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Performance Evaluation and Characteristics of Selected Tube Wells in the Coastal Alluvium Aquifer, Selangor

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ABSTRACT

Alluvial aquifers can be found in most of the coastal areas of Peninsular Malaysia. Seven tube wells located in such aquifers in the west coast of Selangor state had their performance evaluated by carrying-out step drawdown tests. The performance of these wells was evaluated in terms of aquifer loss, well loss, specific capacity and well efficiency. The aquifer loss coefficient and well loss coefficient were found to be in the range of 0.0198 hrm^{-2} to 0.4014 hrm^{-2} and from 0.0001 hr^2m^{-5} to 0.0410 hr^2m^{-5}, respectively. The drawdown in tube wells TW1 and TW7 is mainly influenced by well loss component as compared to the aquifer loss component, while in tube wells TW2, TW3, TW4, and TW5, the drawdown is mainly influenced by aquifer loss component. The drawdown in tube well TW6 is influenced by aquifer loss component at a low discharge rate, but at high discharge rate, it is influenced by well loss component. The specific capacity and efficiency of the tested tube wells varied from 1.329 m^2hr^{-1} to 40.166 m^2hr^{-1}, and from 11% to 96%, respectively. Tube wells TW2 and TW4 are categorized as high productive wells, while tube wells TW1, TW3, TW5 and TW7 are categorized as moderate productive wells and tube well TW6 as low productive well.

Keywords: Step drawdown test, well loss, aquifer loss, specific capacity, well efficiency

INTRODUCTION

In Malaysia, tube wells are used widely for various purposes as in agriculture and for domestic and industrial uses. Heng (2004) reported that there are about 2,466 wells drilled throughout Peninsular Malaysia starting from 1983 with a total yield of 552,000 m^3day^{-1}. Since the last century, extraction of groundwater in Malaysia has

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increased because of many factors such as surface water depletion due to drought and increasing water demands for the domestic, agricultural and industrial sectors (Heng, 2004). Kelantan is one of the states in Malaysia which is still using groundwater as a major source for domestic water supply (Samsudin *et al.*, 2008), with a total consumption of 146 Mld^{-1} in 2010 abstracted from 94 production wells at 14 well fields and treated by 7 groundwater treatment plants (Ismail *et al.*, 2011). All the production wells should be monitored and maintained each year in order to make sure that each well can produce enough quantity of water according to its design capacity.

Tube wells for water production are designed based on soil lithology and information obtained from exploration well during site investigation. When tube well has been constructed and developed, its performance evaluation is carried out. As mentioned by Shekhar (2006), groundwater users are always concerned with the performance of well structure and the relationship between discharge and drawdown at the pumping wells. Step drawdown test is widely used to identify well behaviour, determine well loss and calculate well efficiency (Kawechi, 1995). The drawdown inside the pumping well is influenced by aquifer loss component, BQ and well loss component, CQ^n, with n as the well loss exponent (Todd & Mays, 2005; Mohammed & Huat, 2004; Rahman & Dhar, 1997; Sheahan, 1971). The values of aquifer loss coefficient, B, and well loss coefficient, C (Mishra & Sahay, 2011), as well as reliable yields estimation of water well (Misstear & Beeson, 2000) are important for a successful modelling and proper management of groundwater resources.

Drawdown that occurs at the face of the well is known as aquifer loss, whereas drawdown that occurs as water moves through the well screen and inside the well to the pump suction area is known as well loss (Mohammed & Huat, 2004). According to Todd and Mays (2005), the coefficient of well loss, C, is controlled by its radius, development and condition. The relationship between well loss coefficient, C, and well conditions is shown in Table 1, while the relationship between specific capacity and types of well productivity is shown in Table 2. Therefore, this paper aimed at evaluating tube well performance and identifying its characteristics by evaluating the parameters of well loss, aquifer loss, specific capacity, and well efficiency.

