CEG 8507 Borehole Design and Construction

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Introduction

This report serves for two purposes. The first one, as support of Simpson's Sausages Ltd abstract licence application. The target abstraction rate is 93 m^3/hour with a daily maximum of 1,500 m^3/day and 400,000 m^3/year. The second one, as a preliminary draft for a new borehole to be drilled at a nearby location (NGR SE 4280 7600). This report used available data from previous tests (Appendix 1) and published information by the British Geological Survey (BGS, 2019).

Project site

The borehole evaluated in this study is located just outside Asenby in North Yorkshire (Grid Reference SE 4153 7539), near the existing industrial estate. It is part of the Cod Beck catchment. General characteristics for the topography, geology and aquifer are shown in the following paragraphs.

Topography

An estimate of the topography of the site was done using data available via Google Earth (www.earth.google.com) and it is shown in Figure 1. The altitude of Simpson's and Jenkins' borehole were estimated at 20m$\pm$0,5 above sea level. The surrounding near Moorside has a similar elevation with changes in the order of$\pm$2m. The site lowers near the river reaching at elevation of around +16m$\pm$0,5.A schematic view of the topography is shown in Figure 1.

Geology

The geology of the site was investigated using existing borehole-log and maps accessible from the British Geological Society website (BGS, 2019). As shown in Figure 2c, the location of the borehole (PBH) is near the intersection of two superficial layers: Alne formation and Breighton sand. The first one characterised by "laminated clay with silt (varved) and subordinate fine-grained sand beds" (BGS, 2019) with a thickness that can reach 22m. The second one by a well sorted medium grain sand with minor bands of coarser material. Regarding bedrock formation, the borehole is and located on a Sherwood Sandstone aquifer (Figure2b,d). This layer layer is usually made of with fine to medium grained sandstone (Powell et al., 1992). A schematic section is shown in Figure 1.

Aquifer characteristics

From the data collected, the production borehole seems to sit on an aquifer (Figure 2b). This is confirmed by available literature that described Sherwood Sandstone in this area as an aquifer (Allen et al., 1997). In the proximity of the extraction borehole, the Sherwood Sandstone was assumed to be uniform in composition at least on the transects connecting the different boreholes(PBH-JBH and PBH-MBH).This is supported by the data taken during distant drawdown test at Jenkin and Moorside that show similar values.

