construction begins, as it will govern the choice of drilling or construction method and the drafting of a drilling contract where applicable. The design, therefore, has to be based on existing information, and the most comprehensive this information is, the more successful will be the design [2].

Much of the early well-design information was developed by trial and error procedures, resulting in a variety of rules-of thumb, However, in more recent years, study under both field and laboratory conditions have resulted in the development of scientific criteria for the proper design of well screens and filter pack. Now it generally is known that optimum well design should start with an analysis and interpretation of the aquifer properties, including the particle-size distribution of the aquifer materials [3].

Well design is the process of specifying the physical materials and dimensions for a well[4].the three main components in the design of a drilled well are the pump, the pipe which houses it (the pump-chamber casing) and the intake section of the well which may be unlined where the aquifer is stable, or installed with a well screen and gravel pack where the aquifer material requires support [2] .

The main objective of this paper is an achieving optimum well design for Khartoum Bahri area Which located In Khartoum state lies between latitudes 15.7 N to16.08333 N and longitudes 32.57194 E to 32.65 E. Figure (1**).**

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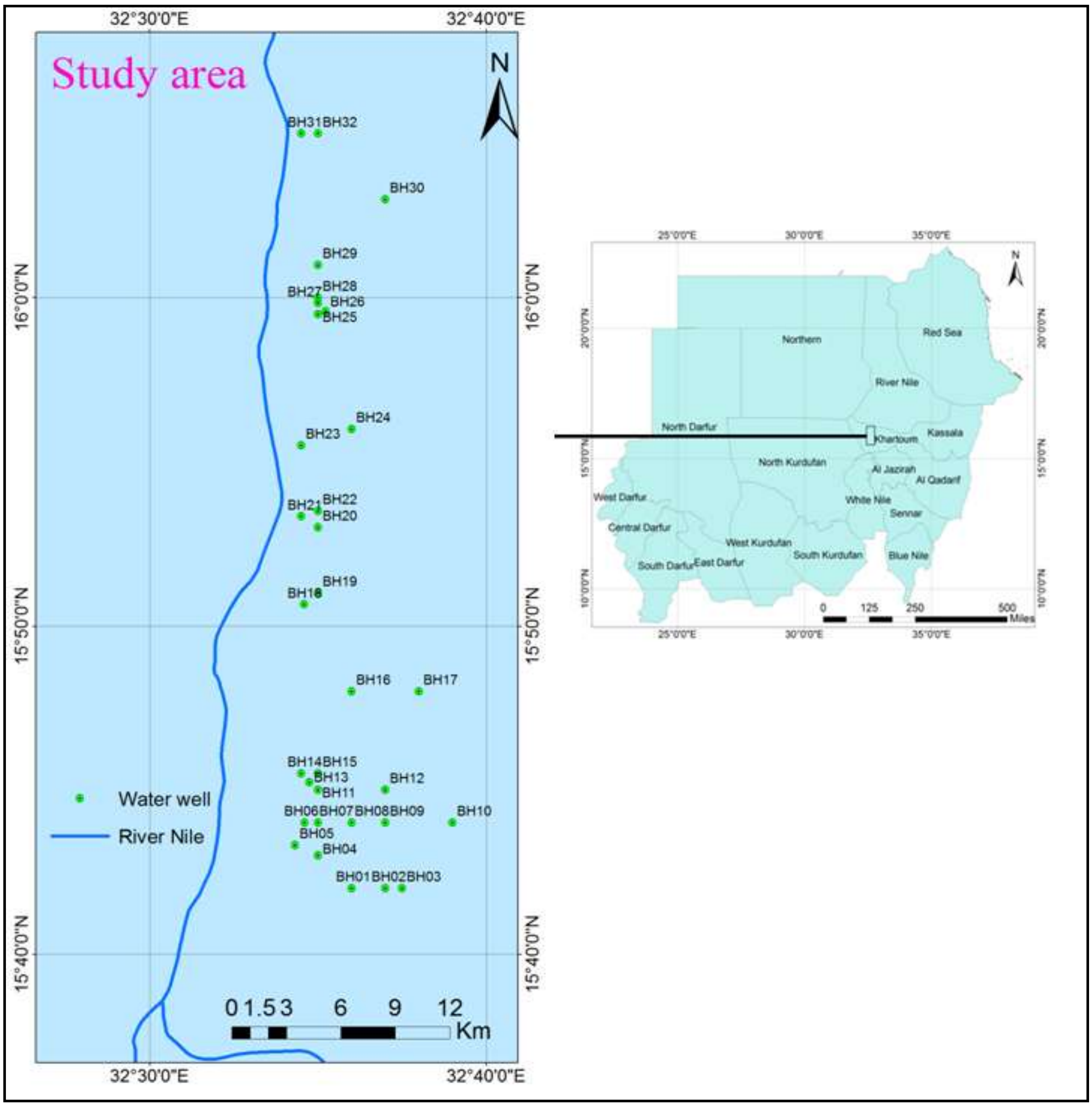

Figure 1 illustrated the study area.

1.1. Basic design parameters

- ***Purpose of the well***
- ***Water demand and Identify formation with potential to support yield required*****:** Must be determine the demand of water (peak, daily, and annual) and Select design discharge for a production well and Identify formation with potential to support yield required.
- ***Type and diameter of pump; power source:*** The hydrogeologist or water engineer must be aware of the crucial importance of pump selection for water well design, for at least two main reasons: 1- The type and, particularly, the diameter of the pump intake will often determine the diameter of the well casing. 2- The type of pump selected must be suited to the resources. If not, it cannot be maintained and the well will soon fall into disuse.
- ***Suitable drilling site:***
  The well site should be accessible for all operations i.e. cleaning, testing, monitoring, maintenance and repair. The ground surrounding the well should be as far as possible from sources of potential contaminations such as sewage tanks, sewage wells, fuel stations...etc[1] . A well must be located so that it meets the minimum isolation distances between the well and utilities, buildings, and potential

sources of contamination. these distances are based on the ability of soil and bedrock to remove certain types of contaminants from the groundwater before they reach the well [5].

