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Evaluation of Groundwater well rehabilitation

Diploma Thesis

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Abstract

The pumping test carried out at the well of the municipality of Bela Crkva in Serbia to evaluate the process of Rehabilitation. Basically, well rehabilitation method is a useful procedure to expand the life of well. This process also makes the well the more productive and efficient. For calculating we used the Cooper Jacob method. To measure the parameter, we Theis method. This method is the simplification of Cooper Jacob method. By those method we measure the parameters like Storativity and Transmissivity. To estimate Transmissivity, it is needed to measure drawdown and time interval from pumping well. Observation well is used to calculate the storativity. After getting the value of drawdown and time interval it is placed in a semi log graph to obtain a Theis curve.

To evaluate the result Additional resistance is calculated before and after cleaning well. Additional resistance is the main cause of Pressure drop or additional drawdown. On the other hand, skin-effect are mainly responsible for having additional resistance. To measure the difference of Additional resistance before and after rehabilitation is the main aim of whole procedure.

Key words: Well, Pumping well, Rehabilitation , Additional resistance

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1 INTRODUCTION

Groundwater arises almost everywhere under the surface of the earth and is an important part of a complex hydrological cycle involving continuous water movement on Earth. The abundant presence of potable groundwater is a significant reason for its use as a means of worldwide water supply. Additionally, irrigation, which depends on freshwater, provides much of the world's grain. During dry periods, groundwater plays a crucial role in preserving streamflow and is important to many lakes and wetlands. Several plants and aquatic animals rely, in addition to human uses, on the groundwater that discharges into streams, lakes and wetlands. Groundwater is a valuable resource. Knowledge is collected at individual wells and spring sites by indirect calculation methods such as surface geophysics and flow and water level measurements at hydrologically related water bodies such as streams, lakes, and wetlands. Such data are used to infer groundwater presence, movement, and properties. (Gene E. Likens, 2009).

Groundwater is a simple source of water. It is typically free of contaminants relative to surface water and is less prone to soil-derived pollution. Evaporation losses are small, so surface impoundments are not used with any ground. Wide aquifers are also less vulnerable to annual water cycle vagaries and can provide a stable and reliable source. Globally, over 50% of drinkable water comes from groundwater (Beckie, 2013).

When focusing on groundwater flow problems, the geologist must find reliable values for the hydraulic properties of the geological formations that the fluids. Pumping tests have been shown to be one of the most efficient ways to obtain some values. Nevertheless, interpretation and assessment of the pumping test data is just as much an art as a theory. It is based on mathematical models that must be interpreted by the geologist or technician, and on thorough research to be performed in the test area into the geological formations. It is an art, as different types of aquifers can show specific drawdown actions that allow the geologist to have understanding skills (G.P. Kruseman N.A. de Ridder, 1994). In pumping test, we basically measure transmissivity and storativity. Which is most important parameter for evaluation of pumping.

2 OBJECTIVE OF STUDY

The main purpose of the study is to analyse the pumping test of a well which is situated at Bela Crkva in Serbia. Transmissivity and storativity are the main components we will have to find. We will measure those components both before and after cleaning. Then we can measure additional resistance and skin factor by using that transmissivity and storativity.

The main question of my thesis will be "Analyse the pumping test before and after of a well"

And the subqueries will be

- ✓ Evaluate the effect of cleaning.
- ✓ Measuring of additional resistance and skin factor.
- ✓ Measuring Transmissivity.
- ✓ Measuring sotarivity of an aquifer.
- ✓ Comparison of parameters before and after cleaning.

3 LITERATURE REVIEW

3.1 Groundwater Characteristics and Resources

It is important to know about groundwater characteristics prior to installing groundwater well. Water quality, flow, location of groundwater are the essential factors to notice before withdrawing water. Groundwater applies to all the water that fills the voids, pores, and fissures within geological formations that emerged either directly from runoff penetration or indirectly through rivers, lakes or canals through atmospheric precipitation. Rock, gravel, sandstone are the typical sources of ground water. Even a considerable amount of water can be found inside impermeable rock like granite (Olumuyiwa, 2012). The amount of groundwater that exists beneath the surface is formed from the following three sources. Meteoric water is produced from precipitation in the atmosphere by mainly rain and snow, which provide rivers, streams, and creeks with surface and sub-surface runoff. Connate water is found inside gravel, limestone, and sandstone. Another one is magmatic water which is formed inside pores and voids of rocks during the formation of magmatic rock. (Jones, 2018).

3.1.1 Groundwater Distributions

There are mainly two zones under subsurface soil. One of the saturated zones and another one is the unsaturated zone. These zones are classified according to air and water is filled pore space. If pore space is filled by water, then it is called a saturated zone. On the other hand, if pore space is filled with air it is known as an unsaturated zone. Unsaturated zone is the bigger portions of the subsurface area. Unsaturated zones contain no water, but root zone, intermediate zone and capillary fringe zone of unsaturated zone help water to enter the saturated zone. Various factors are also important to recharge of the saturated zones like plant uptake, evaporation, and precipitations (D. R. NIELSEN, 1989).

3.1.2 Driving Forces on Groundwater

There are different kinds of forces are acting on ground water like gravitational forces, the pressure of top layer, atmospheric pressure. Some other forces between soil and water molecule are adhesive and cohesive forces. Differences in potential energy are caused by the distribution of both surface water and groundwater. In other words, water flows downhill, from high energy potential to low energy potential. In the case of surface water, flow happens in response to variations in gravitational potential energy caused by changes in elevation. Things are a bit complex on groundwater networks.

Like surface water, which is in contact with the atmosphere and therefore never under control, it is separated from the soil surface of groundwater systems. This means that groundwater can have pressure-related potential energy, too. Water is confined aquifers can in extreme cases be under sufficient pressure (society, n.d.). we can calculate potential energy by measuring hydraulic head. The hydraulic head includes two components: (1) potential energy due to its height above a reference point, usually mean sea level

Pressure head

Therefore, Bernoulli’s equation is defined as follows:

$$h = z + \frac{p}{\rho g} + \frac{v^2}{2g} \tag{3.1}$$

Here h is the hydraulic head, z is the height above a reference point (m), p is pressure (Pa), ρ is ~~called~~ density of water (kg/m^3), v is the velocity of water, (m/s) and g is gravity acceleration, (m/s^2). Pressure head can be written as

$$h = \frac{p}{\rho g} \tag{3.2}$$

Because groundwater velocity is negligible, so energy head from Bernoulli equation is

$$h = z + \frac{p}{\rho g} \tag{3.3}$$

3.1.3 Aquifers

Aquifers can stretch over hundreds and thousands of kilometres of square underground, while the thickness of an aquifer can range from tens to hundreds of meters. For this reason, aquifers are often modelled as large yet thin sheets of porous material with properties that are constant across their depth and can differ only on the sheet surface. Such a two-dimensional representation, referred to as the hydraulic model of an aquifer, is commonly used in the regional study of groundwater flow when depth differences in water quality are essentially negligible (Bacmat, 2005).

The aquifer is a highly permeable geological structure that can move possible quantities of water. (G.S., 2015). An unconfined aquifer is not surrounded by a confined layer and become refilled by directly downward and upward seepage of water. Confined aquifer is surrounded by impermeable layer and semi permeable layer.

3.1.4 Water table

water table is known as an atmospheric pressure surface which is like the top of the saturation zone. But many experts argued that saturation zone and capillary fringe can be found above the water table. Even there can be unsaturated under the water table (Hozler, 2010).

3.1.5 Core Analysis

Another element of reservoir is core analysis. Core analysis are mainly used for log analysis. Reservoir descriptions, critical analysis are the parameters which are collected from core analysis.

3.1.6 Permeability

Permeability is a characteristic of soil, this factor can be measured.

3.1.7 Saturated and unsaturated zone

There are two zone where water can be present. Each zone contains pore space. If pore space is fill with fluid, then it is called saturated zone. Underground zone close to surface is known as unsaturated zone. Fluctuations of storage of water is high at unsaturated zone because of evapotranspiration.

3.1.8 Motion in Groundwater

Groundwater flows underground until it enters a discharge zone, and region just above surface of the earth. Springs are discharge zones which are completely visible. The groundwater which flows into wetlands or contributes to stream flows is less evident. During growing season, if the water table is close to the ground surface, large amounts of groundwater may be removed by plant roots and released into the air by plants. In some areas even evaporation will discharge groundwater into the air.

