



Groundwater Feasibility Assessment Using Pumping Test Analysis at Selebar District of Bengkulu City

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Abstract

In recent years, groundwater has become crucial for regional development, both in terms of construction and business permits. Therefore, the demand for groundwater is increasing along with population growth, agricultural and industrial development, which can be determined by the presence and potential of groundwater (Mohammed, 2023). The main obstacle to groundwater development is a lack of understanding of the geological and hydrogeological conditions necessary for effective groundwater management. Information on geological and hydrogeological conditions requires an integrated approach to provide detailed information on aquifer characteristics, thus ensuring the sustainability of groundwater supplies. Inadequate knowledge leads to groundwater pollution, improper groundwater management, and failed well drilling. The Step Drawdown Test is a well testing method used to evaluate well performance and the characteristics of the surrounding aquifer. This test involves pumping water from the well at several different flow rates (in stages), then measuring the drawdown at each flow rate. This method is used to evaluate well productivity, including production rate and efficiency. The Step Drawdown Test is relatively short, consisting of several steps at varying flow rates, pumping at gradually increasing flow rates, and measuring the pressure drop (drawdown) at each step. Based on the results of the pump test and groundwater feasibility analysis, it can be concluded that the aquifer potential at the test site has sufficient capacity to meet water needs. The pump test provides information on the aquifer's hydraulic characteristics, such as hydraulic conductivity and transmissivity. This data provides an estimate of the optimum discharge that can be maintained without causing significant water level decline, thus enabling sustainable groundwater utilization planning. It is recommended that the wells be further apart than the existing wells, and monitoring wells are required. Groundwater feasibility analysis also showed that water quality at the test site meets the required standards for its planned use. However, this groundwater utilization still requires sustainable management. Regular monitoring of water discharge and quality is crucial to prevent overexploitation and avoid potential problems such as land subsidence and seawater intrusion, particularly in coastal areas. These efforts will ensure that groundwater resources continue to support the needs of the community and the environment in the future..

Keywords - groundwater, pumping test, palm oil, sustainability, water resource management

1. Introduction

In recent years, groundwater has become crucial for regional development, both in terms of construction and business permits. Therefore, the demand for groundwater is increasing along with population growth, agricultural and industrial development, which can be determined by the presence and potential of groundwater (Mohammed, 2023). The main obstacle to groundwater development is a lack of understanding of the geological and hydrogeological conditions necessary for effective groundwater management. Information on geological and hydrogeological conditions requires an integrated approach to provide detailed information on aquifer characteristics, thus ensuring the sustainability of groundwater supplies. Inadequate knowledge leads to groundwater pollution, improper groundwater management, and failed well drilling (Agyemang, 2022).

Factors influencing the presence and flow of groundwater and aquifer parameter estimation can be developed to understand the characteristics of groundwater aquifers (Urom et al ., 2022). Hydrogeological parameters , including hydraulic conductivity, storativity, and transmissivity, are crucial in evaluating

aquifer productivity (Eyankware et al., 2022). The ideal method for estimating these parameters is by conducting pumping tests to provide information on aquifer yield and withdrawal (Fetter, 2018; Vijayaprabhu et al., 2022).

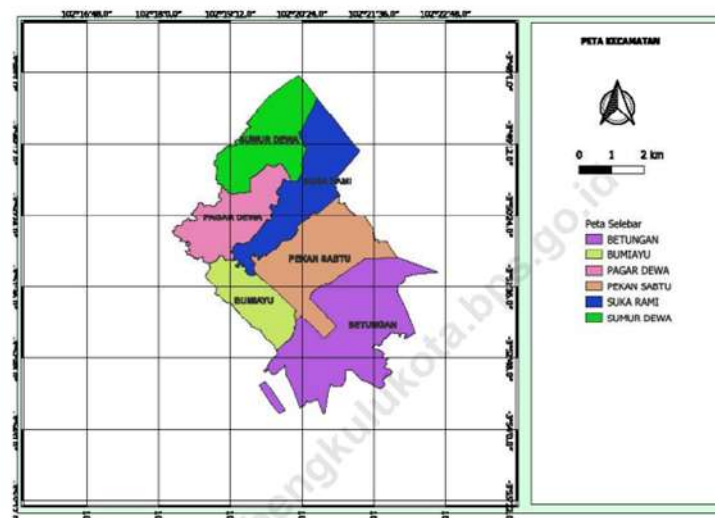
The pumping test aims to analyze groundwater discharge. The goal is not only to determine the well's ability to produce groundwater but also to determine the permeability of the water-bearing layer / aquifer. (Mohammed, 2023). Pumping tests involve pumping water from a well at a certain flow rate, observing the decrease in water level during pumping, and observing the recovery of the water level after the pump is turned off at a certain time interval. Pumping tests are conducted to test the durability and performance of the well, in this case a groundwater well.

PUMPING TEST LOCATION CONDITIONS

1. Company Profile Data

Selebar is one of the largest sub-districts in Bengkulu City, consisting of six sub-districts with an area of 46.36 km² located in the southern part of Bengkulu City (BPS Bengkulu City, 2024). Betungan Sub-district is the largest sub-district in Selebar District, namely 15.02 km². covers approximately 32% of the total area of Selebar District (Figure 1).

PETA WILAYAH KECAMATAN SELEBAR
MAP OF SELEBAR DISTRICT



(Source: Selebar District in Figures, 2024)

Figure 1. Map of Selebar District

PT. Surya Andalan Primatama is located at Jalan RE Martadinata No. 80, Kandang Village, Kampung Melayu District, Bengkulu City. PT. Surya Andalan Primatama has a business/activity in the form of a factory engaged in CPO processing. The type of business carried out is the manufacture of cooking oil. This CPO processing factory is located at Jalan Suprpto Dalam No. 22 RT 08 RW 06, Betungan Village, Selebar District, Bengkulu City.