- ***Geology and aquifer type – aquifer characteristics, boundaries, regional groundwater levels and recharge***
  An aquifer is a geologic formation that is water bearing or saturated with water and is capable of yielding sufficient quantity of water for economical exploitation [6]. If the aquifer is confined between two almost impervious beds and slopes gradually downwards towards its terminal boundary it is named as confined, artesian or potentiometric aquifer [7]. And, if the aquifer is exposed to the atmosphere or possesses a free surface, it is named as unconfined aquifer. The terms "water-table", "ordinary", or "gravitational" are also used to denote unconfined aquifers. The hydraulic head at any level within a water- table aquifer is equal to the depth from the water-table to the point under consideration [1].The Aquifer characteristic includes hydraulic conductivity, transmissivity, storativity and grain size.
- ***Groundwater quality:***
  The quality of groundwater depends on the type of soil, sediment, or rock through which the water is moving, the length of time water is in contact with geologic materials, and whether any contaminants are present. Gases, minerals, and other chemicals may dissolve into water as it moves underground [5]. The quality of groundwater affect on selection of design material (steel, plastic …etc) and their relation with corrosion/incrustation problems.

1.2 Design the well structure

The main elements to well structure are the casing and the well screen at the intake zone where the water enters the well.

1.2.1Upper Well Casing:

a. Length of Casing

The length of the upper casing is controlled by the requirements of the pump. The pump usually needs to remain submerged, with the minimum submergence recommended by the manufacturer. The “operating” water level in the well can be calculated as the distance below ground level of the static piezometric level “static water level” **(H)** less the anticipated drawdown at the well **(sw)** less a safety margin**(SF)** The anticipated well drawdown **(sw)** is usually calculated for steady state conditions, as a function of the well design discharge and the aquifer transmissivity (or the product of the screen length and the aquifer permeability) [8]. The Safety margin **(SF)** should include allowance for: (The variation in aquifer transmissivity due to aquifer heterogeneity; Well deterioration; Well energy losses (arising from flow through the screen and gravel pack);Future contingencies for well interference, seasonal or over-year decline in static water levels etc.) So, the length of the upper casing becomes;

L = H+ Sw + SF + PR ………………………. (1-1)

Where:

L ≡length of the upper casing (m)
H ≡depth to static water level (m bgl)
Sw≡ anticipated drawdown (m)
SF ≡Safety margin (safety factor)
PR≡ Pump requirements that includes :(Pump submergence to the impeller inlet plus Length of pump below this point plus Manufacturer’s recommended clearance below this point).

b. Diameter of casing

The diameter of upper well casing required is that needed to accommodate the pump, with some margin for clearance around the unit. Manufacturers of pump will recommend a “minimum” casing The diameter must be large enough for the pump to be a comfortable fit, making allowances for non-verticality of the borehole [8].

The drilled hole at any depth should have a minimum diameter about 50mm greater than the OD of the casing and screen string, although larger clearances are needed for grouting operations and installing a gravel pack. For grouting, the National Ground Water Association[9] for example, recommends an annular clearance of at least 50mm between the casing and hole wall, i.e. the drilled diameter

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should be at least 100mm larger than the casing OD. The diameter of a borehole to be equipped with an artificial sand or gravel pack has to be at least 150mm greater than the screen OD to accommodate the pack, which should be at least 75mm thick [2].

1.2.2. Well Screen:

a. Screen Length and Location

The optimum length of well screen for a specific well is based on aquifer thickness, available drawdown, stratification within the aquifer, and if the aquifer is unconfined or confined [8]. Criteria for determining the screen length for homogeneous and heterogeneous confined and water-table aquifer wells are described as the following:

Homogeneous Confined (Artesian) Aquifer

The maximum drawdown in wells in confined aquifers needs to be limited to the top of the aquifer. Provided the pumping level will not induce drawdown below the top of the aquifer (the aquifer does not become unconfined), **70 to 80 percent** of the thickness of the water-bearing unit can be screened [8][9].

The general rules for screen length in confined aquifers are as follows :(If the aquifer thickness is less than 8 m, screen 70% of the aquifer(If the aquifer thickness is (8 - 16) m, screen 75% of the aquifer, If the aquifer thickness is greater than 16 m, screen 80% of the aquifer) [8].

Heterogeneous Confined (Artesian) Aquifer

In heterogeneous or stratified confined aquifers, the most permeable zones need to be screened; these zones can be determined by one or several methods: (Permeability tests, Sieve analysis and comparison of grain-size curves, Well-bore velocity surveys and Interpretation of borehole geophysical logs)

In heterogeneous or stratified aquifers, (80-90) % of the most permeable layers needs to be screened [8].

Homogeneous Unconfined (Water-Table) Aquifer

Screening the bottom one-third of the saturated zone in a homogeneous unconfined aquifer normally provides the optimum design [4][9]. In some wells, screening the bottom one-half of the saturated layers may be more desirable for obtaining a larger specific capacity (if well efficiency is more desirable than the maximum yield).

In water-table wells, larger specific capacity is obtained by using as long screen as possible; therefore, convergence of flow lines and the entrance velocity through the well screen are minimized. However, there is more available drawdown when a shorter screen is used [8].

Heterogeneous Unconfined (Water-Table) Aquifer:

If the aquifer is heterogeneous, the well design can incorporate short sections of screen placed opposite the most permeable layers, with appropriate screen slot sizes for each layer, and blank casing against the intervening aquicludes, similar to the design for a consolidated aquifer system[2]. Field identification of screenable aquifer will largely be made on the basis of the lithological log. Clays and unproductive sections are usually screened as blank casing is cheaper than screen. Unconsolidated formations with grain size less than the "design" formation must be cased out. This: Protects the material from being eroded thereby placing the casing under stress. and Protects the pump from the ill effects of pumping sand [8].

b. Well Screen Diameter

Screen Diameter Design Procedures

- Design on upflow losses – select a screen size that reduces these to a value of a few percent of the overall pumping head (or the economic optimum size) a rule of thumb is that the upflow velocity limit of 1.5 m/s will produce a well with reasonable upflow losses.
- Screen sizes usually standard, in increments of about 1 in. for small sizes and 2 in. above 6 in. diameter.

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- If the cost of increasing diameter is significant, and no significant reduction is upflow losses accrues, use of large diameter would only be advised if the following are recognized problems in the area (well deterioration, incrustation, screen corrosion)
- The screen diameter is selected to fulfill the essential principle: the total area of the screen openings needs to be provided so the entrance velocity will not exceed the design standard. Diameter can be varied after length and size of the screen openings have been selected.