3.2 Dracy's law

3.2.1 Darcy's law in 3 dimension

To explain this equations law for mass conservations can be used**.** In mass conservations law it is said that mass of fluid does not change in small aquifer. The one-dimensional type of Darcy's Law can be summed up to three measurements with the end goal that the potential head, element of the three space arranges, x, y, and z. Subsequently the velocity v is a vector with segments, and to such an extent that the potential head is reliant on the position (Macleod, 1995). The three-dimensional speculation of Darcy's Law

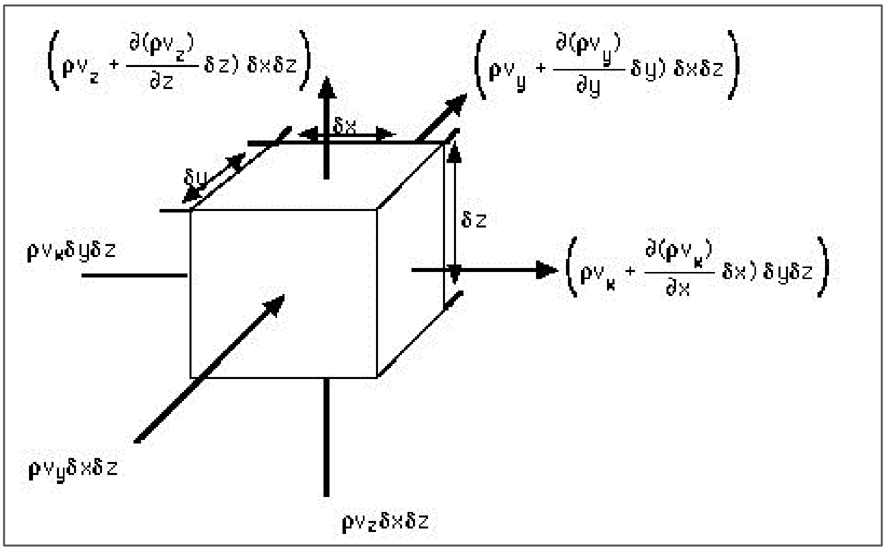

Figure 1: Three-dimensional figure of Darcy's Law (Hitejema, 1995)

$\rho v_x\delta_y\delta_z$, $\rho v_y\delta_x\delta_z$ and $\rho v_z\delta_x\delta_y$ are the amount of inflow. Here ρ is density of water, v_x, v_y and v_z are the velocity respectively to the x, y and z direction. Comparing with the law of conservation of issue suggests this all must equivalent to mass regarding time

$$(\frac{\partial(\rho v_{x)}}{\delta x} + \frac{\partial(\rho v_{y)}}{\delta y} + \frac{\partial(\rho v_{z)}}{\delta z}) \text{ v} = -\frac{\partial(M)}{\partial t} \quad (3.6)$$

If ρ is constant, then velocity

$$v_s = -K\frac{\partial h}{\partial s} \quad (3.7)$$

3.3 Wellbore-storage and Skin effect

Production of pumping water can fluctuate because of extension and compression of underground fluid. Liquid connection is mainly responsible for this for this fluctuation. This incident known as wellbore-storage effect. (Jelmet, 2003). Many well test methods apply in a steady rate. Assume that surface stream rate, q, steady. Initially water originates from the wellbore storage and not form the supply of reservoirs. Reservoir discharge q_{sf}, and flow rate form wellbore storage $q_{wb.}$ Pumping rate at surface q. If we put this in equation

$$q = q_{sf} + q_{wb.} \quad (3.8)$$

Skin factor is one of the most important dimentionless factor to calculate before design and understand any well performence. Skin factor consists with geometric properties and fluid properties around of the well.

There are mainly two type of skin factor one is positive skin factor and another is negative skin factor . Positive skin factor rise pressure drop and decrease the flow rate and negative skin factor reduce the pressure drop increase flow rate. (M.T. Byrne, 2012).

It was recommended that a skin impact could emerge physically in various ways. One basic precedent is expected that an annular volume nearby the wellbore is decreased consistently to a lower penetrability than the first esteem. This would be like the composite repository issue. Maybe a superior precedent would be to accept that the porousness increments consistently from a low an incentive at the wellbore to a steady esteem in the whole repository.

In another case, the harmed area would have a limited storage and would prompt transient conduct inside the skin area. (H. J. RAMEY). A negative skin impact could emerge from an increment in porousness inside an annular area adjoining the wellbore.

This may physically happen because of acidizing. In any case, it is assumed that cases of progressively visible down to earth significance are those in which negative skin impacts are brought about by hydraulic cracking. A high-permeability break connect with the wellbore can negative skin impact.

More accurate result can be achieved which will show more similarity between theory and well production. If we account permeability close to around wellbore. Instead of measuring pressure drop its better to calculate skin factor. Relation between well productivity and skin effect are not unique. Because variance of radius of drilling (Murray F).

3.4 Hydraulic conductivity

Hydraulic conductivity set apart as K, or K-values, is one of the basic and most essential parameters at soil hydrology It is a vital factor in water transport in the aquifer. It is utilized in all equations for the subsurface water stream. For calculating infiltration process k is used repeatedly (Stibinger,). It can be described as the capacity of soil media to transmit water. This property of water basically relies on shape and size of soil particles, pore diameter and permeability of soil media. conductivity showed by sign K unit of hydraulic conductivity is (M.T-1) where M means of length and T is express time. The meaning of the conductivity comes from Darcy's Law.

In the immersed stream conditions the speed of water stream v (M.T-1) in the soils or in the different permeable media. Conductivity is proportional to the pressure gradient. In practice, the hydraulic gradient value is usually less than 0.1, so usually, v is less than0.1K. Because K's value is usually less than 10 m / d, v is almost always less than 1 m / d. A saturated soil's K-value represents its average hydraulic conductivity, which depends primarily on the pores ' size, shape, and distribution.

It also depends on the temperature of the soil and water's viscosity and density. The hydraulic conductivity of the soil was defined in Darcy's Law as the constant of proportionality (Nijland, 1994).

$$v = K \frac{dh}{dx} \qquad (3.9)$$

v is the water, K is hydraulic conductivity, h hydraulic head, x Distance in the groundwater flow direction. dh/dx represents the hydraulic gradient (s) in Darcy's equation, which is the difference between a small difference of x. It is, therefore, possible to express the hydraulic conductivity as

$$K = \frac{v}{(\frac{dh}{dl})} \tag{3.10}$$

3.5 Transmissivity

The transmissivity is explained as the flow rate of fluid through fully saturated media (G.P. Kruseman, 1994). The ratio in which water is transmitted by a unit. The rate of transmission depends on the elements of fluids like density and viscosity also thickness of an aquifer. The accumulation of properties can be described as hydraulic conductivity. The transmissivity can be express as

$$T = K.b \tag{3.9}$$

Where b is defined as thickness of aquifer (m), and K is known as hydraulic conductivity.

3.6 Storativity

Storativity is expressed as an amount of water, that can be extracted from an aquifer at a unit area at per distance of hydraulic gradient under the force of gravity flow at water table water is drained because of hydrostatic pressure in a void below the water table from an aquifer (Stephen A. Rackley, 2017).

The small effect of rock and fluid compressibility is generally neglected for an unconfined aquifer, and S is equal to the specific yield (Sy), which is defined as the volume of water draining from the aquifer's unit bulk volume under the force of gravity.in a void below the water table. The specific storage is the volume of water that can be drained in a formation at a alternation of hydraulic head.

3.7 Governing equation of ground water flow

It is assumed an ideal confined aquifer without recharging and leakage from an aquifer with an infinite length of constant thickness. Transmissivity and storativity across the aquifer length are homogeneous and isotropic. The pumping is done at a constant discharge rate (Q) and the time and space of the hydraulic head is constant. Darcy's law, which is written as follows, can calculate the discharge. (Mirza, 2016)

$$Q = -2\pi r T \frac{\partial h}{\partial r} \qquad (3.11)$$

Where T is the transmissivity (m^2/s), r is the radial distance at a given point in an aquifer (m) and h is an aquifer's hydraulic head (m).

The basic equation for unsteady radial flow of groundwater to well in radial coordinates can be written as (Theis, 1935)

$$\frac{\partial^2 h}{\partial r^2} + \frac{\partial h}{\partial r}\frac{1}{r} = \frac{S}{T}\frac{\partial h}{\partial t} \qquad (3.12)$$

Where T= K.b is the transmissivity with saturated thickness b. By using radial coordinates, it's possible to obtain the same equation. To solve the flow equation, the initial and boundary conditions must be specified. The initial conditions are a constant hydraulic head, h(r,0) = h_0, r_w< r < ∞ where r_w is the well radius. The infinity boundary conditions. h(∞,t) = h_0 for all t ≥ 0. (Engesgaard, August 2003)

$$2\pi \mathrm{Tr} \frac{\partial h}{\partial r} = Q_w \qquad (3.13)$$

where Q_w is the pumping rate (m^3/s)

Solving the drawdown s= h_0-h_a is common practice, therefore

$$\frac{\partial^2 s}{\partial r^2} + \frac{\partial s}{\partial r}\frac{1}{r} = \frac{S}{T}\frac{\partial_s}{\partial_t} \qquad (3.14)$$

And in the same way, the initial and boundary conditions are changed. The so-called solution of Theis is provided by

$$s\ (r,\ t) = \frac{Q_w}{4\pi r T}\ W(u) \qquad (3.15)$$

where W(u) is the Theis well function

$$W\ (u) = \int_u^{\infty} \frac{e^{-u}}{u}\ du \qquad (3.16)$$

and u is known as argument of Theis well function

$$u = \frac{Sr^2}{4Tt} \qquad (3.17)$$

3.8 Pumping Test

The pumping test is a method that is used to measure transmissivity and storativity of a geological formation between two or more wells. With this technique, the withdrawal of water from the pumping well is attempted to impact the hydraulic head in the development in a direct connection. Accepting the arrangement is homogeneous, isotropic, restricted, confined, and single porosity.

