INFLUENCE OF SAND PERMEABILITY AT SAND COLUMN TO GROUNDWATER RECHARGE

Akhmad Azis, Hamzah Yusuf and Zulviyah Faisal

correspondent author: akhmad_azis@yahoo.com

ABSTRACT: The need for ground water supply is increasing; however, with the excessive exploitation, the surface of the groundwater has gone down, and that has resulted in the lowering of the land subsidence, sea water intrusion, and the decreasing groundwater quality. In order to keep the groundwater supply, various attempts have been taken, such as implementing the natural or artificial recharges. One of the artificial recharging methods which had previously been studied was the constructing a recharge reservoir on the soil with the permeability of less $10^{-2}$ cm$^3$/sec using a sand column. The purpose of research is to determine how much influence the permeability of the sand in the sand column. More specifically, the aim of the research was to determine exactly the kind of the sand column which could be used in the field, in order to reduce the groundwater problems. The measurement of the physical model test instrument was 180 cm x 115 cm x 60 cm with the parameters of the number of sand columns (4; 6; 12) pieces, the reservoir water level of (5; 7.5; 10) cm, the sand column height of (30; 32.5; 35) cm, three variations of sand permeability. The conclusion of this study namely, that the greater the density of the sand column and sand permeability, discharge into the aquifer layers greater. While the height of sand column opposite. The greater the height of sand column, the smaller discharge into the aquifer layers.

Keywords: Sand Permeability, Groundwater, Sand Column.

INTRODUCTION

Background

Rapid development of urban area is indicated by the existence of settlements and industries which increases water demand and disturbs the water supply and demand balance. This is worsen by the government incapability to provide clean water through Regional Drinking Water Company (PDAM). It fails to reach the overall area in supplying clean water. Thus, to obtain alternative clean water resource, people pump the groundwater by making and drilling wells. In large cities, the ground water exploitation has been intensive. Many industries and hotels have production wells up to 20 wells with more than 8,000 m$^3$ taking per day (Kodoatie and Sjarif, 2010), (Azis, A, 2014).

The existence of groundwater is strongly correlated to surface water. When the groundwater surface height experiences continuous decrease due to excessive exploitation, according to Tresnadi (2007), it will result in: land subsidence, sea water intrusion, degrading groundwater surface and decreasing groundwater quality.

To cope with those problems, there have been efforts of both natural and artificial recharge by developing infiltration well, bio-pores holes as well as other absorbance techniques. However, the results have not been maximal. Thus, the development of recharge reservoir, which is being intensified in Indonesia, is hoped to cope with the problem. However, when recharge reservoir is to be constructed on certain area with small permeability coefficient and low absorbance power, water will be very slow to reach the aquifer layer and fail to function as a recharge reservoir. Therefore, it is required to study the use of recharge column model, within sand permeability variation, that is put in the base of recharge reservoir. This study is expected to provide solution for the problem of groundwater recharge in the above-mentioned condition.

The objective of this research is to analyze the influence of sand permeability variation of the sand column to the amount of occurring recharge.

LITERATURE STUDY

The groundwater crisis especially in large cities in Indonesia has reached danger level. Groundwater recharge almost never increases, but decreases instead, and with increasing usage on the other hand. The development of superblock and high buildings also contribute to decreasing groundwater supply. The building structure with deep basements also

---

1 Civil Engineering Department, Polytechnic State of Ujung Pandang, Makassar, 90245, INDONESIA
2 Civil Engineering Department, Polytechnic State of Ujung Pandang, Makassar, 90245, INDONESIA
3 Civil Engineering Department, Polytechnic State of Ujung Pandang, Makassar, 90245, INDONESIA
decreases the capability in absorbing rain water. Open green space and attachment area which previously function as The Office of Geology expects that Jakarta will endure groundwater crisis in 15 years ahead if no special treatments are taken. At present, groundwater uptake is quite high reaching 27 million m³/year with groundwater absorbance of only 17 million m³/year (Putranto, 2009).

