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A Comprehensive Approach to Optimizing Production Capacity through Integrated Evaluation of Well Performance and Pump Setting Scenarios

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Abstract. This paper evaluates the performance of a groundwater well by analyzing its well development, pump setting scenarios, and production capacity. The well's condition is assessed by calculating its well development factor, and pump setting analysis is conducted to determine the best pump position for maximum yield and safe drawdown. Pumping tests are performed to measure water levels and predict future well performance, sustainability, and maintenance needs. The specific capacity of the well equation is used to describe productivity, and steady-state drawdown values are calculated for four different pumping rates. The well development factor is excellent, and well efficiency values range from 82% to 72% for flow rates of 22.6 L/s to 39.5 L/s. The optimal discharge rate is calculated, and the appropriate pump location is determined to accommodate the desired discharge rate and water table decrease. The results provide valuable information for future well management and maintenance planning.

Keywords: *groundwater wells; optimum discharge; pumping test; pump setting; step-drawdown test; well performance.*

1 Introduction

Groundwater wells are vital resources that provide clean water to millions of people worldwide. Over time, however, a well's performance tends to decline due to natural wear and tear, clogging, or reduced permeability1. Well servicing is essential to maintain optimal performance and extend the life of the well. Before performing any servicing, it is necessary to assess the well's current condition and identify any underlying issues. Pumping tests are commonly used to assess well performance by measuring water levels in response to pumping at various rates2. These tests provide valuable data for predicting future well performance, assessing well sustainability, and planning for future maintenance3. This paper assesses the performance of a well in terms of its well development, pump setting scenarios, and production capacity, while determining its condition through calculating the well development factor. Furthermore, it analyzes pump settings to identify the optimal position for maximum yield and safe drawdown.

2 Methods

In step-drawdown test tests, a minimum of three different pumping rates are used. The lowest rate is applied during the first step until the groundwater level stabilizes, and then the rate is gradually increased until the highest planned rate is reached. According to Kruseman and Rider (1994), Jacob first conducted this test in 1947, which resulted in an equation that describes the drawdown of groundwater due to aquifer and well losses during a pumping test. In 1953, Rorabough simplified Jacob's equation to:

$$Sw = BQ + CQ^p \qquad (1)$$

where Sw is the drawdown of the water level (in meters), Q is the pumping rate (in cubic meters per second), B is the aquifer loss coefficient, C is the well loss coefficient, and p is a constant ranging from 1.5 to 3.5. Jacob used a value of 2 for p in his research as cited by Kruseman and Rider (1994). B and C values can be determined by linear regression analysis of the data from the Sw/Q versus Q plot (Figure 1) B is the intercept of the regression line with the y-axis, while C is the slope of the regression line.

According to Walton, the value of C can be used to interpret the condition of the well4. Based on Walton's classification, the well condition can be categorized into four categories: excellent, experiencing slight clogging, clogged in some places, and difficult to restore to its original condition (Table 1).

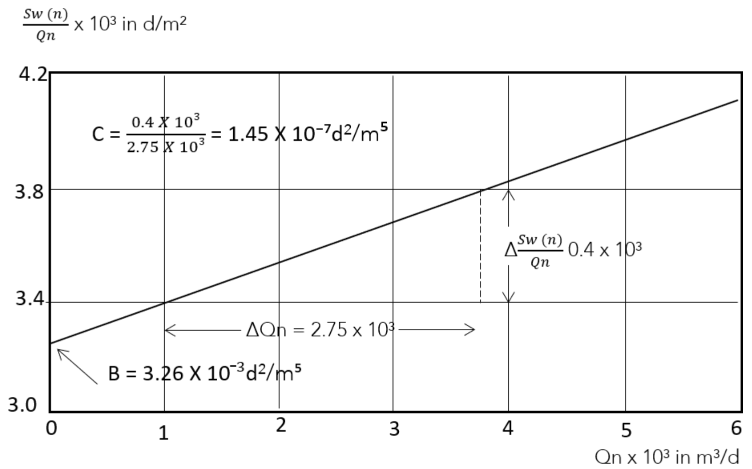

Figure 1 The graphic of B and C determination (Kruseman and Rider, 1994)

Table 1 The Classification of well condition based on Walton (1970).

Well loss coefficient *C* (minute^2/m^5)	**Well condition**
< 0.5	Properly designed and developed
0.5 to 1.0	Mild deterioration or clogging
1.0 to 4.0	Severe deterioration or clogging
> 4.0	Difficult to restore well to original capacity

Based on Freeze and Cherry (1979), the well development factor (Fd) can be calculated using the equation:

$Fd = C \times 100$ (2)

B

Where Fd is the well development factor, B is the aquifer loss coefficient, and C is the well loss coefficient. There are four classes of Fd, which are very good, good, fair, and poor, with certain Fd values (Table 2).

