REDUCTION OF FLOOD DISCHARGE USING PERFORATED HORIZONTAL RECHARGE PIPES

Edy Susilo[1,*], Diah Setyati Budiningrum[1], Anik Kustirini[1]

[1]Jurusan Teknik Sipil Universitas Semarang
Jl. Soekarno Hatta, RT.7/RW.7, Tlogosari Kulon, Kec. Pedurungan, Kota Semarang, Jawa Tengah 59160
[*]Correspondent Author: edysusilo@usm.ac.id

Abstract
Despite implementing many recharge wells, the groundwater recharge with wells is still minimal. The hydrostatic pressure of the recharge well is only experienced at the bottom of the well which caused surface runoff. This study aims to formulate water recharge with Type T Perforated Horizontal Recharge Pipes (PHRP-T) to analyze the need for reducing surface runoff discharge. Water recharge with PHRP-T is greater than recharge wells. Using the experimental method, the recharge test was carried out with the independent variables of soil permeability (K), pipe wall porosity (P), pipe diameter (D), the length of the perforated horizontal pipe (L), and water pressure level (H). The recharge was observed from lowering the water level in the vertical pipe PHRP-T. A statistical program was performed to analyse the relationship between water absorption (Q) as the dependent variable with a regression equation. PHRP-T implementation to reduce surface runoff discharge can be applied to the hydrograph and rational methods. The findings of PHRP-T are significant for reducing flooding and increasing groundwater availability.

Keywords*: flooding, recharge pipe, infiltration, recharge well, groundwater*

INTRODUCTION

Buildings and infrastructure development in urban areas is getting more expansive due to population growth and urbanization. The direct impact of this development is an increase in surface runoff and a decrease in groundwater infiltration. Urbanization and changes in land use are significant factor in risk of flooding (Szwagrzyk et al., 2018). The need for water in several urban areas is fulfilled by exploiting groundwater aquifers, causing worldwide environmental problems. There is no balance between replenishment and extraction, so artificial groundwater recharge is needed (Kumar et al., 2022).

The study about groundwater demand in Bari Doab, Pakistan, shows more significant than rainwater infiltration (Basharat & Basharat, 2019). Studies on water infiltration for artificial groundwater recharge in the topsoil and aquifers have been carried out, such as recharge wells (Elsa et al., 2018), recharge boxes (Adinda & Ikhsan, 2014), and recharge ditches (Sunjoto, 2008). However, the use of recharge wells to reduce flooding is not effective enough (Edy et al., 2020) due to the relatively small infiltration. Recharge wells are still effective if the groundwater depths are over 2 meters (SNI 8456, 2017). The use of recharge wells for groundwater replenishment has been performed by several countries, including Lahore in Pakistan, with a groundwater level of 5 meters which can raise the ground level by 3.54 feet every rainy season extraction and recharge must be balanced (Purnomo & Lo, 2020), and groundwater recharge is done using recharge wells. Filling water into the soil is a solution for the availability of groundwater (Mohan et al., 2018). Due to limited land availability, usage of retention ponds and water storage structures is not the most appropriate solution in urban areas. Thus, recharge wells cannot overcome the problem of flooding because the recharge capacity is small and is not effectively installed at a greater depth than the depth of the groundwater surface. So the innovation of recharge equipment with a larger absorption capacity is needed (Edy et al., 2018). Infiltration caused by hydrostatic pressure above is only experienced by the bottom cross-section of the recharge well. So to enlarge the absorption area, a wider absorption area is indispensable.

Type T Perforated Horizontal Recharge Pipe (PHRP-T) is an equipment that infiltrates surface water into the ground. It is installed horizontally and has a wider infiltration area. The depth of groundwater does not limit PHRP-T. Recharge wells are ineffective in overcoming floods (Felix et al., 2020; Wigati & Cahaya S, 2014). Hence, research on PHRP-T recharge is required. Recharge of PHRP-T is expected to be able to overcome the increase in discharge due to changes in land use (zero delta Q).

RESEARCH METHODS

PHRP-T was made of PVC material arranged in the shape of an inverted T. (Hussain et al., 2019). Overexploitation of groundwater in India has led to subsidence of groundwater levels and seawater intrusion. Meanwhile the groundwater

The PHRP-T recharge is more significant than the Perforated Vertical Recharge Pipe (PVRP), such as recharge wells and another vertical recharge instrument. The pipe length is not linear to the PHRP-T recharge because of the energy loss due to friction between the water and the pipe wall. For the PHRP-T recharge to be greater, apart from extending the pipe, it is also necessary to pay attention to energy losses.