According to Herlambang (2009), having poor quality of water surface, people of Jakarta shifts to groundwater. With uncontrolled uptakes, groundwater surface decreases from 50 m to 150 meter, causing the landscape degrades and sea water rises as tidal flood. In Yogyakarta, groundwater crisis is mostly due to many factors such as the options taken by the decision makers in the local government. According to Pramudya (2009), groundwater quality and volume degradation in Yogyakarta can be seen based on three aspects: poor layout, bad sanitation management and weak law enforcement for environment violator. There has been land changing function from wetfield into dry farm or settlements, shopping complex and other type of buildings. In Bandung, if there is no restoration of the groundwater condition, in 2013 there will be 116 % additional critical zone and 570 %, damaged zone of presssed groundwater surface which is under the upper limit of the pressed aquifer (groundwater mining). The estimated total area of groundwater mining is 244 km² or 41 % of the total area of restricted aquifer (Hutaoit, 2009).

**Groundwater**

Groundwater is the most important mineral source taken from under the soil surface at water saturated zone. In Regulation No.7 year 2004 about Water Resource, it is mentioned that groundwater is water existed in the rocky layer (Sudjarwadi et, al, 2008). About 30% of daily consumption in the world is supplied by groundwater indicating its significant contribution to human lives and activities. The rest is provided by surface water from river or lake (Soedarmo and Purnomo, 2001).

Groundwater is one of the phases in hydrology cycle. It starts from an event where due to the heat of the sun, water changes its form to steam such as evaporation of river water, reservoir water or sea water and surface water, as well as evapo-transpiration, which is evaporation from the plantation surface. At certain height, the steam resulted from evaporation becomes cloud. Due to various causes, the cloud is condensed into precipitation in the form of snow, ice rain, rain or dew. Rainfall water sometimes is restrained by leaves or buildings. Some of it reaches the ground and becomes surface flow entering the catchment area and heading to the network system of river, lake or reservoir. Then it goes to coastal area and ends to the sea. Some of the flow is absorbed into the ground in the form of infiltration and percolation that becomes shallow or deep groundwater (Kodoatic and Sjarief, 2008), (Azis, A, 2014).

**Groundwater flow**

Groundwater requires energy to move and flow trough spaces between grains. Such energy comes from the potential energy. This is reflected from the water surface level (piezometric) of the related place. Groundwater flows from point with high to lower potential energy. There is no groundwater flow between points with the same potential energy. Imaginary line connecting the points with the same potential energy is called the contour line of groundwater surface or isohypse line. Along the contour line there is no groundwater flow because its direction is perpendicular to the contour line.

**Permeability**

Permeability is defined as the characteristic of pored material that enables the flow and seepage flow from the fluid, such as water or oil, to flow through the pore space connected to each other. Then, water can flow from point with high to lower energy point. For the soil, the permeability is described as the soil characteristics in flowing water through soil pore spaces (Hardiyatmo, 2010).

**Soil permeability coefficient**

Soil permeability coefficient is the amount of water that can be flown in each time unit through one unit of aquifer section area. The amount of water flown in the overall thickness of the aquifer is called the transmissibility coefficient. The Soil permeability coefficient (k) is used to identify the amount of seepage and the problems of dams, irrigation channel, main embankment, infiltration well, etc.

![Figure 1. Fixed (a) and diminishing (b) Stress Tests (Das et.al, 1995)](image)
Precise determination of soil permeability coefficient should be taken by laboratories method. There are two ways to determine the permeability coefficient in the laboratory: by fixed head experiment and falling head experiment. The first is used for soil with coarse grain and high permeability coefficient. The sand is set for soil with fine grain and low permeability coefficient. Both experiments are presented in Figure 1.