Table 2 Well development facor classification based on Freeze and Cherry (1979).

Well development factor *Fd* (day/m^3)	**Class**
< 0.1	Excellent
0.1 to 0.5	Good
0.5 to 1.0	Fair
> 1.0	Poor

According to Kruseman and Rider (1994), the productivity of an aquifer and well can be described through the specific capacity of a well equation, which is Q/Sw, where Q is the pumping rate and Sw is the drawdown. Furthermore, well efficiency can be calculated using the equation:

where E is the well efficiency, B is the aquifer coefficient loss, C is the well loss coefficient, and Q is the pumping rate. The optimum pumping rate is determined by the intersection point of the quadratic regression of data from the drawdown-pumping rate graph with the maximum pumping rate. The maximum pumping rate is determined by considering the allowed drawdown (Sw) that keeps the minimum available head above the pump. The allowed Sw value depends on the initial water table level and the pump depth.

3 Results and Discussions

3.1 Step-drawdown Test

This test employed four different pumping rates, namely 22.6 L/s (Q1), 27.4 L/s (Q2), 31.6 L/s (Q3), and 39.5 L/s (Q4), each running for two hours. Based on the logarithmic-logarithmic graph of the drawdown versus time, the steady-state drawdown values for each pumping rate were found to be 4.50 m for Q1, 5.66 m for Q2, 6.95 m for Q3, and 8.88 m for Q4 (Figure 2)

Figure 2 The graph of step-drawdown test

Based on the regression analysis of the Sw/Q data on the Q graph (Figure 3), the values of B and C were found to be 164.38 dt/m2 and 1593.6 dt2/m5, respectively. With the knowledge of B and C, the value of Fd was determined to be 0.01 day/m3. According to Walton's classification, the well is in good condition (well- designed and developed). Based on the Fd value and well performance classification, the well development factor falls into the category of excellent.

Using the well efficiency equation previously mentioned, the well efficiency values for each stage can be obtained based on the B and C values and the respective flow rates. The well efficiency values range from 82% to 72% with flow rates ranging from 22.6 L/s to 39.5 L/s (Table 3).

Figure 3 The graph of determination well loss and aquifer loss coefficient

Table 3 The calculation of determination well loss, aquifer loss, and well efficiency.

Step test	Q	Q	Sw	Sw/Q	Q/Sw	B	C	Sw calculation	Well efficiency
	(l/sec)	(m3/s)	(meter)	(s/m2)	(m2/s)	(dt/m2)	(dt2/m5)	(m)	
1	22.58	0.02	4.50	199.05	0.01	164.38	1593.60	4.52	82%
2	27.39	0.03	5.66	206.43	0.00	164.38	1593.60	5.70	79%

3	31.59	0.03	6.95	219.98	0.00	164.38	1593.60	6.78	77%
4	39.48	0.04	8.88	224.94	0.00	164.38	1593.60	8.97	72%

To calculate the optimum discharge rate (Qopt), we use the intersection point between the regression line of the data on the graph of the decline in drawdown against discharge rate (Q) and the maximum discharge rate (Qmax) determined based on the allowable specific yield (Swmax). The value of Swmax is determined by considering the initial water table (39.14 m), the pump depth (57.6 m), and the safe distance to anticipate a 2 m drawdown in groundwater table. Based on these factors, the allowable Swmax value is determined to be 16.46 meters, thus resulting in a Qopt value of 0.034 m3/s or 34 L/s (Figure 4).

Figure 4 The determination graph of optimum pumping rate (Q_{opt}).

3.2 Pump Setting

In analyzing pump setting, parameters such as well construction (location of casing), SWL, SwOpt due to Qopt, and the current pump location are taken into account. Pump setting is determined to find the appropriate pump location to accommodate Qopt with the determined water table decrease (SwOpt). The pump setting value can be calculated using the following equation:

SWL + SwOpt + d (4)

where SWL is the static water level (m), SwOpt is the optimum water table decrease (m), and d is a safety distance to anticipate changes in the aquifer conditions and to accommodate NPSH (Net Pump Suction Head). The value of d is assumed to be 10 m.

When determining pump setting, two scenarios of Qopt value are used. The first scenario is based on the actual field conditions obtained from step pumping test results. The second scenario uses Qopt value by simulating the pump location to the bottom of the well. Here are the details for each scenario.

