Journal of Natural Resources and Environmental Management
13(2): 258–266. http://dx.doi.org/10.29244/jpsl.13.2.258–266
E-ISSN: 2460-5824
http://journal.ipb.ac.id/index.php/jpsl

The Concept of a Zero Runoff System (ZROS) in reducing the volume of rainwater runoff using infiltration wells at the Syiah Kuala University

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Article Info:
Received: 12 - 05 - 2022
Accepted: 12 - 12 - 2022

Keywords:
Infiltration wells, rainfall, planned flood discharge, surface runoff

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Abstract. *High rainfall with a very high intensity can cause inundation. The purpose of this study was to determine the magnitude of the designed flood discharge that occurred, and the number of infiltration wells needed to reduce rainwater runoff. This research uses data of maximum 10 years of daily rainfall for observation. The results showed that the rainfall intensity for the 5 years return period was 47.24 mm/hr resulting in a design flood discharge of 2.27 m^3/second. The average well water level is 5.08 cm with an average soil permeability value of 5.03 cm/hour. Infiltration wells are designed with a depth of 1.5 m with a diameter of 1.4 m. The use of wells is calculated based on 2 types, type 1 (lined well walls) and type 2 (non-lined walls) in each roof class. The total area of roof covering 15.38 ha requires ± 2.678 type 1 wells, or ±2.440 type 2 wells which can reduce rainwater runoff by 17% (type 1) or 30% (type 2) of the total flood discharge of the Syiah Kuala University.*

How to cite (CSE Style 8th Edition):
Mutia S, Ramli I, Fachruddin. 2023. The Concept of a Zero Runoff System (ZROS) in reducing the volume of rainwater runoff using infiltration wells at the Syiah Kuala University. JPSL **13**(2): 258–266. http://dx.doi.org/10.29244/jpsl.13.2.258–266.

INTRODUCTION

Changes in land use, such as building construction and housing development, can damage water catchment areas and reduce their ability to capture and store water (Bahunta and Waspodo 2019). This can lead to increased runoff and a higher risk of flooding (Sugiyanto and Kodoatie 2022). One solution to this problem is to use rainwater more effectively (Ghisi et al. 2009). Syiah Kuala University has an acute problem, the drainage system. It is inadequate, resulting in frequent puddles after the rain, even with only small rainfall intensity. Kumar et al. (2011) and Afolayan et al. (2012) have noted that rainwater conservation can help provide water during dry seasons. One way to prevent flooding and conserve water is to use methods that allow rainwater runoff to be absorbed into the ground and stored as groundwater. This can help reduce the amount of water flowing over the land and causing inundation. Water infiltration into the ground can be achieved by creating a drainage system in the Syiah Kuala University area, such as by building absorption wells.

Drainage planners must consider the environmental impact of drainage design. Eco-drainage systems can help reduce erosion (Contreras et al. 2013) and protect public facilities (Papafotiou and Katsifarakis 2015).

The use of infiltration wells as a flood or runoff control measure has been widely studied. For example, Wirasembada et al. (2017) showed that infiltration wells can reduce surface runoff in the Cidanau watershed by 35.26–2.34%, and Fachruddin et al. (2015) showed that infiltration wells can absorb surface runoff of 0.03–1.63 liters per second, which can improve the productivity of nutmeg in Aceh Province. Soil infiltration is essential because it reduces the inundation volume and minor flooding. This research aims to study the flood discharge at Syiah Kuala University, design infiltration wells for the campus, and determine the number of infiltration wells needed to reduce inundation.

METHODS

Location and Time of Study

The research location is at the Syiah Kuala University, Banda Aceh District, Aceh Province (Figure 1). This study was conducted in April 2021–Juli 2021.