MATERIALS AND METHODS

The study area is located in the coastal area of Selangor involving Sabak Bernam, Kuala Selangor and Kuala Langat districts as shown in Fig.1. The study area is covered with alluvium sediments which consist of peat soil, silt, sand and gravel. The wells were developed by the Department of Mineral and Geoscience Malaysia (DMGM) by using rotary mud drilling machine (BOMAG & Holy Machine Model CD80). The wells were drilled up to bedrock layer, with depths ranging between 30 m to 60 m. All tube wells use gravel pack in the sizes of 3 mm to 6 mm, except for tube wells TW5 and TW6 which use gravel pack in sizes of 3 mm to 4 mm. The diameter of the tube well casing varies between 200 mm and 250 mm. PVC material was chosen as the casing and screen at most of the developed wells, while TW5 and TW6 used mild steel and stainless steel as their casing and screen material, respectively. Further information on the tube wells is given in Table 3.

TABLE 1
Relationship between well loss coefficient, C, to well condition (Walton, 1962)

Well loss coefficient, C (hr^2m^{-5})	Well Conditions
C< 0.0001	Great – Well is designed and developed properly
0.0001< C < 0.0002	Good – Mild deterioration due to clogging
0.0002 < C < 0.0011	Fair to Poor – Severe deterioration due to clogging
C > 0.0011	Bad – Difficult to restore well to original capacity

TABLE 2
Specific capacities values and well productivity classification (Şen, 1995)

Specific Capacity, Sc ($m^3hr^{-1}m^{-1}$)	Well Productivity
C > 18	High
18 > C > 1.8	Moderate
1.8> C > 0.18	Low
0.18 > C > 0.018	Very Low
0.018 > C	Negligible

Fig.1: Locations of the tube wells at the coastal area of Selangor
(Selangor Map, 2012)

TABLE 3
A detailed description of the tube wells studied

Well Name	District	Coordinate	Well Depth (m)	Gravel Pack Size (mm)	Water Table Depth (m b.g.l)	Casing Diameter (mm)	Screen Diameter (mm)	Screen Location (m)	Screen Length (m)	Aquifer Thickness (m)	Drilling Method*	Year of Testing
TW 1	Sabak Bernam	412300 N 348600 E	48	3-6	0.07	203	203	42-48	6	15	1	2003
TW 2	Kuala Selangor	377100 N 372500 E	40	3-6	0.47	200	155	28-40	12	27	1	2000
TW 3	Kuala Selangor	377500 N 380300 E	40	3-6	2.35	200	155	28-40	12	30	1	2000
TW 4	Kuala Langat	328800 N 378800 E	57	3-6	4.97	254	254	44-56	12	15	1	2005
TW 5	Kuala Langat	318033 N 403740 E	27.8	3-4	1.66	250	250	11.5-14.5, 18-21, 24-27	9	12	2	2009
TW 6	Kuala Langat	318687 N 402942 E	31.8	3-4	0.95	250	250	21-30	9	16	2	2009
TW 7	Kuala Langat	312200 N 395100 E	60	3-6	1.78	200	150	23-60	37	38	1	1995

*1: Rotary Mud Drilling (Model BOMAG), 2: Rotary Mud Drilling (Model Holy Machine CD80)
m.b.g.l- meter below ground level, N-north, E-east

Most of the tube wells were developed for the purpose of groundwater resources potential study for future groundwater development plan. Some of the water wells were constructed for the emergency plan or as an alternative source of water if forest fire happens since most of the study areas are covered with peat soil. Step drawdown test was executed between the year 1996 and 2009 and this test was carried out immediately after well construction had been completed. Submersible pumps were used to pump the water from the tube wells and the discharge rates were measured with a weir tank. The valve was installed to control and vary the discharge rates.

Step drawdown test is a single well test where the water is pumped at a low constant discharge rate until the drawdown within the well stabilizes. The lowest discharge rate is known as step 1 and the test is repeated by increasing the rate of pumping to the second pumping rate (step 2) until the drawdown within the well stabilizes once more, as in step 1 (Krusseman & de Rider, 1994). Mahajan (1989) mentioned that step drawdown tests are started at a low step; for instance, 25% of the designed capacity and increased up to 50%, 70%, 100% and 125% of the designed capacity, depending on the number of steps chosen. In this study, every step was designed with four to five steps with each step period between 1 and 2 hours. The time, water level inside the tube well, and discharge data were taken during the test. Data on water level data were taken by using an automatic water level transducer or manually by using a water level indicator. Water level data were taken every 0.5 minutes for the first 10 minutes and every 5 minutes thereafter.