PHRP-T is a recharge pipe with a vertical pipe as the inlet and two horizontal perforated pipes. PHRP-T, which has a large recharge capacity, has greater efficiency than L-type PHRP-T because the energy loss due to major losses is smaller . Type-L Perforated Horizontal Recharge Pipe (Susilo & Kustirini, 2020) has a greater energy loss than PHRP-T. The objective of this study aims to formulate recharge as a basis for analyzing the calculation of the need for PHRP-T in reducing discharge.

Research on existing recharge equipment has not met the need to reduce discharge significantly. Horizontal pipe sections were drilled with a 10 mm diameter drill bit. The ratio of the entire hole area to the area of the pipe wall, called porosity, was 0.048. Holes covered with insulation can be opened by removing and producing a hole wall porosity of 0.006 (P1); 0.012 (P2); 0.018 (P3); 0.024 (P4); and 0.048 (P8) according to the stages of research needs. The 1-meter-long vertical PHRP-T pipe wall was not drilled and remained tight.

The length of the pipe used to test is 2 m (L2), 4 meters (L4), 6 meters (L6), and 8 meters (L8). PHRP-T was installed at a depth of 1 meter from the ground surface. The end of the PHRP-T in the ground was closed with a dop, while the other end was connected to a T socket and a vertical pipe remains open above the ground level. Furthermore, the PHRP-T was installed in an inverted T position in the ground with a small quantity of a vertical pipe tip left and water recharge testing, as seen in Figure 1.

The PHRP-T test was carried out by filling the water until it was full and then allowing the water level to drop. The infrared meter sensor records the decrease every 5 seconds until the water runs out, as shown in Figure 2.

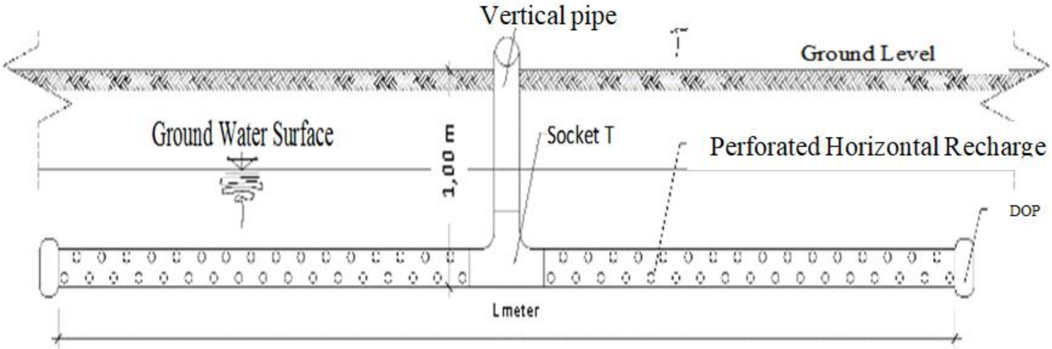


Figure 1. PRHP shape and dimensions

Figure 2. Assembly and installation of PHRP-T for testing

Soil testing was carried out in the form of soil gradation and soil permeability. Soil permeability needs to be included in the testing as one of the variables affecting water recharge. Data of PHRP-T in form of decreased water depth was processed into a debit of water recharge into the soil at each height of water pressure. Infiltration was observed for pipe lengths of 2 meters, 4 meters, 6 meters, and 8 meters by removing the duct tape covering the holes according to the desired length. Testing the variable porosity of the pipe wall was carried out using a fixed pipe length of 2 meters. Thus, the relationship between the recharge to the length variable of the pipe (L) and the water pressure (H) was obtained, and the relationship between the recharge to the porosity (P), as well as the combined variables (P and L) to the recharge of the pipe (Q).

Analysis of the variables that had the most influence on a model was performed with regression equation using the NCSS v.22.0.4 program. The criteria for the model can be accepted based on the value of the correlation coefficient (R2), which is closer to 1.00.

Changes in the land use of a watershed were observed using Google Earth for the first and last year to obtain the initial year's flow coefficient and the final year's flow coefficient. It is common knowledge that the magnitude of the runoff coefficient affects the discharge of surface runoff, both rational and hydrographic methods. PHRP-T will reduce this increase in surface runoff. To reduce this increase in discharge until it reaches the initial debit (zero delta Q), a trial and error method was carried out to simulate the number of PHRP-Ts that need to be installed.

The implementation of reducing discharge using PHRP-T in the Tegalkangkung watershed in Semarang City will further clarify the calculation of the need for PHRP-T to reduce flood discharge due to changes in land use. The Tegalkangkung watershed runoff coefficient covering 1.24 km^2 in 2012 was 0.366, increasing to 0.446 in 2022, which impacts increasing river discharge (Istiqomah et al., 2022).