Sands and gravel are considered high-storativity media. the fractured rock contains low-storativity. To analyse, the pumping data mathematical curve is used.

Pumping test is also affected by permeability of area around well. (Novakowski, 1989).

The well test is a procedure used to assess the transmissivity and storativity properties of soil material for water-supply purposes. Reaction information from a well test can be utilized to assess subsurface properties utilizing inversing plans dependent on diagnostic or on the other hand numerical remedy for the proper stream conditions.

Because of advancements before the boundless utilization of PCs and the typical sparsity of monitoring well data, inversing plans dependent on investigative arrangements have principally been utilized for assessment of framework properties (James, 1988).

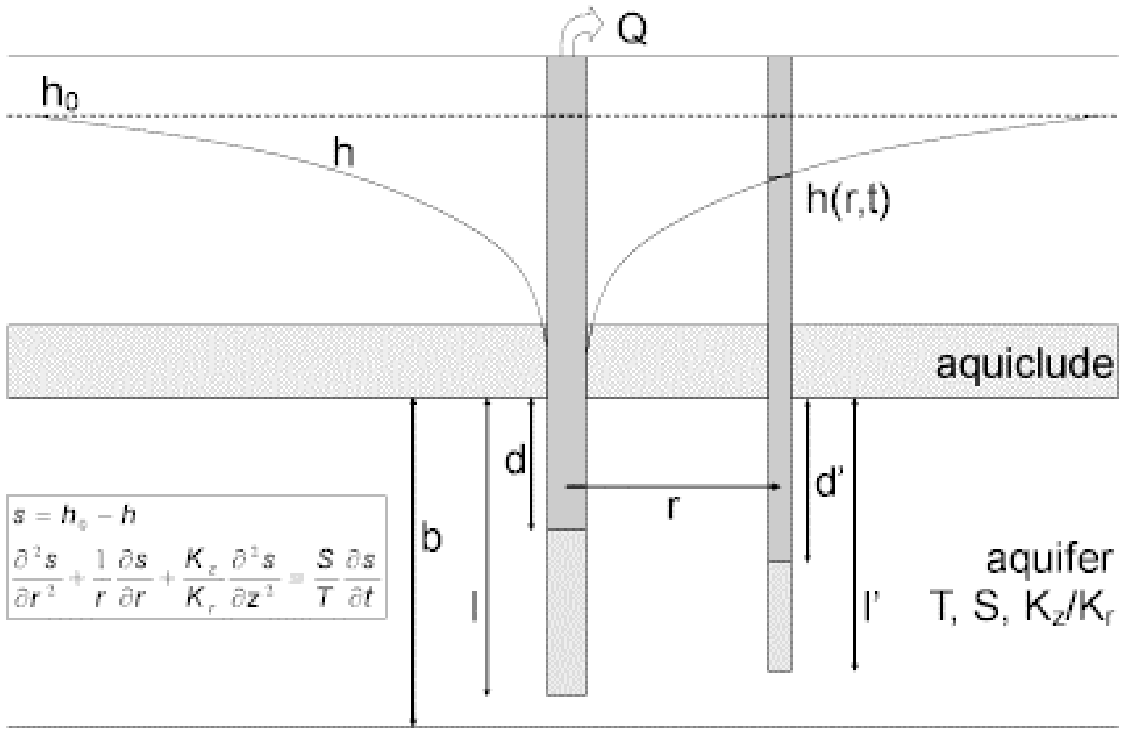

Figure 2: Pumping Test (JAMES J. BUTLER, 1988)

3.8.1 Drawdown test

The drawdown test is feasible for new wells or wells that have been shut in for an extensive stretch. Another drawback is that it might be hard to keep the flow rate steady. The preferred standpoint is that one may create while testing. Well test evaluation relies upon scientific models. The watched weight conduct in a test is coordinated to a conceivable model. The objective variable(s) are evaluated from the coordinated model. In the event that the accepted model is off base, the translation will prompt mistaken assessments. Understanding of the drawdown test may fill in as the first case of this system. The suppositions are Static harmony at first, steady flow rate, homogeneous and vast acting reservoirs. (Testing, 2013).

- Increment the discharge rate from 0 to q at time t = 0 Keep the rate consistent
- Measure the pressure reaction.
- Make validation by observing the previous model.

3.8.2 Pressure Buildup Test

A pressure drawdown test needs to begin from a no-flow condition. Thus, along the streaming period before shut-in is required. Moreover,8- it is hard to keep the rate consistent. The last issue is alleviated in a development test.

The creation rate is basically zero (consistent) once after flow ends up irrelevant. What's more, the development test might be directed whenever. The drawback of the technique is that the well must be shut and won't create outflow. From a monetary point of view, the shut-in time ought to be as short as could be expected under the circumstances. The shorter shut-in period prompts less data. (Jemlet, 2003).

3.8.3 Additional Resistance

The pressure drops in a well per unit flow rate highly depends on the formation resistance, fluid's viscosity, and the additional resistance distributed around the wellbore. Drilling, processing methods and production practices are mainly responsible for creating that resistance. The skin factor is one of the additional resistances which causes the pressure drop. The skin factor has a great impact on well capacity. Methods are used to evaluate quantitatively (a) the magnitude of S, (b) the final pressure build up and (c) the sum of average permeability times the producing formation thickness (van Everdingen, 1953).

4 Materials and Methods

This part of the thesis paper consists with research proposal, a brief descriptions of study area, calculations, and equipment. Different methods of pumping test and calculations of additional resistance.

4.1.1 Research Plan

For pumping test, a huge number of data were collected from pumping well and observation well. Pumping test happened in a pumping well which is inside research area.

We collected data for date, time, draw-down, head and discharge. The accuracy of pumping highly depends on data collection of pumping tests as well as observations. Basically, data we collected from observation well were used to measure storativity and transmissivity of well.

Table 1: Formats for taking observation from pumping well

Date	Time	t (sec)	t(min)	log t (s)	h1 (m)	Drawdown s (m)	Q (l/s)

For observation well we estimated these parameter from following observation

Table 2: Formats for taking observation from observation well.

Date	Time	t (sec)	h1 (m)	h2 (m)	Drawdown s (m)

4.1.2 Research Area

VODNI ZDROJE, a.s, has been doing business since September 2015. The infrastructure collaboration project "Establishing a sustainable drinking water supply system for the municipality of Bela Crkva" has been carried out in the Romania. The project aims to establish a sustainable system of drinking water supply for the citizens of the municipality of Bela Crkva, located in Vojvodina Autonomous Province. This project follows previous development collaboration activities of the Czech Republic in Serbia undertaken as part of the project "Sewerage network construction in the village of Kruscica"(2012-2014). Bela Crkva municipality is in located at the south-eastern part of Vojvodina province nearly 100km from Belgrade. It's in close to the border of Romania.

Figure 3: 1 Situation of wells of Bela Crkva (Google, 2012)

Firstly, B3 was cleaned. Until the borehole was washed the borehole was examined following removal of the original pump and discharge pipe. From the enclosed images, which are seen before the restoration of the filter holes, it is apparent that a relatively low degree of loads on the interior of the well. The filters are clean, ferrous growths only appear in the lower sections of the filter eyes, which are a most likely metabolic waste because of bacteria. Longitudinal circular holes in steel with a transverse diameter are 5 inches, fitted with stainless mesh was used at recover operations. After regenerating of boreholes, we used camera to observe the situation. But we cannot take the picture because of turbidity.

For well B6, Post-regeneration inspection, whose findings showed a substantial clean-up of the borehole equipment up to a depth of 80 m. Because of the chemical component of the regeneration, it is probably that there was a partial clean-up under the stranded steel wire. we cannot take photos to verify. However, a camera cannot check the sweeping.

