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Influence of the Use of Sand Columns at Recharge Reservoir

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Abstract - The recharge reservoir is one of artificial recharge method, which is built on the permeability of soil layers above 10^{-3} cm^3/sec. The problem will occur if the permeability value of the recharge dam's soil less than 10^{-5} cm^3/sec and low penetrating power, such that the analysis used toward the sand columns model that have a large permeability placed at the base of the recharge dam to reach the aquifer layers. The purpose of this research was to determine the magnitude of debit occurred by using a sand column in the absorption reservoir. The methodology used in this study was conducted by experimental laboratory, which form the modelling of recharge reservoir with sand columns. The primary data is the seepage flow which consists of several parameters, including height water of reservoir,, height of sand columns and number of sand columns. The data obtained from the model test results will be in the form of debit.. The conclusion that can drawn from result of on the use of 6 columns of sand, debit occurring 1.49 times compared with 4 sand columns, and by 3 times while the use of 12 sand column., Height water in the reservoir and the height of the sand column effect is not too large. However, according to the research, the higher the water in the reservoir, the greater the discharge occurs. While, if the height of the sand column increase will decrease debit that occurs. The sand column recommended for use in recharge reservoir areas with surface water sources are great, but the permeability of the soil is below 10^{-5} cm3/sec that help ground water and reduce runoff in the rainy season.

Index Term- **Recharge Reservoir, Sand Columns,Influence.**

I. INTRODUCTION

The highly growth of urban areas is indicated by the emerge of residential, hotels, commerce and industrial area, causing the increasing demand of water supply. The situation is even worsen by the disability of water authorities to supply water due to the limited production and the vast number of water pipeline leakage. Therefore, an alternative to obtain water is by groundwater intaking, either by constructing well or by drilling. When the level of groundwater table is undergoing continously decrease, land subsidence, sea water intrusion and the decrease of groundwater quality could occur [11]. To manage the problems, recharge to groundwater reservoir should be conducted to boost the absorption of water, either naturally or artificially. However, the very fast growth of cities has changed the nature of absorption area from permeable to impermeable due to the building-covered surface. Alteration of landuse induces the elimination of open areas functioning as absorption areas to infiltrate the water in rainy season so most of the water precipitation will become surface flow causing flood in rainy season and the lackness of groundwater in dry season. Efforts that have been conducted to raise the rainwater infiltration are to construct absorption well, biopore well and other infiltration techniques, despite of the results which has not been maximized. Therefore, the construction of recharge reservoir recently being campaigned could be a solution. High capacity of recharge reservoir to infiltrate the surface flow compared to ponds or small lakes which traditionally functioning as recharge reservoir is due to the design of recharge reservoir that reach aquifer layer of soil with high level of absorption of 10^{-3} cm3/sec, which is much higher than the level of absorption of clay layer ranging around 10^{-5} cm3/sec [6]. But a problem occurs when recharge reservoir is built in a region with low soil permeability and infiltration level, causing the water to reach the aquifer slowly therefore the function as recharge reservoir will not be achieved. Thus, the use of sand columns will be studied. Sand columns will be located in the bed of recharge reservoir directly connected to aquifer layer with several parameters, expected to be a solution for groundater recharge problem for the condition. The purpose of this research was to determine the magnitude of debit occured by using a sand column in the absorption reservoir.

II. LITERATUR REVIEW

A. Recharge Reservoir

A challenge in the future is the scarcity of surface water sources, as well as the increasing demand for various purposes that will lead to the over-exploitation of groundwater. To maintain the balance of groundwater, water conservation efforts should be made which are the acts of exploitation, development and protection of water resources by augmenting water into the soil by groundwater recharging, either naturally or artificially [8]. Based on the hydrological cycle, the main source of underground water is derived from rainwater or surface water. Indonesia, due to the wet tropical climate, generally receives relatively high rainfall, more than 1,000 mm/year, with a relatively long rainy day. This condition is very beneficial in natural augmentation of groundwater through the trees, forests, and lakes there, which occurs during the rainy season for charging and replenishment of groundwater deficit that occurs during the dry season. Thus the aquifer will receive additional water reserves. The problem is that, in areas that have been developed particularly in big cities, recharging of underground water in the rainy season is hampered because of changes in land use. Areas that had previously been catchment areas have