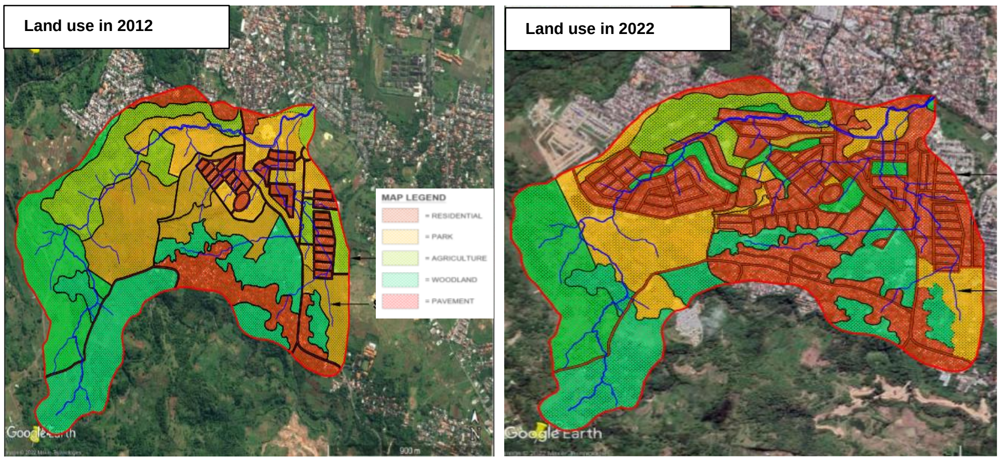


Figure 3. Tegalkangkung watershed and its land use (Istiqomah et al., 2022)

Recharge water with PHRP-T must be compared with other recharge instruments, namely recharge wells. The test was carried out at the Gunungpati District Office, Semarang City. It is also necessary to compare the recharge of PHRP-T in this research with another type of PHRP, i.e PHRP-L, in reducing flood discharge.

This PHRP-T research was carried out on Jalan Bulusan Utara Raya, Tembalang District, Semarang City, as seen in Figure 4.

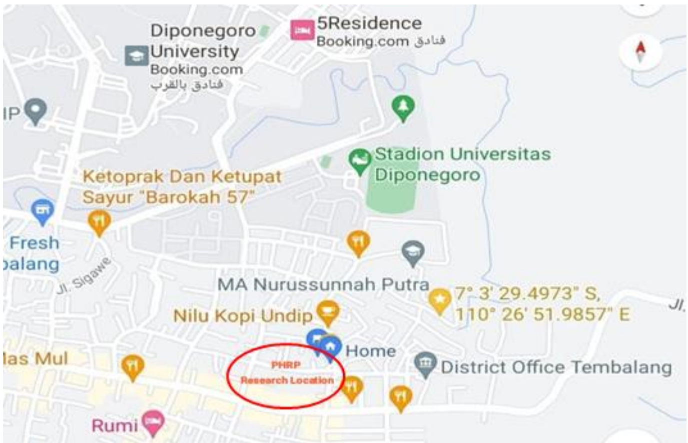


Figure 4. PHRP-T Research Locations

This spot is located south of Diponegoro University and west of the Tembalang District Office, Semarang City. The area is an open place without land cover.

RESULTS AND DISCUSSION

a. Soil Permeability Test

The type of soil greatly influenced the recharge of water. A vital soil parameter that affects recharge is soil permeability. The results of permeability tests at the study sites can be seen in Table 1.

Table 1. Soil permeability at the test site

No. Sample	Pipe Diameter (cm)	Specific Gravity gr/cm^3	Soil Permeability cm/sec
1.	10	2.685	7.982×10^{-6}
2.	20	2.670	8.305×10^{-7}
3.	30	2.675	8.321×10^{-7}

According to the results at 3 locations where the PRHP-T permeability test was carried out, two soil locations were close to the same, while the other was different. This was quite influential on the results of research on soil permeability variables.

b. Water recharge test

The first test was performed to observe the influence of the porosity of the horizontal pipe wall holes and the water pressure level. Another variable was that the length of the pipe which was kept constant at 2 meters, and the test was carried out in the same place. PHRP-T infiltration test results with diameters of 10 cm, 20 cm, and 30 cm with a pipe length of 2 meters and porosity 0.006 (P1), 0.012 (P2), 0.018 (P3); and 0.024 (P4) can be seen in Figure 5.