The general equation for calculating total drawdown in the pumping well is given by Rorabaugh (1953), as in Equation 1. In order to solve this equation, Jacob (1947) proposed a graphical method by assuming the power of well loss, *n*, as equals to 2. Under this assumption, Equation 1 can be rewritten as Equation 2. Bierschenk (1964) mentioned that the values of *B* and *C* from Equation 2 could be obtained from the plot of specific drawdown, $\frac{S_w}{Q}$ (hrm^{-2}) against discharge rate (m^3hr^{-1}). Specific drawdown is defined as the ratio of drawdown to the discharge rate. From the graph, *B* is the intercept of y-axis and *C* is the slope of the best straight line. Equation 2 can also be applied to the confined, unconfined and leaky aquifer types.

$$S_w = BQ + CQ^n \tag{1}$$

$$\frac{S_w}{Q} = B + CQ \tag{2}$$

Where *S* is drawdown in pumping well (m), *Q* is discharge rate (m^3hr^{-1}), *B* is aquifer loss coefficient (hrm^{-2}), and *C* is well loss coefficient (hr^2m^{-5}). Rorabaugh (1953) argued that the power of well loss exponent is not always equal to 2, but its values are varying between 1.5 and 3.5, depending on its discharge rate. However, well loss exponent equals to 2 as proposed by Jacob is still accepted and commonly used (Todd & Mays, 2005; Bierschenk, 1964; Skinner, 1988; Ramey, 1982, as cited in Krusseman & de Rider, 1994). In the present paper, time-drawdown data were analyzed by using the regression technique, as suggested by Bierschenk (1964), as well as the trend line fitting polynomial plot (Shekhar, 2006) to obtain the values of *B* and *C*.

Well efficiency is defined as the ratio between theoretical drawdown and actual drawdown from step drawdown test and it was calculated based on Equation 3 (Todd & Mays, 2005):

$$\eta_w = \frac{BQ}{BQ + CQ^2} \tag{3}$$

Where η_w is well efficiency (%), BQ is aquifer loss, (m) and CQ^2 is well loss, (m). The specific capacity of the tested well was also calculated by dividing the discharge rate with its corresponding drawdown (Mohammed & Huat, 2004), as follows:

$$S_c = \frac{Q}{S} \tag{4}$$

Where S_c is specific capacity (m^2hr^{-1}), Q is discharge rate (m^3hr^{-1}) and S is drawdown inside the pumping well (m).

RESULTS AND DISCUSSION

Fig.2a shows the regression equation and the plot of specific drawdown versus discharge rate from step drawdown test. The coefficient of determination, R^2, showed a strong relationship between drawdown and discharge rate at TW1, TW2, TW5, TW6 and TW7, with R^2 greater than 0.8. Tube well TW4 showed a moderate relationship between drawdown and discharge rate, with R^2 equals to 0.5. The lowest coefficient of determination ($R^2 = 0.1$) is recorded for tube well TW3 due to the large variation between specific drawdown and discharge rate in each step. This implied that the plot of specific drawdown and discharge data for tube well TW3 and TW4 did not show a linear trend. Thus, the trend line fitting polynomial plot (Shekhar, 2006) was applied to the drawdown-discharge data from step drawdown test for tube wells TW3 and TW4 (see Fig.2b). The polynomial plot approach shows approximation of Rorabaugh general equation with well loss exponent equals to 2 and the equation formed shows a strong relationship (R^2=0.9) between drawdown and discharge. The aquifer loss coefficient, B, of the tested wells ranges from 0.0198 (in TW2) to 0.4014 (in TW6), while the well loss coefficient, C, ranges from 0.0001 (in TW2) to 0.0410 (in TW6). All the tube wells have the value of aquifer loss coefficient greater than the value of well loss coefficient. Based on Table 1, tube well TW2 is properly designed and developed since the value of well loss coefficient is 0.0001 hr^2m^{-5}.

Fig.3 exhibits the comparison between the observed and predicted drawdown in every step for each well. The observed drawdown (taken during execution of step drawdown test) was compared to the predicted drawdown, which is calculated from drawdown discharge relationship as shown in Equation 1, based on the computed values of aquifer loss and well loss. The plots were done to verify Equation 1 between field data and model developed (drawdown-discharge equation). In general, the results showed good concordance between the observed and predicted drawdown, especially at the low discharge rate (in the first and second steps). However, tube well TW3 showed a slight difference between the observed and predicted drawdown.