Frequently, the length of the screen and the slot size are fixed by the natural characteristics of the formation; thus screen diameter is the main variable. Laboratory tests and experience indicate that if the screen entrance velocity is maintained at about 0.03 m/sec: (Frictional losses in screen openings will be negligible, the rate of incrustation will be minimized and the rate of corrosion will be minimized). The entrance (V_n) is equal to the expected or desired yield (Q) divided by the total area of openings in the screen (T_{OA}) equation 2-1. If the entrance velocity is greater than 0.03 m/sec. the screen diameter needs to be increased to provide sufficient open area so the entrance velocity is about 0.03 m/sec. The pump needs to be set above the top of the screen for these designs [8].

$V_n = Q/T_{OA}$………………. (2-1)

c. Screen Slot Size:

The size of slots in artificially gravel-packed wells is generally recommended to be around the D10 of the pack material [4] [10] [9][2].

For naturally developed wells, well-screen slot openings need to be selected from sieve analysis for representative samples from the water-bearing formation. For a homogeneous formation that consists of fine, uniform sand, the size of the screen opening (slot size) is selected as the size that will be pass (50-60) % of the sand [8][11] .

- The 60-perecnt passing value needs to be used where the ground water is not particularly corrosive, and there is minimal doubt as to the reliability of the sample.
- The 50-perecnt passing value is used if the water is corrosive or if there is doubt as to the reliability of the sample; the 50-percent passing value is the more conservative design.

In general, a larger slot-size selection enables the development of a thicker zone surrounding the screen, therefore, increasing the specific capacity. In addition, if the water is incrusting, a larger slot size will result in a longer service life. However, the use of a larger slot size may necessitate longer development times to produce a sand-free condition.

A more conservative selection of slot size (for instance, a 50% passing value) is selected if there is uncertainty as to the reliability of the sample; if the aquifer is overlain or underlain by fine-grained, loose materials; or if development time is expensive [8].

1.2.3 Filter or Gravel Pack

Artificial gravel packs are used in unconsolidated aquifers where the aquifer material is either very fine or well-sorted (that is, of uniform grading). A significant advantage of the artificial pack is that, because the pack material is coarser than the geological formation, screens with larger slot sizes can be used. Artificial packs are useful in allowing thin-bedded heterogeneous aquifers to be screened much more safely than with direct screening and natural development [2]

.**Dx:** The sizes of particles such that x percent is passed.

Uniformity coefficient: Ratio of the D60 size to D10 size of the material (low coefficient indicates uniform material).

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The gravel pack is intended to fulfill the following functions:(support the aquifer formations and prevent collapse into the casing, laterally restrain the casing, effectively strengthening the casing and prevent the movement of fine aquifer material into the well).

The normal approach is to use a filter pack when:

- The uniformity coefficient < 3;
- The aquifer is fine, with D10 of the formation < 0.25 mm [8].

Gravel Pack Materials

Filter pack materials shall consist of clean, rounded to well rounded, hard, insoluble particles of siliceous composition (Industrial grade quartz sand).The required grain-size distribution or particle sizes of the filter pack materials shall be selected based upon a sieve analysis of the aquifer materials or the formation to be monitored [3][11].

Thickness of Gravel Pack

In theory, a pack thickness of 2 or 3 grains is all that is required to retain formation particles but In practice around 10 cm is used to ensure an envelope around the well. 20 cm is Upper limit of thickness of the gravel pack otherwise, final well development becomes too difficult and cost of drilling escalates. Packs with a thickness of less than 5 cm are simply formation stabilizers, acting to support the formation, but not effective as a filter [8].

Gravel Pack Grading

Several methods of determining the gravel pack grain sizes have been suggested. And all these based initially on a sieve analysis of the aquifer. A common consensus is that a gravel pack will normally perform well if the uniformity coefficient is similar to that of the aquifer material, i.e. the grain size distribution curves of the filter pack and the aquifer material are similar [2][8]. The grain size of the aquifer material should be multiplied by a constant of approximately (4-7) with average **(5)** to create an envelope defining the filter grading [8].

1.3 Select construction materials

a- casing materials:

The materials most commonly used as casing and screen in drilled wells and boreholes are steel (mild or low-carbon steel, carbon steel and stainless steel), plastic [polyvinyl chloride (PVC), acrylonitrile butadiene styrene (ABS), polyolefins and other plastics] and fibreglass [glass-reinforced plastic (GRP)].

The choice of construction materials will be influenced by many factors, including their strength, jointing system, durability, chemical inertness, ease of handling, cost, local availability and familiarity. National regulations, specifications or guidance documents on water well construction will also influence our choice. The relative importance of the various factors will differ according to the type and purpose of the well or borehole being designed [2].

Steel casing:

Steel is the traditional material used for water well casing primarily because of its strength. It can be installed to great depths and pressure-grouted – and it can withstand fairly rough treatment on site, including driving and jacking.

Plastic and fibreglass casing:

Plastic is widely used in shallow aquifers because it is cheap and corrosion-free. Common plastic materials are PVC, ABS, rubber-modified styrene and polypropylene. Fibreglass (GRP) casing is stronger than plastic casing and is corrosion-resistant [2].

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b- Screen material:

The choice of a particular screen type for a well will depend on a combination of factors: the strength and corrosion resistance, the slot design and open area and cost. The first two factors are a function of the materials used for screen manufacture – which include steels, plastics and fibreglass [2].

– If the groundwater is corrosive, then corrosion-resistant screens should be used such as plastic, fiberglass and stainless steel.(the indicators of corrosive water are low ph less than 7 and high total dissolved solid TDS exceed 1000 ppm [12]).

– If the groundwater is incrusting, then a screen with a large open area should be used to offset the effects of screen blockage. [2](the indicator of incrusting water is high Ph above 7.5[12]).

c. Grouting materials:

After the well casing has been placed in the bore hole, it is necessary to fill the annular space to keep surface water and other contaminants from entering the well. *Grout* is the material used to fill this annular space which consists of a mixture of water and either cement or a special type of clay called *bentonite*. The grout must be pumped in from the bottom of the well upward (according to Minnesota law) to assure a complete seal around the casing. Usual method is to insert *agrout pipe* (¾- to 1¼-inch diameter pipe) down to the bottom of the space between the well casing and the bore hole. The grout is then pumped in until it comes to the ground surface. The grout must not be poured from the surface[5].

1.4 Economic considerations in well design:

- Do not drill deeper than necessary.
- (2) Do not drill at larger diameter than necessary: (Do not design a gravel pack thicker than needed, do not design a screen or casing of greater diameter than necessary).
- Do not use expensive materials where cheaper ones will do.
- Do not use more screen than is necessary [2].