**The Law of Darcy.**

The Law of Darcy explains the ability of water to flow between pores of the soil and then give influencing characteristics. There are two main assumptions used in the Law of Darcy. First, the fluid flow in the soil is laminar. Second, the soil is in saturated condition. The flow speed and water quantity/debit per time unit is proportional to the hydraulic gradient (Soedarmo and Purnomo, 2001), (Azis, A, 2013).

\[ Q = k_i A \]  \hspace{1cm} (1)
\[ V = \frac{q}{A} = k_i \]  \hspace{1cm} (2)

Where:
- \( q \) = volume of water flow per time unit (cm3)
- \( A \) = soil section area flown through by water (cm2)
- \( k \) = permeability coefficient (cm/sec)
- \( i \) = hydraulic gradient
- \( v \) = flow speed (cm/sec)

**Recharge Reservoir**

**The function of recharge reservoir.**

One of the forms of artificial recharge is the recharge reservoir that mainly functions as water absorbance media which easily and quickly enters the aquifer layer. Such reservoir model is suitable for land with shallow and wide area (Kusnadi, 2005), (Azis, A, 2014). According to Sudinda (2004) acting as the Team Leader of recharge reservoir development project of the Ministry of Research and Technology, the basic philosophy of the recharge reservoir development is how to minimize the surface runoff and increase the ground capacity to absorb the surface flow. The making of recharge reservoir is different from common reservoir. It is constructed with recharge base directly connected to the aquifer layer. Recharge reservoir is basically classified to single purpose recharge, functioning as the flood controller with a working system that increases the aquifer function optimization, such as increasing the water storage capacity in the aquifer layer (Azis, A, 2013). The benefit of recharge reservoir includes:

1. Optimizing the aquifer function that may increase the water storage capacity in the aquifer
2. Functioning as flood controller in downstream or runoff areas.
3. Functioning as water storage in dry season.

Research by The Ministry of Research and Technology (Ristek) that has been taken since 2003 indicated that the application of recharge reservoir can cope with the annual flood and drought problems in Indonesia. The absorbance level (infiltration rate) of the recharge reservoir is quite high.

**Previous researches.**

Based on the above-mentioned understandings, some researchers have studied recharge reservoir as the followings:

1) The results of recharge reservoir simulation under different methods for the area of Universitas Indonesia (UI) which includes about 0.5 hectare. It shows absorbance of surface flow in infiltration rate of 1,933 m³/day or 22.37 lt/sec. When converted to water demand, it equals to water demand of 32,213 people of rural area or 16,106 people of urban area, which is 60-120 lt per capita and capable to supply agricultural area of 41.4 ha and potable water demand of industrial area of 30-40 hectare (Sudinda, 2004).

2) According to Djudi (2006), for Tambakboyo recharge reservoir in Regency of Sleman of Daerah Istimewa Yogyakarta, the results show that 25 m depth of drilling indicates sand of volcanic sedimentation with permeability coefficient of 1.1 x 10^-4 cm/sec to 9 x 10^-3 cm/sec. Therefore, the reservoir base consists of soil that is homogeneity permeable and interacts to each other to aquifer that the percolation of the base soil is larger than normal. With 5.6 ha of inundation and 427,349 m³ storage volume, recharge reservoir can provide water recharge to the ground in 34.36 lt/sec averagely, indicating that it gives contribution to potable water availability for 49,479 people of Yogyakarta in. The reservoir water demand is supplied by River Tambakboyan.

3) Broto and Susanto (2008) made a model design of recharge reservoir of the City of Bogor by using the tank model application. Bogor is an area of groundwater filling. It supplies water to the urban area especially the city of Jakarta, which is susceptible to frequent flood. recharge reservoir is required as the precautions to the flood hazard. It optimizes the aquifer function by increasing the absorbance power of the aquifer in order to reduce the surface
runoff as the main cause of flood due to the river incapability to store the water. The simulation results show that water demand can then be absorbed from the recharge reservoir to the aquifer layer by 1,150 m³/day.

4) Based on the simulation result shows that the amount of water absorbed from the recharge reservoir to the aquifer layer is 1,150 m³/day. Based on a study by Akhmad Azis (2012) about the use of sand column for recharge reservoir for anticipating soil layer with small permeability on the reservoir base, the absorbance debit at density of 0.0157 was 62.41 cm³/sec.

Physical model of sand column
In this study, the sand column is used as the median to absorb recharge reservoir water to the aquifer layer. The traditional method in making sand column is by drilling holes on the clay layer with small permeability and refilling it with graded sand. Sand should be flown by water without bringing fine soil particles.