The comparison between aquifer loss and well loss in each step is shown in Fig.4. From this comparison, the tested tube wells can be categorized into three groups. The first group is the tube wells with the well loss greater than the aquifer loss in every step. The tube wells that fall in the first group are TW1 and TW7. The second group of the tube wells is the tube wells with the aquifer loss greater than well loss in every step. These tube wells are TW2, TW3, TW4 and TW5. The third group of the tube well is the tube well with the aquifer loss greater than well loss at the lower discharge rate, but at the higher discharge rate, the well loss is greater than aquifer loss. Only TW6 falls in the third tube well group.

The relationship between specific capacity and discharge rate at each tube well is presented in Fig.5. Tube well TW2 has the highest value of specific capacity. The resulting drawdown in this tube well is low as compared to the volume of groundwater abstracted. Tube well TW6 has

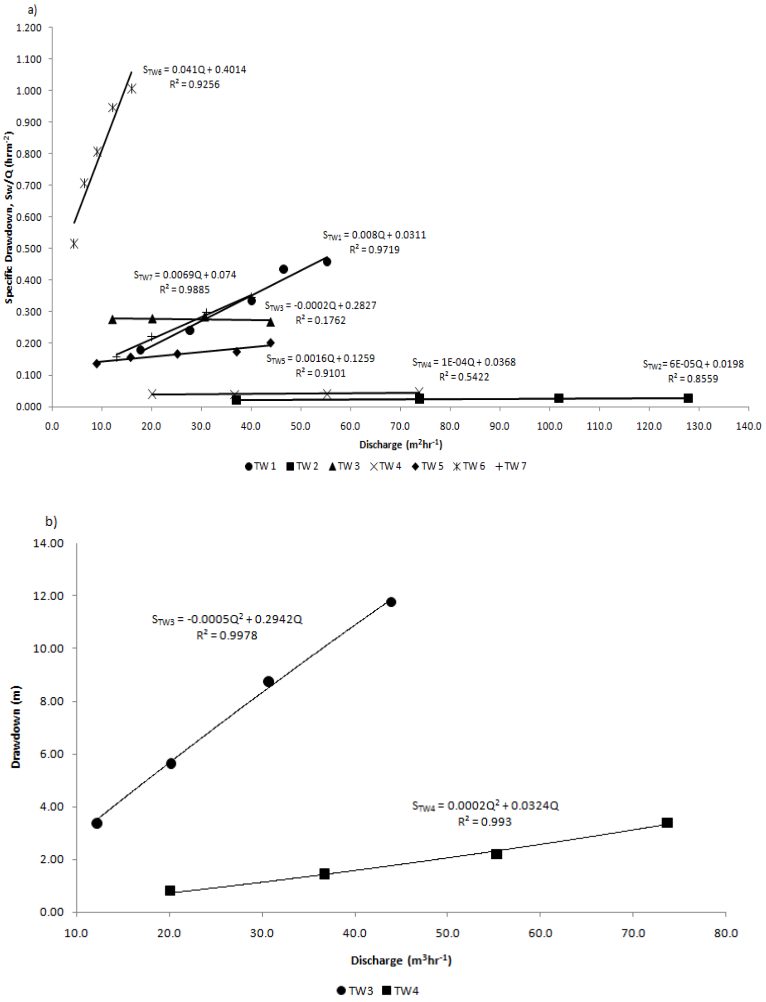

Fig.2: a) Regression equation and plot of specific drawdown versus discharge rate; b) Polynomial plot of drawdown and discharge rate (for TW3 and TW4) from step drawdown pumping test to determine aquifer loss coefficient, B and well loss coefficient, C.