This CPO processing plant requires a sufficient amount of water in its production process, so an adequate water source is required for smooth factory operations. The amount of water required is estimated at **300 m³ / hour (=0.08 m³ / s)**, with the following details :

- ✓ Sanitation water requirement of 25 m³ / hour
- ✓ Cooling water requirement of 50 m³ / hour
- ✓ Boiler feed water requirement is 25 m³ / hour
- ✓ Process water requirement of 200 m³ / hour

To meet this need, groundwater will be tapped through drilled wells. Two of these wells will be constructed within the CPO processing plant (Figure 2).



(Source: Airbus Satellite Imagery, CNES)

Figure 2. Location of the Drilling Well

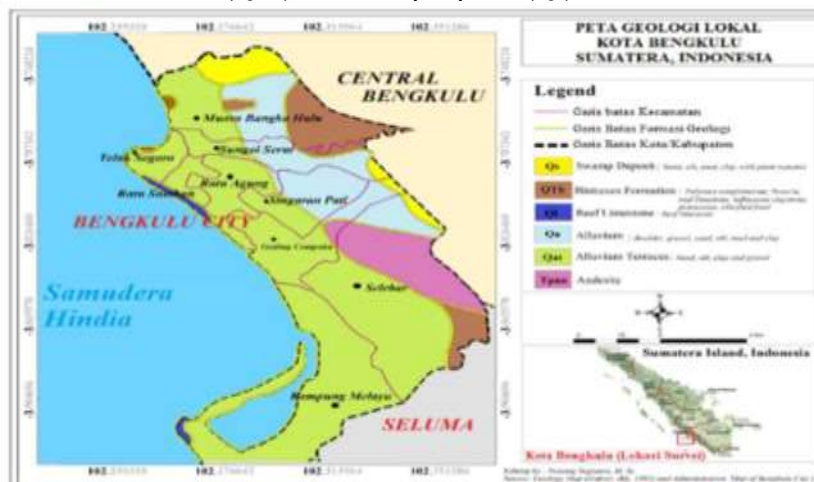
Details of the drilled well points are as follows:

- ✓ Borehole 1: Coordinates 3°52'53.2"S 102°20'39.2"E
- ✓ Drilling Well 2: Coordinates 3°52'54.35"S 102°20'40.589"E

2. Regional Geological Conditions of the Pumping Test Location

Tectonically, Bengkulu City is a coastal city formed in a subduction zone, where the Indo-Australian plate subducts under the Eurasian plate. Earthquakes in this zone are better known as the megathrust zone, with a small subduction angle of 10-20 meters and a depth of 30 km (Natawidjaja, 2007). This endogenous force is what caused the formation of several formations in the Bengkulu City area.

According to Gafoer (1992), Bengkulu City has 6 types of geological formations, namely alluvium (Qa), Reef limestone (Ql), swamp deposits (Qs), Alluvium terraces (Qat), andesite (Tpan) and bintunan formation (QTb). 5 of these formations are found in Selebar District, namely Alluvium terraces (Qat), andesite (Tpan), alluvium (Qa), bintunan formation (QTb), and swamp deposits (Qs).



(Source: Sugianto, 2017)

Figure 3. Geological Map of Bengkulu City

Betungan Village is dominated by Alluvium terraces (Qat) formations. Alluvium Terraces (Qat) are geological units formed by alluvial deposits that are lifted and deposited along river valleys (Sugianto,

2016). Alluvial Deposits: Consist of gravel, sand, silt, and clay, which are deposited by rivers over a period of time. This material is usually uncemented and irregular. Various Grain Sizes: Rocks composed of various grain sizes, ranging from coarse gravel to fine silt and clay, depending on the transport energy of the river that formed them (Sugianto, 2016).

Due to their alluvial nature, Qat are often good groundwater reservoirs, especially if they are composed of porous sand and gravel. However, their efficiency as aquifers depends on the proportion of clay or silt that restricts water movement. Due to these characteristics, Alluvial Terraces (Qat) are often considered important indicators of the geomorphological history of a particular region and serve as potential water resource reservoirs (Sugianto, 2017).

3. Regional Hydrogeological Conditions of the Location Pumping Test

The hydrogeological conditions of Betungan Village, Selebar District, Bengkulu City, reflect the geological characteristics, morphology, and groundwater dynamics of the area. The alluvial deposits that dominate Betungan Village generally contain sand, gravel, silt, and clay, forming shallow aquifers. In some places, older bedrock layers may be present, which can serve as boundaries for groundwater movement and influence its hydrogeological properties. (Kodoatie, 2012)

Shallow aquifers can store a fair amount of water, depending on the composition of their constituent materials. Sand and gravel have high permeability, while clay or silt can reduce the aquifer's ability to transmit water.

Groundwater levels are affected by heavy rainfall, particularly during the rainy season. During the rainy season, groundwater levels tend to rise, while during the dry season, they can drop significantly. Recharge from rainfall that seeps into the ground replenishes aquifers (Davis, 1966).

Agricultural activities, infrastructure development, and urbanization can impact the hydrogeological conditions in this area. Deforestation or river diversion can affect infiltration and aquifer recharge patterns.

4. Environmental Conditions and Impacts of Groundwater Extraction

The groundwater conditions in Betungan Village are highly dependent on natural factors such as rainfall, as well as human activities that can impact water quality and availability. Proper management and awareness of the importance of maintaining groundwater quality are essential to ensure the sustainability of water resources in the area.

Groundwater quality in Betungan Village can vary depending on the location and depth of the well. Water from shallow wells is at greater risk of contamination than from deeper wells. The potential for contamination from domestic waste and daily activities is quite high, especially in shallow wells, as the area is located on the outskirts of a developing city. Poorly managed household waste (for example, leaking septic tanks) can contaminate groundwater with bacteria and nitrates (Suripin, 2003).