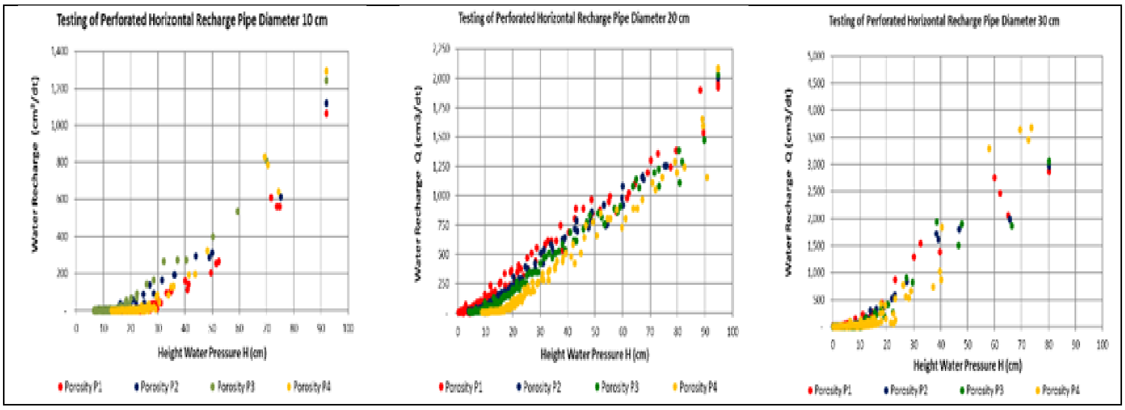


Figure 5. Infiltration pipe recharge with a diameter of 10 cm, 20 cm, and 30 cm

Figure 5 shows the relationship of recharge pipe diameter of 10 cm with a length of 2 m, Porosity 0.006 (P1); 0.012 (P2); 0.018 (P3); and 0.024 (P4) to the water pressure height. The estimated model from the results of the non-linear regression analysis seen from each parameter are indicated in Table 2.

Table 2. Model Estimation Section for Diameter 10 cm

Parameter Name	Parameter Estimate	Asymptotic Standard Error	Lower 95% C.L.	Upper 95% C.L.
A	0.0002560976	3.378619E-05	0.0001897384	0.0003224567
B	0.1694923	0.008813917	0.1521809	0.1868036
C	2.537395	0.02756916	2.483246	2.591543

Model: Q10 = 100*A*P10^B*H10^C

Model Estimation Information

R-Squared 0.977564

Iterations 45

Estimated Model

(0.02560976)*(P10)^(0.1694923)*(H10)^(2.537395)

The equation of a horizontal recharge pipe with a diameter of 10 cm and variable porosity (P) and water pressure height (H) is as follows:

$$Q = 0.0256*(P)^{0.169}*(H)^{2.540} \quad (1)$$

The correlation coefficient for the regression equation above was 0.9775, which means that the relationship between porosity (P) and water pressure height (H) on infiltration recharge is perfect.

With the same porosity P1, P2, P3, and P4 using a pipe diameter of 20 cm, the estimated model from the results of the non-linear regression analysis from each parameter is shown in Table 3.

Table 3. Model Estimation Section for Diameter 20 cm

Parameter Name	Parameter Estimate	Asymptotic Standard Error	Lower 95% C.L.	Upper 95% C.L.
A	0.005527136	0.0006532022	0.0001897384	0.006810281
B	0.02213286	0.01745985	-0.01216512	0.05643084

C	1.46856	0.02212639	1.425095	1.512025

Model: Q20 = 1000*A*P20^B*H20^C
Model Estimation Information
R-Squared 0.954091
Iterations 39
Estimated Model
(5.527136)*(P20)^(0.02213286)*(H20)^(1.46856)

The equation of a horizontal recharge pipe with a diameter of 20 cm and variable porosity (P) and water pressure height (H) is formulated as Eq. 2:

$$Q = 5{,}5270*P^{0{,}022}*H^{1{,}469} \quad (2)$$

The correlation coefficient of the above regression equation for a diameter of 20 cm is 0,9541. With the same porosity P1, P2, P3, and P4 using a pipe diameter of 30 cm, the estimated model from the results of the non-linear regression analysis seen from each parameter can be seen in Table 4.

Table 4. Model Estimation Section for Diameter 30 cm

Parameter Name	Parameter Estimate	Asymptotic Standard Error	Lower 95% C.L.	Upper 95% C.L.
A	0.002338537	0.0001920475	0.001961272	0.002715801
B	0.012011	0	0.012011	0.012011
C	1.479977	0.01910548	1.442446	1.517509

Model: Q30 = 1000*A*P30^B*H30^C
Model Estimation Information
R-Squared 0.956051
Iterations 46
Estimated Model
(2.338537)*(P30)^(0.012011)*(H30)^(1.479977)

Equation 3 shows the formulation of a horizontal recharge pipe with a diameter of 30 cm and variable porosity (P) and water pressure height (H):

$$Q = 2.339*P^{0.012}*H^{.1.48} \quad (3)$$

The correlation coefficient of the regression equation for a pipe diameter of 30 cm is 0.956051.