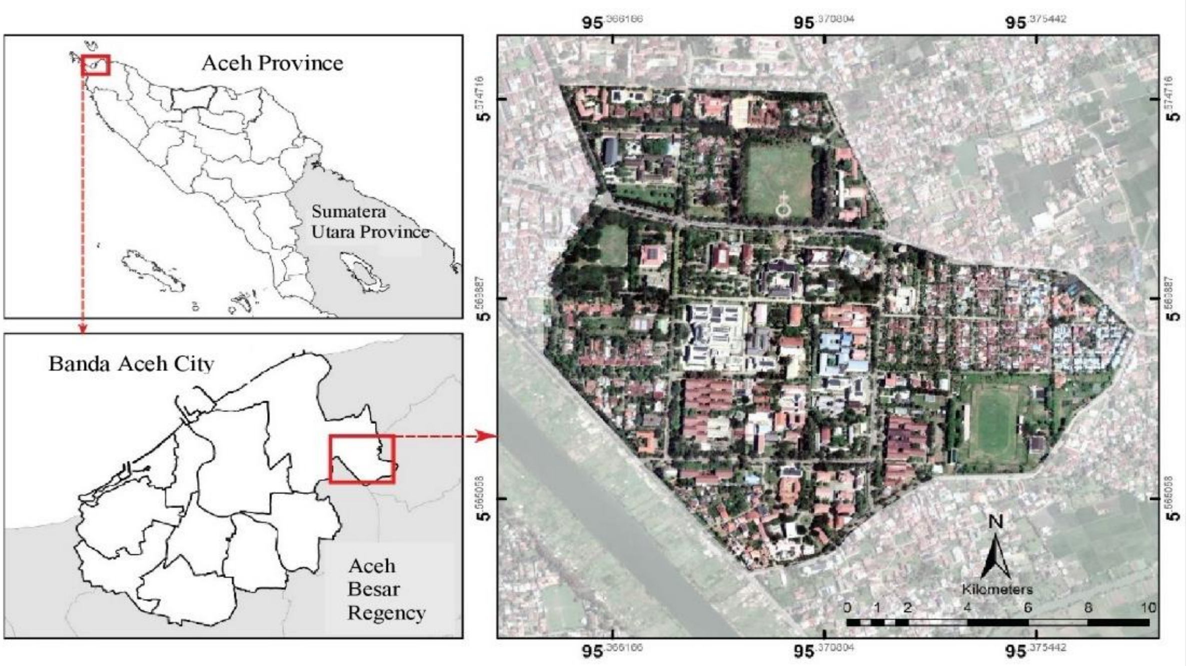


Figure 1 The research site is located at the Syiah Kuala University

Data Collection

The study used two types of data; primary data, which was obtained through direct contact with the research subject, and secondary data, which was obtained indirectly from other sources. Primary data was collected through surveys and field experiments, such as testing soil samples at the Soil and Environmental Physics Laboratory at the Faculty of Agriculture at Syiah Kuala University. The researcher also measured the water level in 5 wells on campus using a meter and then used a double-ring infiltrometer to measure infiltration. Secondary data was obtained from the Meteorology, Climatology, and Geophysics Agency (BMKG) in the Aceh Besar District. This data included notes from other research results, literature journal studies, research location maps, and a digitized map of the Syiah Kuala University.

Data Analysis

The soil samples were observed at the Laboratory of Soil and Environmental Physics, Faculty of Agriculture, Syiah Kuala University. Determination of soil permeability can be determined:

$$K = Q/t \times L/h \times 1/A$$

Where:

K = Permeability (cm/hour)
Q = Average amount of water flowing in each measurement (ml)
t = Measurement time (hours)
L = Thickness of soil sample (cm)
h = height of the water surface from the surface of the soil sample (cm)
A = Surface area of the soil sample (cm^2)

The well water table is the level of the water below the surface of the well and the moisture area below the well. The water level in the well was measured at the Faculty of Agriculture using a tape measure. The measurement was repeated several times to obtain the average water level in the well. This average value was then used in the calculations. The digitization process was used to calculate the cistern area by digitizing a map of the Syiah Kuala University. The roof area was divided into several classes based on the Sturges formula, which considered the number of buildings in each class. The discharge from each roofing class was then calculated to determine the number of infiltration wells needed in each class. This information is used to design the infiltration well system for the campus.

$$Q_{roof} = 0.002778\ C \times I \times A$$

Where:
Q : total roof discharge (m^3/second)
C : flow coefficient ($0.75 < C < 0.95$)
I : rainfall intensity (mm/hour)
A : roof area (Ha)

