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Artificial Recharge Effectivity of Water Table Fluctuation

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Abstract— *Excessive exploitation of ground water is one of the impacts of the high demand for clean water. This excessive exploitation can have an impact on the imbalance of groundwater recharge and discharge and result in intrusion, land subsidence and contamination of groundwater. One way to overcome this imbalance is through groundwater recharge. Groundwater recharge is a process of filling aquifers that can occur naturally through natural or artificial water movements with intentional or unintentional human intervention. Natural recharge is hampered by narrowing of the infiltration land so that the of artificial groundwater recharge can be used as an alternative. There are several methods of artificial recharge using either surface or subsurface, but there has been no systematic study comparing the use of Artificial Recharge methods in the form of ponds percolation, infiltration wells and shaft-pits. This research is expected to produce a comparison of some groundwater Artificial Recharge methods of ponds percolation, infiltration wells and shaft-pits so it can be used as a reference in determining good methods and their advantages and disadvantages compared to each other. This study models and evaluates the effectiveness of groundwater filling using Artificial Recharge subsurface method in the form of ponds percolation, infiltration wells and shaft-pits by using the Ground Flow tool in the Hydraulics and Beach Laboratory, Civil Engineering Department, Faculty of Civil and Environmental Engineering, and Geology. The implementation of each method uses the same soil type and soil conditions, and conditions that are same. It is expected to get a comparison of the effectiveness of each method. The effectiveness observed was the magnitude of the increase in groundwater level, and the time of increasing groundwater level in each method. Both shaft pit and percolation have the fastest initial increase time with 1 minutes, and the recharge well is the slowest. On the other hand, both recharge well and shaft pits has the highest initial increase. Based on both water table fluctuation factor, and recharge time factor, shaft pit is the one that has the fastest recharge time, widest initial increase and earliest initial increase.*

Keywords— *Artificial recharge, groundwater.*

I. Introduction

Clean water availability become one of issues of human being. One of the important water resources is groundwater. There will always time when the amount of groundwater that available is not as much as the discharge of groundwater. Groundwater exploitation that bigger than the existing amount will bring any other new problem. Such as degradation of groundwater quality, degradation of river water quality or even land subsidence that occur when the groundwater discharge is bigger than its availability.

Therefore, on certain condition there must be an effort to add the groundwater quantity. This effort often defined as recharge. Recharge happens naturally and artificially. Natural recharge happens by the time the precipitation happens and the water that comes down to soil surface will be infiltrated. The only problem with this kind of recharge is it will take too much time to fill up the empty space within the soil. Therefor artificial recharge will take place to fasten the recharge process. There is quite a lot of artificial recharge, some of barrier them are percolation pond, recharge well and shaft-pit. These methods used based on how big the space that available to be used as artificial recharge. Other than that, there’s still not comparation between them on how will the water table will fluctuate based on each method.

Because of that, this study will discuss about:

1. How is the difference of water table response of recharge between percolation pond, recharge well and shaft-pit with the variation of depth?
2. How is the difference of recharge time between percolation pond, recharge well and shaft-pit with the variation of depth?
3. Which artificial recharge that effectively increasing the water table?

II. Research Methods

A. Experiment Setup

This research is done in Hydraulics and Coastal Engineering Laboratory, Department of Civil Engineering, Civil, Environmental and Earth Engineering Faculty of Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia. To support this research tools that used in this research are:

1. *Ground flow abstraction with its equipment such as:*
   a. Basin as the sand
   b. Manometer board as piezometer indicator

Fig. 1. Ground flow abstraction.

2. *Sand as trial media. The sand used is coarse sand.*

B. Soil & Aquifer Properties

1. *Soil moisture*

Sand that will used, will be tested its water content. Sampled sand will be put inside the oven for 24 hours.

$$w = \frac{b-c}{c-a} \times 100\% \quad (1)$$

Where

w	=	Water content	(%)
a	=	Weight of empty bowl	(gr)
b	=	Weight of empty bowl + wet sand	(gr)
c	=	Weight of empty bowl + dry sand	(gr)

2. *Bulk density*

This test used to control the homogeneity of each experiment.

$$\gamma = \frac{W}{V} \quad (2)$$

Where

γ	=	Bulk Density	(kg/l)
W	=	Total Weight of sand inputted	(kg)
V	=	Volume total of sand	(l)

3. *Porosity*

Porosity interpreted as comparison of void volume and sand total volume.