The water recharge in the soil is influenced by porosity holes around the walls of horizontal pipes and soil media that absorb water (Sriyono, 2013). Observing the pipe wall porosity parameter (P) in equations (1), (2), and (3), all of which have small values (0.169, 0.022, and 0.012), indicates that the addition of porosity does not significantly increase water infiltration into the soil. At the same time, the parameters of the water pressure height (H) are quite large (2.540, 1.469, and 1.478). The result shows that water recharges into the soil are greatly influenced by the water pressure height, while the porosity of the pipe wall is not too influential. The water recharge into the ground was determined more by the type of soil than the porosity of the pipe wall holes. However, the walls of the horizontal recharge pipe must still be perforated for water to recharge into the ground. Therefore it is necessary to carry out further testing by adding the variables for correlation with water infiltration into the soil, namely soil permeability (K), porosity (P), pipe diameter (D), pipe length (L), and water pressure height (H). Regarding the regression equation test, it was obtained using the NCSS v.22.0.4 software. The estimated model from the results of the non-linear regression analysis seen from each parameter are shown in Table 5 below:

Table 5. Estimation Section PHRP-T Model

Parameter Name	Parameter Estimate	Asymptotic Standard Error	Lower 95% C.L.	Upper 95% C.L.
A	1749.531	0.03053563	-0.04235343	0.07734405
B	0.9177197	0.1048186	0.7122788	1.12316
C	0.06837431	0.1342157	-0.1946837	0.3314323
E	0	0.1823132	-0.3573273	0.3573273
F	0.6720363	0.07835609	0.5184612	0.8256115
G	1.789207	0.05002937	1.691151	1.887263

Model	Q = A*K^B*P^C*D^E*L^F*H^G
R-Squared	0.819235
Iterations	15
Estimated Model	

(1749.53)*(K)^(0.9177)*(P)^(0.0684)*(D)^(0.4518)*(L)^(0.6720)*(H)^(1.7892)

Thus the model of recharge of surface water into the ground using PHRP-T is as Equation 4:

$$Q=1749.53*(K)^{0.917}*(P)^{0.068}*(D)^{0.451}*(L)^{0.672}*(H)^{1.789} \quad (4)$$

K = soil permeability (cm/s)
P = porosity of the pipe wall
D = pipe diameter (cm)
L = pipe length (cm)
H = water pressure height (cm)
Q = water recharge (cm^3/s)

The correlation coefficient of the regression equation is 0.8192, which shows that the relationship between the variables used and the recharge is quite significant.

c. Discharge reduction with PHRP-T

PHRP-T was installed in the canal by taking it through an inlet pipe placed 5 cm to 20 cm from the bottom of the channel to make sure that the incoming water being rainwater, not dirty water discharged from household or industrial waste, which can cause groundwater pollution.

The purpose of water recharge with PHRP-T in watersheds is to reduce surface runoff, resulting in reduced discharge in ditches and rivers. This decrease in discharge is needed for planning so as not to cause runoff because the capacity of the river does not meet or return the shot as it was before the change in land use. For small areas, the discharge calculation can be done using the rational method, while for large watersheds, it is better to use the hydrograph method.

An area of A km^2 with a rainfall intensity of I (mm/hour) and a runoff coefficient of C will generate a flow rate of Q m^3/s as formulated in the rational discharge equation that is commonly used. (Yusuf et al., 2021):

$$Q = 0.278 \times C \times I \times A \quad (5)$$

C = Runoff coefficient
I = Rain intensity (mm/hour)

A = Watershed area (km^2)
Q = Maximum discharge (m^3/s)

This rational method is more appropriate for small watersheds. Referring to equation (5), changes in land use that cause a change in the runoff coefficient of ΔC for a land area of A km^2 with a rain intensity of I (mm/hour) will increase the flow rate of ΔQ m3/s as formulated in the rational discharge equation (6).

$$\Delta Q = 0.278 \times \Delta C \times I \times A \quad (6)$$

ΔC = runoff coefficient changes
ΔQ = discharge change (m^3/s)

Using the discharge change equation for rain intensity I mm/hour, the change in runoff coefficient ΔC and catchment area A km^2 can be seen in Table 6. To simplify calculation, ΔC.A is the multiplication of the change in runoff coefficient with the catchment area (km^2).