4.1.3 Measurement of Parameter

For data collection, there should be no open zone between well drilling, pumping and monitoring wells in the same groundwater reservoir. Inside the well, the measurements are made by downhole recorders. Firstly, to measure the temperature and pressure we use a pressure gauge. Wireline connection is used for the calculation of surface pressure.

The drawdown can be measured using a small-diameter pressure transducer using a direct push system. To reduce the expense and time consumption, we use the transducer. This direct push approach does not use the movement of the cable Alternatively, a polythene tube

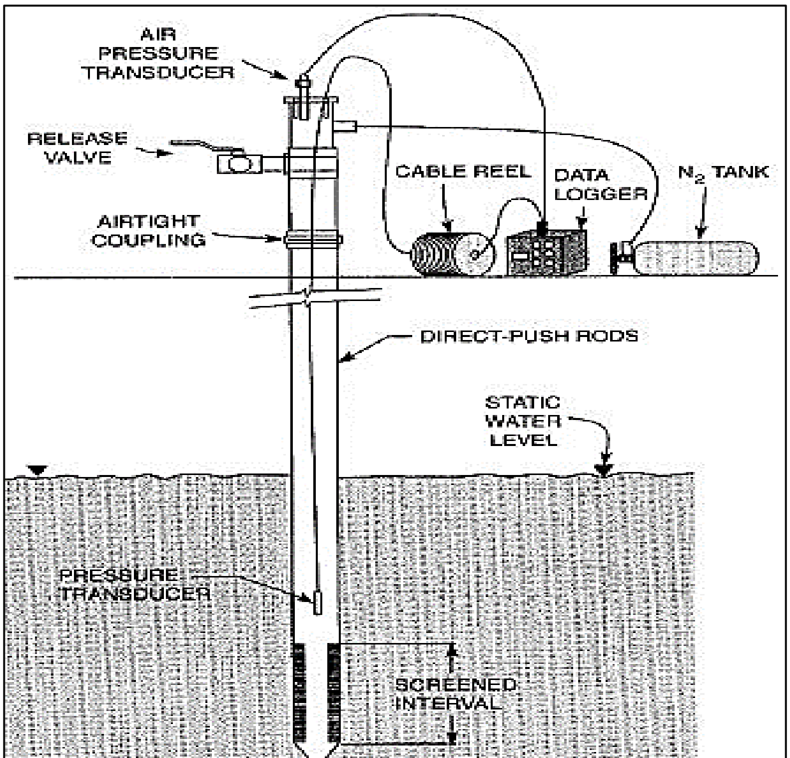

Figure 4: 3 The measurement of well condition (Loheide, 13 December 2005)

is used to connect the transducer that measures air pressure above the column of water in the existing tube. (James *et al.*, 2005).

4.1.4 Methods to Evaluate Pumping Test

Groundwater is pumped through well and an observation well observes the reaction of the pumping well, which provides hydraulic head drawdown. The resistance flow is created by the soil around the pump. Even a head loss by the soil causes depression cone and a hydraulic gradient. A hydraulic head drawdown is used to define an aquifer's hydraulic characteristics which include storage coefficient or storativity (S), hydraulic conductivity (K) and transmissivity (T).

The storativity is the volume of water produced in a hydraulic head per unit area of an aquifer surface. The rate of flow per hydraulic gradient is called hydraulic conductivity. For different kinds of water flow and aquifer pumping test is also different.

4.1.5 Pumping Test for Steady And Unsteady Flow

Two types of well hydraulic equations are present: those depicting steady-state flow in a pumped well and those describing the unsteady-state flow. The steady state does not depend on time. It implies that the water level in the well pumped and in the surrounding piezometers does not change with time.

Steady-state flow occurs when the pumped aquifer is recharged by an external source, which could be precipitation, leakage through aquitards, or direct hydraulic contact of open water. In practice, if the change of water table is very little with respect to time then it is considered as steady-state flow (Kruseman and Ridder, 1994).

When pumping of the fluid starts, the flow becomes unsteady. After a while, the flow again goes to steady state. If we pump fluid at a constant rate from confined aquifer, then flow will be always unsteady flow. practically, as long as the changes in water level in the well and piezometers are visible or hydraulic gradient varies significantly, the flow is called unsteady flow.

4.1.6 Confined Aquifer -Thiem Analysis (Steady-state flow)

Confined aquifer is surrounded by impermeable layer. When a well drains water from a confined aquifer, the effect of pump expands with time radially towards the outwards the well, and the pumped water is removed entirely from inside of the storage. By principle, since the pumped water may come from a decline by storage within the aquifer, there can be only unstable-state flow. If the change of drawdown is so little, then the flow is considered as steady flow.

The assumptions and conditions for the pumping test for a steady-state flow are as follows:

- The aquifer is confined by impermeable layer.
- The areal extent of the aquifer if not finite.
- It follows Darcy’s law
- Across the test area thickness of aquifer is uniform and characteristics are homogenous and isotropic.
- piezometric surface will be changed because of pumping test.
- Discharge rate of fluid from aquifer is constant.
- Aquifer is filled by water form horizontal flow.

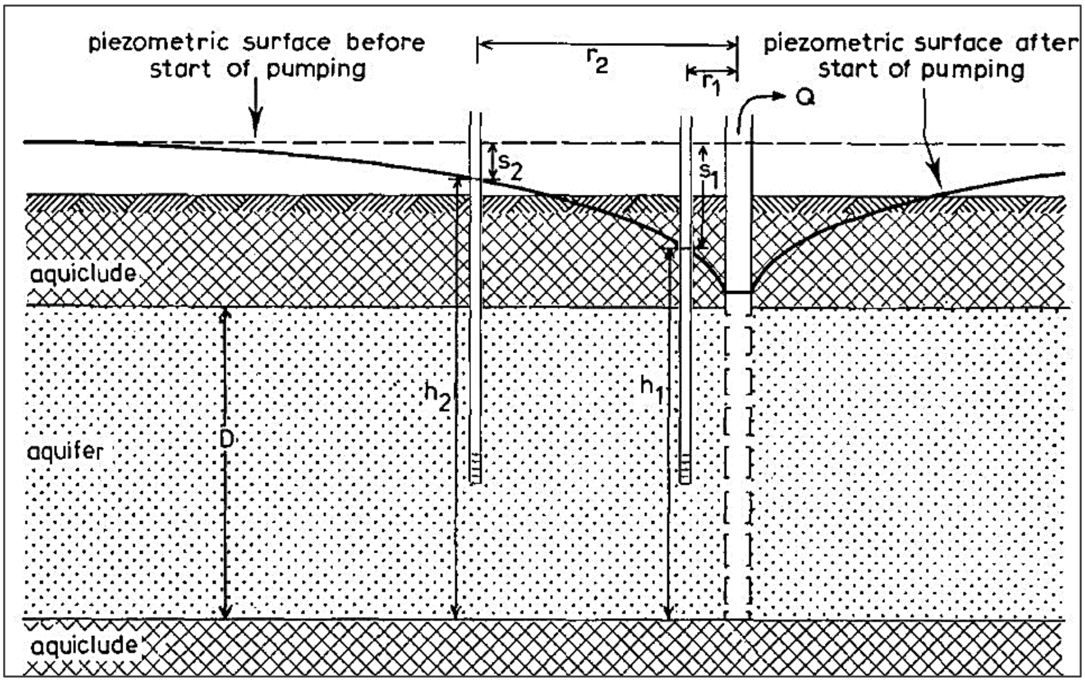

Figure 5: 4 Cross-section of a pumped confined aquifer (G.P. Kruseman, 1994)

water pumping well goes through a confined aquifer. Discharge rate Q is unchanged because in steady- state condition water enters in the well from aquifer. For steady-state condition the continuity equation is

$$Q = v.\ A \tag{4.1}$$

Where,

$$A = 2\pi\ r\ b \tag{4.2}$$

and Darcy's law

$$v = -K\ \frac{\partial h}{\partial r} \tag{4.3}$$

From the equations (4.1), (4.2) and (4.3) we can write

$$Q = -2\pi rbK\ (\frac{\partial h}{\partial r}) \tag{4.4}$$

Q is known as discharge rate, radius of the circular section of influenced area is denoted by r, b is the thickness aquifer, K is the hydraulic conductivity and $\frac{\partial h}{\partial r}$ is called as hydraulic gradient.