Scenario 1

In this scenario, the Qopt value is 34 L/sec with SwOpt of 7.49 meters and SWL of 39.14 meters. Therefore, the pump setting value in this scenario is 57 meters.

Scenario 2

In this scenario, the optimum simulated discharge (Qopt') value is determined by using Sw allowable to the depth of the well screen (Swmax') of 250 ft or 76.2 meters (Figure 5).

The Qopt' value resulting from Swmax' of 76.2 meters is 62 L/sec. The resulting SwOpt' value from Qopt' is 14.3 meters (Figure 6). Based on the SWL value of 39.14 meters and SwOpt' value of 14.3 meters, the pump setting value is obtained as 63 meters.

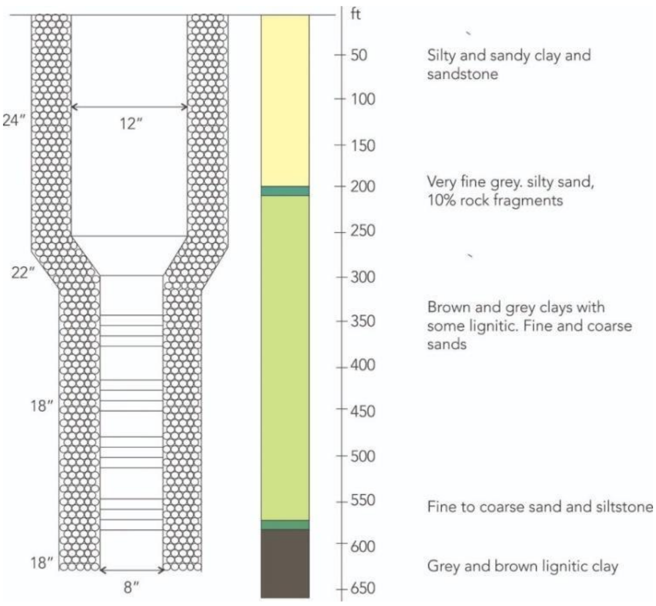

Figure 5 Well Construction

Figure 6 Graph of Optimum Pumping Rate (Qopt') Determination Simulation

4 Conclusion

Based on the data obtained from the pumping test, two scenarios were considered to determine the optimal pump setting for the well. In Scenario 1, the existing data indicated that a pump depth of 57 meters would achieve an optimum discharge rate (Qopt) of 34 L/sec with a static water level (Sw) of 7.49 meters. This finding highlights the importance of selecting the appropriate pump depth to achieve the desired pumping rate while maintaining a specific static water level.

Furthermore, the analysis of the well's performance reveals excellent results. The aquifer loss coefficient (B) of 164.38 sec/m^2 and the well loss coefficient (C) of

0.4 min^2/m^5 indicate a relatively high rate of water loss from both the aquifer and the well itself. However, these losses are mitigated by the well's well development factor (Fd) of 0.01 days/m^3, which signifies an excellent well design and construction. This factor demonstrates that the well has been optimized to maximize water extraction from the aquifer while minimizing water loss.

Additionally, the optimum pumping rate of 34 L/sec (0.034 m^3/sec) showcases the well's capability to supply a substantial amount of water to the community. This indicates its efficient performance and ability to provide a steady and reliable source of water.

In conclusion, the data from the pumping test and the evaluation of well performance suggest that the selected pump depth of 57 meters in Scenario 1 can achieve the desired discharge rate and static water level. The well's excellent performance, as evidenced by the high well development factor and the ability to supply a significant volume of water, ensures a reliable water source for the community. These findings underscore the importance of carefully designing and optimizing well systems to efficiently manage groundwater resources and support sustainable water utilization.

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Appendix

Data Processing

1. The calculation Walton and well performance parameter

Exhibit 1 Calculation of well performance parameter

					Classification
B	164.38	(dt/m^2)			
C	1593.6	(dt^2/m^5)	0.4	(min^2/m^5)	good
Fd = $\frac{C}{B} x\ 100$	9.69 x 10^{-2}	(dt/m^3)	0.01	(day/m^3)	Excellent

2. SWmax calculation

$$SWmax = pump\ depth - SWL - safe\ distance$$

Exhibit 2 SWmax calculation

SWL	39.14	m
Pump depth	57.6	m
Safe distance	2	m
SWmax	16.46	M

3. Qmax calculation

$$SWmax\ = BQmax + CQmax^2$$

Exhibit 3 Qmax calculation

B	164.38	dt/m^2
C	1593.6	dt^2/m^5
SWmax	16.46	m
Qmax	0.062	m^3/s

4. Pump Setting

1st Scenario: in accordance with the current position of the pump

Step:

- plot Q_{max} and SW_{max}
- The intersection points of the Q_{max} and SW_{max} lines represent the value of Q_{opt} and SW_{opt}.