Table 6. Changes in surface runoff due to changes in the runoff coefficient

ΔC.A (km^2)	Surface runoff changes (m^3/s) Rain Intensity I (mm/hour)							
	I=20	I=40	I=60	I=80	I=100	I=120	I=140	I=160
ΔC.A = 0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ΔC.A = 0.20	1.11	2.22	3.34	4.45	5.56	6.67	7.78	8.90
ΔC.A = 0.40	2.22	4.45	6.67	8.90	11.12	13.34	15.57	17.79
ΔC.A = 0.60	3.34	6.67	10.01	13.34	16.68	20.02	23.35	26.69
ΔC.A = 0.80	4.45	8.90	13.34	17.79	22.24	26.69	31.14	35.58
ΔC.A = 1.00	5.56	11.12	16.68	22.24	27.80	33.36	38.92	44.48
ΔC.A = 1.20	6.67	13.34	20.02	26.69	33.36	40.03	46.70	53.38
ΔC.A = 1.40	7.78	15.57	23.35	31.14	38.92	46.70	54.49	62.27

The calculation of discharge using the rational method only obtains the maximum discharge, so the need for PHRP-T is calculated against changes in the maximum discharge according to Equation (7):

$$N = \frac{\Delta Q_{land}}{Q_{PRH-T}} \quad (7)$$

ΔQ_{Land} = discharge change (m^3/s)
Q_{PRHP} = water recharge with PHRP-T (m^3/s)
N = The need for the number of PHRP-T

Practical PRHP-T needs analysis for small watersheds with rational formulas that can also use the nomogram in Figure 6. The use of the PRHP-T recharge formula in the calculation of the hydrographic method of discharge was carried out by converting the water recharge by some PHRP-T to be used in units of cm^3/s to the average infiltration rate of a watershed area in units of mm/hour as seen in Equation (8):

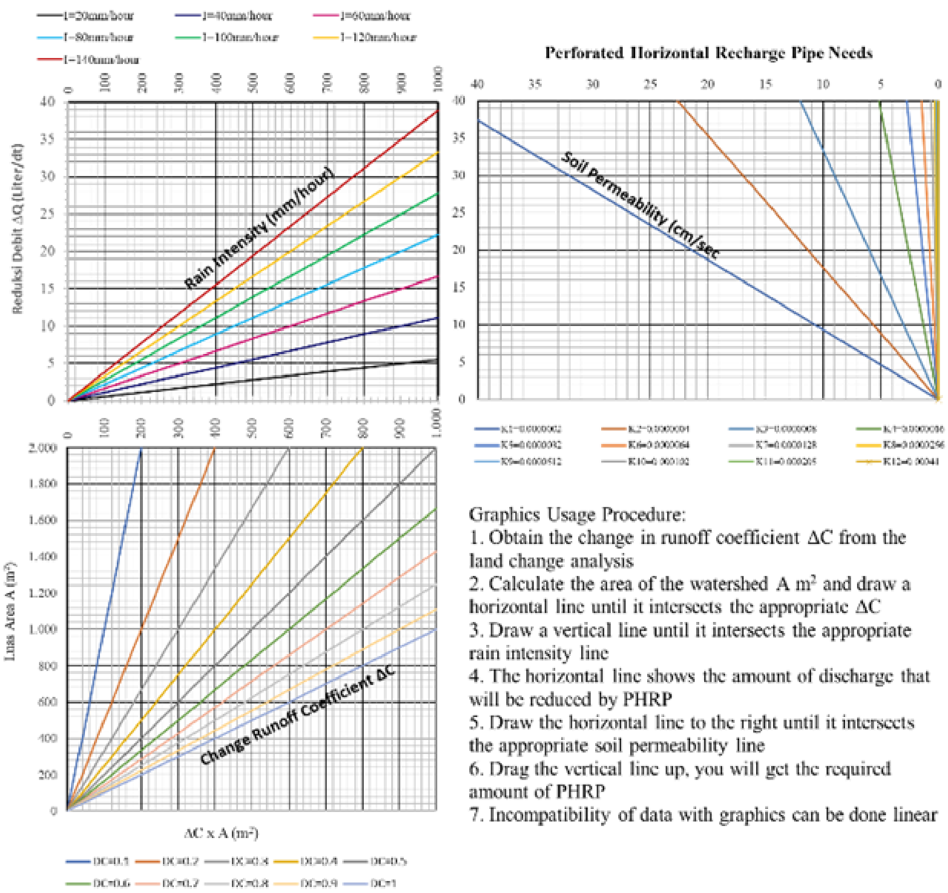


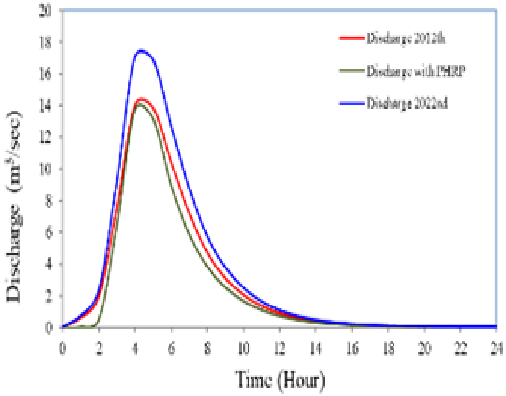
Figure 6. PRHP requirements using the Nomogram