In addition, because of its proximity to the coast, there is a risk of seawater intrusion, especially if there is excessive use of groundwater in this area, thereby increasing the salt content (salinity) in the groundwater, making it unsuitable for consumption.

The best water resource for clean water and drinking water is groundwater. Rapid development growth can pose a serious threat to the availability of groundwater reserves. Rapid development often ignores the analysis of groundwater reserve availability. This can have negative impacts on the environment and the sustainability of future development. However, information on groundwater reserve availability is often difficult to access and difficult to quickly analyze. Without a good understanding of groundwater reserves, development can face the risk of water supply shortages, environmental damage, and long-term unsustainability (Wahyudi, 2009).

Exploitation of groundwater resources without proper controls and principles based on hydrological principles leads to an imbalance in carrying capacity and storage capacity. The utilization and reservation of water resources must be adjusted to meet the quantity requirements as a threshold for availability and the quality standards for suitability for use, ensuring that spatial and regional planning is effective and able to guide policies toward their intended purpose.

5. Social Conditions of the Community Around the Pumping Test Location

Based on data from the Bengkulu City Statistics Agency (BPS), Selebar District in Figures (2024), the population of Selebar District in 2023 reached 86,103 people, with a sex ratio of 43,513 men and 42,590 women. In Betungan Village there are 4,726 heads of families with a population density of 1,071 per km² with the main livelihood as vegetable farmers.

Table 1. Population of Selebar District, Bengkulu City

Desa/Kelurahan Village/Kelurahan	Penduduk/Population			Jumlah Kepala Keluarga/ Number of Family Heads (000)
	Laki-Laki/ Male	Perempuan/ Female	Jumlah/ Total	
Betungan	8.180	7.887	16.067	4.726
Pekan Sabtu	5.464	5.347	10.811	3.195
Sukasari	7.319	7.090	14.409	4.238
Pagar Dewa	10.971	10.857	21.828	6.519
Buru Ayu	8.311	8.196	16.507	3.753
Sumur Dewa	5.248	5.197	10.445	3.038
Selebar	43.513	42.590	86.103	25.668

(Source: Selebar District in Figures, 2024)

The water needs of the community in Betungan Village, Selebar District, Bengkulu City, are met through several sources. Information was obtained through interviews with a random sample of 10 people living near the PT. Surya Andalan Primatama CPO processing plant. Based on these interviews, the sources of water needs for the community around the plant can be summarized as follows:

- a. Dug Wells. Dug wells are usually shallow (5-15 meters) and draw water from shallow aquifers.
- b. Borehole Wells. For communities seeking better quality water and a more consistent quantity, they may use deeper boreholes (30 meters or more). These borehole wells tend to be safer from surface contamination and can reach deeper aquifers.
- c. Regional Drinking Water Company (PDAM). Some communities obtain clean water from PDAM through a piped network. However, not all areas may have equal access to the PDAM network, especially in more remote or developing areas like Betungan.
- d. Rainwater Utilization. When rainfall in Bengkulu City is quite high, especially during the rainy season, residents also use rainwater harvesting as an alternative water source, especially for non-consumptive purposes such as washing or watering plants.
- e. Refillable Water. For some communities without direct access to adequate clean water, using water from mobile water vendors or refillable water depots is an option for drinking and cooking.

Materials And Methods

1. Step Drawdown Test

The Step Drawdown Test is a well testing method used to evaluate well performance and the characteristics of the surrounding aquifer. This test involves pumping water from the well at several different flow rates (in stages), then measuring the drawdown at each flow rate (Cem Avci , 2010).

This method conducted to evaluate the productivity capacity of the well in the form of well production rate and well efficiency. The duration of the Step Drawdown Test is quite short and is carried out in several steps with different flow rates through pumping with gradually increasing flow rates, and each step measures the pressure drop (drawdown).

2. Step Drawdown Test Analysis

The Step Drawdown Test is performed at a gradually increasing rate. H. An (2022) mentions several situations in which the Step Drawdown Test is necessary:

a. Performed After Drilling New Well.

Step Drawdown Testing is performed after drilling and before the well is fully commissioned. It serves to evaluate the well's initial productivity and determine the optimal flow rate for production operations. It also helps identify potential problems such as skin effect (pressure loss due to formation damage near the well).

b. Evaluation of Formation Damage or Skin Effect:

When there is suspected formation damage around the well or the presence of obstructions that cause lower than expected flow rates, the Step Drawdown Test can help determine if damage is occurring around the well, such as mud buildup or blockages in the formation, which can affect the well's efficiency.

c. Determination of Maximum Flow Rate (Well Capacity):

When it's necessary to determine the maximum well capacity without causing significant pressure loss , a Step Drawdown Test can help determine the maximum production rate achievable before significant formation damage occurs and identify the well's capacity limits.

Step Drawdown Test is important to determine the well capacity and aquifer conditions, so that it can be used for planning the use of groundwater efficiently and sustainably.