According to Liang (2000), soil with coarse grain has small surface specific (clean sand with surface specific of 10⁻³ m²/g). Thus, the surface force can be ignored relatively to its own weight. That its own weight force is more dominant than the surface adhesive force. Thus, the composition between the particles of coarse grain soil is called single and composed as a group of randomly packed balls. Each soil and gravel particle relates to other particles or it can be said as no cohesion. Sand and gravel are non cohesive soil. Due to self weight force being more dominant than the surface force, the sand and gravel behavior are not influenced by water. Particle distribution is a relevant parameter. The influence of water is visible only for free fine sand that is water saturated and has experienced dynamic loading (Joleha, 2001), (Azis, A, 2014).

Sand columns with a Principle that water from the surface is stored in the reservoir at certain height. Then water is flown through the sand columns that sand with large permeability coefficient can accelerate and enlarge recharge as well as to become filtration that water entering the aquifer layer is in clean condition (Azis, A, 2012).

sand column density
Hypothetically, the sand column density placed in the base of the recharge reservoir has significant influence to the recharge debit. The higher the density level, the larger the recharge debit will be (Azis, A, 2012). To obtain the sand column density, the following formula is applied:

\[ \xi = \frac{\text{kolom pasir}}{\text{diameter}} \]

\[ \text{kolom pasir} = \xi \times \text{diameter} \times N_{kp} \]

Where : 
- \( \xi \) = diameter of sand column
- \( N_{kp} \) = numbers of sand column

RESEARCH METHOD
Data collecting Technique
Data collecting was carried out by the followings:
This study used a testing tub in square dimension of 180 cm x 115 cm x 60 cm. The identified soil which fulfilled the required permeability, was put into the tub. Then test was taken without using sand column. Then the sand column was installed. On the surface of the tub, it was given with input debit \( Q_1 \) for the reservoir and \( Q_2 \) for the energy height difference. To identify the size of the debit, time was recorded for the 5 times filling of each 1000 ml, and so was the runoff debit \( Q_3 \) and the debit coming out of the aquifer layer \( Q_4 \). When the soil experienced water saturated, observation was taken for each three variations for sand permeability, sand column density \( \xi \) and three variations of energy height difference.
RESULTS
Characteristics of Soil and Sand Material

Soil Sample
According to USCS and ASTM systems, soil is classified as ML (inorganic silt with low plasticity, fine sand with silt or clay) and CL (inorganic clay with low plasticity, clay with silt or skinny clay), because the fine fraction (58.9%) > 50% and liquid limit (42.6%) < 50%, plasticity index (5.9%) is between required 4 ≤ PI ≤ 7.

Based on AASHTO and HRB system, the soil was classified as soil A4 (with silt), because fine fraction (58.9%) > 36% passed no. 200 sieve, with liquid limit (27.5%) < 40%, plasticity index (5.9%) < 10%, and group index (1.49) < 8.
Soil permeability coefficient (k) = 0.000033 cm/sec that the soil type is classified into the compact silt or silt with clay. Based on the systems of classification and the obtained permeability coefficient, it can be concluded that soil used in this research is silt soil with clay and with low plasticity.

Sand Sample
Based on USCS and ASTM systems, the three types were classified as SW (good gradated sand, slight or with no fine grain) and SP (poor gradated, slight or with no fine grain), because fine fraction (2.58%) < 5% and coarse fraction (97.42%) > 50% passed number 4 sieve.

Under the AASHTO and HRB systems, the soil is classified in A-1-b (sand), because the fine fraction (2.58%) < 5% passed the number 200 sieve, liquid limit (4.1%) < 25%, plasticity index (0%) < 6%. Permeability coefficient of sand (k) was k1 = 0.201 cm/sec, k2 = 0.034 cm/sec and k3 = 0.023 cm/sec, respective. The soil type was classified as coarse sand.

Based on the four systems of classification and the obtained permeability coefficient, it can be concluded that the three sand used in this study was coarse sand.