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been covered by buildings, so only little of rain water would have a chance to infiltrate and recharge groundwater. For such areas, an effort of artificial augmentation is necessary [7]. Artificial augmentation is increasingly being used for underground storage of short or long term, because it has several advantages over surface water storage. Artificial augmentation needs permeable soil surface. If not available, trenches or shafts in the unsaturated zone can be used, or water can be directly injected into the aquifer via wells. To design a system for artificial augmentation, soil infiltration rate should be determined and the unsaturated zone between soil surface and the aquifer should checked, permeability must be adequate and there is no contaminated area. One form of artificial augmentation is the recharge reservoir, a type of reservoir that has a primary function as a medium of water to infiltrate easily and quickly into the aquifer layers. Reservoir model is suitable for land with shallow groundwater and available space [1]. Meanwhile, according to Chairman of the recharge reservoir development project team of the Ministry of Research and Technology, The Republic of Indonesia, the basic philosophy in the development of the recharge reservoir is how to minimize surface runoff and increase the infiltration capacity of soil to absorpt run-off [10]. The construction of the recharge reservoir is different from the construction of common reservoir. Recharge reservoir is constructed with reservoir bed is directly connected to the aquifer layers. Recharge reservoirs can be classified essentially into single purpose reservoir which serves as a flood control system with a working system to increase optimization of aquifer function, adding the capacity to store water in the aquifer layers. However, in some conditions, the recharge reservoir has other functions (multi purpose). The purpose of the construction of recharge reservoir is similar to recharge wells, but have different extents and intention. Recharge reservoir built in larger area than that of the wells increase the volume of groundwater reserves as well as flood control compared to the relatively small volume of wells. However the application of the various ways should be studied in depth to obtain a picture of how effectively it can cope with flooding. Essentially, techniques of land arrangements, the implementation of measures and soil conservation, recharge wells and reservoirs are to control flooding by trying to reduce runoff and increase infiltration and percolation. Thus rain water potentially causing runoff can be reduced and, in majority, would fill the aquifer beneath. Each of the above has advantages and disadvantages; infiltration wells have a small size so that the amount of water absorbed into the soil will be less but it also would a little easier to do in household scale. Recharge reservoir will infiltrate more water if the location is on the groundwater recharge aquifer though the cost will be enermous [1].

B. Physical Models Of The Use Of Sand Columns

Currently sand column is widely used as vertical drainage that aims to increase the pace of consolidation in the soft soil layer which largely has very small grains size, high compressiveness and low permeability coefficient. In addition, vertical drainage has the objective to reduce the height of drainage path so that the distance between the drainage layer must be smaller than the ground layer, for there is no point in using vertical drainage in a thin layer [3]. In this study, sand column is functioned as a medium to infiltrate water from recharge reservoir to the aquifer layer. The traditional method of constructing a sand column is to drill a hole in the clay layer which has low permeability and to replenish with graded sand. Sand must be drained with water without carrying fine soil particles. Coarse grained soil has small specific surface (clean sandy soil has specific surface around 10^{-4} m^2/g), therefoe the surface forces are negligible relative to its weight which means its own gravity is far more dominant than the surface gravitational forces [5].

