Optimum Discharge Analysis of Shallow Well Using Pumping Test Method

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Abstract

This study aims to analyze the optimum discharge of shallow wells using a pumping test method. The study took place in Sariwangi Village, West Bandung. The study was conducted through a staged pumping test which was then analyzed using the Jacob method. The analysis was conducted to determine the relationship between pumping rate and the resulting water level decline. The collected data were analyzed to determine the characteristics of the well condition based on the well loss coefficient (C), the development factor coefficient (Fd), and determine the optimum discharge (Qopt) based on the permitted water level decline limit and an analysis of optimum utilization. The analysis results showed that there was a blockage in the well, but the development factor was still in the good category. The calculation of the optimum discharge obtained a value large enough so that one well could be used by several families. These findings can be used as a reference for the management and planning of groundwater utilization in Sariwangi Village. Information regarding the optimum discharge is crucial to ensure efficient and sustainable groundwater utilization without causing excessive water level decline or damaging the aquifer structure.

Keywords: shallow well, pumping test, optimum discharge, step-drawdown, Sariwangi

1. INTRODUCTION

The investigation of groundwater conditions is a crucial aspect in civil construction projects as well as in environmental management. The need to understand the existing state of groundwater often becomes a significant challenge for scientists and civil engineers in conducting accurate planning or designing appropriate strategies for the protection of groundwater resources.

As an example, Sariwangi District requires detailed information regarding the availability of water within the area. Such information is highly important for future calculations and planning needs so that the availability of water can be clearly determined and properly managed. This information includes groundwater data such as the optimum discharge and the characteristics of shallow wells.

The optimum discharge in groundwater availability refers to the volume of water that can be pumped or extracted from groundwater sources (such as wells or infiltration points) without causing long-term damage to the groundwater resource. This implies that the rate of withdrawal must correspond to the recharge rate, ensuring that the balance between extraction and replenishment of groundwater is maintained.

Information regarding the characteristics of shallow wells is also highly necessary for various reasons, particularly in the management of water resources and the sustainability of water supply. By understanding the characteristics of shallow wells, it is also possible to reduce the negative impacts that may arise from excessive or improper groundwater use.

1.1. Pumping Test Concept

A pumping test is conducted in a well to determine aquifer characteristics, such as its ability to transmit and store groundwater. It also assists in evaluating the groundwater potential within a basin, identifying subsurface boundaries that may either hinder or benefit groundwater exploitation, and assessing the long-term performance capacity of a well when subjected to continuous pumping (Sudarsono and Untung, 1998).

Pumping tests can be carried out in several ways, such as constant discharge pumping tests (long-term tests), constant drawdown pumping tests, step-drawdown tests, variable discharge or variable drawdown pumping tests, pumping tests for multiple aquifers, and pumping tests with observation wells.

1.2. Step-Drawdown Method

The step-drawdown pumping test method is conducted to observe the response of the groundwater level to fluctuations caused by pumping, which is carried out at several discharge variations. This process begins with the measurement of groundwater levels at different pumping rates over a specific period of time. The parameters measured include pumping duration, discharge volume, and changes in groundwater level during the pumping process (Agussalim, Djafar, & Rizal, 2022).

One of the main objectives of the step-drawdown test is to evaluate well efficiency under actual field conditions. This method enables the assessment of well performance, such as the well-loss coefficient and well efficiency, while also providing an estimate of the optimum pumping rate based on different groundwater depths. In this test, the pumping rate of the well is gradually increased in several stages, with a minimum of three steps.

