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Regional Case Study

Rainwater Harvesting Planning using Infiltration Wells in Amlapura City Karangasem Regency

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Abstract

Amplapura is located in the highlands having a potential area of green open land which can absorb rainwater freely into the ground. However, in recent times, land conversion has begun to develop with new housing buildings, Griya Galiran Regency Housing. Furthermore, the effectiveness of the land area is still able to absorb water and maintain groundwater balance. A rainwater harvesting plan (RH) is needed, or, more popularly, rainwater harvesting. In this area. The aim is to provide a portion of residential land space for rainwater infiltration into the pores or soil cavities using the infiltration well method. The results showed that the Griya Galiran Regency Housing had an acceptable sand soil type and absorbed soil quickly, with a soil permeability coefficient (k) of 0.0014 cm/s. Designing the dimensions of the infiltration well at the Griya Galiran Regency Housing with an area of 70 m^2 based on SNI 03-2453-2002 for a circular cross-section, an infiltration well with a diameter of 1.2 m with a depth of 2 m is made. In contrast, as a rectangular cross-section, an infiltration well has a side length of 1 m with a depth of 2 m.

Keywords: Rainwater; soil water conservation; soil permeability; the infiltration well

1. Introduction

Economic development and the increase in population in any area, including in the study area of Amlapura City, will increase the need for settlements. It can cause the function of land use to change. As a result of the process of green open land being diverted as residential land, there is a reduction in the area that can absorb rainwater (Iriani et al., 2013). Rainwater serves to overcome the drop in water catchment areas, increasing domestic water needs, groundwater reserves, and meeting domestic needs, one of which is in Jember Regency (Wiyonoet al., 2021). Covering the ground surface by residential development can reduce the area of rainwater infiltration into the ground. At the same time, groundwater absorption continues with greater intensity to decrease the groundwater level (Dirman, 2018). The decrease in the ability of the soil to absorb water as a result of environmental changes is the impact of the development process (Ridwan and Nagu, 2020).

The problems that are often faced today are related to water, such as lack of clean water, drought, construction of new settlements, which result in reduced water catchment areas, and others.

Thus, it is necessary to balance filling runoff and infiltration of rainwater so that the absorption of rainwater into the soil is good. Soil pores and strive for water conservation. Groundwater conservation is carried out by keeping the soil absorbing water optimally (Kopaba and Anwar, 2019). The research location is at Perum Griya Galiran Regency, located in the Galiran area, Amlapura, Karangasem Regency. One of the housing types is 36/75, with an open land area of 25.76 m² per plot. Indirectly there is a change in land use and can interfere with rainwater catchment areas. In addition, this area is located at a relatively high elevation, which is interested in supporting the availability of groundwater, namely as a water catchment area.

The basic principle of Rainwater Harvesting (RH) is to drain rainwater that falls on the roof surface through gutters to be accommodated. Runoff water that comes out of an entire storage tank is channeled into infiltration wells (Sylviana and Hendriyana, 2018). Infiltration wells are holes made for rainwater to seep into the soil or rock layers that carry water (Minister of Environment, 2009). Rainwater that falls on the roof of the house is not conducted into the gutter or yard but is conducted using pipes or water channels into the well to reduce the amount of runoff (Babakan and Bogor 2019). The way of working from infiltration wells is through distribution and storage of rainwater to the well so that the water can have more time to settle on the ground surface so that the soil can slowly absorb water into it. Some of the functions of infiltration wells for human life are flood control, protecting and conserving groundwater, and suppressing the erosion rate (Marliansyah 2018). Even though the use of RH is quite common, the evaluation and detailed planning of RH combined with infiltration wells is not well-developed in the current literature.

In this study, infiltration well planning was carried out regarding SNI 03-2453-2002 from harvesting rainwater on a roof area of 70 m² and land area for placing infiltration wells of 25.76 m² per plot. The purpose of this infiltration building analysis using this SNI is to apply a design criterion issued by the government and provide a reference for its application.

2. Research Methods

This research was conducted in several stages, collecting secondary and primary data. The secondary data collected were housing area, situation map, and rain data, while the primary data was soil permeability testing. Soil permeability testing was carried out at the Soil Mechanics Laboratory, Faculty of Engineering, Udayana University.