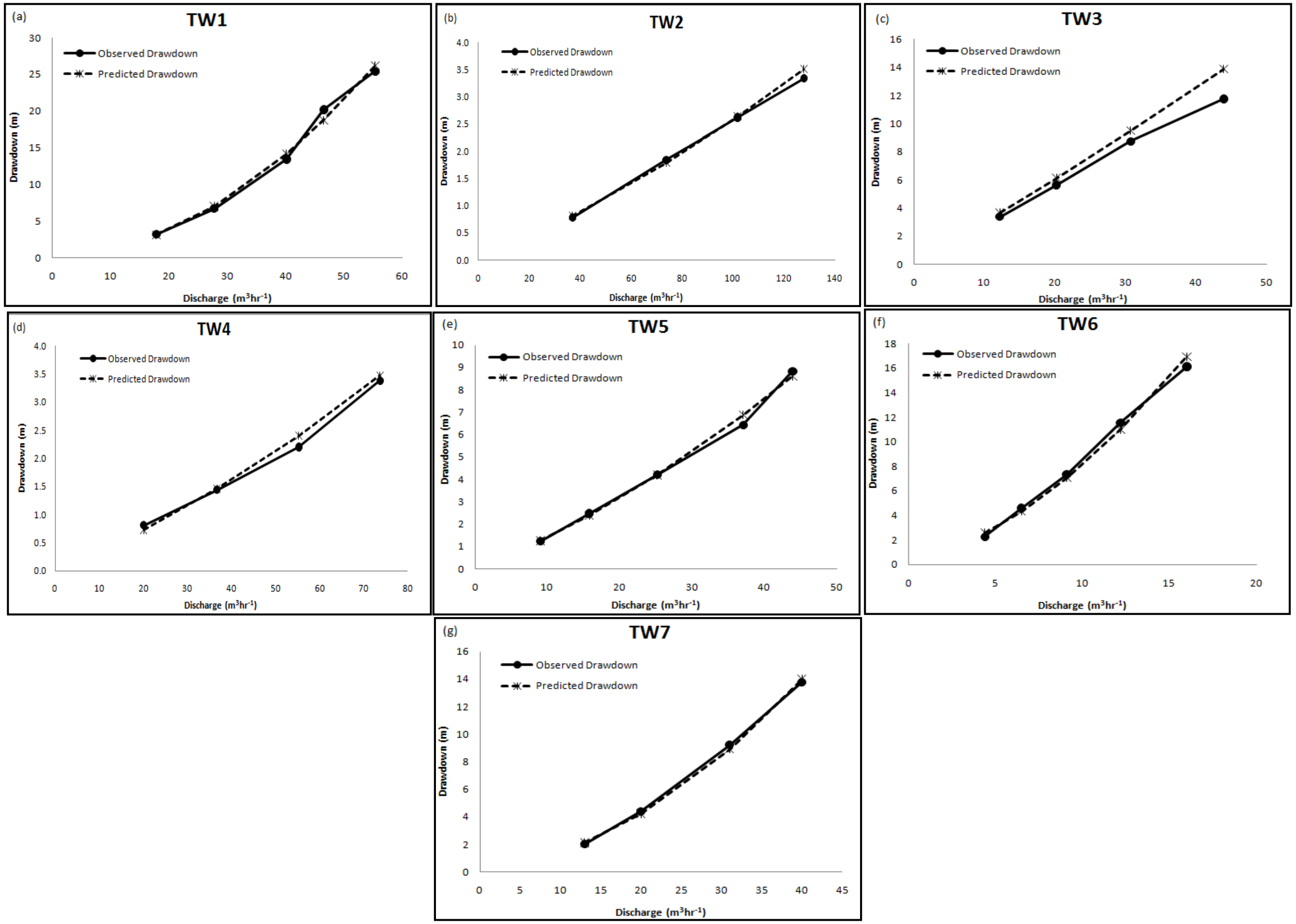

Fig.3: A comparison between the observed and predicted drawdown at: (a) TW1, (b) TW2, (c) TW3, (d) TW4, (e) TW5, (f) TW6, and (g) TW7