Influencing factors to Groundwater recharge Debit
The amount of water entering the aquifer layer through the soil layer as well as the sand column in this research were influenced by sand permeability and energy height difference.

The Influence of sand permeability
Based on the results of this research either with or without sand column, as well as the analysis results as seen on Table 1, Table 2 and Table 3 and Figure 3, it can be indicated that the amount of groundwater recharge debit, on the soil layer thickness or sand column height of 30 cm, 32.5 cm, 35 cm and density of (g) 10 : 0.0019 ; 0.0028 ; 0.0033 ; 0.0050 ; 0.0052 ; 0.0057 ; 0.0079 ; 0.01 and 0.0157, respectively, increased in line to the increasing sand permeability. The increasing groundwater recharge debit can be explained below:

Table 3 shows that groundwater recharge debit increased slowly from the density of 0.0019 to 0.0028 and then from 0.0019 to 0.0033 that the higher would be from 0.0019 to 0.0157 at 9 variations of energy height differences. Based on the calculation of average percentage of groundwater recharge debit, significant difference was visible between the lowest and the highest density. It was also indicated that due to the increasing density from 0.0019 to 0.0028 (47.37%) there was increasing percentage or 50.92%, and from 0.0019 to 0.0157 (726,32%) by 846.68%.
Table 1. Groundwater recharge debit at sand permeability 1

<table>
<thead>
<tr>
<th>δ</th>
<th>37.4</th>
<th>35</th>
<th>34.9</th>
<th>34.2</th>
<th>32.8</th>
<th>32.5</th>
<th>32</th>
<th>30.9</th>
<th>30.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0019</td>
<td>6.62</td>
<td>6.40</td>
<td>6.35</td>
<td>5.98</td>
<td>5.82</td>
<td>5.96</td>
<td>5.61</td>
<td>5.47</td>
<td></td>
</tr>
<tr>
<td>0.0028</td>
<td>10.20</td>
<td>9.49</td>
<td>9.31</td>
<td>9.58</td>
<td>8.93</td>
<td>8.77</td>
<td>8.92</td>
<td>8.37</td>
<td>8.91</td>
</tr>
<tr>
<td>0.0033</td>
<td>12.26</td>
<td>11.40</td>
<td>11.28</td>
<td>11.39</td>
<td>10.62</td>
<td>10.51</td>
<td>10.87</td>
<td>10.15</td>
<td>10.05</td>
</tr>
<tr>
<td>0.0050</td>
<td>18.37</td>
<td>17.03</td>
<td>16.77</td>
<td>17.26</td>
<td>16.09</td>
<td>15.84</td>
<td>16.12</td>
<td>14.99</td>
<td>14.80</td>
</tr>
<tr>
<td>0.0052</td>
<td>18.78</td>
<td>17.52</td>
<td>17.24</td>
<td>20.35</td>
<td>19.15</td>
<td>18.63</td>
<td>21.90</td>
<td>20.39</td>
<td>19.92</td>
</tr>
<tr>
<td>0.0057</td>
<td>20.43</td>
<td>18.94</td>
<td>18.65</td>
<td>19.14</td>
<td>17.80</td>
<td>17.42</td>
<td>17.86</td>
<td>16.68</td>
<td>16.31</td>
</tr>
<tr>
<td>0.0079</td>
<td>28.00</td>
<td>27.60</td>
<td>25.85</td>
<td>30.20</td>
<td>28.15</td>
<td>27.65</td>
<td>33.00</td>
<td>30.95</td>
<td>30.29</td>
</tr>
<tr>
<td>0.0100</td>
<td>36.48</td>
<td>33.83</td>
<td>33.31</td>
<td>34.25</td>
<td>31.92</td>
<td>31.44</td>
<td>32.16</td>
<td>29.91</td>
<td>29.52</td>
</tr>
<tr>
<td>0.0157</td>
<td>56.51</td>
<td>52.78</td>
<td>51.62</td>
<td>60.79</td>
<td>56.54</td>
<td>55.32</td>
<td>65.05</td>
<td>59.55</td>
<td>59.20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>57.48</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>846.68</td>
</tr>
</tbody>
</table>

As seen on Table 2 below, at sand permeability 2 of 0.034 cm/sec, the condition was almost the same as sand permeability 1 of 0.201 cm/sec.