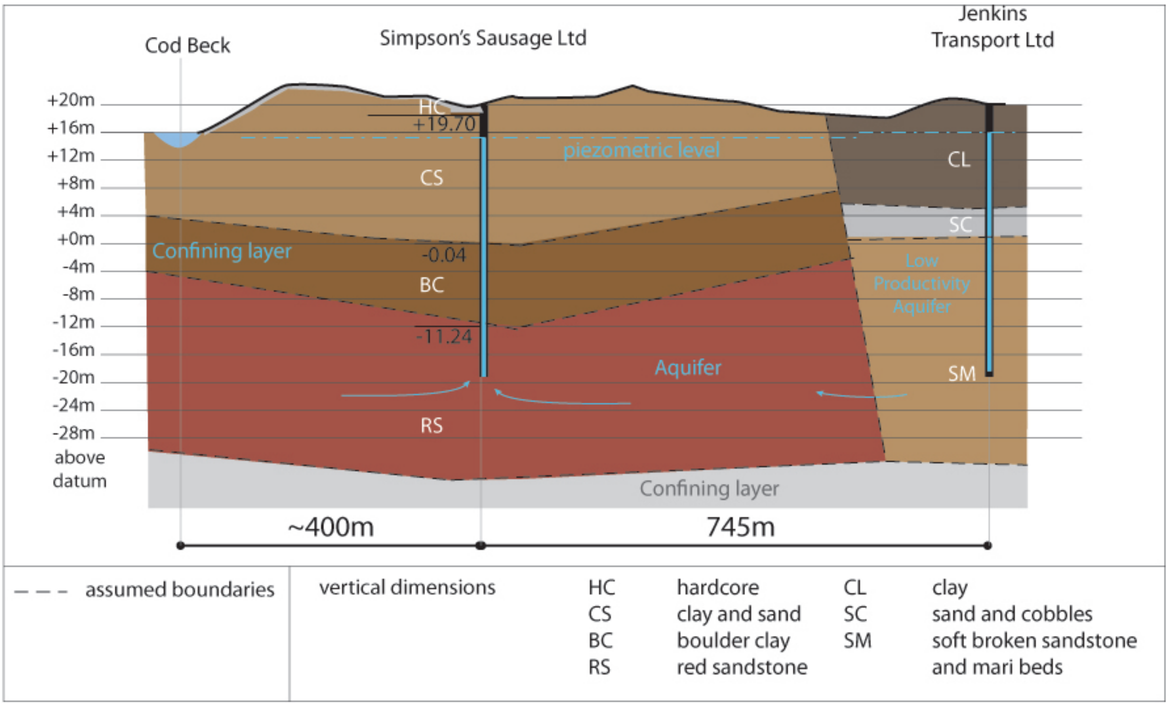

Figure 1: diagram showing topographic characteristic of the site estimated from Google Earth model. Soil composition based on borehole log. Due to uncertainty of geological composition between the two boreholes the hatching was not extended.

The acquifer seems to be confined. Evidence supporting this description are:the clay nature of the soil above the acquifer (Figure1), the mudstone below the Sherwood Sandstone that forms an impermeable base ((Allen et al., 1997)). This should cause the water to settle at a higher level that the acquitard ((Younger, 2007)). This was measured approximately 6.5m above the aquifer level. The Cod Beck and the acquifer seem to be separate by a clay layer of significant thickness (>20m). The thickness and consistency of this impearmeable layer is confirmed by the log of another borehole (BGS ID: 114659 : BGS Reference: SE47NW74) located few hundred meters north. This condition supported the assumption that the acquifer and the river belong to two separate hydraulic systems.

Data and discussion.

Different tests were carried at the site. An overview of each one is given in the following paragraphs. Collected data is included in the Appendix. The basic assumptions for the acquifer are:

Step test. A step test analysis was carried out giving drawdown (s_w) values over pumping rate (Q). Results are shown in Figure 3. By visual inspection of the plot the maximum yield was initially estimated around 43 m^3/hr. Estimating specific capacity (S_c) within the range 0-43 m^3/hr gave a value of 90 m^2/hr that should be used as a reference but most likely not obtained in practice. This value was than used to estimate theoretical drawdown for the proposed pumping rate giving the following results: 1m