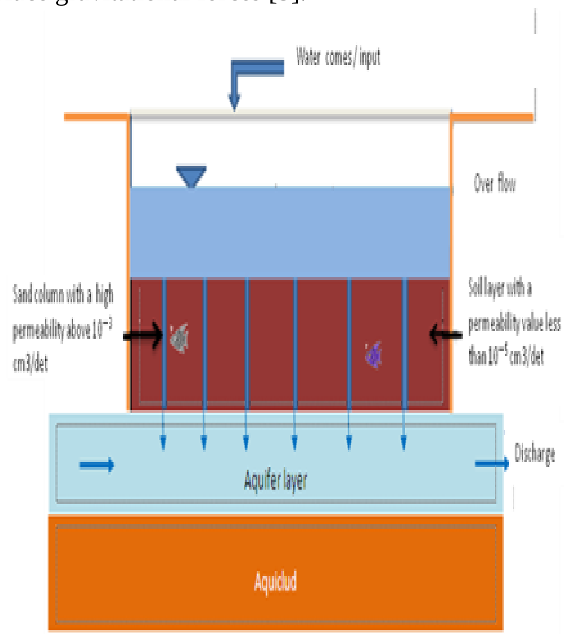

Fig.1. Recharge Reservoir Concept Using Sand Columns

The picture above shows the sketch of the use of sand columns with the principle that water comes from surface water collected in reservoirs at a certain height. Then the water is streamed through sand columns, expecting that sand which has high permeability coefficient, can accelerate and enlarge recharging.

C. Darcy's Law

Darcy's law describes the ability of water to flow in cavities (pores) in the soil and the influencing properties. There are two assumptions used in determining the Darcy's Law; the first assumption states that the flow of fluid / fluid in the soil is laminar, while the second assumption states that the land is in a state of saturation. The relationship between flow rate and hydraulic gradient as follows [2].

$Q = V. A$ (1)

$V = k.i$

$Q = k.i.A$

$i = dh/L$

$dh = H_w + H_{sc}$

$A = \frac{1}{4}.\pi.D^2.N_{sc}$

$$Q = k.\frac{h+L}{L}.\frac{1}{4}.\pi.D^2.N_{sc} \quad (2)$$

Where Q = debit through sand column (cm^3/sec) ;
A = cross-sectional area through which ground water flows (cm^2); v = flow velocity (cm/sec); k = coefficient of permeability (cm/sec); i = hydraulic gradient; H_w = height water of reservoir; H_{sc} = height of sand column; D = Diameter sand column; N_{SC} = number of sand column.

III. RESEACH METHODOLOGY

A. *Data Collection Techniques*

For data collection, the research is conducted in several stages as follows: The first stage is the stage of sampling and test samples of soil and sand properties. Material samples are taken at the location that is expected to meet the sampling criteria. Soil sampling uses a cylindrical shaped drill or shovel, which is then put into a sack [9]. Both kinds of samples are taken to Laboratory of Soil Mechanics Department of Civil Engineering Hasanuddin University for testing of permeability. The second phase of testing is conducted in the Laboratory of Hydraulics, Department of Civil Engineering, Hasanuddin University, to obtain the debit of recharge occuring through sand column. This study uses a squared test tub with the size of 160 cm x 75 cm x 50 cm, with seepage hole at the bottom. Clay soil samples that meet requirements of soil permeability test is then inserted into the tub. That on clay soil, sand columns is inserted to increase the pace of debit of recharge. Next, on the surface of the bath an entry debit (Q_1) is given continuously (constantly) so that water level can be maintained, while for the over flow (Q_3), a receptacle container was prepared. By the time the soil has been saturated with water, note the time every 1000 ml water out of the hole under the tube stream through clay soil and sand column (Q_2). Reseach at this model applied each 3 various for height water of reservoir (Hw), height of sand column (Hsc) and number of sand column (Nsc)

$\sum Q_1 = Q_2 + Q_3$ (constant flow) (3)

Where =
Q1 = Debit of incoming water (cm^3/sec)
Q2 = Debit of recharge through clay soil and sand column (cm^3/sec)
Q3 = Debit of over flow (cm^3/sec)