$$f_{PHRP-T} = \frac{3{,}6 * n * Q_{PRH-T}}{A} \qquad (8)$$

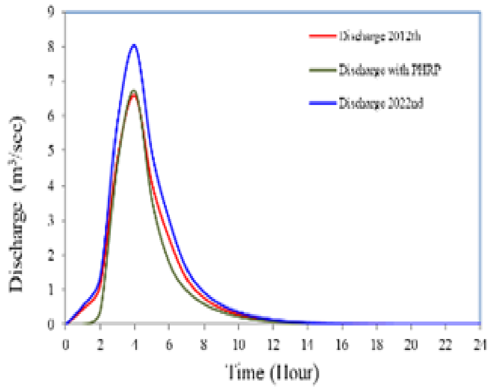
A	=	Watershed area (m^2)
Q_{PRHP}	=	water recharge with PHRP-T (cm^3/s)
f_{PHRP-T}	=	infiltration by PHRP-T (mm/hour)
3.6	=	unit conversion number

Effectively distributed rain as formulated in Equation (8) is the distributed rain substracted by natural infiltration and infiltration by PHRP-T, which subsequently was used as the rain data into the calculation of the hydrograph discharge. The hydrograph discharge of the 50-year return period for each land use was calculated using effective rainfall. The results of this simulation can be seen in graphical form in Figure 7. Figure (7) shows a simulation of using PHRP-T on hydrographs using the Gama-1 (a) and Nakayasu (b) methods which can reduce discharge in 2022 and reduce it as well as the discharge in 2012. Using 165 units of PHRP-T with a pipe diameter of 6 inch (15 cm) and a length of 400 cm, with average soil permeability of

5.16x10-5 cm/sec, PHRP-T were averagely installed every 87 meters distance. It is still very possible to install it in the watershed compared to using other recharge instruments. The peak discharge of the Gama-1 method is greater than that of Nakayasu, but the need for PHRP-T to reduce floods is almost the same. However, this research is not to evaluate the flood discharge analysis method but to analyze PHRP-T needs.



(a)



(b)

Figure 7. Reduction of hydrograph discharge by the Gama-1 method (a) and Nakayasu Method (b)

d. PHRP-T comparison with recharge wells

Sunjoto has proposed recharge wells as an instruments for water infiltration (Sunjoto, 1989). Recharge wells have been widely used in Indonesia to absorb surface water in order to reduce the flow rate and flooding. However, recharge wells cannot work effectively for areas with shallow groundwater levels. Recharge wells are still effective if groundwater depths are over 2 meters (SNI 8456, 2017). Recharge wells will infiltrate water into the ground as wide as the bottom of the well. In addition to the sediment that settles in the infiltration area, fine particles will cover the soil surface at the bottom of the infiltration well, thereby reducing its infiltration capacity. A comparison of PHRP-T infiltration with recharge wells was carried out in the same location, namely the courtyard of the Gunungpati sub-district office, as seen in Figure 8. PHRP-T, with a diameter of 30 cm, a length of 2 meters, and installed at a depth of 1.20 meters, according to Figure 4, can recharge much more significant water than a recharge well with a diameter of 80 cm and a depth of 2.50 meters.

Based on the water pressure diagram in Figure 9, the water pressure in the PHRP-T vertical pipe, according to Pascal's law, is transmitted to the horizontal pipe so that the water pressure diagram was in the form of a trapezium after deducting major energy losses. At the same time, the graph of water pressure in recharge wells is triangular.