In infiltration measurements using a double-ring infiltrometer, the infiltration rate measurement was based on the volume of water added at each time interval. To calculate the f value of the water volume data added to the double ring infiltrometer at each measurement interval, it became the infiltration rate with Equation 3 of the Horton infiltration method:

$$\mathrm{fp(t)} = \mathrm{fc} + (\mathrm{f0} - \mathrm{fc})\mathrm{e} - \mathrm{kt}$$

Where:
fp(t) : Infiltration rate at time t (cm/hour)
fc : Cconstant infiltration rate (cm/hour)
f0 : Infiltration rate at the start of the measurement (cm/hour)
k : Constant for soil type

A hydrological analysis was used to obtain the initial runoff discharge value before the infiltration wells usage. Rain intensity was calculated from the height of rainfall per unit of time. The hydrological analysis began with an analysis of rainfall based on mathematical models 4 (four) continuous probability distributions, namely Normal, Log Normal, Gumble Type I, and Log Pearson Type III. Next, it will be tested to determine the most suitable for use with the statistical parameters of Ck and Cs values. Rain intensity measurements using the Mononobe equation (Suripin 2004) can be calculated using Equation:

$$\mathrm{I} = \frac{\mathrm{R24}}{24}\ \mathrm{x}\ \frac{24}{\mathrm{tc}}^{0.667}$$

Where:
I : Rainfall intensity (mm/hour)

R24 : Daily maximum rainfall in 24 hours (mm)
Tc : Time of concentration (hours)

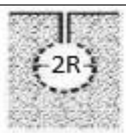
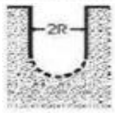
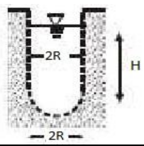
The runoff coefficient is the ratio between the amount of runoff and rainfall. Mathematical equations are rational methods for estimating surface runoff rates. The measurement of surface runoff (Suripin 2004) can be determined by Equation:

$$Q = 0.002778\ C \times I \times A$$

Where:
Q : Total flood discharge (m^3/second)
C : runoff coefficient ($0 \leq C \leq 1$)
C : $\frac{\sum CA}{\sum A}$ (C_{roof} = 0.95, $C_{asphalt}$ = 0.95, C_{page} = 0.1)
I : Rainfall intensity (mm/hr) with a return period of 5 years
A : Total drainage area or area (Ha)

This study's design of the infiltration well plan focused on two types of infiltration wells: (1) Type I, the circular well walls were left without coating. The inside of the well was left without filler, so more water could be accommodated; (2) Type II, infiltration wells whose walls were coated (Table 1).

Table 1 Geometry factor of design infiltration well

Type	Image	Value F (m)
Spherical in shape and infiltration is located in all layers of porous soil		$4\pi R$ (7)
The infiltration is located in a porous subsoil with impermeable infiltration walls and a hemispherical base		$\pi^2 R$ (8)
Infiltration is located in completely porous soil with all permeable well walls and a hemispherical bottom		$\frac{2\pi\ (H+ln2)}{\ln[\frac{H+2r}{R}+\sqrt{(\frac{H}{3r})^2+1)}]}$ (9)

The wells were added to a water channel using a pipe measuring 110 mm with a slope (S) of 2%. The depth of the was planned to be as deep as 1.5 meters. Further, the researcher also planned to cover the well using a reinforced concrete plate with a thickness of 10 cm according to the technical instructions for implementing environmentally sound drainage in the Syiah Kuala University area (Muliawati 2015). The depth of the well proposed by Sunjoto (1988) in Suripin (2004) expressed in equation:

$$H = Q/FK\ [1–\exp((–FKT)/\pi r^2)]$$

Where:
H : Design infiltration well depth (m)
(C) : 0.95 (0.75< Croof <0.95)
T : Stream time (seconds)
K : Soil permeability coefficient (m/s)
Q : Water discharge entering the well from the roof (m^3/s) with roof flow coefficient
F : Geometry factor (m)
r : radius of well (m)