Results And Discussion

PUMPING TEST ACQUISITION AND ANALYSIS

1. Pumping Test Data Acquisition Stages

The following are the procedures or steps for collecting data in the Step Drawdown Test (A. Louwyck, 2010) :

a. Initial Preparation:

Equipment Setup: Ensure the well and pumping equipment are in good condition. The equipment used includes an electric water level sounder, a stopwatch , and an observation sheet.

b. Static Water Level Measurement:

Before starting pumping, measure the static water level to determine the depth of the water in the well when no pumping is taking place. Record this measurement as a baseline.

c. Step Pumping Stage :

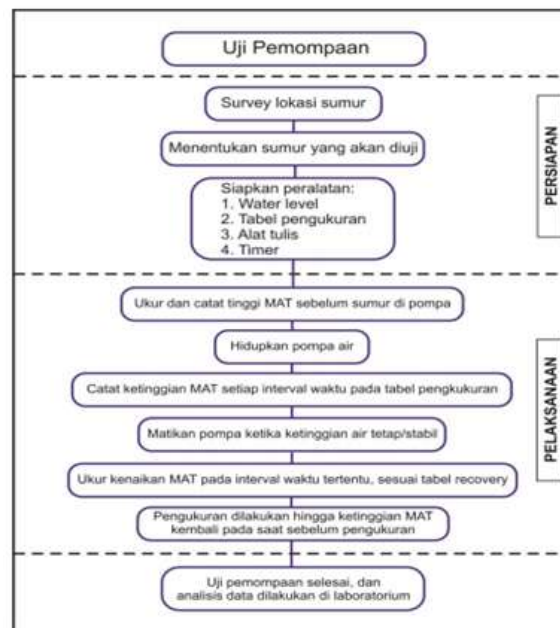
Pump water at a steady, low flow rate. Record the pump flow rate and measure the water level drop (drawdown) at specific time intervals. Record these on the observation sheet. Repeat the flow rate and drawdown measurements .

d. Stopping Pumping (Hold Instillation)

After completing the final pumping phase, stop the pump and observe the recovery of the groundwater level. Measure how the water level rises from its drawdown state after pumping stops. Record the rate of recovery periodically until the water level stabilizes and approaches its initial level.

e. Data Analysis and Interpretation:

Plotting Data: Create a graph of the pumping and recharge stages for each stage. This relationship between discharge and drawdown will reveal the characteristics of the well and surrounding aquifer using empirical analysis.



(Source : Geodynamics, Hydrogeology and Planning Lab, Diponegoro University

Figure 4. Pumping Test SOP Diagram

2. Pumping Test Results Analysis

Pumping test analysis , also known as pumping test, is a method used to determine the hydraulic characteristics of an aquifer, such as transmissivity (T), hydraulic conductivity (K), and storage coefficient (S). This test is carried out by pumping water from a well at a constant rate, while the water table in the well and a nearby observation well is measured periodically.

After collecting water level and time data, analysis is performed to calculate hydraulic parameters. The This method is commonly used in pumping test analysis.

The This method is used for confined aquifers and is based on a mathematical solution to the problem of water flow to a pumping well. This uses a type curve that matches measured groundwater level decline with a theoretical curve to calculate transmissivity (T) and storage coefficient (S).

The basic formula of the Theis method is:

$$S = \frac{Q}{4\pi T}W(u)$$

Where:

s = groundwater level drop (drawdown) in the observation well (m),

Q = pumping rate (m³/sec),

T = aquifer transmissivity (m²/sec),

W(u) = Theis well function,

u = dimensionless parameter calculated by the formula:

$$u = \frac{r^2 S}{4Tt}$$

Where:

r = distance from the observation well to the test well (m),

S = storage coefficient,

t = time since start of pumping (seconds).

This analysis steps:

Drawdown and time data are plotted on a semi-logarithmic graph. Using a Theis-type curve, field data are matched to find T and S values for aquifer analysis.

❖ Analysis of Transmittivity, Hydraulic Conductivity, and Optimum Discharge

Groundwater discharge analysis is performed to measure the rate of water flow produced by an aquifer through a well or other water source. Groundwater discharge (yield) is the volume of water that flows from a well in a given unit of time. Groundwater discharge analysis is important for understanding

groundwater availability for domestic, irrigation, or industrial purposes, and for ensuring that groundwater pumping does not exceed safe limits to maintain the sustainability of groundwater resources. Discharge is calculated using the formula:

$$Q = \frac{V}{t}$$

Where:

Q = water discharge (m³/s or L/s),

V = volume of water pumped (m³ or liters),

t = time (seconds).