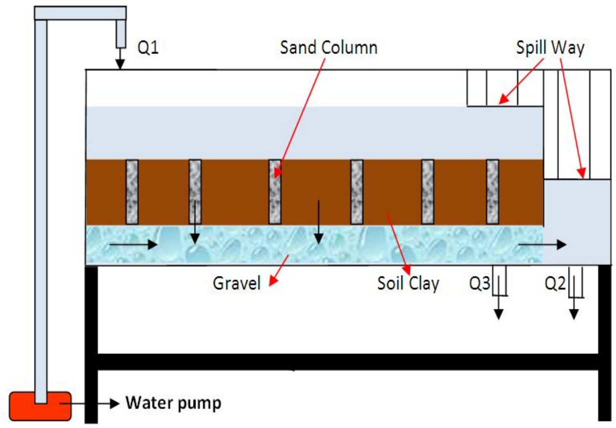

Fig. 2. Typical Recharge Reservoir Model Using Sand Column

Fig. 3. Measures Water Out From Spill Way (Over Flow)

B. *Analysis Techniques*

Data from observations on the recharge reservoir physical model testing with sand column are plotted into graph of relationship between debit of recharge through sand column and the parameters consisted number of sand column, height water of reservoir and height of sand column.

IV. RESULT AND DISCUSSION

A. *Permeability Of Soil Clay and Sand*

The results testing of soil clay and sand consisted : permeability of soil clay is : $3,3x10^{-5}$ cm/det and sand is $1,9 \times 10^{-1}$ cm/det.

B. *Influence Number Of Sand Column*

Table 1.below shows the amount of debit through the sand column at each level water reservoir (5 cm, 7,5 cm and 10 cm) with height of each sand column (30 cm, 32,5 cm and 35 cm). Figure 4,5 and 6 shows the relationship between debit and height water of reservoir for each sand column height (30 cm, 32,5 cm and 35 cm).

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Table 1. Debit as Result of Sand Column Height Influence

Hw (cm)	Debit through sand column, Q (cm3/det)								
	Hsc= 30 cm			Hsc = 32,5 cm			Hsc = 35 cm		
	N_{SC} 4 pcs	N_{SC} 6 pcs	N_{SC} 12 pcs	N_{SC} 4 pcs	N_{SC} 6 pcs	N_{SC} 12 pcs	N_{SC} 4 pcs	N_{SC} 6 pcs	N_{SC} 12 pcs
5	18,78	28,00	56,51	18,60	27,80	55,80	18,40	27,50	55,16
7,5	20,35	30,20	60,79	19,67	29,80	59,20	19,48	29,30	58,50
10	21,90	33,00	65,05	21,00	31,50	64,51	20,80	31,05	62,21
Average	20,34	30,4	60,78	19,75	29,7	59,83	19,56	29,28	58,79
			N_{SC} 4 = 19,88		N_{SC} 6 = 29,79		N_{SC} 12 = 59,71		

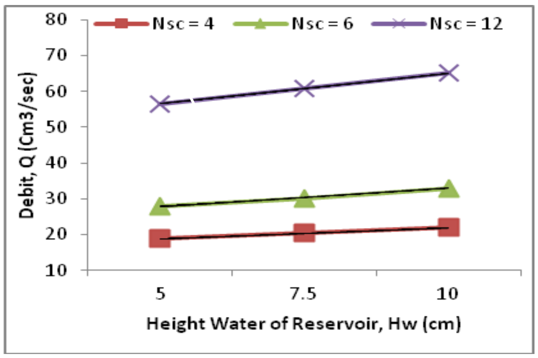

Fig. 4. The Relationship Between Debit With Height Of Reservoir at Height Of Sand Column 30 Cm

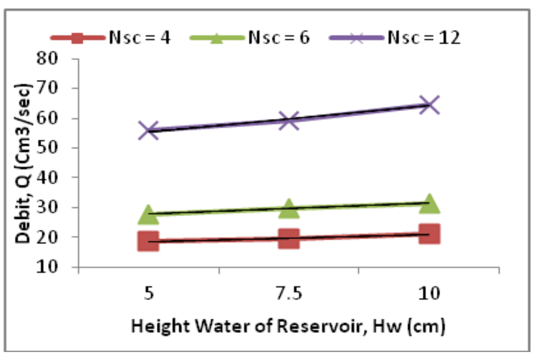

Fig.5. The Relationship Between Debit With Height Of Reservoir at Height Of Sand Column 32,5 Cm