After modifying the equation, we can write.

$$\frac{Q}{2\pi Kb}\int_{r_1}^{r_2}\frac{1}{r}dr = \int_{h_1}^{h_2} dh \quad (4.5)$$

$$h_2 - h_1 = \frac{Q}{2\pi Kb} ln\frac{r_2}{r_1} \quad (4.6)$$

$$s_1 - s_2 = \frac{Q}{2\pi T} ln\frac{r_2}{r_1} \quad (4.7)$$

$$T = \cancel{Kb}\ \frac{Q}{2\pi(s_1 - s_2)} ln\frac{r_2}{r_1} \quad (4.8)$$

4.1.7 Confined aquifer – Theis method (unsteady-state flow)

Theis (1935) was the first to create an unsteady-state flow method which applies the time factor and the storativity. He observed that when a well penetrated broad confined aquifer is discharged at a constant rate, the discharge's effect spreads outward over time. The rate of head loss, compounded by the storativity and averaged over the area of influence, is equivalent to the discharge. The unsteady-state formula (Theis) that was generated from the analogy between groundwater flow and heat transfer is written as

$$s\ (r,\ t)\ =\ \frac{Q}{4\pi T}\int_{u}^{\infty}\frac{e^{-u}}{u}\ du \quad (4.9)$$

$$s\ (r,\ t) = \frac{Q}{4\pi T}\ W(u) \quad (4.10)$$

where, s is the drawdown (m) estimated at a distance r by m in a piezometer. Q is the constant pumping rate. T is the transmissivity of aquifer and u is the argument of Theis well function and can be written

$$u = \frac{r^2 s}{4Tt} \quad (4.11)$$

where r is the radius (m), s is known as dimensionless storativity. The time in seconds since pumping started is denoted by t and W(u) is the well-function and u is the well-functioning dimensionless parameter. The collection of logarithms and rearrangement of these equations

$$\log s = \log \left(\frac{Q}{4\pi T}\right) + \log [w(u)] \tag{4.12}$$

and,

$$\log t = \log \left(\frac{1}{u}\right) + \log \frac{r^2 s}{4T} \tag{4.13}$$

The curve-fitting approach used by Theis is based on the assumptions given at the following limiting condition

- The flow to the well is unsteady.
- The difference of drawdown is considerable.
- Discharge is not constant.
- The features of flow can be described by Darcy's law.
- Storativity(s) and transmissivity(T) do not changing with time and space.
- The aquifer inside the influenced area is homogenous, anisotropic and thickness is uniform.
- There are no boundaries of the aquifer in areal extent.
- The well penetrates completely into a confined aquifer.
- Confined aquifer

Procedure to measure parameters in Theis method

- Make the Theis well function curve on loglog paper well by plotting W(u) values a gainst 1/u arguments.
- Plot the measure data to another piece of log- log graph and prepare a curve relation between s vs t/r^2.
- By maintaining the axis parallel superimpose the curve of s vs t/r^2 on to W(u) vs 1/u.
- Find a suitable position where most of the point of these two graphs will fall on each other.
- Substitute the value and calculate transmissivity and drawdown

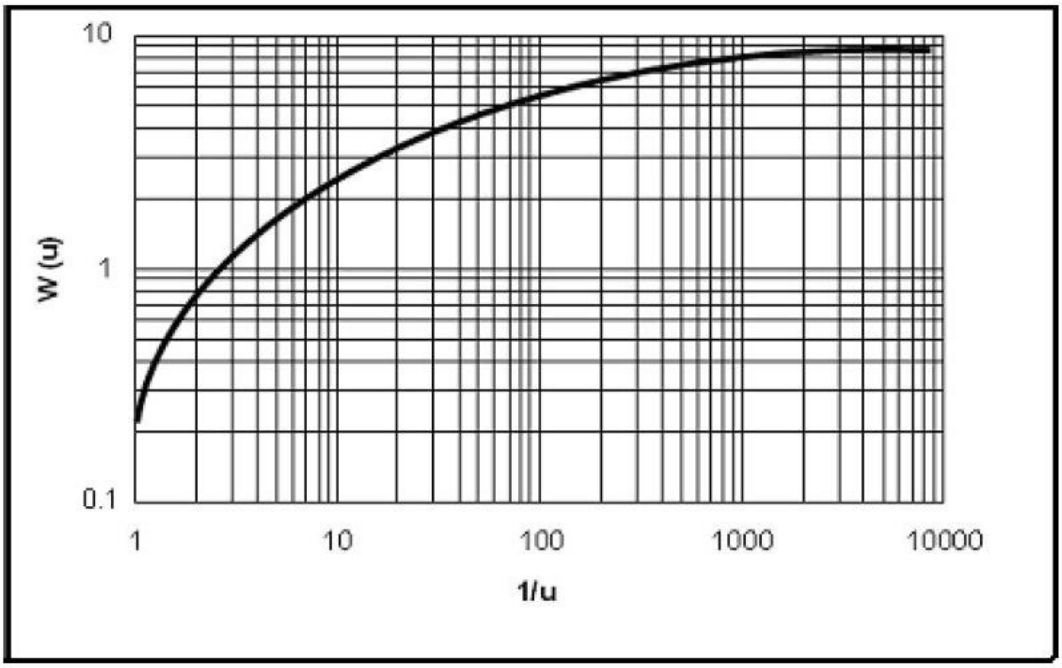

Figure 6: Theis type curve for W(u) versus u and W(u) versus l/u (Theis, 1935)

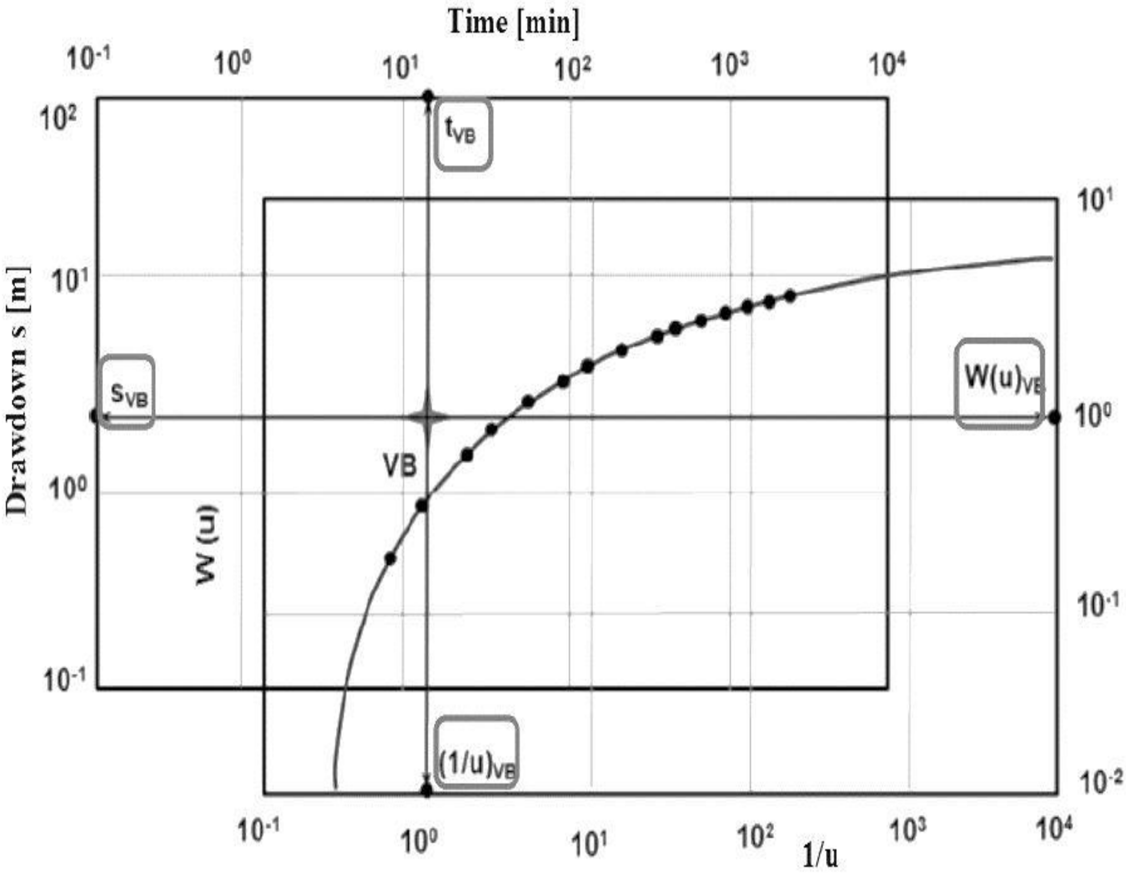

Figure 7: Field data plots on logarithmic paper for Theis curve-marching technique (Theis, 1935)

4.1.8 Confined Aquifer- Jacob Method

The Cooper and Jacob solution (1946) is a late-time approximation based on the Theis solution of basic equation describing unsteady flow to a well. Research with the Cooper and Jacob approach involves following a straight line with drawdown as a function of the logarithm time since the pumping began Cooper and Jacob (1946) derived a ~~different~~ form of the Theis (1935) formula for transient flow to a well discharging at a constant rate from an infinite extent area, isotropic, homogeneous aquifer (Hydro SOLVE, 1998-2020). We can write drawdown according to Theis equation is

$$s = \frac{Q}{4\pi T} \int_u^\infty w(u) \tag{4.14}$$

and,

$$u = \frac{r^2 S}{4Tt} \tag{4.15}$$

Q is discharge rate, r is radius of influence, T is the transmissivity, s is called drawdown, S is known as storativity, W(u) is denoted as function of well. Theis well function can be expressed by Taylor series expression.