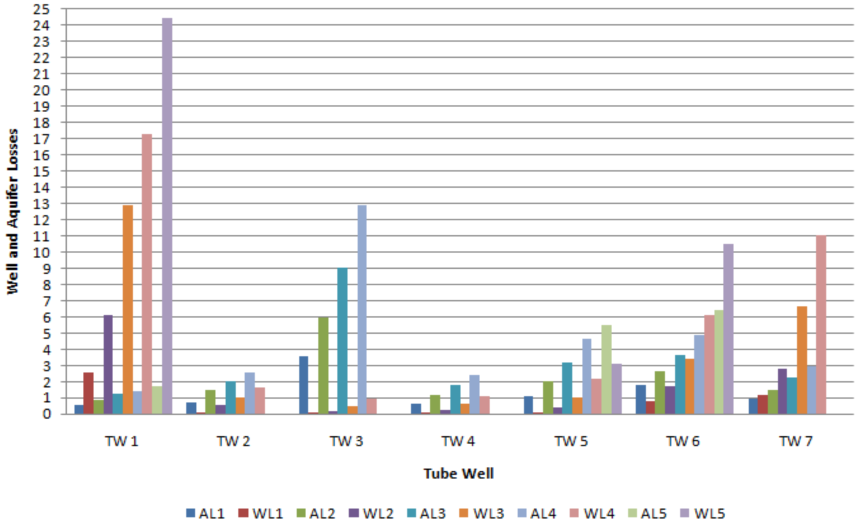

Fig.4: A comparison between aquifer loss and well loss for each step in step drawdown test (AL1 is aquifer loss from step 1, WL1 is the well loss for step 1, and so on)

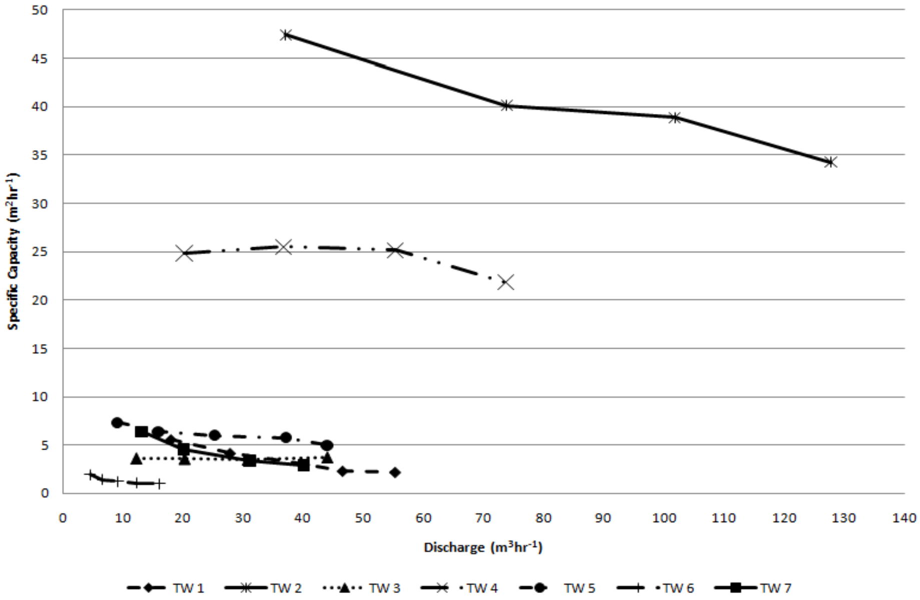

Fig.5: The plot of specific capacity versus discharge rate from step drawdown test

the lowest specific capacity due to the large amount of drawdown resulting from the increasing volume of groundwater withdrawal. Based on the specific capacity classification (see Table 2), according to Şen (1995), tube wells TW2 and TW4 are categorized as high productive wells with the specific capacity greater than 18 m^2hr^{-1}. Meanwhile, tube wells TW1, TW3, TW5 and TW7 are categorized as moderate productive tube wells, with the specific capacity ranging between 1.8 and 18 m^2hr^{-1}. Tube well TW6 is categorized as a low productive tube well, with the specific capacity having less than 1.8 m^2hr^{-1}.

Fig.6 shows the well efficiency of each step for every tube well. The results show that the efficiency of tube wells decreases as the discharge increases. The most efficient tube well is TW3, with an average efficiency of 96%, whereas the least efficient tube well is TW1, with an average well efficiency of 11%. TW1 has the lowest efficiency due to the poor design of well screen, particularly in terms of screen length and screen diameter, apart from the fact that it might be influenced by poor aquifer potential in that area. Nevertheless, the most efficient tube well does not mean that it is the most productive tube well. This is because well efficiency measures how much losses influence the drawdown of the pumping well. If there is no well loss and the drawdown in the pumping well is only influenced by aquifer loss, the well is the most efficient. However, this ideal condition is difficult to be achieved due to improper well construction and installation, pump factor, improper design of well screen and unsuitable screen length. The productivity of tube well is also influenced by the hydraulic characteristics of the aquifer (transmissivity and storage coefficient), as well as the effect of drawdown on pumping rate (types of aquifer either unconfined or confined aquifer). A detailed result of the step drawdown test is summarized in Table 4.