The laboratory test was conducted using the Constant Head Permeameter method for coarse grains and a high permeability coefficient. Furthermore, a hydrological analysis was carried out to obtain the initial runoff value before the infiltration well was applied (Muliawati and Mardyanto 2015). Hydrological analysis requires rainfall data for frequency analysis, including selecting distribution types, analysis of planned rainfall, analysis of rainfall intensity, and calculation of planned discharge.

Before conducting infiltration well analysis, it is necessary to pay attention to several general and technical requirements based on SNI 03-2453-2002 (National Standardization Agency, 2002). We can proceed to infiltration well analysis if all of these requirements have been completed. Furthermore, the design of infiltration buildings follows the procedure for planning for rainwater infiltration wells referring to this SNI. The number of infiltration buildings is determined based on the volume of the flood share that will be accommodated and absorbed into the infiltration building (Babakan and Bogor, 2019). In designing the dimensions of water absorption wells for residential areas, three main parameters need to be considered: soil permeability, rainfall, and roof area or watertight surface (Setiabudi, 2009).

The general requirements based on SNI 03-2453-2002 concerning Procedures for Planning Rainwater Infiltration Wells for Yard Land are as follows:

1) Rainwater infiltration wells are placed on relatively flat land.
2) The water that enters the infiltration well is unpolluted rainwater.
3) Must pay attention to local regulations.
4) The competent authority must approve Matters that do not meet this provision.

Technical requirements based on SNI 03-2459-2002 are as follows:

1) The shape and size of the body and length of rainwater infiltration wells are:
   a) The cross-section of rainwater infiltration wells is rectangular or circular.
   b) The minimum size of the side of the cross-section or diameter of 80 cm and a maximum of 120 cm.
   c) Inlet pipe diameter 110 mm.
2) Construction materials
   The construction materials used for rainwater infiltration wells can be varied, such as 10 cm wide concrete slab, 10 cm wide reinforced concrete slab, 10 cm wide enforcement, brick-red masonry, brick cement mixture 1:4 plastered sands and cemented with cement. Pairs of 1: 4 mixed concrete blocks, 80 – 100 cm diameter precast reinforced concrete, 10 – 20 cm crushed stone, 5 – 10 cm red brick shards, 110 mm diameter PVC pipe and accessories, 200 mm diameter concrete pipe, pipe concrete circle diameter 200 mm.

2.1. Soil Permeability

Soil permeability is soil that can show the ability to pass water. Soils with high permeability can increase infiltration, decreasing runoff (Tiwery, 2020). Calculation of the coefficient of soil permeability based on SNI 03-2453-2002 as follows:

$$K_{average} = \frac{K_v.A_h + K_h.A_v}{A_{total}} \quad (1)$$

$K_{average}$ = Mean soil permeability coefficient (m/day)
K_v = Well wall soil permeability coefficient (m/day) = 2 K_h
K_h = Well bottom soil permeability coefficient (m/day)
A_h = Area bottom of the well with a circular cross-section = 1/4πD2 (m^2)
= Area bottom of the well with a rectangular cross-section = P.L (m^2)
A_v = Area of the well wall with a circular cross-section = π.D.H (m^2)
= Area of the well wall with a rectangular cross-section = 2.P.L (m^2)

2.2. Hydrological Analysis

At this stage, the annual maximum daily rainfall data is used for hydrological analysis to get the value of rainfall intensity per period of a specific period, which is the basis for calculating the planned flood discharge at locations that are part of the planning (Kusumawardi, 2015).

2.3. Frequency Analysis

Several parameters are related to analyzing data in statistics. Below are several parameters from statistics that are used, including (Pradani 2013):

a. Average Price

$$\bar{x} = \frac{1}{n}\Sigma_{i=1}^{n} = {}_1X_i \quad (2)$$

b. Standard Deviation

$$s = \left[\frac{\sum_{i=1}^{n}(\log x_1 - \log x)^2}{n-1}\right]\frac{1}{2} \quad (3)$$

c. *Skewness Coefficient*

$$c_s = \frac{\Sigma_{i=1}^{n} n(x_1 - x)^3}{(n-1)(n-2)s^3} \quad (4)$$

d. Kurtosis Coefficient

$$c_k = \frac{n^2 \sum_{i=1}^{n}(x_i - \bar{x})^4}{(n-1)(n-2)(n-3)s^4} \quad (5)$$

e. Variation Coefficient

$$c_v = \frac{s}{x} \quad (6)$$

2.4. Selection of Distribution Type

In the following planning, four types of distribution are used, which will later become choices adjusted to statistical requirements. These distributions include the following (Triatmodjo in Iriani, et al., 2013) :

a. Normal Distribution
   $Cs \approx 0$
   $Ck \approx 3.0$
b. Normal Log Distribution
   $Cs = Cv^3 + 3\ Cv$
   $Ck = Cv^8 + 15Cv^4 + 16Cv^2 + 3$
c. Gumbel Distribution
   $Ck \approx 1.396$
   $Ck \approx 5.4002$
d. Pearson Type III Log Distribution
   $Cs \neq 0$