Table 2. Groundwater recharge debit at Sand permeability 2

<table>
<thead>
<tr>
<th>δ</th>
<th>37.4</th>
<th>35</th>
<th>34.9</th>
<th>34.2</th>
<th>32.8</th>
<th>32.5</th>
<th>32</th>
<th>30.9</th>
<th>30.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0019</td>
<td>3.21</td>
<td>3.05</td>
<td>2.96</td>
<td>3.02</td>
<td>2.86</td>
<td>2.77</td>
<td>2.80</td>
<td>2.67</td>
<td>2.59</td>
</tr>
<tr>
<td>0.0028</td>
<td>4.80</td>
<td>4.57</td>
<td>4.42</td>
<td>4.50</td>
<td>4.29</td>
<td>4.18</td>
<td>4.20</td>
<td>4.01</td>
<td>3.90</td>
</tr>
<tr>
<td>0.0033</td>
<td>5.63</td>
<td>5.53</td>
<td>5.20</td>
<td>5.28</td>
<td>5.01</td>
<td>4.87</td>
<td>4.92</td>
<td>4.68</td>
<td>4.55</td>
</tr>
<tr>
<td>0.0050</td>
<td>8.44</td>
<td>8.02</td>
<td>7.81</td>
<td>7.91</td>
<td>7.51</td>
<td>7.32</td>
<td>7.39</td>
<td>7.03</td>
<td>6.84</td>
</tr>
<tr>
<td>0.0052</td>
<td>8.89</td>
<td>8.45</td>
<td>8.22</td>
<td>8.34</td>
<td>7.91</td>
<td>7.69</td>
<td>7.78</td>
<td>7.40</td>
<td>7.17</td>
</tr>
<tr>
<td>0.0057</td>
<td>9.50</td>
<td>9.02</td>
<td>8.80</td>
<td>8.90</td>
<td>8.45</td>
<td>8.24</td>
<td>8.31</td>
<td>7.90</td>
<td>7.69</td>
</tr>
<tr>
<td>0.0079</td>
<td>13.34</td>
<td>12.68</td>
<td>12.34</td>
<td>12.51</td>
<td>11.87</td>
<td>11.57</td>
<td>11.67</td>
<td>11.10</td>
<td>10.81</td>
</tr>
<tr>
<td>0.0100</td>
<td>16.88</td>
<td>16.04</td>
<td>15.61</td>
<td>15.83</td>
<td>15.02</td>
<td>14.64</td>
<td>14.77</td>
<td>14.05</td>
<td>13.67</td>
</tr>
<tr>
<td>0.0157</td>
<td>26.67</td>
<td>25.32</td>
<td>24.68</td>
<td>25.02</td>
<td>23.74</td>
<td>23.14</td>
<td>23.34</td>
<td>22.21</td>
<td>21.61</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>23.97</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>731.97</td>
</tr>
</tbody>
</table>

It was indicated that groundwater recharge debit slowly increased from density 0.0019 to 0.0028 and then from 0.0019 to 0.0033 and the highest from 0.0019 to 0.0157 at 9 variation of energy height difference. Due to the increasing density from 0.0019 to 0.0028 (47.37%), the average percentage of groundwater recharge debit of 49.9% was the smallest increase. The quite large increase was obtained from density 0.0019 to 0.0157 (726.32%) by 731.97%.

For sand permeability 3 of 0.023 cm/sec as presented on Table 3, the condition was similar to sand permeability 1 of 0.201 cm/sec and permeability 2 of 0.034 cm/sec, but with smaller increasing percentage. This was because the smaller the sand permeability, it will give more influence to the increasing level. It was also visible that groundwater recharge debit slowly increased from the sand column density of 0.0019 to 0.0028 then from 0.0019 to 0.0033 that the highest was from 0.0019 to 0.0157 cm at 9 variations of energy height difference. The average percentage of the smallest groundwater recharge debit was 50.86%, due to the increasing sand column density from 0.0019 to 0.0028 (47.37%), and the largest was from 0.0019 to 0.0157 (726.32%) with increasing debit of 734.57%.