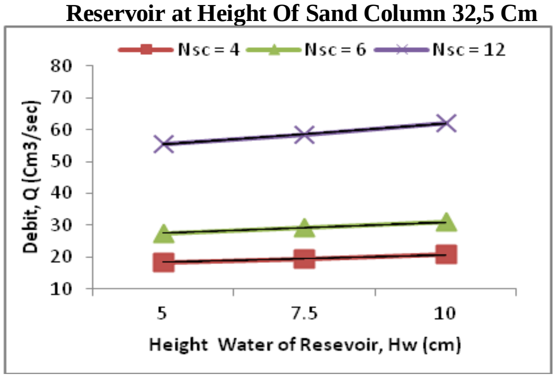

Fig. 6. The Relationship Between Debit With Height Of Reservoir at Height Of Sand Column 35 Cm

According to Table 1, Figure 4, 5 and 6 shows an increase in debit of 4 sand columns to 6 columns and 12 columns at the water reservoir and sand column height variations.

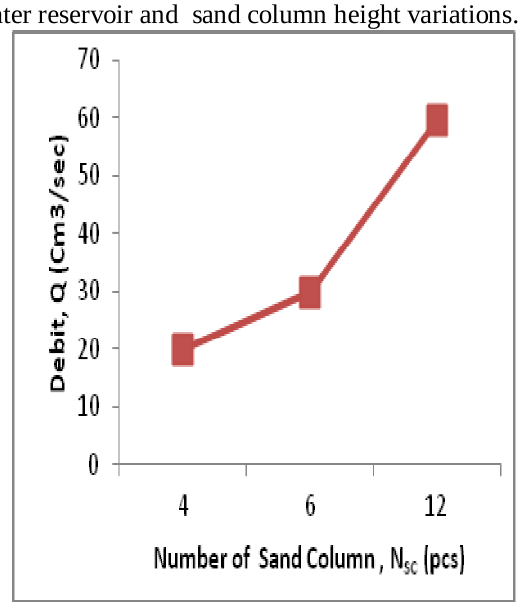

Fig. 7. Average Of Debit Each Number Sand Column

In figure 7, it appears also that by using 4 sand columns, the average discharge occurred at 19.88 cm3/sec, 6 sand column at 29.79 cm3/sec and 12 sand columns at 59,71 cm3/sec, or there is an increase about 1.49 times of debit when using 6 sand columns than using 4 sand columns, and 3 times when using 12 sand column. This according to equation 2, growing number of sand columns, so as the cross-sectional area (A) must be greater debit because in this equation, the cross-sectional area is proportional to the debit.

C. Influence Of Reservoir Water Height

Table 2 below shows the amount of debit through the sand columns at each sand column height (30 cm, 32.5 cm and 35 cm) from each sand column number (4 pcs, 6 pcs and 12 pcs). Figure 8, 9 and 10 illustrate the relationship between the debit and the height of the sand in each sand column number (4 pcs, 6 pcs and 12 pcs).

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Table Ii. Debit As Result Of Height Water Of Reservoir Influence

Hsc (cm)	Debit through sand column, Q (cm3/det)								
	$N_{SC} =$ 4 pcs			N_{SC} = 6 pcs			N_{SC} = 12 pcs		
	Hw 5 cm	Hw 7,5 cm	Hw 10 cm	Hw 5 cm	Hw 7,5 cm	Hw 10 cm	Hw 5 cm	Hw 7,5 cm	Hw 10 cm
30	18,78	20,35	21,90	28,00	30,20	33,00	56,51	60,79	65,05
32,5	20,35	19,67	21,00	27,80	29,80	31,50	55,80	59,20	64,51
35	21,90	19,48	20,80	27,50	29,30	31,05	55,16	58,50	62,40
Average	18,59	19,83	21,23	27,76	29,76	31,85	55,82	59,49	63,92
			Hw 5 = 34,05		Hw 7,5 = 36,36	Hw 10 = 39			