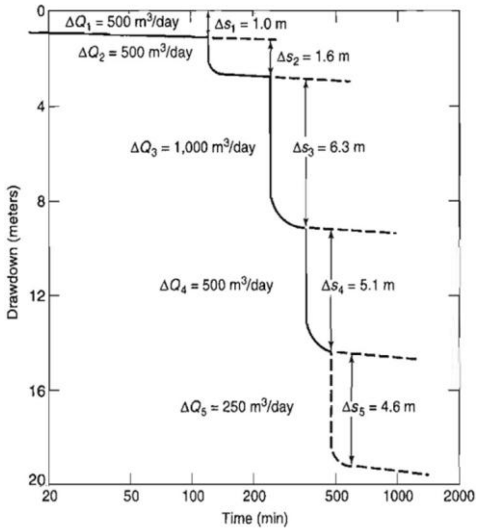

Fig. 1. Step-Drawdown

1.3. Well Characteristics

After the measurements were taken, the calculation began with determining the total drawdown at each pumping stage. In addition to total drawdown, the pumping discharge was also required. The discharge was calculated using the volumetric method during measurement. These data were then used to calculate S/Q, resulting in a graph showing the relationship between S/Q and Q.

From this graph, an equation was obtained, in which the coefficients B and C could be determined. The value of B is defined at the point where the X-axis equals 0, making B equal to the Y-intercept, while the value of C corresponds to the slope (X) of the equation.

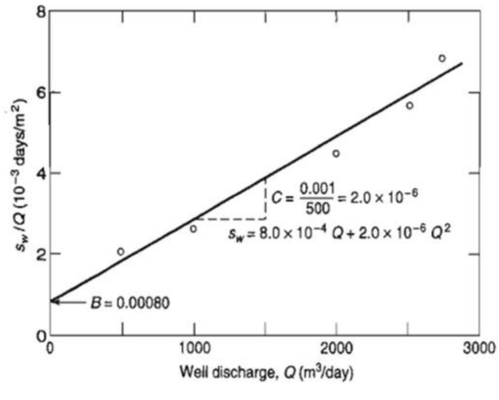

Fig 2. Determination of B and C from Graph Sw/Q Versus Q

Table 1. Well Condition according to C Value

C (min^2/m^5)	Well Condition
< 0,5	Properly designed and developed
0,5 -- 1	Mild deterioration or clogging
1 -- 4	Severe deterioration or clogging
> 4	Difficult to restore well to original capacity

Table 2. Factor Development Classification

Fd (day/m³)	Classification
< 0,1	Very Good
0,1 - 0,5	Good
0,5 - 1,0	Enough
> 1	Poor

1.4. Optimum Discharge

According to Paresa et al. (2023), the optimum discharge of a well refers to the amount of water that can be extracted through pumping by calculating the values of Maximum Discharge (Qmax) and Maximum Drawdown (Swmax). To determine the values of Qmax and Swmax, the following equation can be applied:

$$Q_{\max} = 2\pi \, . \, r_w \, D \left(\frac{\sqrt{K}}{15} \right) \quad (1)$$

Description :

$Q_{\max}$ = Optimum Discharge (m^3/day)

r_w = Well radius (m)

D = Aquifer thickness (m)

K = Soil permeability coefficient (m/second)

$$Sw_{\max} = B \, . \, Q_{\max} + C \, . \, Q_{\max}^2 \quad (2)$$

Description :

B = Aquifer Loss (m)

C = Well Loss Coefficient (min^2/m^5)

Before calculating the optimum discharge, supporting data are required, namely the calculation of the Maximum Discharge (Qmax) and the Maximum Total Drawdown (Swmax) of the well. The supporting data for these calculations were obtained from lithological data around the research area. Once these data are obtained, Qmax and Swmax are plotted on a graph, along with the value of BQ (Aquifer Loss) of the well. The intersection or tangency point of these lines is then interpreted as the optimum discharge of the well.

1.5. Well Optimalitation

The optimum well discharge value serves as a benchmark for calculating groundwater availability. In order to perform this calculation, supporting data on average water consumption and distribution losses are required, ensuring that the estimation of water availability is both accurate and representative of actual field conditions.

To discover

$$\text{Water Resource Avaibility} = \frac{Q_{opt}}{\text{Average Water Consumption}} \quad (3)$$

Description:

Q_{opt} = Optimum Discharge (lt/day)

Average Water Consumption = Average Water Consumption (lt/lives/day)

2. METHOD

2.1. Research Design

Determining the optimum discharge is essential to ensure sustainable groundwater utilization without causing significant depletion of the aquifer's capacity. The research was conducted through a step-drawdown pumping test to obtain the relationship between pumping rate and water level drawdown. The collected data were analyzed using the Jacob equation to calculate the well loss coefficient and to determine the optimum discharge based on the allowable drawdown limit. The results indicate that the optimum discharge varies under different testing conditions. These findings provide insights into the potential use of shallow groundwater in Sariwangi and serve as a basis for sustainable groundwater management and planning.