Table 3. Groundwater recharge debit at Sand permeability 3

<table>
<thead>
<tr>
<th>δ</th>
<th>37.4</th>
<th>35</th>
<th>34.9</th>
<th>34.2</th>
<th>32.8</th>
<th>32.5</th>
<th>32</th>
<th>30.9</th>
<th>30.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0019</td>
<td>0.87</td>
<td>0.82</td>
<td>0.80</td>
<td>0.81</td>
<td>0.77</td>
<td>0.75</td>
<td>0.76</td>
<td>0.72</td>
<td>0.70</td>
</tr>
<tr>
<td>0.0028</td>
<td>1.30</td>
<td>1.23</td>
<td>1.20</td>
<td>1.22</td>
<td>1.16</td>
<td>1.13</td>
<td>1.15</td>
<td>1.10</td>
<td>1.07</td>
</tr>
<tr>
<td>0.0033</td>
<td>1.54</td>
<td>1.46</td>
<td>1.42</td>
<td>1.44</td>
<td>1.37</td>
<td>1.33</td>
<td>1.35</td>
<td>1.29</td>
<td>1.25</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.78</td>
<td>0</td>
<td>50.86</td>
<td>77.86</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The three tables above showed that the increasing sand column density was linear to the increasing recharge debit. This indicated that the sand column density is proportional to the recharge debit, in accordance to the Law of Darcy. The amount of debit is influenced by energy height difference which is a function of hydraulic gradient.

Figure 3 describes the relation between groundwater recharge debits to the sand column density at three sand permeability values. The Figure shows the increasing debit from density 0.0019 to 0.0157 at all sand permeability values. At permeability 1, groundwater recharge debit was larger than permeability 2 and 3 because sand permeability 1 was larger. At the minimum and maximum debit at sand permeability 1 were 5.47 cm$^3$/sec and 65.05 cm$^3$/sec, respectively. At sand permeability 2, minimum and maximum groundwater recharge debits were 2.59 cm$^3$/sec and 26.67 cm$^3$/sec, respectively. At permeability 3, the minimum and maximum groundwater recharge debits were 0.70 cm$^3$/sec and 7.22 cm$^3$/sec, respectively.

![Figure 3. Average Groundwater recharge debit at 3 sand permeability values](image)

Figure 4 describes the increasing percentage of groundwater recharge debit at three sand permeability values. It shows increasing debit from density 0.0019 to 0.0157 at all sand permeability. At permeability 1, the percentage increase of groundwater recharge debit was larger than permeability 2 and 3, and the increase of percentage at sand permeability 2 and 3 was almost the same because sand permeability 2 and 3 had insignificant difference.

![Figure 4. The percentages of groundwater recharge debit increase](image)
CONCLUSIONS
Based on the results, it can be concluded that the larger the sand column density and permeability, the larger the debit entering the aquifer layer will be. As for the side flow debit and the sand column length, the otherwise occurs. The larger the side flow debit and the higher the sand column, the smaller the debit entering the aquifer layer will be. Based on the research results, it shows the percentage of the increasing average debit from the density of 0.0019 to 0.0157 at all sand permeability values. At permeability 1, the increasing percentage of groundwater recharge debit was larger than permeability 2 and 3, and the increasing percentage of sand permeability 2 and 3 was almost the same because sand permeability 2 and 3 had insignificant difference. The influence of energy height difference indicated increasing debit of sand column density from 0.0019 to 0.0157. At density = 0.0019, the average minimum groundwater recharge debit was 2.92 cm³/sec and maximum was 3.63 cm³/sec. At density = 0.0057, the average minimum groundwater recharge debit was 28.89 cm³/sec and maximum was 30.13 cm³/sec.

ACKNOWLEDGEMENTS
We sincerely thank especially to Head of Civil Engineering Department, Ujung Pandang State Polytechnic for supporting and providing opportunity to conduct this research.

REFERENCES