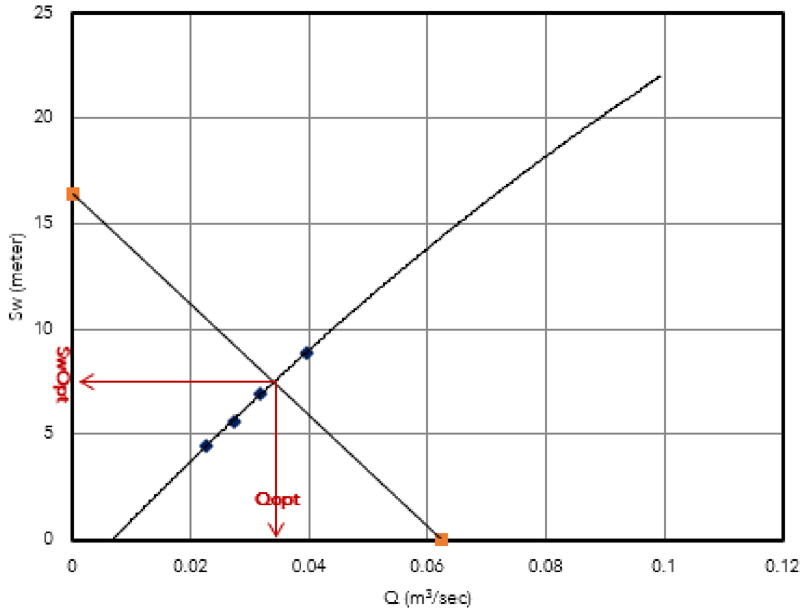

Exhibit 4 The graphic of intersection line for determination Qopt and SWopt 1st scenario.

The value is obtained:

Qopt = 34 L/s SWopt = 7.49 m

SWL (known) = 39.14

$$Pump\ setting = SWL + SWopt + d$$

Pump setting = 39.14 + 7.49 + 10

Pump setting = 56.63 m ≈ 57 m

2nd Scenario: the position of the pump based on the well construction

The same method as in scenario 1 is also used to determine the pump setting in scenario 2.

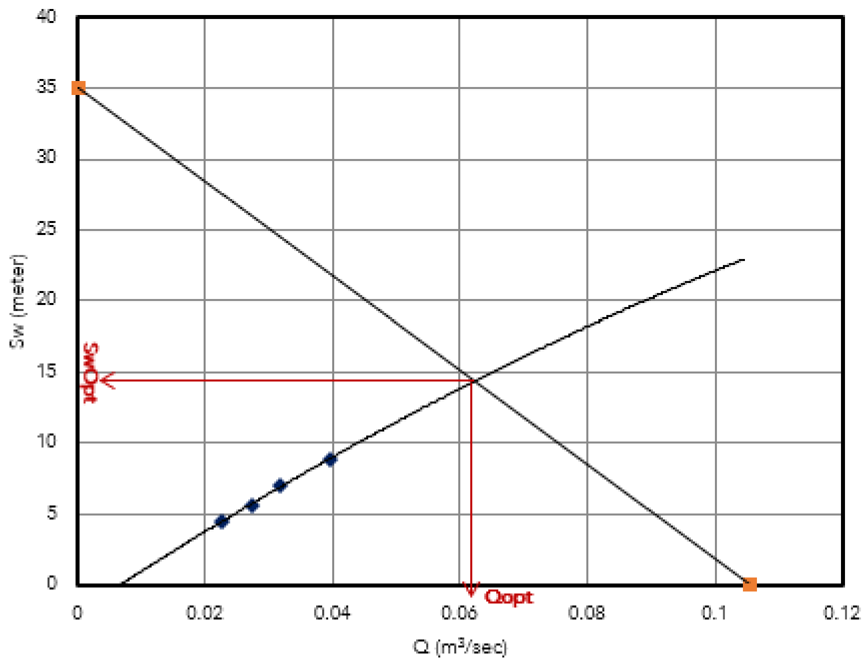

Exhibit 5 The graphic of intersection line for determination Qopt and SWopt 2nd scenario.

The value is obtained:

Qopt = 62 L/s SWopt = 14.3 m

SWL (known) = 39.14

$$Pump\ setting = SWL + SWopt + d$$

Pump setting = 39.14 + 14.3 + 10

Pump setting = 63.44 m ≈ 63 m