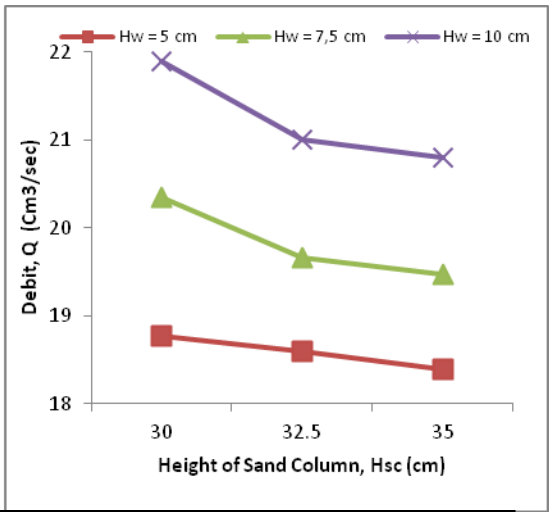

Fig.8. The Relationship Between Debit With Height Of Sand Column at 4 Sand Column

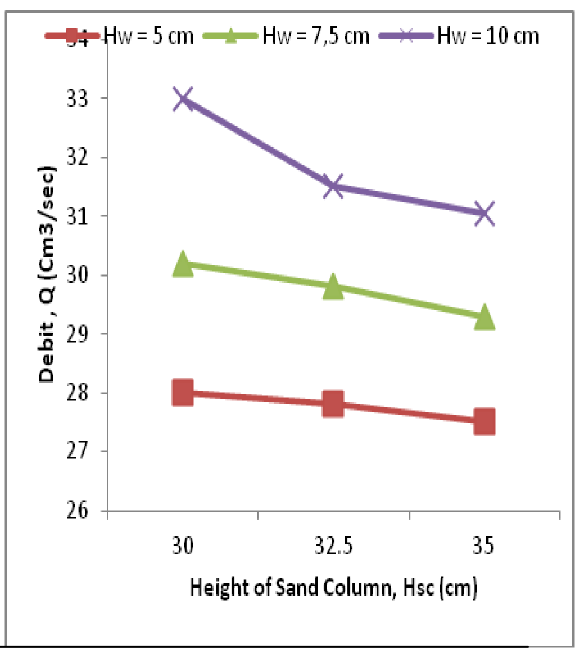

Fig.9. The Relationship Between Debit With Height Of Sand Column at 6 Sand Column

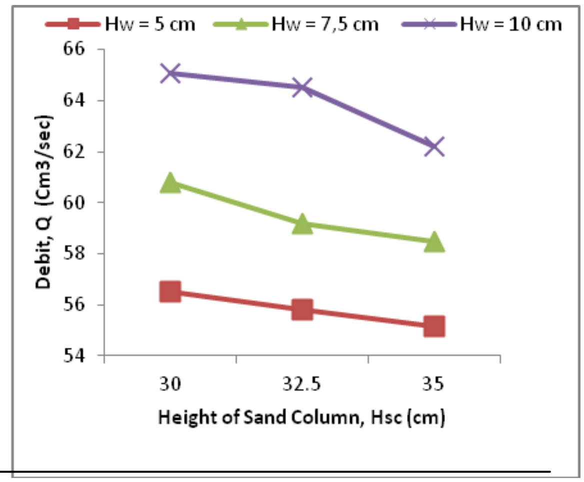

Fig.10. The Relationship Between Debit With Height Of Sand Column at 12 Sand Column

According to the table 2 Figure 8, 9 and 10 shows that the increase debit from the reservoir water level from 5 cm to 7.5 cm to 10 cm and vary the number of columns and height of sand column.