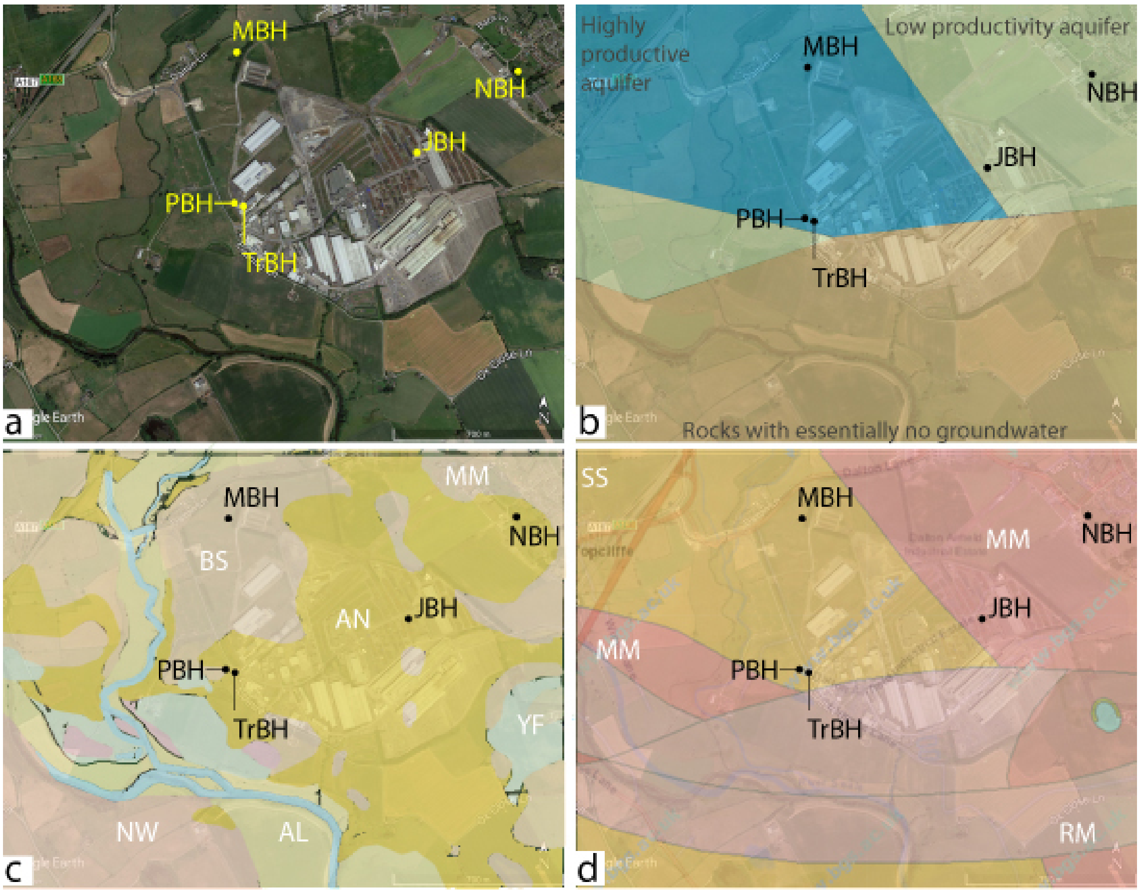

Figure 2: Site map (a) with the borehole location: production borehole (PBH), trial borehole (TrBH), Moorland borehole (MBH), Jenkins (JBH) and new proposed borehole (NBH). Aquifer location (b). Superficial deposits (c): Alne Glaciolacustrine Formation (AN), Alluvium (AL), Newby Wlske (NW), Vale of York fomation (YF), Breighton Sand formation (BS). Bedrock formation (d): sherwood sandstone (SS), mercia mudstone (MM), redcar mudstone (RM). Sources: Google Earth and the British Geological Society.

(91 m$^{\$}$/hr), 0.7m (1500 m$^{\$}$/day) and 0.5m (400,000m$^{\$}$/year).

The well loss was evaluated using the equation $s_w/Q = B+CQ$. Values for B and C where obtained by linear regression (Figure 3 b). The well loss coefficient was estimated at 0.18 min^2/m^5. When compared to values given by Walton [1962] the well can be described as properly designed and developed ($C < 0.5$min^2/m^5).

Lastly the pumping efficiency was calculated as: Efficiency=BQ/s_w where B is given by the equation of the linear fit of the plot specific capacity / pumping rate (Figure 3). Optimum pumping rate (efficiency 0.7) was estimated around 60 m^3/hr. It should be noticed that specific capacity is a theoretical value for "steady drawdown" and just an approximation of what would happen in reality.

Pumping data for constant rate. A constant pumping test was carried between 10.00 am of 8/7/1996 for four days with a constant discharge (Q) rate of 2272.32 m^3/day. Drawdown levels over log-time for different borehole at a distance (r) are shown in Figure 4. For JBHe r =74 7m, for MBH =742 m for TrBH= 15m. It may be

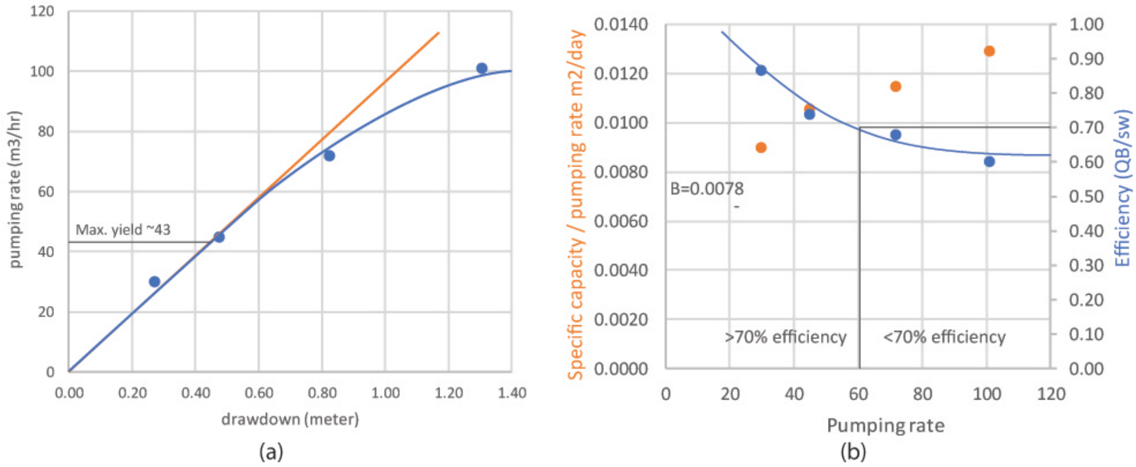

Figure 3: Diagrams showing pumping rate over drawdown (a), specific capacity over drawdown (b) with linear regression (orange) and efficiency calculated as $Q * B/s_w$ (blue) where B is given by the intercept of diagram in the centre (0.00779).