2. MATERIALS AND METHODS

Borehole data were obtained from the Information Centre of Ground water and Wadis Directorate - Ministry of Water Resources and Electricity, Khartoum, Sudan[13].

From lithology model figure (2) and lithology cross sections for Bahri area which given from rockworks software program[14] there are three types of strata water bearing were determined to determination stratification and aquifer nature figure (3).

The contour maps for Bahri area which obtained by arc GIS software program SWL contour[14] and draw the drawdawn contour figure (4) using data in table (1) for Bahri area were used to estimate optimum casing length. TDS and Ph contour [14] were used to estimate matrial of casing for Bahri area.

There are two samples taken from two wells Almaslakh well 1 the coordinates (15.747094 N, 32.586873E), Almaslakh well 2 the coordinates (15.746916N,32.589028 E) which were used for sieve analysis see tables (2,3) and formation distribution curves were drawn to determine optimum slot openning figures (5,6).

water well design procedures were applicable for bahri area using BH08 as a model figure (7) to obtain optimum well design by using the resulting data (lithological data which obtained from lithological cross sections for Bahri area and hydrolgeological data which obtained from arc GIS and sieve anlysis resulting).

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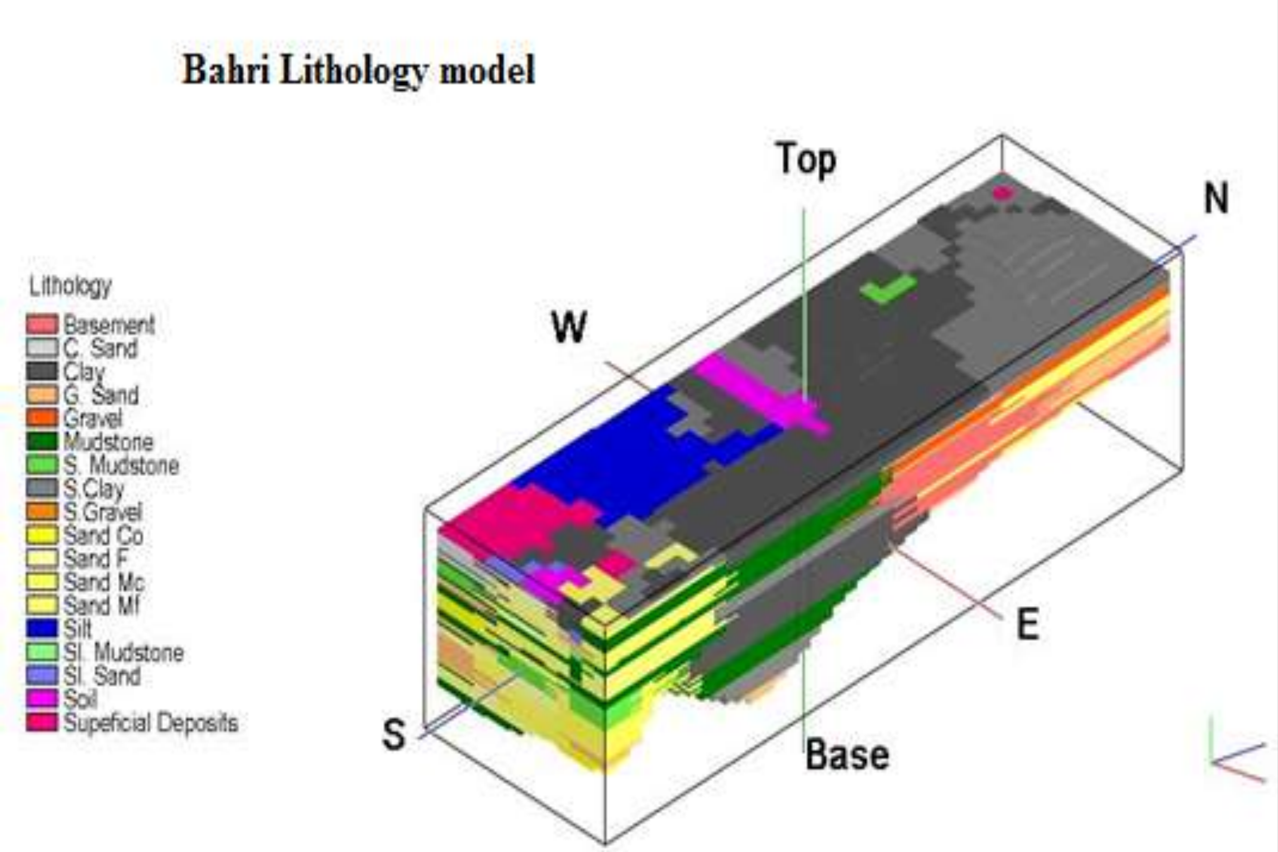

Figure.2 illustrated Bahri Lithology model [14]