$$W(u) = -0.5772 - \ln(u) + u - \frac{u^2}{2.2!} + \frac{u^3}{3.3!} + \frac{u^4}{4.4!} + .. \quad (4.16)$$

For 1/u > 100 we can use only first two terms in W(u) (Cooper-Jacob, 1946)

$$W(u) = -0.5772 - \ln(u) \quad (4.17)$$

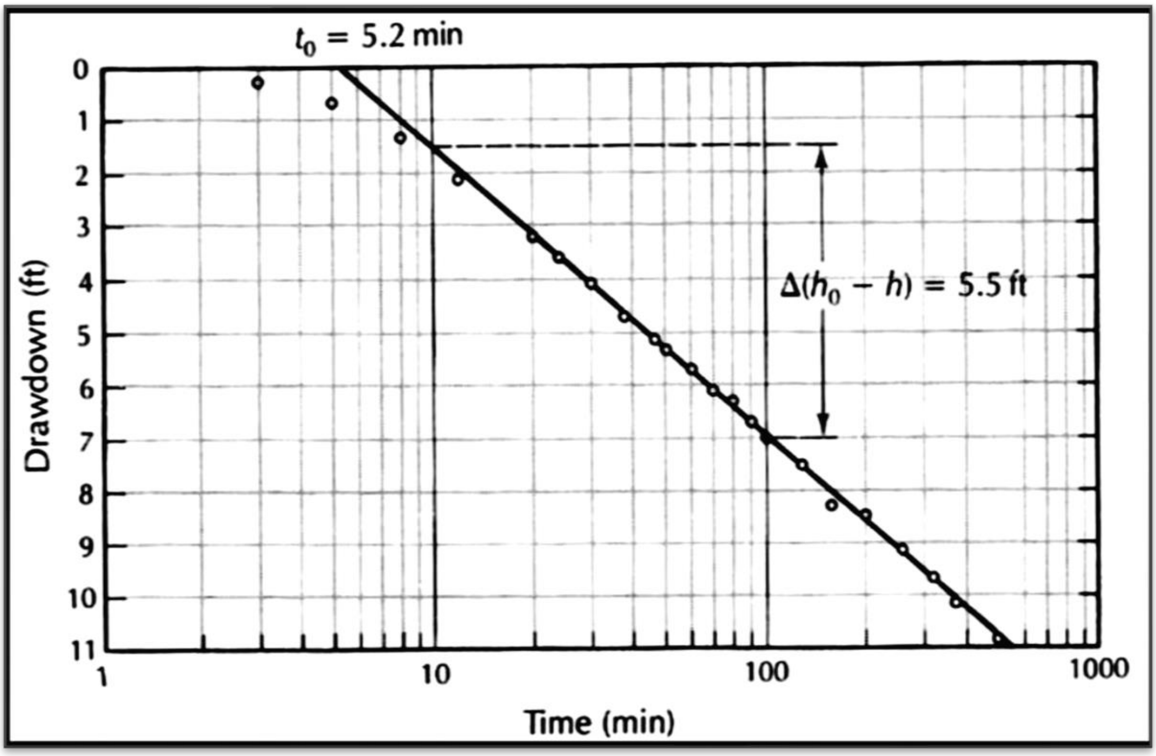

Figure 8: Pumping test data by Jacob method for confined aquifer (Time vs Drawdown)

The accuracy of Cooper-Jacob approximation is highly depending on value of u. Value is u ≤ 0.05. smaller value can give better approximation.

Combining the equations, we can write

$$s = \frac{Q}{4\pi T}\left(-0.5772 - ln\frac{r^2 S}{4Tt}\right) \quad (4.18)$$

If we convert it to the decimal logarithm

$$s = \frac{2.303Q}{4\pi T} \log \frac{2.25Tt}{r^2S} \qquad (4.19)$$

After projecting the Cooper-Jacob equations plot s versus function of log t and draw the straight line through the data. Transmissivity, T can be evaluated with the equation

$$T = \frac{2.303Q}{4\pi\Delta s} \qquad (4.20)$$

4.1.9 Types of Well Regeneration

- Chemical regeneration

The chemical component of the restoration was carried out using Sodium Hypochlorite and Syntron B. The number of substances added to the well was determined using the company's internal rules, Vodní Zdroje, a.s Sodium hypochlorite has acted as a material-removing the growths from the well wall and dissolving some in soil. Syntron B retained the iron submerged in the mud, to keep it from settling back on the mantle. The boreholes were left at least 12 hours of rest after application of the chemicals for optimum efficiency of chemical regeneration (at lower reaction times the chemicals may not work over the entire well depth).

- Mechanical regeneration

The hydraulic part of the restoration was done through pressure surges and pumping water using a gigantic pump, or through a mixture of pressure surges and grinding the inner part of the borehole with plastic brushes. The spikes in pressure were triggered by the gigantic pump's bi-directional release.

When the tap is removed, both the borehole itself discharges the gassed water, which allowed the growths to be released from the borehole shell and into the borehole, where the spaces between the individual grains were washed.

The water was drained from the borehole by opening the tap on the discharge pipe which contained dissolved and broken growths.

In each section of the borehole, pressure pulses were applied before isometrically pure water streamed out of the discharge line. The grinding of the borehole devices was done by vertically shifting the plastic brush with the assistance of a crane.

4.1.10 Additional Resistances

The external resistances can be tested in order to compare the resulting pumping values with the ideal condition in actual condition. The cumulative drawdown may be calculated from the equation below for unsteady flow

$$s_w = \frac{Q}{4\pi T}(ln\frac{2.25Tt}{r_w S}+2W) \qquad (4.21)$$

Here s_w means drawdown, Q is discharge, T is ~~called~~ transmissivity, W is coefficient of additional resistance (skin factor), S is storativity, r_w is the well radius . The main reason behind additional resistance is skin factors. We can calculate the skin factor by the equation for steady flow (van Everdingen,1953)

$$s_{skin} = \frac{Q}{2\pi T} W \qquad (4.22)$$

5 RESULTS

We measured drawdown at a constant rate (Q) with time (t). we measure those parameters before and after cleaning.

5.1.1 Pumping test Before Well Cleaning

Drawdown was calculated before cleaning of well with pumping test. The test was regulated nearly 1 hour in pumping well. The test was happened in 2015. The record is shown below

Table 3: The parameter of whole test is visible in figure. Drawdown vs time is plotted on semi-log in the graph.

Date	Time	t (sec)	t(min)	log t (min)	h1	Drawdown s (m)	Q (l/s)
19/11/2015	11:37:50	0.00	0.00	0.00	26.22	0.00	0.00
19/11/2015	11:37:51	1	0.02	1.78		0.1474	14
19/11/2015	11:37:52	2	0.03	1.48		0.4304	14
19/11/2015	11:37:53	3	0.05	1.30		0.557	14
19/11/2015	11:37:54	4	0.07	1.18		0.8061	14
19/11/2015	11:37:55	5	0.08	1.08		1.0202	14
19/11/2015	11:37:56	6	0.10	1.00		1.1983	14
19/11/2015	11:37:57	7	0.12	0.93		1.3891	14
19/11/2015	11:37:58	8	0.13	0.88		1.5605	14
19/11/2015	11:37:59	9	0.15	0.82		1.7387	14
19/11/2015	11:38:00	10	0.17	0.78		1.904	14
19/11/2015	11:38:01	11	0.18	0.74		2.0623	14
19/11/2015	11:38:02	12	0.20	0.70		2.2357	14
19/11/2015	11:38:03	13	0.22	0.66		2.3825	14
19/11/2015	11:38:04	14	0.23	0.63		2.5299	14
19/11/2015	11:38:05	15	0.25	0.60		2.6792	14
19/11/2015	11:38:06	16	0.27	0.57		2.8163	14