2.5. Rainfall Analysis Plan

Rainwater intensity in height per time was analyzed from the annual maximum daily rainfall data. Previously, it was mandatory to calculate the return period of rainfall in a catchment area. Based on Suripin's (2004) explanation, the notion of the return period itself is a hypothetical phase when it rains on a certain amount that has been equalized or exceeded. The analysis of rainfall intensity based on SNI No. 03-2453-2002 in the planning of rainwater infiltration wells used is a return period of 5 years.

a. Normal Method

$$XT = X + Kt\ x\ S \quad (7)$$

Kt = Frequency factor (Gaussian reduction variable)

b. Normal Log Method

$$YT = Y + Kt * S \quad (8)$$

YT = Estimated value expected to occur in the return period T years
Y = Average of sample calculations.

c. Gumbel Method

$$Xt = Xr + (K\ x\ Sc) \quad (9)$$

$$K = \frac{Yt - Yn}{Sn}$$

$$s_x = \sqrt{\frac{\sum_{i=1}^{n}(xt - xr)^2}{n-1}}$$

Yn = Average cost reduced mean
Sn = Reduced standard deviation
Yt = Reduced variate
Xt = Estimated value expected to occur in the anniversary period.
Xr = Average rainfall
Sx = Standard deviation
N = Lots of data

d. Metode Log Pearson III

$$\text{Log}X_T = \text{Log}\ \bar{x} + K.s_1 \quad (10)$$

XT = Rainfall planning for T year anniversary
x = Average rain data count
K = Standard variable with x, which has a magnitude depending on the skewness coefficient or also known as the skewness coefficient
Si = Standard deviation

2.6. Infiltration Well Analysis

According to the explanation below, this plan's calculation of rainwater infiltration wells is sequentially based on SNI No. 03-2453-2002.

2.7. Flood Contribution Volume

This volume is a volume of rainwater that wets the soil surface and then transfers to rainwater absorption wells (National Standardization Agency, 2002). Formula used:

$$Vab = 0.855 \times C_{runoff} \times A_{runoff} \times R \quad (11)$$

Vab = The volume of flood share that has shelter in absorption wells (m^3)
C_{runoff} = Field runoff coefficient (no units)
A_{runoff} = Area of the runoff with the unit (m^2)
R = Average rain height per day ($L/m^2/day$)

2.8. Infiltrating Rainwater Volume

The equation below is used, namely:

$$V_{rsp} = \frac{te}{24} \times A_{total} \times k \quad (12)$$

V_{rsp} = Volume of infiltrated rainwater (m^3)
te = Effective rain duration in units' hours
A_{total} = $L._{well}$ x $height_{well}$ (m^2)
k = Soil permeability coefficient (m/day)

2.9. Rainwater Storage Volume

The following formula is used, namely:

$$Vstorage = V_{ab} - V_{rsp} \quad (13)$$

V_{ab} = volume of flood share (m^3)
V_{rsp} = volume of infiltrated rainwater (m^3)

2.10. Determination of the Number of Infiltration Wells

To determine the number of rainwater infiltration wells, first, the calculation of the total H is carried out, including the following:

$$H_{total} = \frac{V_{ab} - V_{RSP}}{A_h} \quad (14)$$

$$n = \frac{H_{total}}{H_{rencana}} \quad (15)$$

n = Number of rainwater response wells
H_{total} = The depth of the number of rainwater infiltration wells in meters
H_{plan} = Design depth < groundwater depth in meters

2.11. Rainfall Frequency Analysis Methods

The rainfall data used is for the available 10-year series, according to the Decree of the Minister of Public Works of the Republic of Indonesia No. 11/PRT/M/2014 and SNI 03-2453-2002 that the rainfall data used is at least 10 years. The use of rainfall data started from 2009-2018 at the Pid-pid Post rain station and Telengan Post because these two rain stations are the closest to the place to carry out the research.