2.2. Project Measurement Data

The case study analyzed in this research is Shallow Well in Sariwangi

Condition : After The Rain

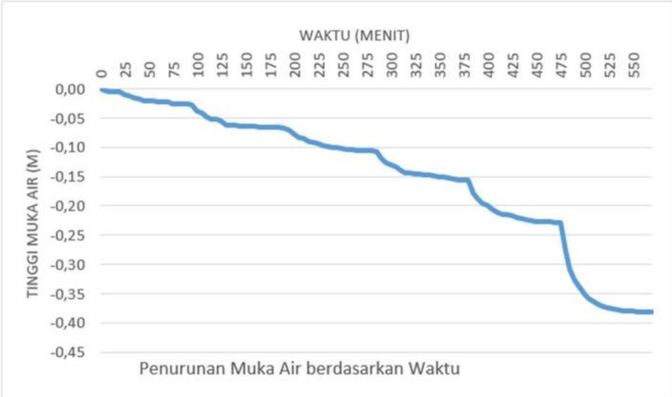

Fig 3. Measurement Result

3. RESULTS AND DISCUSSION

3.1. Well Loss Coefficient and Factor Development

According to Todd, the calculation is carried out by determining the total discharge and the total drawdown. For example, with Q1 = 1.859 m^3/day and Q2 = 5.562 m^3/day, the total discharge Q2 becomes 10.616 m^3/day. In other words, the calculation is performed cumulatively at each stage. The same approach applies to drawdown, where the cumulative total drawdown per stage is used.

Table 3. Q, Sw and Sw/Q Value

Q (m^3/day)	S (m)	S/Q (10^{-3} day/m^2)
1,859	0,027	14,52
5,562	0,067	12,05
10,616	0,107	10,08
17,911	0,156	8,71
28,931	0,228	7,88
52,689	0,382	7,25

From Table 3,4,5,6, the relationship between the values of Q and Sw/Q can be determined, where the curve is illustrated by plotting Q on the X-axis and Sw/Q on the Y-axis on a normal scale. The value of B, based on the intersection of the linear regression line with the Y-axis, can be observed in Figure 7,8,9,10 :

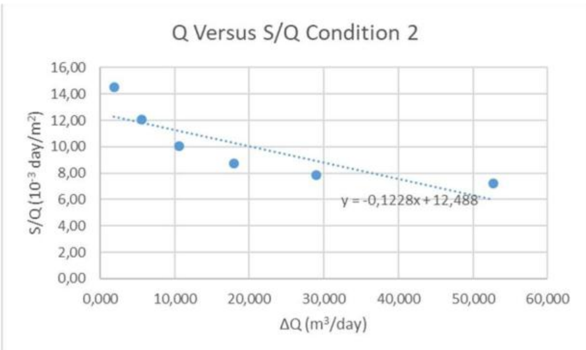

Fig 4. Q Versus S/Q Condition 2

From that graph, the value of B and C can be concluded as follows.

Table 4. C Value at Every Conditions

C (day^2/m^5)	C (min^2/m^5)
0,0001228	254,64

Meanwhile, the value of B is 0.01249 day/m².