Calculation of Infiltration Discharge and Infiltration Well Capacity

Infiltration Discharge

The capacity of the infiltration well depends on the dimensions of the planned infiltration well. Calculation of infiltration discharge in the following way (Suripin 2004):

$$\text{Q infiltration well} = F \times K \times H$$

Where:
Q : Infiltration discharge (m^3/s)
K : Soil permeability (m/s)
H : Water level in the well (m)
F : Well geometry factor (m)

Number of Infiltration Wells

The number of infiltration wells is determined by dividing the calculated well depth value based on roof class by the design depth:

$$\text{Number of Wells (n)} = \frac{\text{Htotal}}{\text{H plan}}$$

Percentage of the amount of water that seeps into the ground:

$$\text{Q infiltration (\%)/well} = \frac{\text{Q infiltration wells}}{\text{Q roof}} \text{ x } 100\ \%$$

$$\text{Total infiltration (\%)} = \frac{\text{Q infiltration x n wells}}{\text{Q design flood}} \text{ x } 100\ \%$$

RESULTS AND DISCUSSION

Description of Research Location

Inundation that often occurs in the Syiah Kuala University is caused by reduced soil absorption of water. The amount of water discharge that exceeds the capacity of the drainage canal and the slope of the land, as well as the high intensity of rain, are also additional issues. The issues are not managed properly by the available drainage system (Figure 2). In Khadijah et al. (2017), drainage channels that do not flow properly occur due to a lack of attention from the government and the inhabitants in maintaining these water channels.

Soil samples were taken at coordinates 5º 34′ 12.763″ N and 95º 21′ 56.321″ E (Sample 1); 5º 33′ 56.020″ N and 95º 22′ 22.135″ E (Sample 2); and 5º 34′ 12.145″ N and 95º 22′ 16.855″ E (Sample 3) (Figure 3). The average value of soil permeability at Syiah Kuala University is 5.08 cm/hour, meaning that the average soil permeability in the area is 5.08 cm, capable of allowing water to pass within one hour of rain. According to Arsyad (2006), the permeability value is a moderate criterion with a dusty clay texture type.

The analysis results obtained two types of soil, regosol, and alluvial. Regosol was the largest type of soil found, with a percentage reaching 94.2%. Meanwhile, only a small proportion of alluvial soil types were found, about 5.8%. Further, bulk density is 1.29–1.3 (gr/cm^3) in the high (weight) category. Thus, the infiltration value at the study site was 1.3 cm/hour, considered the moderate-slow category. Irawan and Yuwono (2016) showed a relationship between infiltration and bulk density. The lower the soil-specific gravity, the higher the infiltration value.

Figure 2 Inundation samples on the Syiah Kuala University

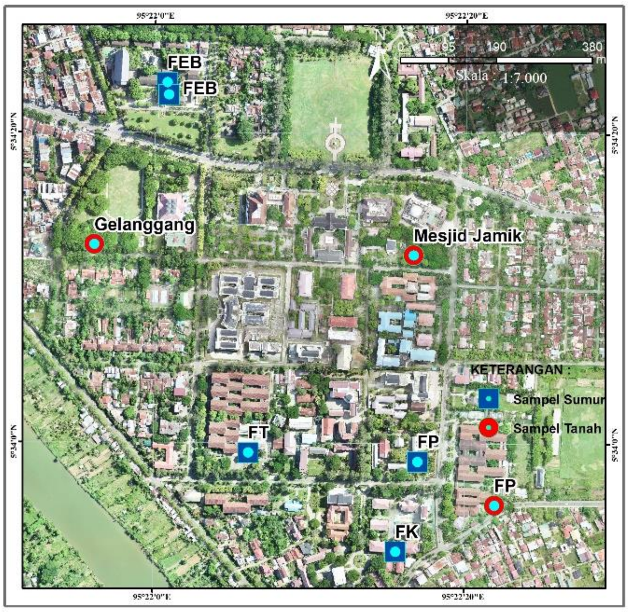


Figure 3 Soil sampling location and well water level

A sampling of the well water level was carried out at the coordinates 5º 33′ 59.357″ N and 95º 22′ 6.291″ E (well 1); 5º 33′ 53.003″ N and 95º 22′ 15.782″ E (well 2); 5º 33′ 58.819″ N and 95º 22′ 17.172″ E (well 3); 5º 33′ 23.229″ N and 95º 22′ 0.962″ E (well 4); 5º 33′ 22.448″ N and 95º 22′ 1.071″ E (well 5). The area of Syiah Kuala University has a height of ± 1 meter above sea level. This fact makes the distance between the ground surface and the water level in this well have an average value of 87.3 cm during the rainy season. Suripin (2004) divided the area into 3 types of closures, namely roads, roofs, and yards.