Table 1. Maximum daily rainfall data

Num	Year	Rain gauge station	
		Pidpid (mm)	Telengan (mm)
1.	2009	93	95
2.	2010	74	80
3.	2011	92	80
4.	2012	89	87
5.	2013	75	99
6.	2014	86	70
7.	2015	77	95
8.	2016	97	59
9.	2017	68,6	50
10.	2018	53,5	59

Source: Meteorology, Climatology and Geophysics Agency, 2019

3. Result and Discussion

3.1. Rainfall Frequency Analysis

In determining the appropriate distribution method, basic statistics are used with several parameters: the average price, the coefficient of kurtosis, the coefficient of skewness, the coefficient of variation, and the standard deviation, as shown in Table 2.

Table 2. Primary statistical parameter calculation results

Parameters	The calculation results
Average	78.96
Standard Deviation	12.38
Coef. Skewness	-1.02
Coef. Kurtosis	0.14

Tabel 3. The suitability of statistical parameters to determine the type of distribution

Distribution	Calculation Results	Description
Normal	Cs = -1.02 Ck = 0.14	Not meet
Log-Normal	Cs = -1.02	Not meet
Gumbel	Cs = -1.02 Ck = 0.14	Not meet
Log-Pearson III	Apart from the above three distributions, Meets	Meet

According to Soemarto in Noerhayati and Rachmawati (2018), each distribution has distinctive properties that each hydrological data tested for suitability with the statistical properties of each distribution (Sri Harto, 1993). The frequency of rainfall data analysis with the practicality of their distribution can be seen in Table 3. Those that have the fulfillment of the requirements are by using Log-Pearson III.

3.2. Rainfall Analysis Plan

Table 4. The results of the calculation of the planned rainfall analysis

Probability in Order	When Repeat	Rain Characteristics (mm) According to Probability and Repeat Period							
		Normal		Log Normal		Gumbel		Log Pearson III	
P(x>=X)	T (years)	K_T	X_T	K_T	X_T	K_T	X_T	K_T	X_T
99.99%	1	-3.72	32.91	-3.04	41.32	-2.18	51.95	-6.64	25.09
50.00%	2	0.00	78.96	-0.08	77.98	-0.16	76.92	0.20	80.63
20.00%	5	0.84	89.38	0.90	90.04	0.72	87.86	0.84	89.98
10.00%	10	1,28	94.82	1.46	97.06	1.30	95.11	1.08	93.78
5.00%	20	1.64	99.32	1.96	103.28	1.87	102.06	1.24	96.35

Table 4 shows the value of rainfall through the Log Pearson III method. The one-year is 29.09 mm, the two-year is 80.63 mm, the five-year is 89.98 mm, the ten-year is 93.78 mm, and the twentieth is 96.35 mm. After getting the results of the frequency distribution analysis, namely the Normal, Log-Normal, Gumbel, and Log-Pearson III methods, followed by the Chi-Square and Smirnov-Kolmogorov compatibility tests to see outliers in the data being tested. The results showed that there were no outlier data. The results of the analysis in Table 4 are acceptable.

3.3. Rain Intensity Analysis

In the following planning, the intensity of rainwater is used as the primary data for analyzing infiltration wells. The data used is time-series data in hourly rainfall and then distributed in minutes. The results of the planned rainfall distribution with 3 return periods in the form of an Intensity Duration Frequency (IDF) curve are shown in Figure 3.