a. WELL 1

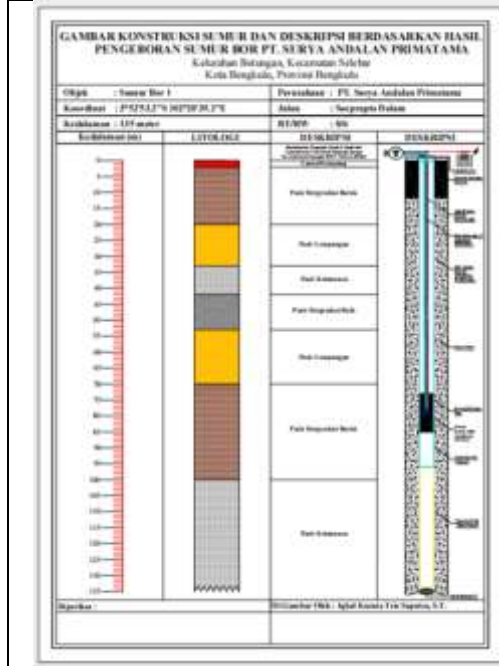


Figure 5. Well Construction Sketch 1

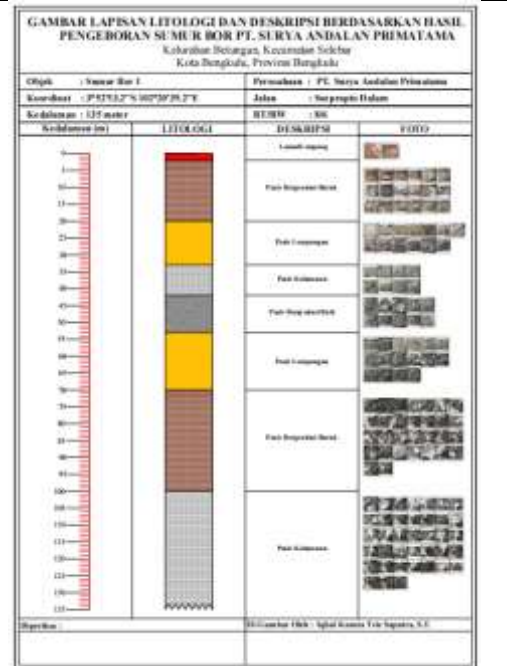


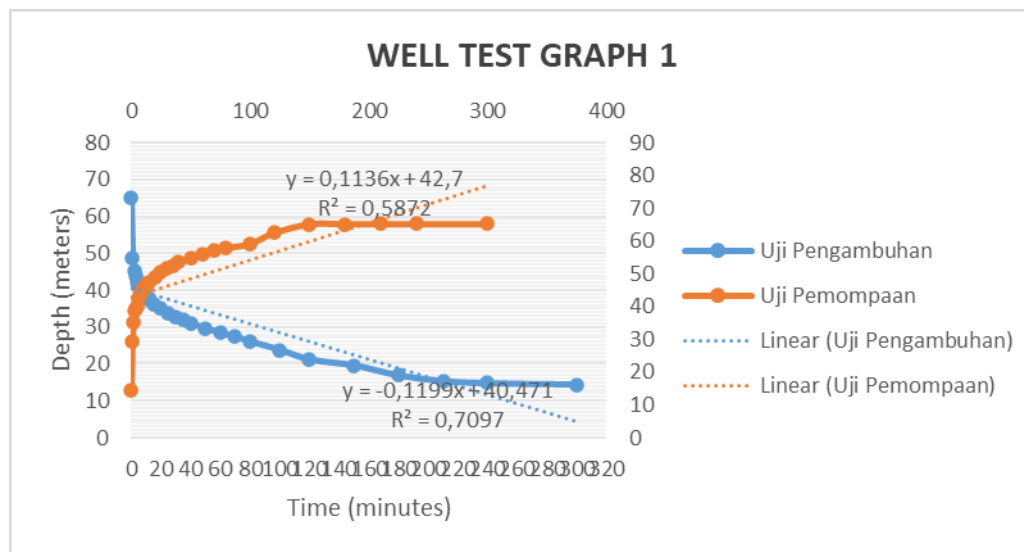
Figure 6. Description of Lithology Layer of Well 1

1 Pumping Test Data Processing

No	Minute	Depth Pumping (m)	Depth Affix (m)	Volume (m ³)	Delta h (m)	Delta time (minutes)	Discharge (m ³ /minute)
1	0	14.42	65.15	1.811152	15.08	1	1.811152
2	1	29.5	48.82	3.7052	5.86	1	3.7052
3	2	35.36	45.32	4.441216	3.34	1	4.441216
4	3	38.7	43.72	4.86072	0.67	1	4.86072
5	4	39.37	42.25	4.944872	0.72	1	4.944872
6	5	40.09	41.20	5.035304	2.25	1	5.035304
7	6	42.34	40.52	5.317904	0.99	1	5.317904
8	7	43.33	39.89	5.442248	0.72	1	5.442248
9	8	44.05	39.40	5.53268	0.68	1	5.53268
10	9	44.73	38.92	5.618088	1.07	2	2.809044
11	11	45.80	37.98	5.75248	0.9	2	2.87624
12	13	46.70	37.17	5.86552	0.74	2	2.93276
13	15	47.44	36.13	5.958464	1.64	5	1.1916928
14	20	49.08	35.00	6.164448	1.34	5	1.2328896
15	25	50.42	33.74	6.332752	1.05	5	1.2665504

No	Minute	Depth Pumping (m)	Depth Affix (m)	Volume (m ³)	Delta h (m)	Delta time (minutes)	Discharge (m ³ /minute)
16	30	51.47	32.78	6.464632	0.99	5	1.2929264
17	35	52.46	31.87	6.588976	0.97	5	1.3177952
18	40	53.43	31.03	6.710808	1.32	10	0.6710808
19	50	54.75	29.65	6.8766	1.4	10	0.68766
20	60	56.15	28.46	7.05244	1.1	10	0.705244
21	70	57.25	27.36	7.1906	0.65	10	0.71906
22	80	57.90	26.11	7.27224	1.25	20	0.363612
23	100	59.15	23.82	7.42924	3.28	20	0.371462
24	120	62.43	21.21	7.841208	2.72	30	0.2613736
25	150	65.15	19.62	8.18284	0.01	30	0.272761333
26	180	65.16	16.87	8.184096	0.01	30	0.2728032
27	210	65.17	15.35	8.185352	0.01	30	0.272845067
28	240	65.18	14.78	8.186608	0.01	60	0.136443467
29	300	65.19	14.41	8.187864			60.74553987
					50.77		2.169483567

the pumping test acquisition data processing on Well 1 produced the following graph:



Well 1 Pumping Test Data Processing Graph

Groundwater transmissivity is a measure of the ability of a soil or rock layer to conduct a specific amount of water through its pores. Technically, transmissivity measures the volume of water that can pass through a specific unit width of an aquifer (groundwater layer) in a given time under a given hydraulic pressure difference. This value depends on two main factors: the permeability of the aquifer's constituent materials and the aquifer's thickness.

The higher the transmittance value, the easier it is for water to move through the aquifer, which is important in groundwater resource planning, irrigation, and other water management projects.