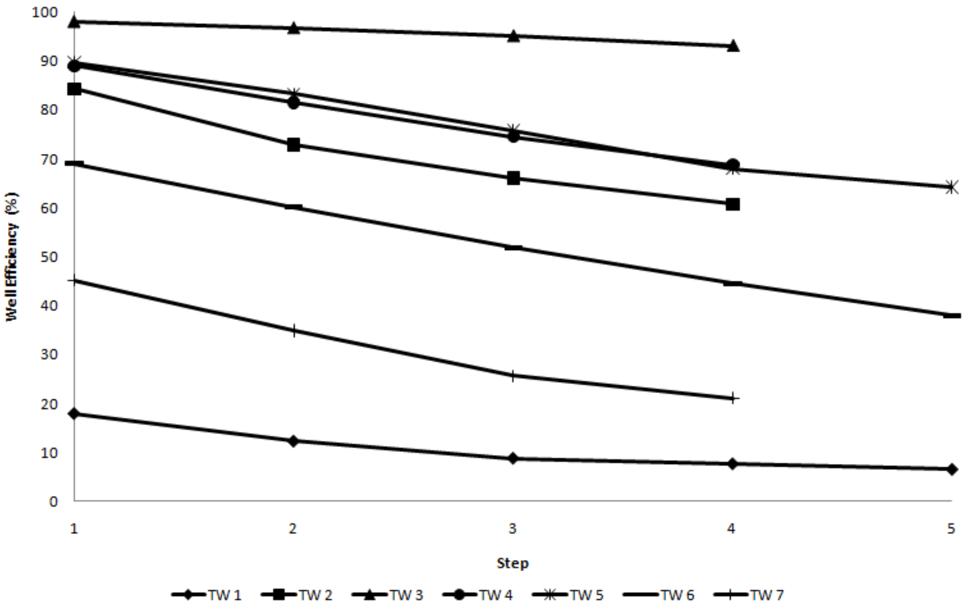

Fig.6: Well efficiency of each tube well in each step

TABLE 4

Step drawdown test result and comparison in each step

Characteristics		Tube Well						
		TW 1	TW 2	TW 3	TW 4	TW 5	TW 6	TW 7
Duration/step (hr)		1.5	2	2	1.5	1.5	1.5	1
	B	0.0311	0.0198	0.2942	0.0324	0.1259	0.4014	0.0740
	C	0.0080	0.0001	0.0005	0.0002	0.0016	0.0410	0.0069
Step 1	Q	17.8	37.0	12.2	20.1	9.0	4.4	13.0
	Sw	3.20	0.78	3.37	0.81	1.23	2.27	2.03
	Q/Sw	5.563	47.436	3.620	24.815	7.317	1.938	6.404
	Sw/Q	0.180	0.021	0.276	0.040	0.137	0.516	0.156
	BQ	0.55358	0.7326	3.5892	0.6512	1.1331	1.76616	0.962
	CQ^2	2.5347	0.1369	0.0744	0.0808	0.1296	0.7938	1.1661
	E	17.93	84.26	97.97	88.96	89.74	68.99	45.20
Step 2	Q	27.7	73.8	20.2	36.7	15.8	6.5	20
	Sw	6.67	1.84	5.63	1.44	2.47	4.59	4.41
	Q/Sw	4.153	40.109	3.588	25.486	6.397	1.416	4.535
	Sw/Q	0.241	0.025	0.279	0.039	0.156	0.706	0.221
	BQ	0.8615	1.4612	5.9428	1.1891	1.9892	2.6091	1.4800
	CQ^2	6.1383	0.5446	0.2040	0.2694	0.3994	1.7323	2.7600
	E	12.31	72.85	96.68	81.53	83.28	60.10	34.91
Step 3	Q	40.1	101.8	30.7	55.3	25.2	9.1	31.0
	Sw	13.42	2.62	8.75	2.20	4.20	7.34	9.22
	Q/Sw	2.988	38.855	3.509	25.136	6.000	1.240	3.362
	Sw/Q	0.335	0.026	0.285	0.040	0.167	0.807	0.297
	BQ	1.24711	2.01564	9.0319	1.7917	3.17268	3.65274	2.294
	CQ^2	12.86408	1.036324	0.4712	0.6116	1.01606	3.39521	6.6309
	E3	8.84	66.04	95.04	74.55	75.74	51.83	25.70
Step 4	Q	46.5	127.8	43.9	73.7	37.1	12.2	40.0
	Sw	20.18	3.34	11.77	3.38	6.43	11.54	13.79
	Q/Sw	2.304	38.263	3.730	21.805	5.770	1.057	2.901
	Sw/Q	0.434	0.026	0.268	0.046	0.173	0.946	0.345
	BQ	1.4462	2.5304	12.9154	2.3879	4.6709	4.8971	2.9600
	CQ^2	17.2980	1.6333	0.9636	1.0863	2.2023	6.1024	11.0400
	E	7.72	60.77	93.06	68.73	67.96	44.52	21.14
Step 5	Q	55.3	NA	NA	NA	43.9	16.0	NA
	Sw	25.39	NA	NA	NA	8.83	16.10	NA
	Q/Sw	2.178	NA	NA	NA	4.972	0.994	NA
	Sw/Q	0.459	NA	NA	NA	0.201	1.006	NA
	BQ	1.7198	NA	NA	NA	5.5270	6.4224	NA
	CQ^2	24.4647	NA	NA	NA	3.0835	10.4960	NA
	E (%)	6.57	NA	NA	NA	64.19	37.96	NA
	∑(Q/Sw)	3.4372	40.1658	3.6118	24.3105	6.0912	1.3290	4.3005
	∑E	10.67	70.98	95.69	78.44	76.18	57.68	31.74