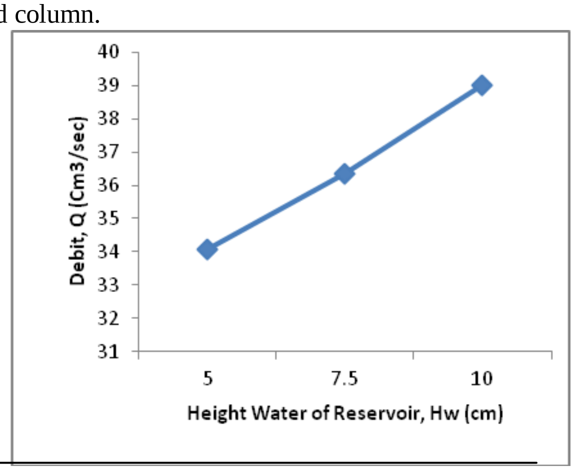

Fig.11. Average Of Debit Each Height Water Of Reservoir

In figure 10, it appears also that an increase in the debit of 34.05 cm3/sec at 5 cm water height to 36.36 cm3/sec at 7.5 cm height and 39 cm 3/sec at 10 cm of water height of reservoirs , or an increase by 1.06 times if the debit used water reservoir height 7.5 cm. While at the 10 cm height of water reservoir about 1.14 times.This is according to equation

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2, the higher the water reservoir, the hydraulic gradient (i) is greater so as debit, because the hydraulic gradient is directly proportional to the debit.

D. Influence of Sand Column Height

Table 3 below shows the amount of debit through the sand column on any number of sand columns (4 pcs, 6 pcs and 12 pcs) of each of the height of water reservoir (5 cm, 7.5 cm and 10 cm). Figure 12, 13 and 14 illustrate the relationship between the debit and the number of sand columnsin each reservoir water level (5 cm, 7.5 cm and 10 cm).

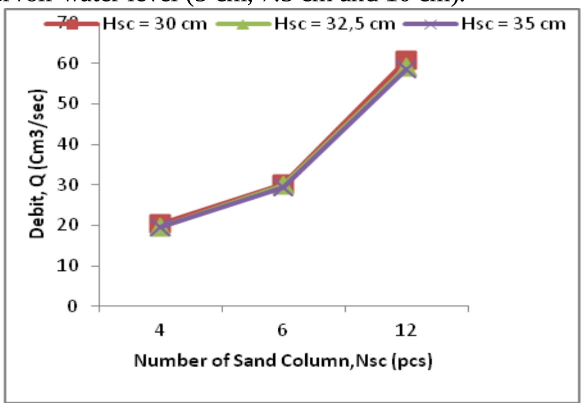

Fig.12. The Relationship Between Debit With Number Of Sand Column at Height Water Reservoir 5 Cm

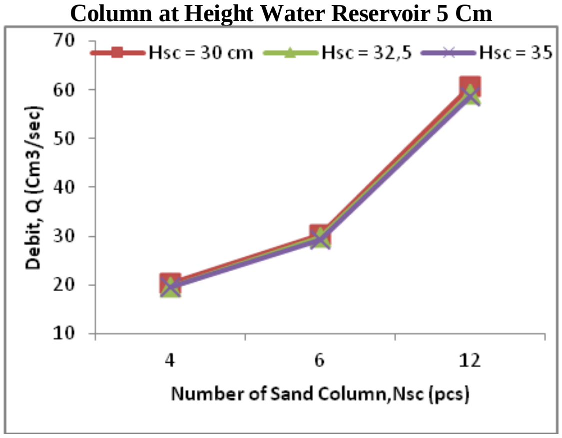

Fig.13 The Relationship Between Debit With Number Of Sand Column at Height Water Reservoir 7,5 Cm

N_{Sc} (pcs)	Debit through sand column, Q (cm3/det)								
	Hw = 5 cm			Hw = 7,5 cm			Hw = 10 cm		
	Hsc 30 cm	Hsc 32,5 cm	Hsc 35 cm	Hsc 30 cm	Hsc 32,5 cm	Hsc 35 cm	Hsc 30 cm	Hsc 32,5 cm	Hsc 35 cm
4	18,78	18,60	18,40	20,35	19,67	19,48	21,90	21,00	20,80
6	28,00	27,80	27,15	30,20	29,80	29,30	33,00	31,50	31,05
12	56,51	55,80	55,16	60,79	59,20	58,50	65,05	64,51	62,21
Average	34,43	34,07	33,68	37,11	36,22	35,76	39,98	39,00	38,02
	Hsc 30 = 37,17			Hsc 32,5 = 36,39			Hsc 35 = 36,15		