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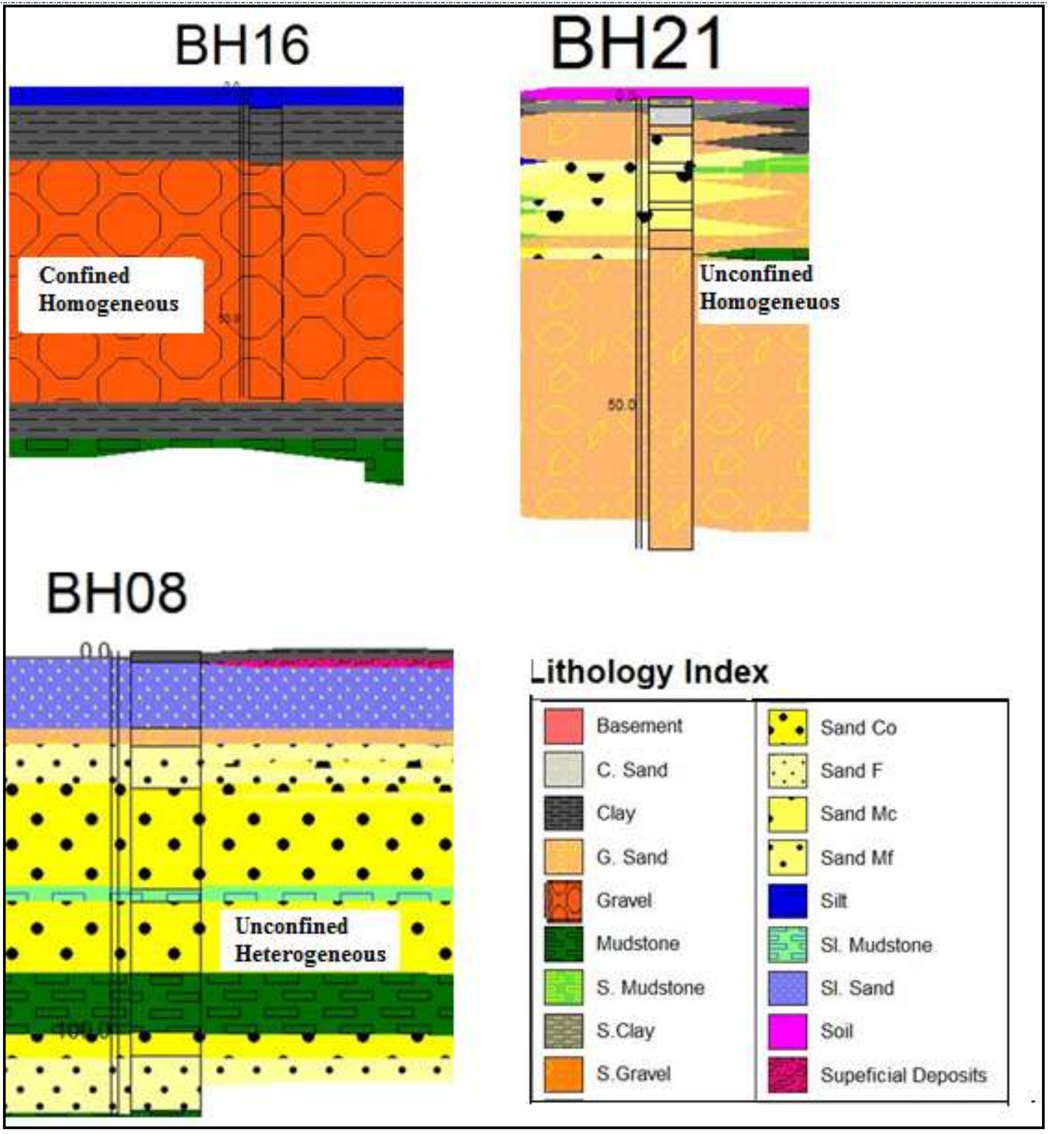

Figure.3 illustrated different stratification of Bahri area

Table (1) study area wells data

Bore	Location	Longitude Decimal Degree	Latitude Decimal Degree	Total Depth m	S.W. L From Surface m	Drawdown m	Yield m^3/h	TDS mg/L	PH
BH01	EL HALFAYA	32.6	15.7	105	22	10	50	-	-
BH02	UMM DUREIWA	32.61666	15.7	98.8	22	6	31	335	7.9
BH03	UMDUREWEIA NORTH	32.625	15.7	117.9	23	8	29	300	7.9
BH04	AL DOUROSHAB	32.58333	15.71666	128.1	27.1	7.9	40.91	335	8.1
BH05	EL DUROSHAB(AL	32.57194	15.72194	105.2	26.5	4.3	13.6	412	7.2
BH06	E DROUSHAB NORTH	32.57666	15.73333	137.2	24.1	3.3	27.3	417	7.3
BH07	ELDROSHAB	32.58333	15.73333	132.6	22	3	16	210	8.2
BH08	ELDURASHAB SOUTH	32.6	15.73333	125	23	3	14	300	7.7
BH09	UMM DIRAWA	32.61666	15.73333	97.4	22	16	46	-	8.9
BH10	ELAOLYAB(2)	32.65	15.73333	61	26.6	2.1	16.36	522	8.4
BH11	UM ALGORA WEST	32.58333	15.75	106.7	18	14	25	304	7.2
BH12	EL ZAKIAB	32.61666	15.75	106.7	19	8.4	34.1	360	7.5
BH13	UMM ELGOURA WEST	32.57916	15.75388	106.7	20.6	7.1	32.7	453	7
BH14	EL KASR EL GADID	32.575	15.75833	79.3	29	4	23	435	7.2
BH15	UMM EL GORA WEST	32.58333	15.75833	106.7	18	4	25	385	7.8
BH16	EL TIBNA	32.6	15.8	67	-	-	-	-	-
BH17	ABO SEDIR NORTH	32.63333	15.8	152.4	116.5	1.2	16.36	277	7.2
BH18	AL FAKI	32.57638	15.84416	61	14.4	0.8	18.2	-	7.7
BH19	EL KHILALA	32.58333	15.85	77.7	13	19	40	300	7.8
BH20	EL KABBASHI	32.58333	15.88333	75.6	2	25	80	320	8.4
BH21	KABBASHI	32.575	15.88888	73.1	-	-	-	-	-
BH22	EL KABBASHI2	32.58333	15.89166	67.1	13	20	40	370	7.5
BH23	EL SAGGAI EL BATALAB	32.575	15.925	56.4	11	7	11	476	7.2
BH24	EL TUMANAT	32.6	15.93333	48.7	-	0	-	-	-
BH25	DEIM ABU FRAWAH	32.58333	15.99166	80	7	14	60	240	8
BH26	ABO TELEH	32.58722	15.99305	61	25.6	5.2	34.09	286	7.4
BH27	ELNAYA	32.58333	15.99722	61	9	7	80	-	-
BH28	WAWISSI(2)	32.58333	16	45.7	22.9	0.9	29.2	264	7.8
BH29	NORTHERN AREA	32.58333	16.01666	44.2	20	0	11	317	7.2
BH30	ELKUNGER	32.61666	16.05	40.9	20	2	33	135	8
BH31	WAWOSSI ELSHEIK ALI	32.575	16.08333	53.4	8.5	2.8	24.79	170	7.7
BH32	WAWESEE	32.58333	16.08333	45.7	-	-	-	-	-