The transmissivity equation for the Cooper-Jacob method is as follows:

$$T = \frac{2,3Q}{2\pi\Delta s}$$

From the data processing of the pumping test of Well 1, it is known that $Q = 2.17 \text{ m}^3/\text{minute} = 0.36 \text{ m}^3/\text{second} = 1,296 \text{ m}^3/\text{hour}$

$$T = \frac{2,3 (0,36 \text{ m}^3)}{2 (3,14) (1,8 \text{ m})}$$

$$T = 0,07 \text{ m}^2/\text{s} = 7.10^{-2} \text{ m}^2/\text{s}$$

Transmissivity (T) values vary greatly depending on the type of aquifer material and its geological conditions. There is no universal "should" value, but there is a general range based on the characteristics of the aquifer material. Transmissivity (T) values vary depending on the type of aquifer material and geological conditions. **The transmittance value in well 1 is categorized as high transmittance** according to Jacob and Lohma's hydrogeological standard literature regarding the general range of transmissivity values for various types of aquifer materials, namely in the range of 10^{-3} to 10^{-1} m²/s (100 to 10,000 m²/day). This aquifer contains sand and gravel, has **excellent water-conducting capabilities, and is often used as the main water source.**

Hydraulic conductivity (K) measures the ability of an aquifer material (such as sand, gravel, or clay) to conduct water under a given hydraulic gradient. Units of meters per second (m/s) indicate how fast water can move through the material under a given water pressure or gradient.

$$K = \frac{T}{D}, \quad T = \text{aquifer thickness} = 11 \text{ m}$$

$$K = \frac{3,5 \cdot 10^{-3} \text{ m}^2/\text{s}}{11 \text{ m}}$$

$$K = 3,2 \cdot 10^{-4} \text{ m/s}$$

According to Randall's Theory, the general range of hydraulic conductivity values 10^{-4} to 10^{-2} m/s contains coarse sand material. **This water conductivity value is quite high, meaning it can pass water well.**

Optimum water flow rate is the ideal flow rate to achieve a balance between demand and flow capacity of a system or channel without causing negative impacts. The optimum flow rate can be used to determine the most efficient flow rate for the system, allowing for maximum water utilization without causing problems such as water shortages.

This concept is often used to determine the rate of groundwater production that can be pumped from a well without causing excessive groundwater subsidence. The optimum water flow rate must take into account system capacity, demand, and sustainability. The optimal flow rate must match the physical capacity of the channel or pipe to prevent damage. Optimal pumping flow rate must be balanced with water demand. Furthermore, the optimum flow rate must be maintained to prevent overexploitation, which could reduce water availability in the long term.

$$Q_{\max} = 2\pi \cdot r_w \cdot D \frac{\sqrt{K}}{15}$$

r_w : well radius

D: aquifer thickness

K : hydraulic conductivity

$$Q_{\max} = 2,3,14 \cdot (0,1\text{m}) \cdot (11 \text{ m}) \left(\frac{\sqrt{0,64 \cdot 10^{-2}}}{15} \text{ m/s} \right)$$

$$Q_{\max} = 0,04 \text{ m}^3/\text{s}$$

The optimum discharge analysis is 0.04 m³/s or 144 m³/hour. This is intended to ensure that this value is appropriate to the needs, system capacity, and its environmental impact. This value must be maintained in the long term in the context of groundwater or limited water resources to avoid overexploitation that could lower the water level or deplete water resources. Ensure that this discharge is not too high or too low to avoid waste. The optimum discharge ideally provides the best results for needs without leaving water unused or flowing without benefit.

The optimum flow rate also considers the impact on the surrounding environment. Too low a flow rate can lead to drought, while too high a flow rate can cause channel erosion. To maintain the flow rate at the optimum value, regular monitoring is necessary. This ensures that changes in channel conditions, water use, or the seasons do not affect the availability of flowing water.