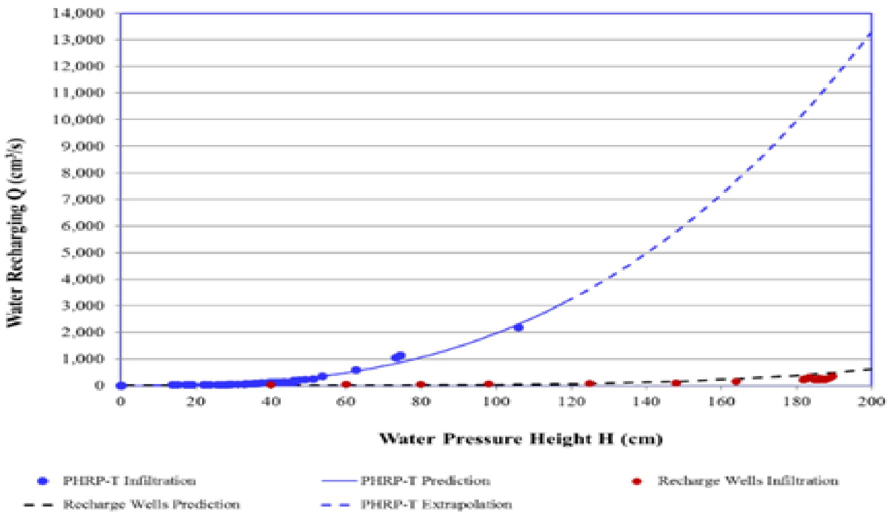


Figure 8. Comparison of water recharge by PHRP-T and recharge wells

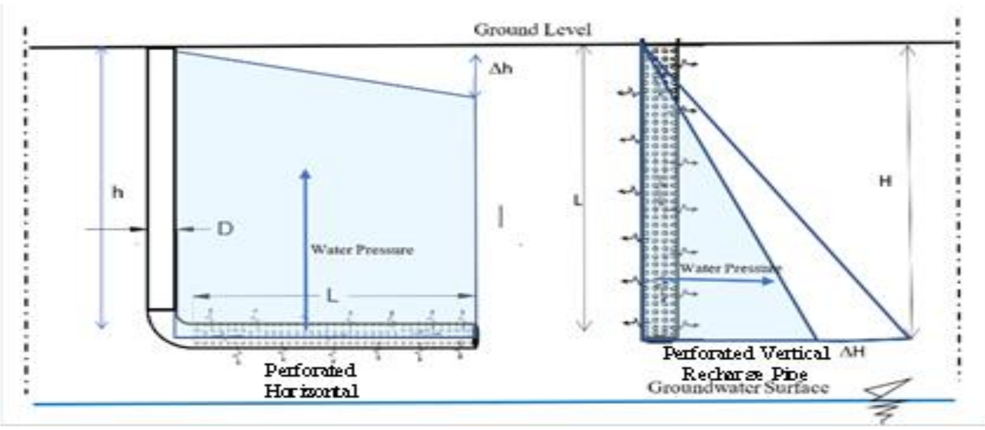


Figure 9. PHRP-T and PVRP water pressure diagrams

PHRP-T represents type T and type L, while PVRP represents vertical recharge instruments such as bio pores and recharge wells. With PHRP-T's water pressure being greater than PVRP's, the water absorption by PHRP-T was far greater than that by PVRP. Moreover, recharge wells with tight walls and subgrade have been covered by fine sediments due to a lack of maintenance.

e. PHRP-T comparison with PHRP-L

PHRP-T analysis for flooding management due to changes in land use in the Tegalkangkung watershed needs 194 units PHRP-L with a length of 4 meters and a depth of 100cm (Istiqomah et al., 2022). Whereas in the same watershed and conditions using PHRP-T with a length of 4 meters and a depth of 100 cm, 164 units are needed. Meaning that PHRP-T is more economical than PHRP-L because the major energy loss in the PHRP-T horizontal pipe is smaller and shorter, even though the minor energy loss is greater in PHRP-T.

PHRP-T maintenance can be done by inserting a spiral pipe into it and pumping water to clean the sediment in the horizontal pipe. With a pump discharge greater than the recharge capacity of PHRP-T, the sediment will come out with the water upward through the inlet pipe so that the PHRP-T performance will return better, and the recharge can be even better.

In addition to PHRP-T having great recharge capacity to reduce surface discharge, it will also be able to increase groundwater supply. As an illustration, for one PHRP-T unit with a recharge of 5,000 cm^3/s in an area with 60 rainstorms in a year,in a duration of 1 hour, it will recharge more than 1,000 m^3 of water into the ground.

CONCLUSION

This study has discusses perforated horizontal recharge pipe study and it can be concluded that PHRP-T has a huge recharge capacity and other advantages. According to the results, it is recommended that PHRP-T for an option to overcome various water disaster problems, especially in urban areas such as flooding, groundwater shortages, land subsidence, and intrusion seawater. PHRP-T implementation has been carried out in Semarang City and expected to be implemented as well in other cities in an attempt to overcome the same problem. However, further study about a broader range of soil permeabilities for soils with more diverse permeabilities is still needed.

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