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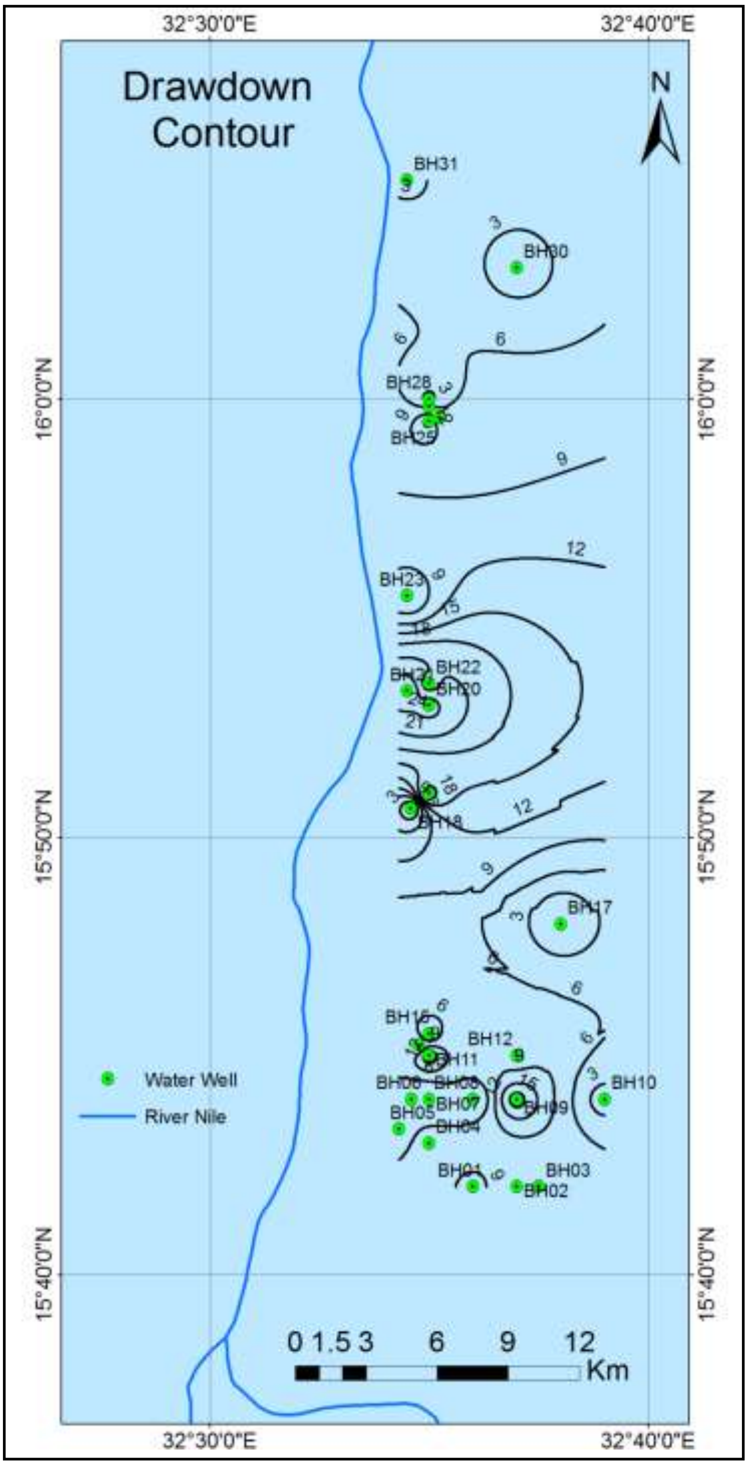

Figure.4 illustrated drawdown contour for Bahri area

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The sample was taken from the lower aquifer for Almaslakh well1 the sample weight 99.8g and the description is fine sand.

Table 2 sieve analysis for Almaslakh well 1 sample

Sieve Opening mm	weight g	retain weight g	passing weight g	passing %	gravel pack mm
2.360	7.400	7.400	92.351	92.582	11.8
1.700	5.000	12.400	87.351	87.569	8.5
1.180	14.400	26.800	72.951	73.133	5.9
0.850	16.700	43.500	56.251	56.391	4.25
0.600	24.100	67.600	32.151	32.231	3
0.425	19.800	87.400	12.351	12.382	2.125
0.300	9.400	96.800	2.951	2.958	1.5
0.150	2.900	99.700	0.051	0.051	0.75
0.075	0.050	99.750	0.001	0.001	0.375
Pan	0.001	99.751	0.000	0.000	0

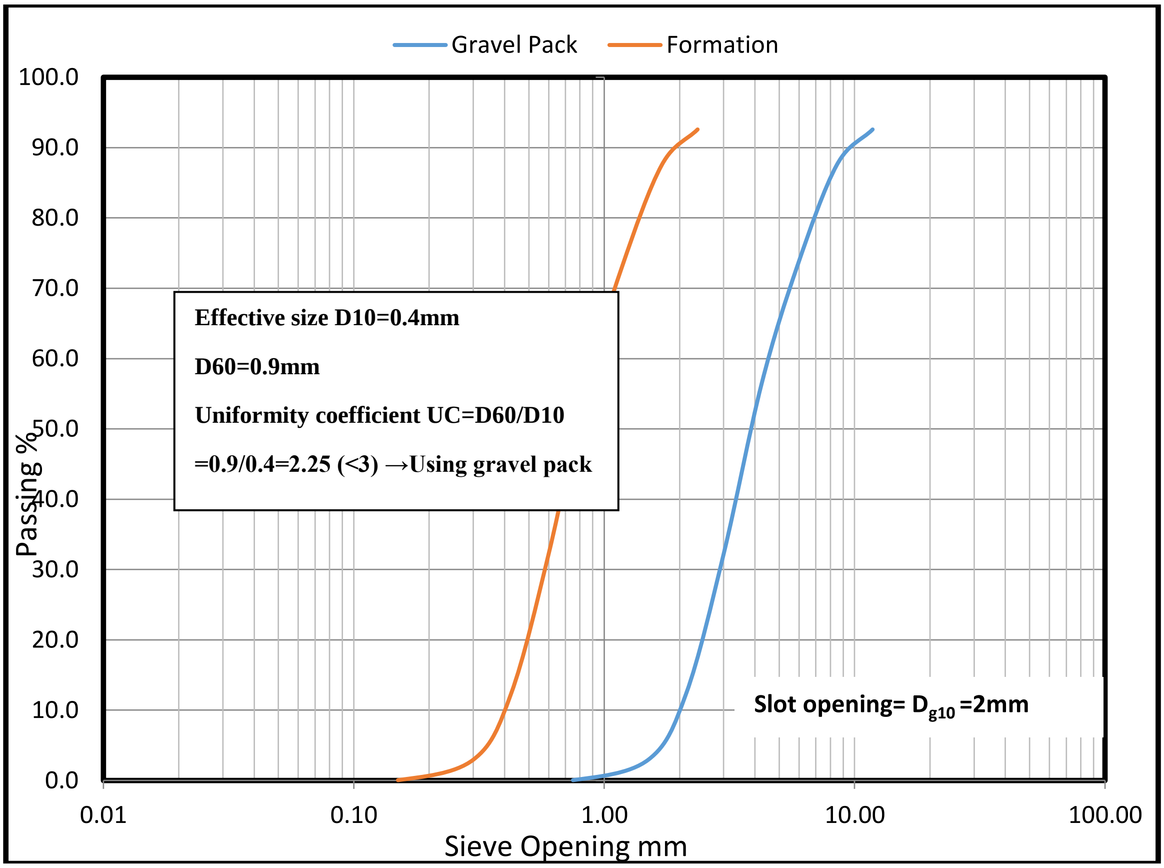

Figure.5 illustrated formation distribution curve for ***Almaslakh well 1***

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The sample was taken from the lower aquifer for Almaslakh well 2, the sample weight 99g and the description is coarse sand.