b. WELL 2

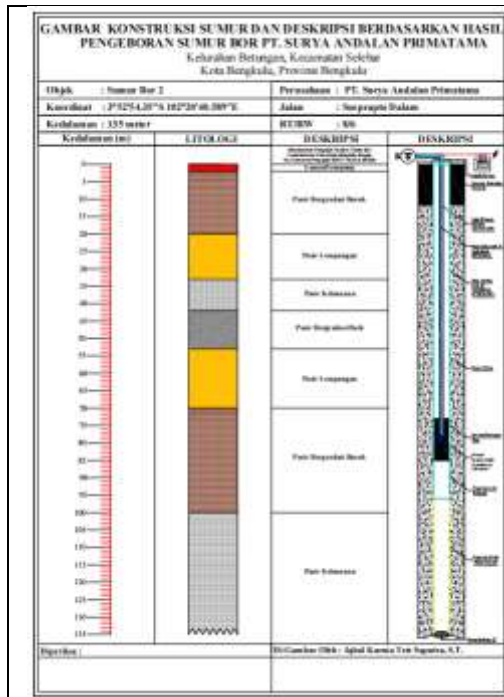


Figure 8. Well Construction Sketch 2

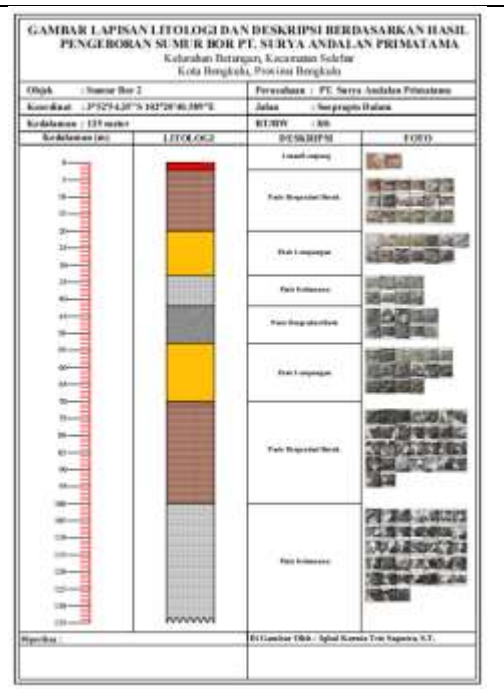


Figure 9. Description of Lithology Layer of Well 1

Data processing of Pumping Test of Well 2

No	Mi nut e	Depth Pumping (m)	Depth Affix (m)	Volume (m ³)	Delta h (m)	Delta time (minute)	Debit (m ³ /minute)
1	0	15.35	72.84	0.48199	4.05	1	0.48199
2	1	19.4	65.72	0.60916	3.9	1	0.60916
3	2	23.3	60.18	0.73162	2.01	1	0.73162
4	3	25.31	57.88	0.794734	3.05	1	0.794734
5	4	28.36	55.35	0.890504	1.34	1	0.890504
6	5	29.7	52.87	0.93258	2.64	1	0.93258
7	6	32.34	50.80	1.015476	0.88	1	1.015476
8	7	33.22	48.76	1.043108	0.88	1	1.043108
9	8	34.1	47.05	1.07074	0.62	1	1.07074
10	9	34.72	45.26	1.090208	1.06	2	0.545104
11	11	35.78	42.10	1.123492	0.92	2	0.561746
12	13	36.70	39.45	1.15238	0.95	2	0.57619
13	15	37.65	36.40	1.18221	1.56	5	0.236442
14	20	39.21	29.58	1.231194	1.21	5	0.2462388
15	25	40.42	27.32	1.269188	0.86	5	0.2538376
16	30	41.28	25.70	1.296192	1.18	5	0.2592384
17	35	42.46	24.69	1.333244	0.65	5	0.2666488
18	40	43.11	24.03	1.353654	0.88	10	0.1353654
19	50	43.99	23.17	1.381286	1.23	10	0.1381286
20	60	45.22	22.56	1.419908	1.65	10	0.1419908
No	Mi nut e	Depth Pumping (m)	Depth Affix (m)	Volume (m ³)	Delta h (m)	Delta time (minutes)	Discharge (m ³ /minute)

21	70	46.87	22.06	1.471718	0.38	10	0.1471718
22	80	47.25	21.62	1.48365	2.65	20	0.0741825
23	100	49.90	20.86	1.56686	2.99	20	0.078343
24	120	52.89	20.01	1.660746	2.36	30	0.0553582
25	150	55.25	19.62	1.73485	1.47	30	0.057828333
26	180	56.72	18.87	1.781008	5.12	30	0.059366933
27	210	61.84	17.36	1.941776	6.31	30	0.064725867
28	240	68.15	16.73	2.13991	4.73	60	0.035665167
29	300	72.88	15.34	2.288432			11.5034842
					57.53		0.410838721

the pumping test acquisition data processing on Well 2 obtained the following graph.

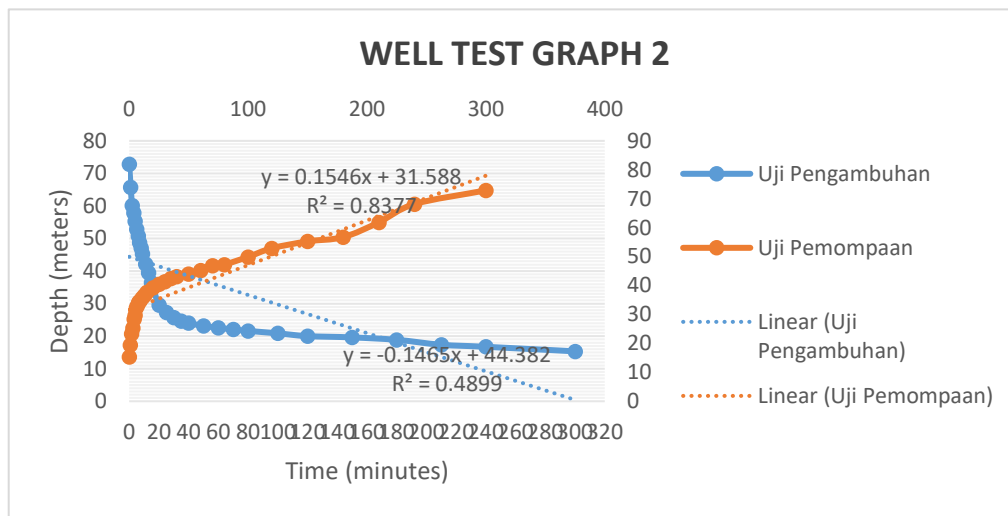


Figure 10. Data Processing Graph for Well 2 Pumping Test

By using the same calculation model as Well 1, then in Well 2 we get:

$$Q = 0.41 \text{ m}^3/\text{minute}$$

$$T = 1.38 \cdot 10^{-3} \text{ m}^2/\text{s}$$

The transmittance value in well 1 is categorized as **high transmittance** according to Jacob and Lohma's hydrogeological standard literature regarding the general range of transmissivity values for various types of aquifer materials, namely in the range of 10^{-3} to 10^{-1} m^2/s (100 to 10,000 m^2/day). This aquifer contains sand and gravel, has excellent water conduction capabilities, and is often used as the primary water source.

$$K = 1.3 \cdot 10^{-4} \text{ m/s}$$

According to Randall's Theory, the general range of hydraulic conductivity values 10^{-4} to 10^{-2} m/s contains coarse sand material. **This water conductivity value is quite high, meaning it can pass water well.**

$$Q_{\max} = 0.08 \text{ m}^3/\text{s} = 288 \text{ m}^3/\text{hour}$$

The optimum discharge analysis of 0.08 m^3/s must be maintained long-term in the context of groundwater or limited water resources to avoid overexploitation that could lower the water table or deplete water resources. Ensure that this discharge is neither too high nor too low to avoid waste. The optimum discharge ideally provides the best results for needs without leaving any unused water or flowing uselessly.

❖ Well Efficiency Analysis

Well efficiency analysis is a critical step in understanding how well a well can deliver water to the surface relative to the energy or effort required. Good well efficiency means the well produces water at an optimal flow rate without experiencing excessive water level drop, leakage, or flow obstruction.