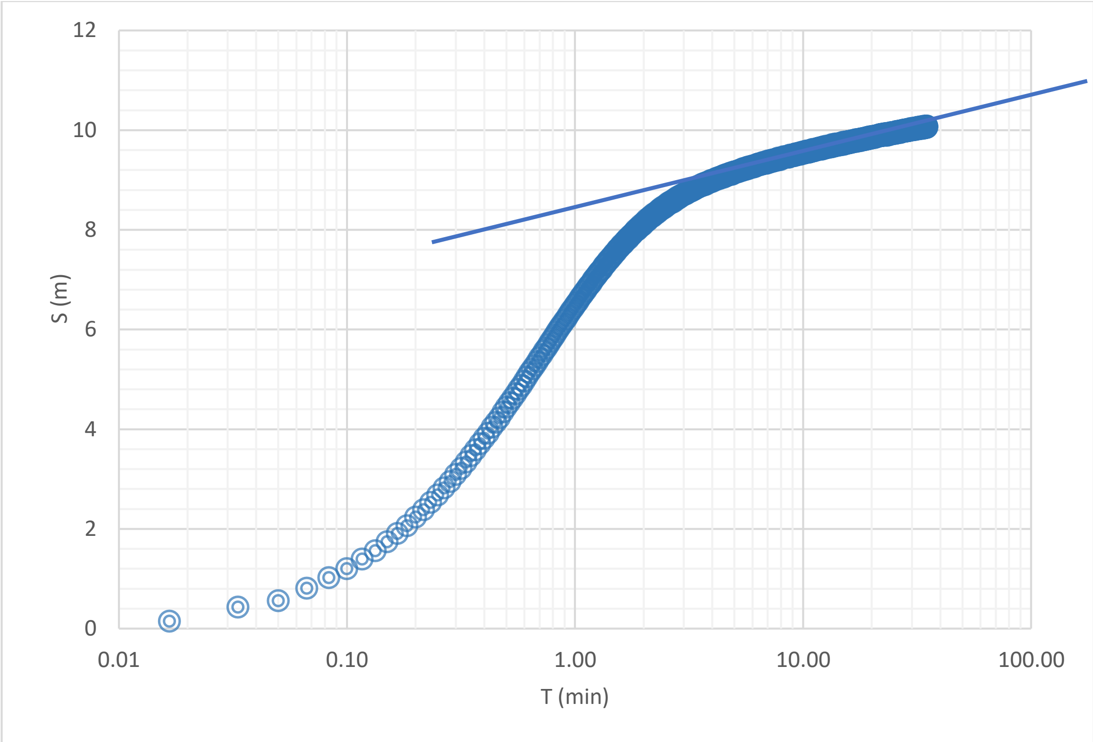

Figure 9: Drawdown (m) vs Time (min) in pumping well before cleaning of test well

The same drawdown test was done in well placed observation, 2 km from the pumping well. The length of this experiment was about 1 hour, and measurements were taken in 10 sec increments of time. The discharge rate was almost the same as well pumping. Drawdown and time data were also plotted on semi-log graph. The discharge rate was almost the same as for pumping. Drawdown and time data are plotted on the semi-log graph as well.

Table 4 The measurement of parameter after cleani

Date	Time	t (sec)	t(min)	log t (min)	HPV (mob) kontrola	Drawdown(s)
20/11/2015	09:25:41	1	0.02	-1.78	30.29	0.1501
20/11/2015	09:25:42	2	0.03	-1.48		0.2049
20/11/2015	09:25:43	3	0.05	-1.30		0.544
20/11/2015	09:25:44	4	0.07	-1.18		0.6486
20/11/2015	09:25:45	5	0.08	-1.08		0.7626
20/11/2015	09:25:46	6	0.10	-1.00		0.9802
20/11/2015	09:25:47	7	0.12	-0.93		1.1915
20/11/2015	09:25:48	8	0.13	-0.88		1.4007
20/11/2015	09:25:49	9	0.15	-0.82		1.5741
20/11/2015	09:25:50	10	0.17	-0.78		1.7314
20/11/2015	09:25:51	11	0.18	-0.74		1.9078
20/11/2015	09:25:52	12	0.20	-0.70		2.0543
20/11/2015	09:25:53	13	0.22	-0.66		2.2069
20/11/2015	09:25:54	14	0.23	-0.63		2.3578
20/11/2015	09:25:55	15	0.25	-0.60		2.5016
20/11/2015	09:25:56	16	0.27	-0.57		2.6687
20/11/2015	09:25:57	17	0.28	-0.55		2.8229
20/11/2015	09:25:58	18	0.30	-0.52		2.9438
20/11/2015	09:25:59	19	0.32	-0.50		3.0754

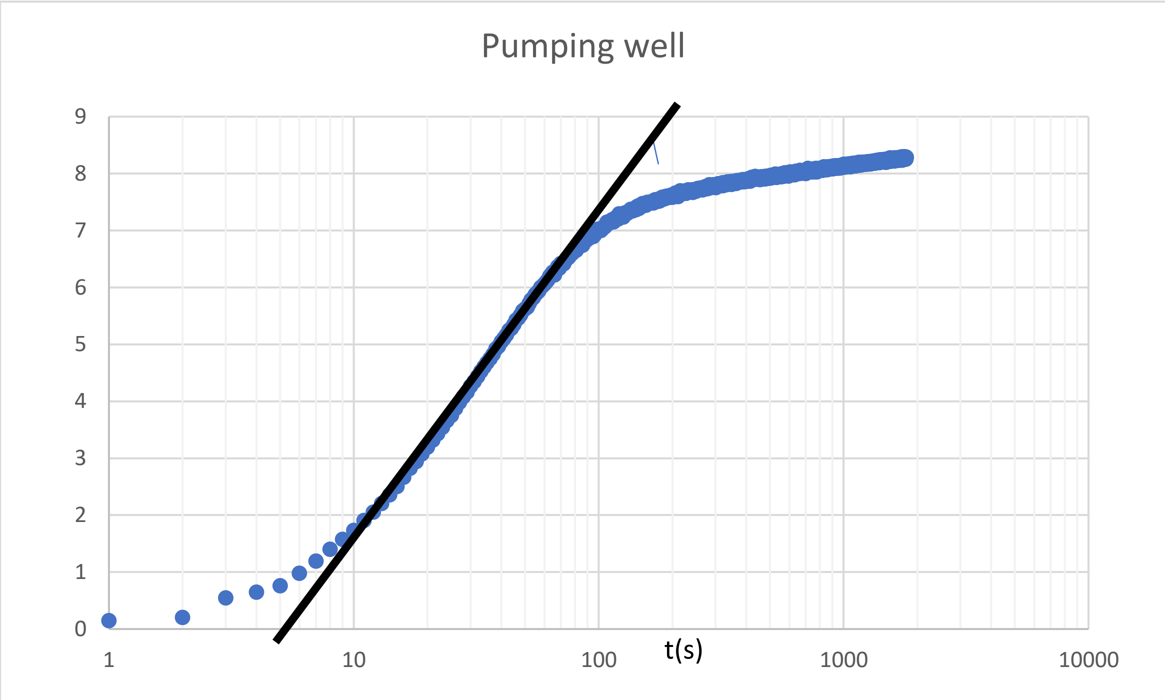

Figure 10: Drawdown (sw) vs Time (t) in pumping well of cleaning of pumping well

From equation 5.1 the drawdown S_w was measured. We calculated drawdown for time(t) at 250 sec and 1405 sec and the result are 9.004 m and 9.912 m respectively. The discharge rate was 0.014 m^3/s. The result was calculated by equation below

$$\Delta s = s_1 - s_2 = \frac{Q}{4\pi T} \ln \frac{t_2}{t_1} \quad (4.23)$$

$$\text{Or } T = \frac{Q}{4\pi \Delta s} \ln \frac{t_2}{t_1} \quad (4.24)$$

The calculated transmissivity is 0.00211m^2/s. Form observation well we can calculate storage coefficient. we use equation below to calculate storativity

$$S = \frac{2.25T}{r^2}\, t \quad (4.25)$$

Time t was calculated when there was no drawdown that means we observed time when Drawdown is zero from figure 5.2. the resulted storativity was calculated is **0.00001589**. The observation well is 120m deep.

5.1.2 Pumping test After Well Cleaning

The method for taking pumping well observations is the same as defined in the test prior to proper cleaning. The measurements were reported in 3 months after approximately 1 hour of washing, with a steady discharge rate of 18 liters per sec. For example, the observation table for evaluation pumping test after well cleaning. To each second time intervals, the drawdown was reported with a steady discharge.

Table 5: After getting the value of pumping test we plot the graph in a semi-log graph.