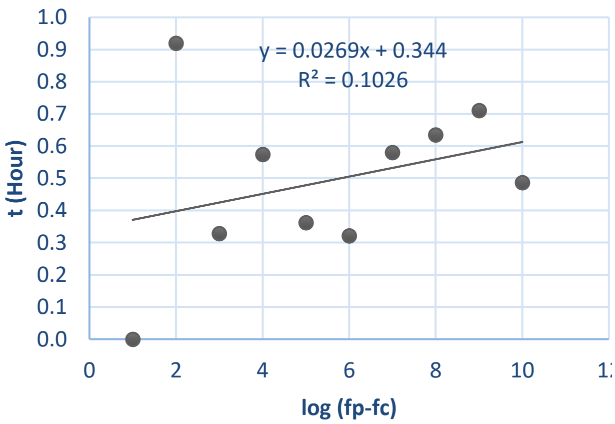


Figure 4 The graph looks for the value of k at the test point

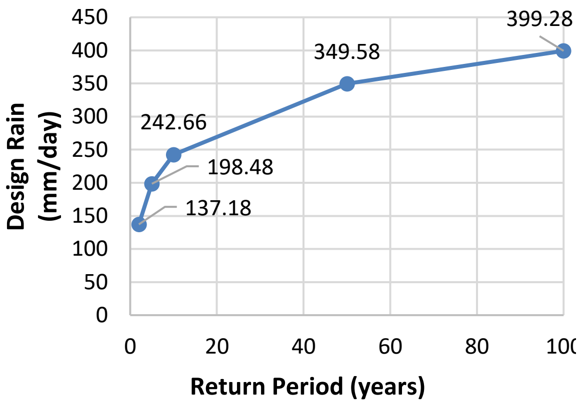


Figure 5 Design rainfall based on return period using Log Pearson Type III (R24) method

The total roof area generated from digitization was 15.38 ha. The result of digitizing the road area was 1.97 ha. Calculation of the page area of 7.98 ha. The trend for the value of k can be seen in Figure 4. The figure shows that the slope of the trendline is 0.0269. According to Triatmodjo (2014), the k value, which is a measure of the infiltration rate of the soil, depends on the texture and vegetation of the soil. A small k value indicates that the soil is covered with plants and has a slow infiltration rate, while a large k value indicates bare soil with a higher infiltration rate. At 0.8 hours, the infiltration rate is 1.3 cm/hour, which falls within the slow infiltration rate criteria. High water content in the soil can reduce its infiltration capacity by saturating it.

The design rainfall for a specific return period can be calculated using the Pearson Log Type III (R24) method, as shown in Figure 5. The design rainfall value for a 5-year return period, with a value of 198.48 mm/day, can be used to measure the infiltration rate of wells. This is in line with Suripin's statement (2004) that in rainwater catchment areas of 10 to 100 hectares, the design rainfall value with a 5-year return period should be used. The flood discharge design of different ground covers can be found in Table 2. The roof area of the campus is 15.38 ha, which produces a flood discharge of 1.918 m^3/s per second. The road area is 1.97 ha with a flood discharge of 0.245 m^3/s, and the yard area is 7.98 ha, resulting in a flood discharge of 0.105 m^3/s. The total runoff discharge for the campus, with a planned rainfall intensity of 47.24 mm/hour, a coefficient of 0.69 for the roof, road, and yard areas, and a total area of 25.3 ha, is 2,268 m^3/s.

Table 2 Design flood discharge from 3 (three) types of ground cover

Type of cistern	Area (Ha)	Flood discharge (m^3/second)
Roof	15.38	1.918
Road	1.97	0.245
Page	7.98	0.105
Total	25.3	2.268

Number of Infiltration Wells required

The application of infiltration wells on the Syiah Kuala University can reduce inundation to the maximum. The dimensions of the designed infiltration well with a depth of 1.5 meters and a diameter of 1.4 meters use two types of geometry factors that have values of 6.9 and 13, respectively (Table 3 and Table 4).