NA: Not available, B: Aquifer loss coefficient (hrm^{-2}), C: Well loss coefficient (hr^2m^{-5}), Q: Discharge rate (m^3hr^{-1}), Sw: Drawdown (m), Q/Sw: Specific drawdown (hrm^{-2}), Sw/Q: Specific capacity (m^2hr^{-1}), BQ: Aquifer loss (m), BQ2: Well loss (m), ∑ (Q/Sw): Average specific capacity (m^2hr^{-1}), ∑E: Average well efficiency (%)

CONCLUSION AND RECOMMENDATIONS

The performance of seven tube wells located in the Selangor coastal area in alluvium aquifer was evaluated in this study. Step drawdown test was used to assess the tube wells' performance and the data were analysed by using the graphical method and regression technique. Based on the results of this study, it can be concluded that:

1. The tested tube wells have the value of aquifer loss coefficients in the range of 0.0198 hrm^{-2} to 0.4014 hrm^{-2}, while well loss coefficients are in the range of 0.0001 hr^2m^{-5} to 0.0410 hr^2m^{-5}. All the tube wells have the value of aquifer loss coefficient greater than the value of well loss coefficient.
2. The drawdown in TW1 and TW7 are mainly influenced by well loss component as compared to aquifer loss component. The drawdown in TW2, TW3, TW4, and TW5 are mainly influenced by aquifer loss component compared to well loss component. Aquifer loss component is dominant in TW6 at the lower discharge rate but at the higher discharge rate, the drawdown is influenced by well loss component.
3. TW2 and TW4 are categorized as high productive wells with specific capacity greater than 18 m^2hr^{-1}. Meanwhile, TW1, TW3, TW5 and TW7 are categorized as moderate productive tube wells, with the specific capacity ranging between 1.8 and 18 m^2hr^{-1}. Only TW6 is categorized as a low productive tube well, with the specific capacity less than 1.8 m^2hr^{-1}.
4. The most efficient tube well in Kuala Selangor is TW3, with the average efficiency of 96%, while TW1 in Sabak Bernam is the least efficient tube well, with the average efficiency of 11%.

Continuous monitoring of the performance of these tube wells by the authorities can ensure that they will be in good conditions since all the wells are rarely used. In fact, the maintenance of the wells should be done frequently or annually to prevent tube wells from clogging and other problems which may reduce their efficiency.

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