observed that after approximately 1 day, the rate drawdown / log-time becomes linear and therefore the slope could be estimated using Cooper-Jacob Method because all the assumptinos were met: aquifer has infinite areal extent, was assumed to be homogeneus, isotropic and of uniform thickness, the well was considered to be fully penetrating with water flow horizontal, drawdown curves suggest that is non leaky and confined, water was considered to be released instantaneously,diameter is very small, values of u are small (the highest being 7.36 10^{-6}).Transmittivity (T) and storarivity (S) were calculated as:

$$T = 2.3Q/4\pi\Delta s \tag{1}$$

$$S = (2.25Tt_0)/r^2 \tag{2}$$

Δs was estimated at 0.703 m/day using the C coefficient of the linear fit shown in Figure 4. Time of drawdown = 0 (t0) were estimated using intercept with x values > 0 and therefore time above 1 day. Results are shown in Table **??**. An average value for T was found to be 600 m^2/day and for S 0.0008 at JBH and 0.0004 at MBH .

Pumping data for recovery test. Measurement during the recovery period after the constant test were recorded. Values of residual drowdown over time ratio (log t'/t) are shown in Figure 5. Using equation 1 transmittivity was estimated at 699 m^2/day where Δs in this case is s' and given by the slope of the curve (0.60 see Figure5). This value seems coherent with T calculated from constant drowdown test. (600 m^2/day).

Pumping data for distance test A distance test was also performed in the same period (10:00 am 8/7/1996 to 10:00 am 12/7/1996). Drawdown at different boreholes were measured at the beginning and at the end of the test. The zone of influence was calculated using the equation:

$$h_1 - h_2 = \frac{Q}{2\pi T} ln \frac{r_1}{r_2} \tag{3}$$

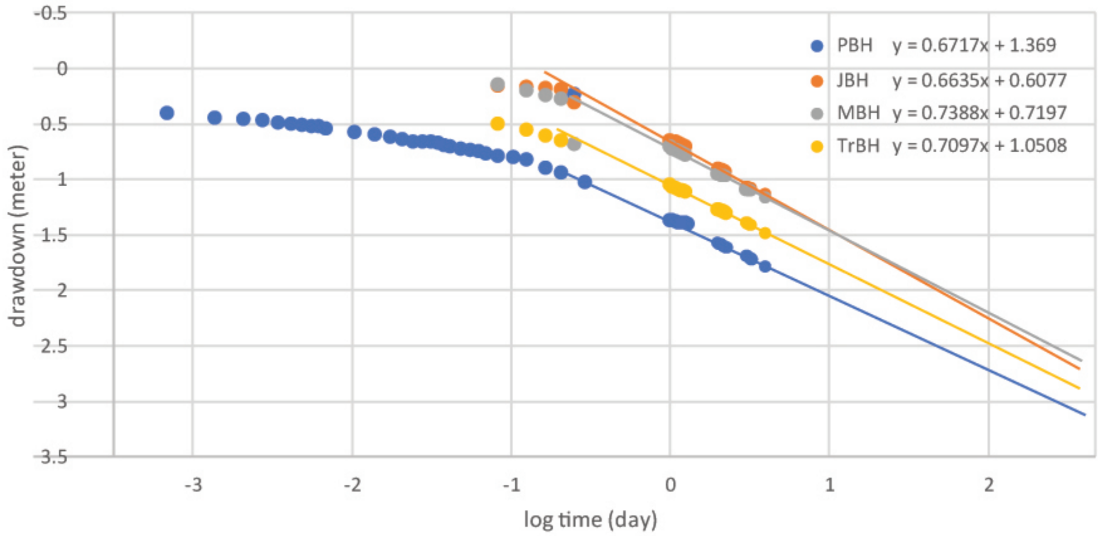

Figure 4: Drawdown in meter over log-time (minutes) during constant rate test for the production borehole (PBH), trial borehole (TrBH), Jenkin's borehole (JBH) and Moorside (MBH).

Estimates using data from JBH and MBH generated radius of 6600m and 6900m respectively. This number may only have a theoretical value since the geology of the site changes significantly within this distance.