Table 3 sieve analysis for ALmaslakh well 2 sample

Sieve Opening mm	weight g	retain weight g	passing weight g	passing Percentage %
2.360	0.500	0.500	98.500	99.495
1.700	14.400	14.900	84.100	84.949
1.180	30.300	45.200	53.800	54.343
0.850	14.700	59.900	39.100	39.495
0.600	13.100	73.000	26.000	26.263
0.425	10.400	83.400	15.600	15.758
0.300	8.000	91.400	7.600	7.677
0.150	6.700	98.100	0.900	0.909
0.075	0.800	98.900	0.100	0.101
Pan	0.100	99.000	0.000	0.000

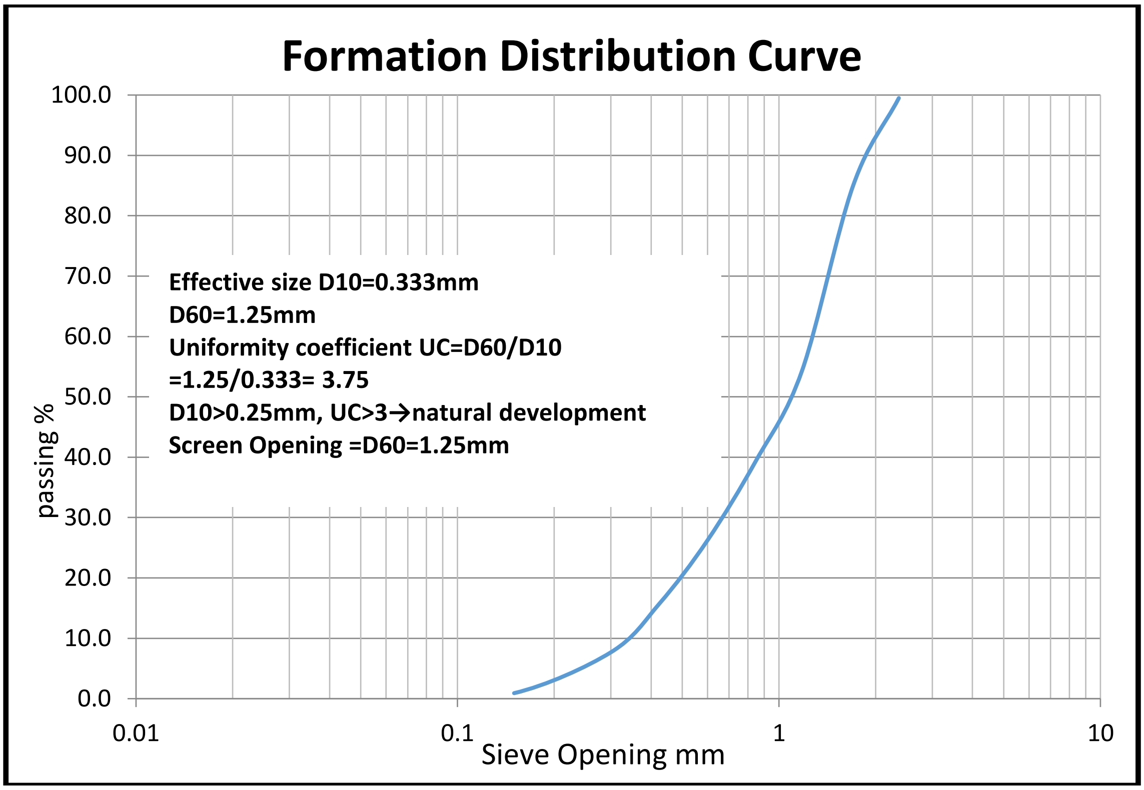

Figure.6 illustrated formation distribution curve for Almaslakh well 2

3. RESULTS AND DISCUSSION

Genral lithological and hydrogeological information for Bahri area:
From lithology model and cross sections the Lower aquifer in some area confined and in other unconfined figure (3).

In Bahri area the average wells depth is 150m except northern area the average wells depth is 50m because basement existing.

The upper aquifer must be sealed because subjected to pollution by sewage wells (all the household have sewage wells drilled down to 30m so that all these encounter the upper aquifer which cause pollution for the upper aquifer).

In lower aquifer in Bahri area The Mean values of the static water levels in all areas near the Nile and Blue Nile are near from the surface (10-20m) and increase when far from the River Nile and Blue Nile.

From drawdown contour for lower aquifer in Bahri area the mean values of drawdown is the 9m and high values 24m see figure (4).

The total dissolved solids (TDS) in the lower aquifer in Bahri area have a mean value of 360 mg/L in almost of the area and high value 522 mg/L in South Eastern of the study area (BH10).

Mean values of PH of Bahri area are 7.4 in the area near from the Nile and Blue Nile and increase when far from the Nile with mean value 7.8 that indicate the lower aquifer water is the incrustation in eastern and northern parts of study area, therefore in eastern and northern parts using large opening for avoid blockage by incrustation water.

From TDS distribution in a Bahri area (less than 1000 mg/L) and PH values (more than7) that indicate lower aquifer water is not corrosive.