Table 3 Calculation of depth and number of wells in type 1 wells

Geometry factors	Roof area (m^2)	Qroof (m3/s)	Rain duration (s)	Radius (m)	Permeability (m/s)	Depth (cm)	Amount
6.9	2,363	0.0295	3,600	0.7	0.00001412	62	41
	4,703	0.0587	3,600	0.7	0.00001412	123	82
	7,043	0.0879	3,600	0.7	0.00001412	184	123
	9,383	0.1171	3,600	0.7	0.00001412	245	163
	11,723	0.1463	3,600	0.7	0.00001412	306	204
	14,063	0.1755	3,600	0.7	0.00001412	367	245
	16,403	0.2046	3,600	0.7	0.00001412	428	285

Table 4 Calculation of depth and number of wells in type 2 wells

Geometry factors	Roof area (m^2)	Qroof (m^3/s)	Rain duration (s)	Radius (m)	Permeability (m/s)	Depth (cm)	Amount
13	2,363	0.0295	3,600	0.7	0.00001412	56	37
	4,703	0.0587	3,600	0.7	0.00001412	112	75
	7,043	0.0879	3,600	0.7	0.00001412	168	112
	9,383	0.1171	3,600	0.7	0.00001412	223	149
	11,723	0.1463	3,600	0.7	0.00001412	279	186
	14,063	0.1755	3,600	0.7	0.00001412	335	223
	16,403	0.2046	3,600	0.7	0.00001412	390	260

The roof area of the campus is divided into 7 classes based on the Sturges formula. The high roof class, with a roof area of 16,403 m^2, requires 285 type 1 infiltration wells with a depth of at least 4.28 meters. This type of well is chosen because the soil on the campus tends to be clayey, and type 1 wells are expected to be effective at preventing landslides that could cover the infiltration holes. The highest roof class has a roof area of 16,403 m^2 and requires infiltration wells with a depth of 3.90 meters. This class requires 260 type 2 infiltration wells. The Syiah Kuala University has a roof area of 25.3 ha, so it will require at least 2,678 type 1 infiltration wells and at least 2,440 type 2 infiltration wells to reduce flooding from inundation.

Infiltration discharge is a measure of the amount of water that can be reduced from the flood discharge at the Syiah Kuala University. The design of the infiltration wells at the study site uses the ZROS concept. Based on the planned flood discharge, type 1 infiltration wells, which have an infiltration discharge of 0.000146 m^3/s, can reduce the runoff by 17%, so that only 83% of the total flood discharge goes to the drainage channel. Type 2 infiltration wells have an infiltration discharge of 0.000275 m^3/s and can absorb at least 30% of the flood discharge, leaving only 70% of the total flood discharge on the campus. Infiltration wells can be used as a solution to reduce flooding from inundation. They can also increase the volume of groundwater and reduce the rate of erosion by reducing surface flow (runoff).

The type 1 infiltration wells design is an open ground without lining, while type 2 infiltration wells are lined. As a result, the F value (geometry factor) of type 1 wells is smaller than that of type 2 wells, so more type 1 wells are needed in the construction of infiltration wells, and they are able to absorb more rainwater infiltration. This is consistent with previous research, which has shown that the use of infiltration wells can reduce flood events and increase groundwater in Bulusan Village (Hatmoko et al. 2021) and can reduce the surface runoff rate by 10–15% in Lowokwaru District, Malang City (Hirijanto et al. 2021).

CONCLUSION

The analysis of all parameters shows that the designed flood discharge of the Syiah Kuala University is 2.27 m^3/s, and the designed discharge from the roof is 1.92 m^3/s. If a roof area of 25.3 ha, so this requires 2,678 type 1 (well walls with lining) and 2,440 type 2 (non-lined well walls) infiltration wells to cope with the planned flood discharge. The use of infiltration wells can reduce the total planned flood discharge on campus by 17% (type A well) and 30% (type B well).

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