Proposed borehole specifications

Acquifer characteristics. The new proposed borehole (NBH) is located North-East from PBH. The geology of the site should have many similarities with the condition at JBH (Figure 1). The superficial layer compromises of Alne Glaciolacustrine Formation. Thickness of the superficial layerwas assumed similar to JBH an approximately 20m. The acquifer layer consist of soft broken sandstone and mari beds (Figure 2. Similarly to JBH, this location belongs to a low productivity acquifer ((Allen et al., 1997)) but unlike JBH which sits at the edge of it, the NBH is located approximately at 350m from the productive zone. Initial estimate of thickness based on literature ((Allen et al., 1997)p.173) could be made at 40-80m. Data from existing boreholes in the same geological area (SE47NW108 and 109) report water struck at around 102m from datum and rest water at completion at 4m.This seem to suggest that the acquifer is confined. Additional tests are needed to better characterise the acquifer in terms of confinement, leakage and thickness.

Well Length: from available geological data the acquifer layer (soft broken sandstone and mari beds) begins around 20m of depth. The first estimate for NBH length was estimated as:

$$L = 20 + 0.8(40 \sim 80) = 52 \sim 84m \tag{4}$$

Well Diameter: Clear extraction for the new borehole rates were not given. Using a similar range to PBH a nominal size pump bowl of 152mm and casing at 254 ID

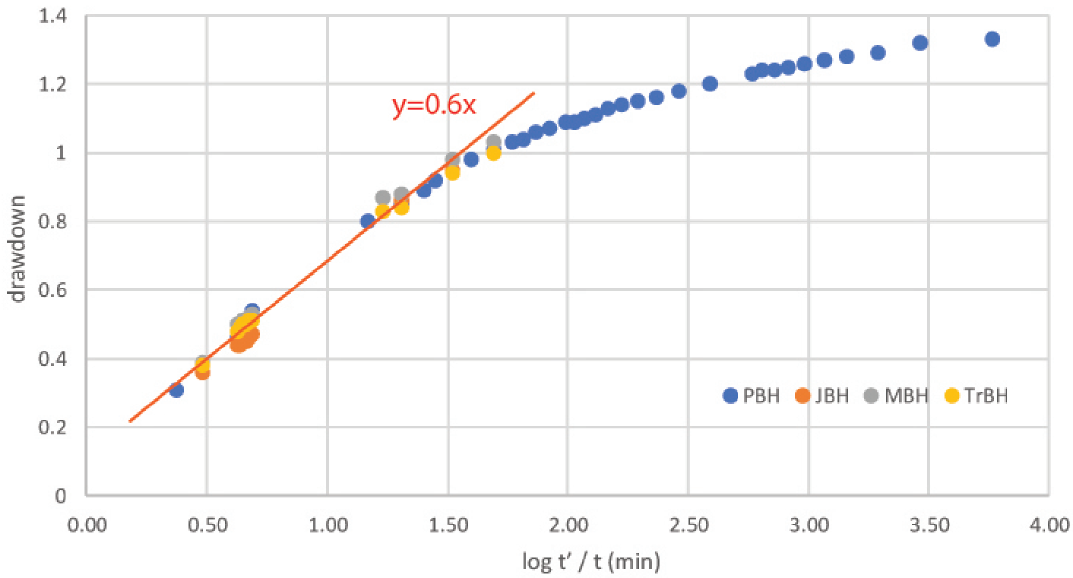

Figure 5: residual drowndown over time ratio during the recovery test for production borehole (PBH), trial borehole (TrBH), Jenkin's borehole (JBH) and Moorside (MBH). Time ratio was calculated as log of time since pumping test started(t) / time since pumping test stopped (t')

could be set as a first reference value ((Driscoll, 1987)). This would imply a drilling bit of 311mm. This first measurement should be revised once extraction rate and well efficiency are clearer.

Materials: the proposed material for the casing is steel according to BS 879 Part 1, this would guarantee better performance than cheaper solutions in a longer time-span. The upper casing should extend beyond the superficial layer and it is estimated 40m long. This choice is also supported by the fact that the surrounding boreholes use the same technology.

Well screen and gravel pack. The length and position of the screening should be determined after a conceptual model of the acquifer condition is developed. Thickness, particle sizing and heterogeneity data will be of Particular importance in the design of the screening. A stainless steel wire-wound screen could help in maximising the yield (Misstear et al., 2017). The slot width will be determined after a quantification of the grain size of the acquifer. The chosen size should retain 40% of the particles. Given the fine grain of the acquifer an artificial gravel pack seems to be required.