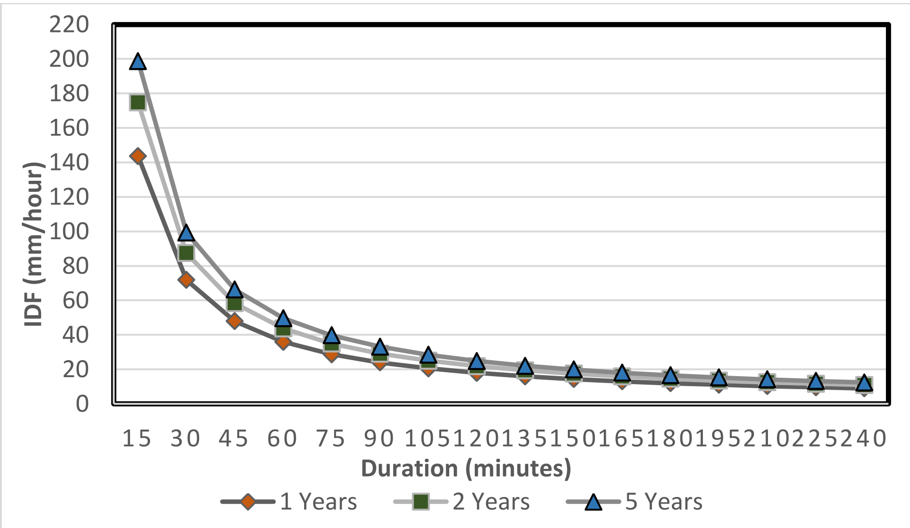


Figure 1 Intensity duration frequency (IDF) curve

3.4. Permeability Coefficient Calculation

The permeability coefficient of the Perum Griya Galiran Regency has been tested and analyzed. Test analysis with the Constant Head Method is shown in Table 5.

Table 5. Constant head method analysis

No	Tool Dimensions and Soil Sample				
			20 minute I	20 minute II	20 minute III
1	Sample Diameter	cm	6.35	6,35	6.35
2	Soil Sample Height (L)	cm	10.7	10,7	10.7
3	Sample Area (A)	cm^2	31.653	31,653	31.653
4	Water level difference (h)	cm	72	72	72
5	Accommodated Water Volume (Q)	Cc	128	119	114
6	Test Time (t)	sec	1200	1200	1200
7	K = (Q.L)(A.h.t)	cm/sec	$5.00801x10^{-4}$	$4.65588\ x10^{-4}$	$4.46026\ x10^{-4}$
		K Value			0,001412

Table 6. Permeability value of soil test results

Name	Permeability (K)			Soil Type
	cm/s	cm/h	m/day	
Griya Galiran Residence	0.0014	5.04	1.21	Fine Sand

Table 6 shows that soil testing results at Perum Griya Galiran Regency have a soil permeability coefficient of 1.21 m/day. Based on the classification listed in SNI 03-2453-2002, the type of soil at Perum Griya Galiran Regency is categorized as soil with relatively rapid permeability and fine sand soil.

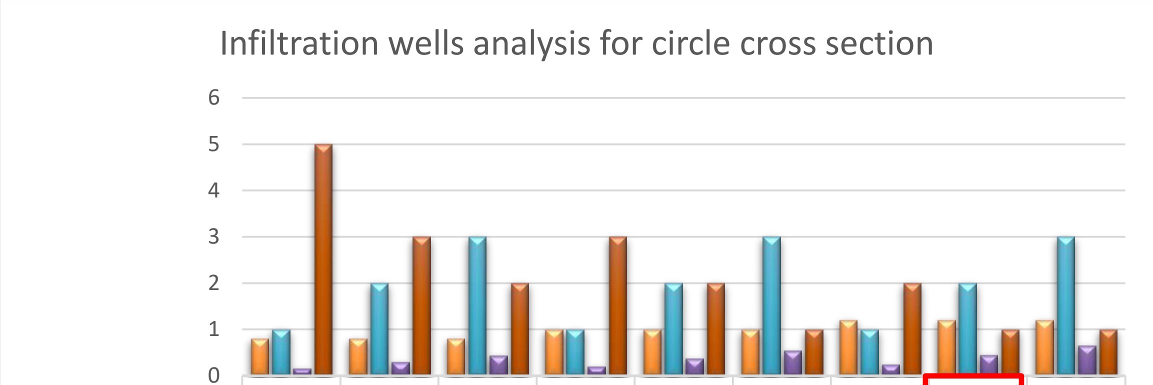
3.5. Infiltration Well Analysis

Planning infiltration wells at Perum Griya Galiran Regency is carried out by referring to SNI 0324532002. A plan is carried out with 2 forms of infiltration well base, namely circular base and square base. As written in SNI No. 03-2453-2002, there are rules for planning infiltration wells, including the following:

1. Flow coefficient of reservoir field
   The runoff from the roof land use ranges from 0.75 to 0.95. The Planning coefficient of 0.85 is used.
2. Area of land
   Based on the survey results of the cistern area, namely the roof area of Perum Griya Galiran Regency is 70 m^2.
3. Daily rain height
   This section uses the value by calculating the hydrological analysis in the five-year return phase with a duration of one hour, 49.67 mm/day, based on SNI No. 03-2453-2002.