From the obtained values of B and C, we can then calculate the Aquifer Loss (BQ), Well Loss (CQ^2), Total Drawdown (Sw) and Factor Development (Fd) which are presented as follows:

Table 10. BQ, CQ2 and Sw Value

ΔQ (m^3/day)	B (day/m^2)	BQ (m)	C (day^2/m^5)	CQ (m)	Sw (m)	Fd (day/m^3)
1,859	0,01249	0,023	0,0001228	0,000	0,024	1,418
5,562		0,069		0,004	0,073	
10,616		0,133		0,014	0,146	
17,911		0,224		0,039	0,263	
28,931		0,361		0,103	0,464	
52,689		0,658		0,341	0,999	

The classification results in this study indicate that under post-rainfall conditions, the value of C falls into the category of "difficult to restore to its original state." This classification suggests that the shallow well in Sariwangi still exhibits relatively low hydraulic efficiency even after rainfall events. Although rainfall generally contributes to groundwater recharge, the internal well conditions indicate that a portion of the water entering the aquifer experiences resistance before reaching the well screen. Consequently, the flow of water into the well is not entirely smooth, reflecting the presence of partial head losses caused by factors such as sediment accumulation, clogging, or limited permeability near the well screen area.

Despite these hydraulic constraints, the pumped discharge remains adequate to meet the water demand of the surrounding community. From an operational standpoint, the well still performs within a technically acceptable range; however, it does not reach its optimal efficiency level. The post-rainfall condition provides a temporary improvement in groundwater inflow, but the persistence of a relatively high well loss coefficient indicates that the aquifer system and the well structure require regular monitoring and maintenance.

Furthermore, the analysis of the Factor of Development (Fd) shows that after rainfall, the value is categorized as "good," reflecting an enhancement in the well's performance. This improvement demonstrates that rainfall plays a significant role in facilitating groundwater recharge, reducing drawdown, and promoting smoother water movement toward the well. In summary, although the post-rain condition improves well performance compared to dry periods, the well's overall hydraulic efficiency remains moderate, suggesting that both natural recharge and technical maintenance are essential for maintaining sustainable groundwater extraction in Sariwangi Village.

3.2. Optimum Discharge and Well Optimization

Before determining the optimum discharge value, it is necessary to first calculate the values of Qmax and Swmax. Based on the measurement results and lithological data obtained, the following data were recorded:

- Well Radius (r) = 0,3 m
- Aquifer Thickness (D) = 1,86 m
- Soil Permeability (K) = 0,000002843

The lithological data were then calculated using Equation (1) to determine Qmax, with the calculation as follows:

$$Q_{\max} = 2\pi \, . \, r_w \, D \left(\frac{\sqrt{K}}{15} \right)$$

$$Q_{\max} = 2\,(3{,}14).\,0{,}3\,(1{,}86)\left(\frac{\sqrt{0{,}000002843}}{15} \right)$$

$$Q_{\max} = 0{,}0003939 \; m^3/sec$$

$$Q_{\max} = 0{,}394 \; lt/sec$$

After Qmax is determined, the maximum drawdown (Swmax) can then be calculated using Equation (2). The value of Swmax varies under different weather conditions, depending on the values of B and C. The calculation of Swmax is presented as follows:

$$Sw_{\max} = B \cdot Q_{\max} + C \cdot Q_{\max}^{2}$$

$$Sw_{\max} = 0{,}01249(0{,}394) + 0{,}0001228(0{,}394^{2})$$

$$Sw_{\max} = 0{,}567 \text{ m}$$

Once these data are obtained, Qmax and Swmax are plotted on a graph, along with the value of BQ (Aquifer Loss) of the well. The intersection or tangency point of these lines is then interpreted as the optimum discharge of the well.

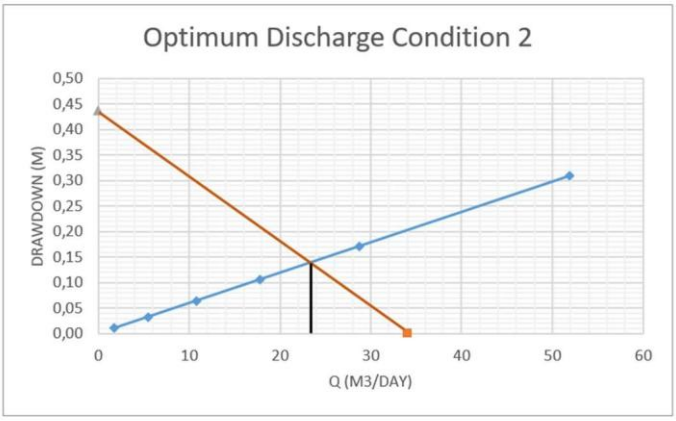

Fig 5. Optimum Discharge

Thus, it is obtained:

Qopt = 23,83 m^3/day

= 0,276 lt/sec

= 23830 lt/day

After obtaining the value of the Optimum Discharge under each weather condition, the next step is to calculate the capacity of the well to supply water for several households. To perform this calculation, several supporting data are required, which are summarized as follows:

- Water Loss = 30% (Kriteria Ditjen Cipta Karya Dinas PU)
- Average Water Consumption = 130 liters/person/day (Kriteria Ditjen Cipta Karya Dinas PU)

To calculate water resource availability in Sariwangi, it is necessary to first average the values of Qopt, resulting in an average Qopt of 23830 liters/day. This Qopt is then divided by the average water consumption, as equation (3), leading to the following calculation:

$$\text{Water Resource Avaibility} = \frac{Q_{opt}}{\text{Average Water Con}}$$

$$\text{Water Resource Avaibility} = \frac{16681\ lt/day}{130\ \frac{lt}{person}/day}$$

$$\text{Water Resource Avaibility} = 128 \text{ Person}$$

From the results of these calculations, the researcher concludes that the well is highly capable and sufficient to meet the needs of several families/households, based on the assumption of an average water demand of 130 liters per person per day.

Under post-rainfall conditions, the analysis shows that the value of the optimum discharge (Qopt) remains relatively stable and within the sustainable range. This stability indicates that after rainfall, the shallow aquifer in Sariwangi has sufficient recharge and storage capacity to provide groundwater continuously without causing excessive drawdown or structural damage to the aquifer. According to Todd & Mays (2005), the optimum discharge represents the pumping rate that can be maintained sustainably without impairing the aquifer's hydraulic balance. In this study, the obtained Qopt value reflects that the aquifer system in Sariwangi remains in a good hydrological state after rainfall, allowing the well to operate effectively and supply adequate water for domestic use.

Although the hydraulic efficiency of the well is classified as "less than ideal," the aquifer's recharge following rainfall contributes significantly to stabilizing water levels and maintaining steady discharge performance. This condition demonstrates that rainfall plays a crucial role in sustaining shallow groundwater potential, especially in areas that rely on wells for daily water needs. Based on the calculation results, the optimum discharge obtained under post-rain conditions is capable of meeting the water demand of approximately 115 people, assuming an average requirement of 130 liters per person per day. Therefore, from the perspective of water availability and sustainability, the shallow well in Sariwangi remains feasible to be utilized as a reliable source of clean water for the surrounding community.

4. CONCLUSIONS

Based on the analysis results, the following conclusions can be drawn:

1. Based on the data and analysis carried out, the value of the Well Loss Coefficient (C) obtained under post-rainfall conditions is classified as "difficult to restore to its original condition." This classification indicates that although rainfall contributes to aquifer recharge, the shallow well in Sariwangi still experiences hydraulic losses due to partial clogging or resistance in the well screen area. Nevertheless, the presence of rainfall helps maintain a lower C value compared to potential conditions during prolonged dry periods, reflecting a relatively stable hydraulic performance after rain events.
2. The Factor of Development (Fd) value under post-rainfall conditions is classified as "Good," suggesting that the well operates more efficiently after rainfall. This condition indicates that groundwater recharge following rainfall improves water inflow to the well and reduces drawdown during pumping. As a result, the well demonstrates better hydraulic response and performance, showing that rainfall plays a positive role in sustaining groundwater flow and minimizing well losses.
3. In conclusion, under post-rainfall conditions, the variations in C and Fd values reflect the influence of recent rainfall on the improvement of well efficiency and aquifer recharge. Meanwhile, the optimum discharge (Qopt) obtained during this condition remains stable, representing the aquifer's adequate storage capacity to supply groundwater sustainably. Although the well's hydraulic efficiency is not fully optimal, the post-rain condition supports stable groundwater availability, making the shallow well in Sariwangi suitable for continuous use as a clean water source for the local community.

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