Well hydraulic efficiency is the ratio between the actual flow rate (the discharge produced by the well) and the theoretical discharge (the discharge that should be produced by the aquifer based on its geological characteristics) under certain drawdown conditions.

Based on the graph or data obtained, analyze the well's efficiency by observing whether the decrease in groundwater level is proportional to the increase in discharge. If there is a significant decrease at low

discharge, this indicates low well efficiency. Ideally, a well's efficiency should approach 100%, meaning the well can draw water without causing excessive water level decline around the well.

$$\begin{aligned} \text{Efisiensi Sumur} &= \frac{\text{Drawdown Akuifer}}{\text{Drawdown Sumur}} \times 100\% \\ \text{Efisiensi Sumur} &= \frac{65 \text{ m}}{72 \text{ m}} \times 100\% \\ \text{Efisiensi sumur} &= 90 \% \end{aligned}$$

Well efficiency analysis aims to ensure that the well can produce water optimally with minimal cost, energy, and environmental impact. At the boundary of the CPO processing plant, PT Surya Andalan Primatama has a well with **high efficiency**. This includes evaluating the well design, efficiency testing through step-drawdown tests, maintenance, and optimizing the pumping rate. High-efficiency wells are more cost-effective, sustainable, and have a lower environmental impact, which is very important for long-term groundwater management. This is influenced by several factors including well design/construction, aquifer transmittance, well diameter, pump type, and pumping speed.

A well with a good design, including the correct casing, filter, and gravel pack, allows for smoother water flow. Design errors can increase hydraulic resistance, reducing efficiency. The transmissivity of the well's aquifer at the site is quite high, with coarse sand material allowing water to move more easily into the well. Wells 1 and 2 have a diameter of 8 inches. A larger diameter improves efficiency because it offers more space for water flow. Likewise, a pump that is too powerful or pumping at too high a rate can cause significant drawdown, reducing efficiency. Proper pumping, tailored to the characteristics of the aquifer and the well design, is key to maintaining efficiency.

❖ Aquifer Analysis

Groundwater aquifer analysis is the process of understanding the physical and hydrological characteristics of aquifers, which are underground layers that store water and allow its flow. This analysis is essential for determining groundwater potential, ensuring the sustainability of pumping, and preventing exploitation that could lead to land subsidence or water shortages.

Data on aquifer characteristics are needed to determine the capacity of groundwater that can be stored in the soil layer and the capacity that can be used. Estimation of aquifer parameters such as transmissivity (T) and storage coefficient (S) can be calculated using specific analytical methods such as the Jacob or Theis methods.

Based on its characteristics, the aquifer in the well in the Batar area of the PT Surya Andalan Primatama CPO processing plant is a confined aquifer, namely an aquifer located between two impermeable layers, so that the water is trapped inside and is under pressure. When the well is drilled until it reaches this aquifer, water will usually gush to the surface (artesian well) due to natural pressure.

The hydraulic characteristics of the aquifer also revealed a relatively high hydraulic conductivity (K). This indicates how easily water can flow. Aquifers with high hydraulic conductivity have a better ability to drain water. Likewise, transmissivity (T) describes the aquifer's total ability to conduct water. The calculations showed a high transmittance value.

To maintain aquifer sustainability, monitoring and management policies are implemented. Routine monitoring of groundwater levels, pumping rates, and recharge rates is necessary. Effective groundwater management policies, such as pumping restrictions and infiltration enhancement, are also crucial.

The groundwater aquifer at the PT Surya Andalan Primatama CPO processing plant **is considered good**. Aquifer analysis is a multidisciplinary process that includes identifying the aquifer type, assessing its hydraulic characteristics, conducting pumping tests, and conducting a sustainability analysis. This analysis enables water resource managers to ensure efficient and sustainable groundwater use. It also considers quality and environmental impacts, ensuring long-term groundwater availability without damaging the ecosystem or the water resource itself.

❖ Well Distance Analysis

The recommended optimal spacing between wells depends on the aquifer type, geological conditions, pumping rate, and intended use of the groundwater. Confined aquifers are typically confined aquifers, with a minimum spacing of 150-300 meters. Confined aquifers have higher water pressure, allowing wells to be spaced closer together than unconfined aquifers. However, the risk of water level subsidence must still be considered.

Referring to the pumping rate (Q), the distance between wells is known that the greater the pumping rate, the greater the radius of influence and the further the distance between wells required. Based on the pumping test and calculation results, it was obtained that the discharge value is > 20 liters/s, so the minimum distance between wells should be more than 500 meters.

Conclusion

Based on the results of the pump test and groundwater feasibility analysis, it can be concluded that the aquifer potential at the test site has sufficient capacity to meet water needs. The pump test provides

information on the aquifer's hydraulic characteristics, such as hydraulic conductivity and transmissivity. With this data, we can obtain an estimate of the optimum discharge that can be maintained without causing significant water level decline, thus enabling sustainable groundwater utilization planning. The recommended spacing between wells is greater than that of existing wells, and monitoring wells are required.

Groundwater feasibility analysis also showed that water quality at the test site meets the required standards for its planned use. However, this groundwater utilization still requires sustainable management. Regular monitoring of water discharge and quality is crucial to prevent overexploitation and avoid potential problems such as land subsidence and seawater intrusion, particularly in coastal areas. These efforts will ensure that groundwater resources continue to support the needs of the community and the environment in the future.

Author Contributions

Fadilah played a key role in the research design, data collection, and analysis of pump test results on both wells. The author also drafted the manuscript and ensured the integration of technical findings with academic discussions. A support team from PT. Surya Andalan Primatama assisted in providing field data and access to the test sites.

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Conflict Of Interest

The author declares that there is no conflict of interest in the research or publication of this article. All stages of the research, analysis, and writing were conducted in accordance with scientific principles and publication ethics, including data authenticity, academic honesty, and information transparency.

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