Optimum design for BH08:

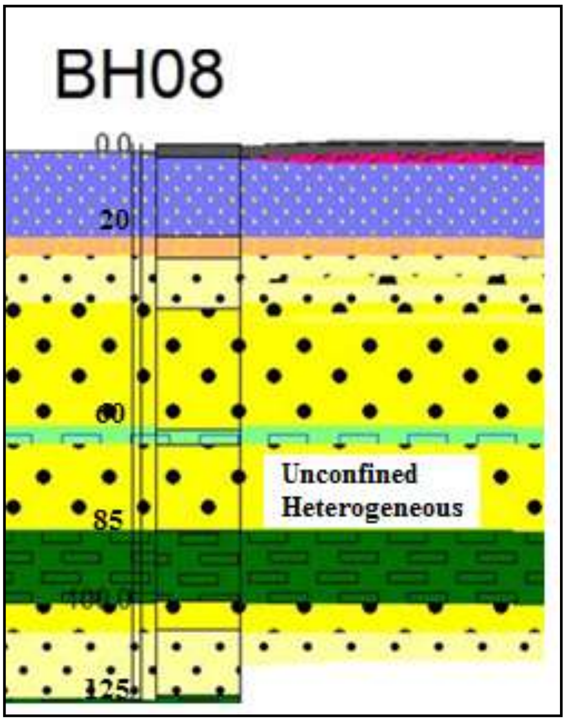

Figure7. Illustrated Bore hole 8 Stratification

Optimum well diameter for BH08:
The purpose of the well is drinking and the well yield required 80m^3/h and from 32 well data from Bahri area the lower aquifer gives this yield.

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From Johnson recommended well diameters [12] for flow rate 80m^3/ h (293.3 gpm) the recommended nominal size of pump bowls 6in and recommended optimum size of well casing10in (ID).

From API casing specification casing out size 10.75in and choose thickness 0.545in.
The clearance for cementing about 100 mm (3.94 in).
Bit diameter = OD casing +3.94 in
=10.75+ 3.94=14.69in

Optimum bit size 15in
The total depth 125m

Optimum casing Length:
Using equation 1-1 to determine length of casing
L = H+ Sw + SF + PR
From well data SWL= 26m, Q =14m^3/h, SW = 3m
Specific capacity= flow rate / drawdown=14/3=4.667
Drawdown in flow rate 80 m^3/h =17.14m
Assume safety factor 8 m
Assume PR=8m
L=26+17.14+8+8=59.14m
But the First screen begins from depth 69M according to stratification then Optimum casing depth 69m (reach to first screen).
The upper aquifer must be sealed because it subjected to pollution by sewage **wells.**

Screen length and Location:
For heterogeneous unconfined aquifer the position of the screen in the lower portions of the most permeable strata in order to provide for maximum available drawdown.[12]
According to stratification of the aquifer figure (7) two screens must be used:
First screen: against coarse sand depth (69m-81m) length 12 m figure (7)
Second Screen: against fine sand depth (104-116m) length 12m figure (7)
The length 12m chosen for the screen to reduce the cost.

Plain casing 81m-104m
Optimum Screen slot size:
Slot size determines by using Sieve analysis for formation sample, out acting I assume the resulting sieve analysis given from Almaslakh well 1 For fine sand model and from Almaslakh well 2 for a coarse sand model.

For Almaslakh 2 well sample (coarse sand):
Effective size D10=0.333mm
D60=1.25mm
Uniformity coefficient UC=D60/D10
=1.25/0.333= 3.75
D10>0.25mm, UC>3→natural development
Screen Opening =D60 (water not corrosive) =1.25mm
Optimum slot size for **first screen 1.25 mm**→ no need gravel pack.

For Almaslakh 1well sample (fine sand):
Effective size D10=0.4mm
D60=0.9mm
Uniformity coefficient UC=D60/D10
=0.9/0.4=2.25 (<3) →Using gravel pack with and screen Slot opening= D_{g10} =2mm
Optimum slot size for ***second screen 2mm*** and using gravel pack.

Optimum Screen Diameter:

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First screen: optimum Screen length 12 m, optimum slot size 1.25mm
to determination the diameter of screen this diameter must be give entrance velocity (standard) not exceed 0.1ft/s 3cm/s [12][15].

Using equation 2-1 to calculate T_{OA} for first screen.
$V_n = Q/T_{OA}$
V_n standard =3cm/s =0.03m/s=108m/h
$Q=80m^3/h$ (yield required)
$T_{OA}=80/108=0.7407m^2 =1148in^2$
Screen length 12m=39.4 ft
T_{OA} for one feet =1148/39.4= 29.13 in^2/ft

From johonson well screen specification [12] for T_{OA} 29.13in^2/ft and slot size 1.25mm the optimum nominal screen size is 8 in (because a 150mm (5.91in) is the minimum diameter is recommended for most water supply wells to accommodate work-over [2]).

Second Screen:
Optimum Screen length 12 m, optimum slot size 2mm and need gravel pack. to determination the diameter of screen this diameter must be give entrance velocity (standard) not exceed 3cm/s [12][15].
Also using equation 2-1 to calculate T_{OA} for second screen.
$V_n = Q/T_{OA}$
V_n standard = 3cm/s =0.03m/s=108m/h
Q=80m/h (yield required)
$T_{OA}=80/108=0.7407m^2 =1148in^2$
Screen length 12m=39.4 ft
T_{OA} for one feet =1148/39.4 = 29.13 in^2/ft
From johonson well screen specification [12] for T_{OA} 29.13 in^2/ft and slot size 2 mm (0.0788in) the optimum nominal screen size is 8 in (because a 150mm (5.91in) is the minimum diameter is recommended for most water supply wells to accommodate work-over [2]).

Gravel pack thickness:
In practice around 10 cm is used to ensure an envelope around the well. [8] [2].

Gravel pack grade: The grain size of the aquifer material should be multiplied by a constant of approximately (4-7) with average **(5)** to create an envelope defining the filter grading [8].
Gravel size (11.8, 8.5, 5.9, 4.25, 3, 2.125, 1.5, 0.75, and 0.375) mm table (2) figure (5).

Plain casing 116-125m.

4. CONCLUSION

Upper aquifer subject to pollution by seewage wells, therefore this aquifer must be sealed and production from lower aquifer.

The lower aquifer water not corrosive according to TDS and PH distribution, therefore the Mild steel is suitable for the Khartoum Bahri area.

The lower aquifer water in eastern and northern parts of the Bahri area when far from Nile is incrusting, and then a stainless steel screen with a large open area should be used to offset the effects of screen blockage.

for lower aquifer in the Khartoum Bahri area when the lithology description is fine sand the optimum design is gravel pack with screen slot size 2mm. and when the lithology discribtion is coarse sand the natural development with slot size 1mm is the optimum design. But the sieve analysis must be done for any well to determination optimum slot size accurately.

In the northern part of the Khartoum Bahri area the well depths arrange 50 m (shallow well) therefore plastic casing is suitable for this area.

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