Table III.DEBIT AS RESULT OF HEIGHT SAND COLUMN INFLUENCE

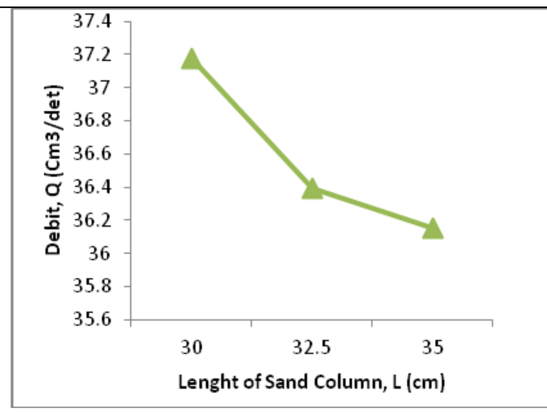

Fig.15. Average of debit each height of sand Column

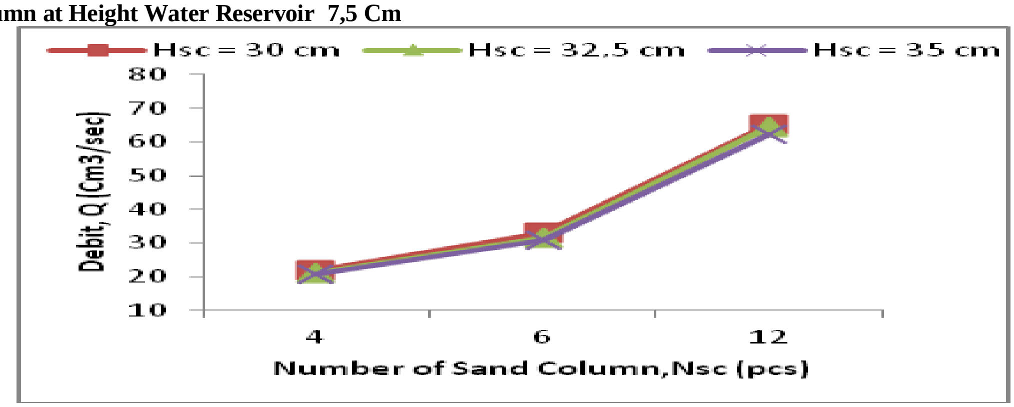

Fig.14. The Relationship Between Debit With Number Of Sand Column at Height Water Reservoir 10 Cm

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Based on Table 3 and Figure 12, 13 and 14 shows that the increase of debit in each variation of number of sand column and height of water reservoirs. However, in figure 15, it appears there is a decrease in the debit of 37.17 cm3/sec with 30 cm sand column height to 36.39 cm3/sec with 32.5 cm and 36.15 cm3/sec at 35 cm or debit decreased by 2.09% when using a 32.5 cm height, and 2.74% for a 35 cm height of sand column. This is according to equation 2, that the higher of the sand column, the hydraulic gradient (i) become smaller and also the debit, because the hydraulic gradient equation is proportional to the debit.

V. CONCLUSION

Based on the results of research conducted, it can be concluded that :

1. The use of the reservoir sand column recharge very influential on amount of debit into the aquifer layers.
2. The amount of debit greatly influenced by the amount of sand column. On the use of 6 sand columns, debit occurring 1.49 times compared with 4 sand columns, and by 3 times while the use of 12 sand column.
3. Height water in the reservoir and the height of the sand column effect is not too large. However, according to the research, the higher the water in the reservoir, the greater the discharge occurs. While, if the height of the sand column increase will decrease debit that occurs.
4. The results of this research should be continued on the application's physical scale in urban areas which have plenty amount of surface water resources but low in soil permeability coefficient (below 10^{-5} cm3/sec). If succeeded, it is hoped that the result can be used to prevent land subsidance, sea water intrusion, ground water deterioration, ground water deficiency in dry season and flood in rainy season.

VI. ACKNOWLEDGMENT

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