Calculating the volume of infiltration water is carried out to see how much water is infiltrated into the ground through infiltration wells. The use of variables to calculate the volume of infiltration water to the environment include:

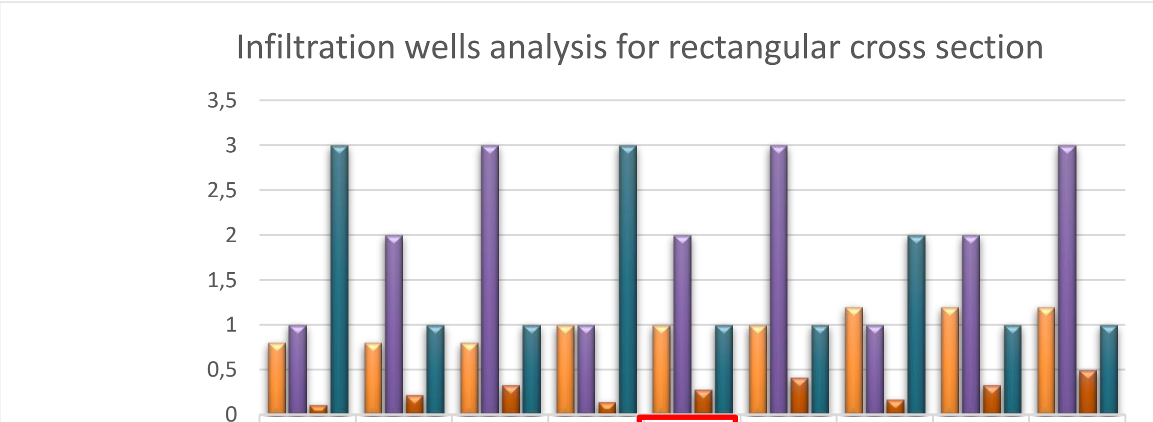
1. The surface area of the infiltration consists of the area of the base and the sound walls.
2. Soil permeability coefficient
   The soil permeability test at Perum Griya Galiran Regency resulted in 0.0014 cm/s.
3. Effective rain duration
   The calculation of adequate rain is based on the Indonesian National Standard No. 03-2453-2002.



	1	2	3	4	5	6	7	8	9
Diameter IW (m)	0,8	0,8	0,8	1	1	1	1,2	1,2	1,2
Heigth IW (m)	1	2	3	1	2	3	1	2	3
Vol. Infil. (m3)	0,15	0,29	0,43	0,19	0,37	0,54	0,24	0,45	0,65
Num IW (many)	5	3	2	3	2	1	2	1	1

Figure 2 Circular cross-section infiltration well analysis

From Figure 2, it is seen that in the Griya Galiran Regency housing with the type of house 36/75, each home is made an infiltration well with a circular cross-section. The practical dimension for one place is the circular section of section 8, namely, 1.2 m in diameter and 2 m in depth, and capable of absorbing 0.45 m^3 of accommodated rainwater.



	1	2	3	4	5	6	7	8	9
Side length IW (m)	0,8	0,8	0,8	1	1	1	1,2	1,2	1,2
side width IW (m)	1	2	3	1	2	3	1	2	3
Vol. Infil. (m3)	0,11	0,22	0,33	0,14	0,27	0,41	0,16	0,33	0,49
Num. IW (many)	3	1	1	3	1	1	2	1	1

Figure 3 Analysis of square-section infiltration wells

From Figure 3, we know that the practical dimension for one house is an infiltration well of rectangular section 5, which has a side length of 1 m and a depth of 2 m because it takes 1 infiltration well to absorb 0.27 m^3 of rainwater that is accommodated. The analysis results summarized in Figures 2 and 3 have been adapted to the explanation of the research method regarding technical requirements based on SNI 03-2459-2002 regarding the shape and size of infiltration.

4. Conclusion

Based on the soil test in the field, it is found that the type of soil in Griya Galiran Regency Housing is a type of fine sand that can absorb ground relatively quickly, and the coefficient of soil permeability (k) is 0.0014 cm/s. In planning the dimensions of infiltration wells based on the Indonesian National Standard No. 03-2453-2002 at Griya Galiran Regency Housing with a roof area of 70 m^2, infiltration wells with different sizes are made. The effective circular cross-section infiltration well is a section with a diameter of 1.2 m with a depth of 2 m, while a square cross-section with effectiveness is a cross-section with a side length of 1 m and the same depth, which is 2 m.

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