Drilling method. Given characteristics of the bedrock (soft broken sandstone and mari bed) a cable percussion drilling technicque could be enough and provide the most cost efficient solution. Otherwise rotary drilling could be a safer and more expensive option.

Additional required tests. During drilling a well-log describing type of forma-

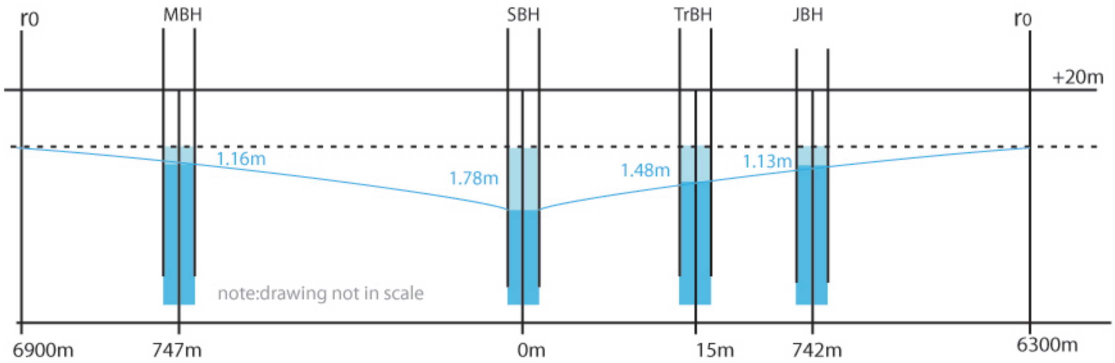

Figure 6: Diagram showing drawdown at different boreholes after the distance test. Radius of influence was estimated along the PBH-JBH transect

tion encountered at different depths. The A water quality test on dissolved ions, pH,alkalinity,conductivity should be done. Additional test may be considered based on the use of the water.To determine the characteristics of the acquifer layer a sieve analysis test is recommended. This will be useful to determine screening slot dimension.To determine key characteristics of the acquifer the usual suite of test is recommended: step, constant discharge, recovery and measurement at surrounding boreholes.

Conclusion

1. Regarding the existing Simpson's Sausage Borehole:
   (a) The acquifer transmittivity was estimated at 640-690 m^2/day.
   (b) Specific capacity at 90 m^3/hr with estimated drawdown at 1m (91 m^3/hr), 0.7m (1500 m^3/day) and 0.5m (400,000m^3/year).
   (c) Maximum yield estimated at 43 m^3 /hr therefore not able to sustain the proposed discharge for daily average (91 m^3/hr) and (1500 m^3/day) but able to sustain yearly average discharge (400,000m^3/year).
   (d) Optimum pumping rate (efficiency 0.7) was estimated around 60 m^3/hr.
   (e) With the given geological information the acquifer seems not to be hydraulically connected with the river Cod Beck and it should not cause environmental impact.
2. Regarding the new proposed borehole:
   (a) The proposed site is situated above a minor acquifer that could produce water. Yield and characteristics of the borehole cannot be determined with the given data.
   (b) A first set of specification for the borehole was suggested: depth of 52-84m, internal diameter of 200mm,steel casing in the first 40m, stainless steel wire-wound screening with gravel pack in the lower part. These specification would

need to be revised as soon as new information is obtained from additional tests.

(c) Cable percussion drilling may be used as a more economical solution to rotary drilling. It is advised to gather additional information from contractors that have worked on the same geological formation.

(d) A set of test to better determine hydrology, acquifer characteristics and water quality was suggested: well-log, step test, constant discharge test, recovery test, distance test, water quality test.

Table 1: Key parameters describing the wells calculated from different test and using Cooper-Jacob approximation.

		Constant rate test			
		PBH	JBH	MBH	TrBH
ds	m/day	0.672	0.663	0.739	0.701
Q	m3/day	2272	2272	2272	2272
r	m	0.1	747	742	15
t0	day	0.04	0.327	0.168	0.167
T	m2/day	619	627	563	593
T_avg	m2/day		600		
S		5198	0.000827	0.000385	0.990
		Drawdown recovery data			
C factor		0.58	0.66	0.60	0.56
C_avg			0.60		
T		713	634	698	750
T_avg			699		
		Distance drawdown			
r_0	m			6634	6983
		Step test			
		sw	Q m3/hr	Sc	sw/Q
step 1		0.27	30	111.1	0.0090
step 2		0.475	45	94.7	0.0106
step 3		0.825	72	87.3	0.0115
step 4		1.305	101	77.4	0.0129

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