Time	t (sec)	t(min)	log t (min)	Drawdown(s)
18:29:52	1	0.01667	-1.7781513	-0.0025
18:29:53	2	0.03333	-1.4771213	0.1419
18:29:54	3	0.05	-1.30103	0.2565
18:29:55	4	0.06667	-1.1760913	0.4171
18:29:56	5	0.08333	-1.0791812	0.5713
18:29:57	6	0.1	-1	0.8226
18:29:58	7	0.11667	-0.9330532	1.007
18:29:59	8	0.13333	-0.8750613	1.1634
18:30:00	9	0.15	-0.8239087	1.3764
18:30:01	10	0.16667	-0.7781513	1.5502
18:30:02	11	0.18333	-0.7367586	1.7358
18:30:03	12	0.2	-0.69897	1.9025
18:30:04	13	0.21667	-0.6642079	2.0319
18:30:05	14	0.23333	-0.6320232	2.158
18:30:06	15	0.25	-0.60206	2.3141
18:30:07	16	0.26667	-0.5740313	2.4267
18:30:08	17	0.28333	-0.5477023	2.5171
18:30:09	18	0.3	-0.5228787	2.7074
18:30:10	19	0.31667	-0.3210771	2.7074

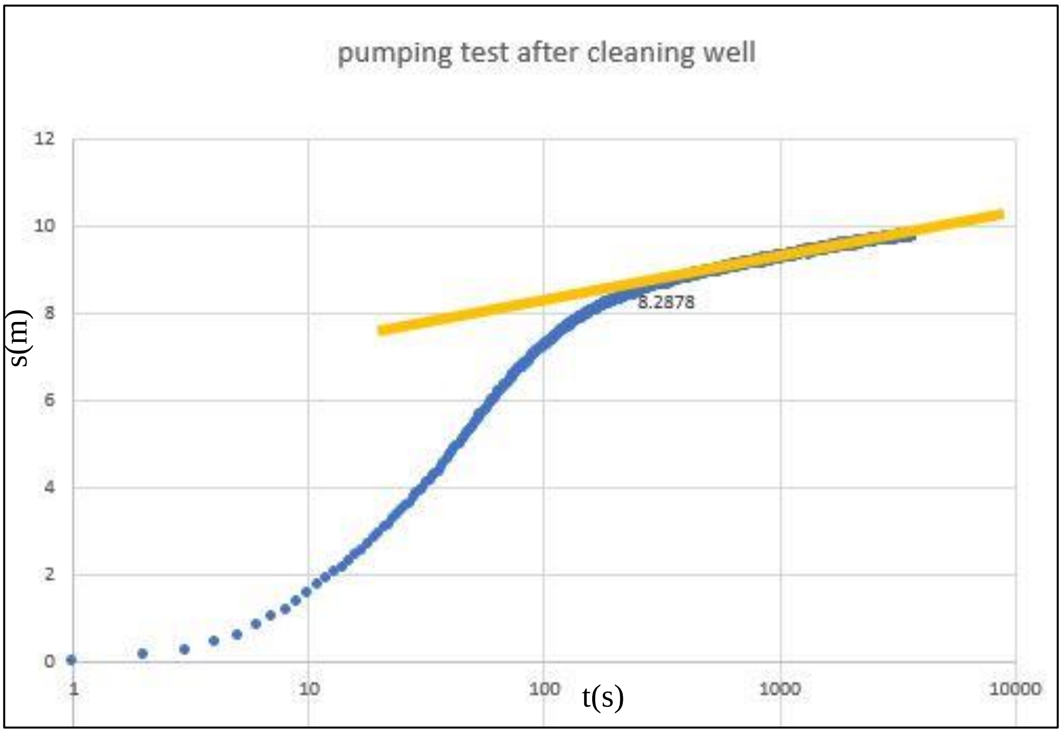

Figure 11: Drawdown(s) vs time after completing pumping test

From equation 5.1 the drawdown s_w was measured. We calculated drawdown for time(t) at 437 sec and 670 sec and the result are 8.814 m and 9.0342 m respectively. The discharge rate was 0.018 m^3/s. The result was calculated by equation below

$$\Delta s = s_{1-} s_2 = \frac{Q}{4\pi T} \ln \frac{t_2}{t_1} \qquad (4.26)$$

$$T = \frac{Q}{4\pi \Delta s} \ln \frac{t_2}{t_1} \qquad (4.27)$$

The calculated transmissivity is 0.002779 m^2/s. Form observation well we can calculate storage coefficient. we use equation below to calculate storativity

$$S = \frac{2.25T}{r^2} t_0 \qquad (4.28)$$

Time t_0 was determined when there was no drawdown that means we observed time when drawdown is zero from figure. The resulted storativity was calculated is 0.000028. The observation well is at distance 120 m.

5.1.3 Additional resistance Before Cleaning of well

We evaluate drawdown (s) and time(t) by using equation we calculate the values of the transmissivity (T) and storativity(S). we use the values of drawdown vs time of pumping well from the plotted graph. We use the equation below to calculate the additional resistance.

$$s_w = \frac{Q}{4\pi T}(ln\frac{2.25Tt}{r_w^2\,S} + 2W) \qquad (4.29)$$

After rearranging the equation, we can write

$$W = \frac{2\pi T s_w}{Q} - \frac{1}{2}(lnt + ln\frac{T}{r_w^2\,S} + 0.8091) \qquad (4.30)$$

We measured additional resistance (W) for three times and has taken the average additional resistance. The value of additional resistance was 10.3980 m. Additional drawdown which was created by skin effect can be calculated the equation below (van Everdingen, 1953)

$$s_{skin} = \frac{Q}{2\pi T}W \qquad (4.31)$$

The value of additional drawdown was caused by the additional resistance 10.94 m.

5.1.4 Additional resistance after cleaning of well

We evaluate drawdown (s) and time(t) by using equation we calculate the values of the transmissivity (T) and storativity(S) after cleaning the well. we use the values of drawdown vs time of pumping well from the plotted graph. We use the equation below to calculate the additional resistance.

$$s_w = \frac{Q}{4\pi T}(ln\frac{2.25Tt}{r_w^2\,S} + 2W) \qquad (4.32)$$

After rearranging the equations, we can write

$$W = \frac{2\pi T s_w}{Q} - \frac{1}{2}(lnt + ln\frac{T}{r_w^2\,S} + 0.8091) \qquad (4.33)$$

We measured additional resistance (W) for three times and has taken the average of additional resistance. The value of additional resistance was 5.633 m. Additional drawdown which was created by skin effect can be calculated the equation below

$$s_{skin} = \frac{Q}{2\pi T} W \tag{4.34}$$

The value of additional drawdown was caused by the additional resistance 5.806 m.

5.1.5 Differences of additional resistance before and after cleaning

The values of the drawdown before and after cleaning of well was used to find the difference between the both cases. We find additional drawdown before cleaning is 10.94 m and the additional drawdown after cleaning is 5.806 m. we got a huge difference in drawdown.

6 DISCUSSION

The rehabilitation process was conducted at Bela crkva in Serbia. The test was carried out before and after cleaning. There was various process involved to remove the foreign materials and clean the well. The name of the processes used was chemical process and mechanical process. Sodium hypochlorite was used as a chemical that separates the growths from the well wall and dissolves some of them in water. The chemical was left for 12 hours to maximum of efficiency. The mechanical procedure has two parts to clean the pump. In this process pressure surge was created by gigantic pump. Pressure surge is performed till fresh water is flowed.

To prolong the life of well and increase the life of fittings and joints it is important to rehabilitation of well. The cleaning can be done by brushing the wall of pipe and screen of pipe. Unwanted materials of wall and screen can be clean by water pressure.

The storativity and the transmissivity are calculated before and after cleaning. After completing process the calculated value of the storativity before cleaning is **0.00001589** and after cleaning is **0.000028**. The transmissivity before cleaning is **0.00211**m^2/s and the transmissivity after cleaning is **0.002779** m^2/s.

There is slight difference of result in both cases because data was collected for different discharge rate even the drawdown is also different for both cases. The time segment also creates a difference on result. Result can change because of difference of drawdown.

Additional resistance is an important parameter to show the effectiveness of the process. We got the value of additional resistance before and after cleaning. we got the result for additional resistance **10.40** m and **5.633** m, respectively. The value of additional resistance became decrease dramatically. Which is showing that the effectiveness of well rehabilitation test is reasonable. The drawdown we measured because of additional resistance was **10.94** and **5.80** respectively.

7 CONCLUSION

Before and after the rehabilitation process of well, objective measurement of storativity and transmissivity was evaluated. The pumping test is carried out using the method of Cooper-Jacob as it simplifies the method of Theis. For both cases, the values of storativity and transmissivity are almost identical, and the little variation is caused by different pumping rate and time intervals through the test process. The time intervals assumed immediately after the pumping starts and the radial distance of the observation well from the pumping well that causes an unreasonable difference in the value. The observation well situated in the neighborhood of the pumping well should provide clear readings of the drawdown vs. time and should provide accurate depression cone information.

The well rehabilitation process is used to clean the foreign materials from the bore holes. This process can increase the productivity of well. The skin effect was used to calculate additional drawdown. The procedure is highly depending on how accurately the data was collected and the parameter of pumping test. The result showed us that there is a relation between skin effect and drawdown. From result we can notice that the difference of the additional drawdown is remarkable. Which indicates that the rehabilitation process is reasonable.

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