$$n = \frac{V_v}{V} \times 100\% \quad (3)$$

Where

n	=	Porosity	(%)
V_v	=	Void Volume	(l)
V	=	Sand Total Volume	(l)

4. *Specific yield*

Specific Yield defined as volume of water yielded through aquifer.

$$Sy = \frac{V_y}{V} \times 100\% \quad (4)$$

Where

Sy	=	Specific Yield	(%)
V_y	=	Volume Released	(l)
V	=	Sand Total Volume	(l)

5. *Specific retention*

Amount of water that retained on soil void space by capillary forces during gravity drainage.

$$Sr = n - Sy \quad (5)$$

Where

Sr	=	Specific Retention	(%)

6. *Hydraulic conductivity*

Hydraulic Conductivity defined as material's capacity to transmit water proportionally to discharge.

$$Q = -K \times A \times \left(\frac{dH}{dl}\right) \quad (6)$$

Where

Q	=	Discharge	(m^3/s)
K	=	Hydraulic Conductivity	(m/s)
A	=	Area	(m^2)
dh/dl	=	Hydraulic Gradient	

C. Experiment Setting

1. *Soil setting*

Weighted soil will be put into the Ground Flow Abstraction, flattened and mashed. After the flattened soil gets into certain height that defined as the artificial recharge base, the artificial recharge frame that made from mesh and wire put on top of the flattened soil. All of the void space left outside the artificial recharge frame filled with soil until it reached the height of 18 cm. Bulk density of each experiment shall be the same, bulk density and soil moisture has to be controlled on each experiment.

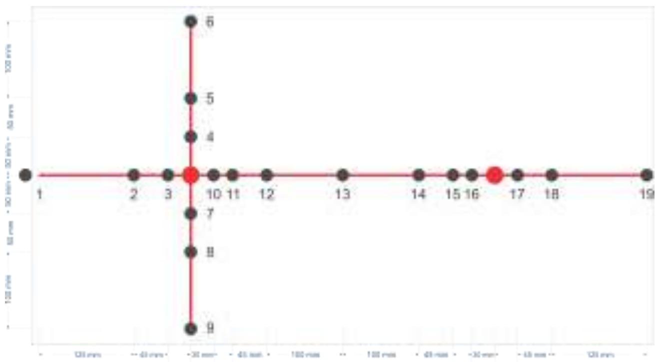

Fig. 2. Observation point of ground flow abstraction

2. *Artificial recharge frame*

Artificial recharge frame made from thick wire as its main frame and big holed mesh as its soil retained. This frame used as a barrier of soil wall of artificial recharge. During the running the soil might collapsed due to water entrance. Each experiment on the same depth level, has the same volume. Experiment setting within the Ground Flow Abstraction showed on Fig. 3, Fig. 4 and Fig. 5.

D. Observation Parameter

1. *Water table level*

Water table level measured on manometer board. This water level recorded during its increasing per minutes. The manometer board has 19 observation point. 13 on X cross section and 6 on Y cross section.

2. *Artificial recharge water level*

Water discharged from artificial recharge through the soil to water table measured each minute before and after water addition.

E. Effective Storage Capacity

Effective storage capacity defined as value that represent of existing water quantity that will be able to extracted through drawdown.

$$Vs(t) = Sy \times V(t) \quad (7)$$

Where

Vs(t)	=	Cumulative Storage Capacity	(l)
V(t)	=	Volume Total	(l)
Sy	=	Specific Yield	(%)

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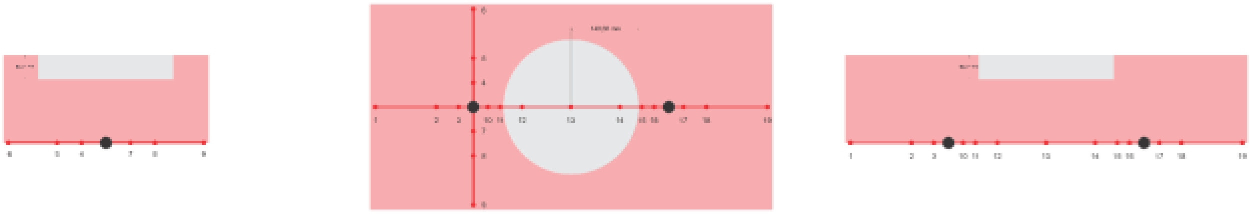

Fig. 3. Recharge well experiment setting.

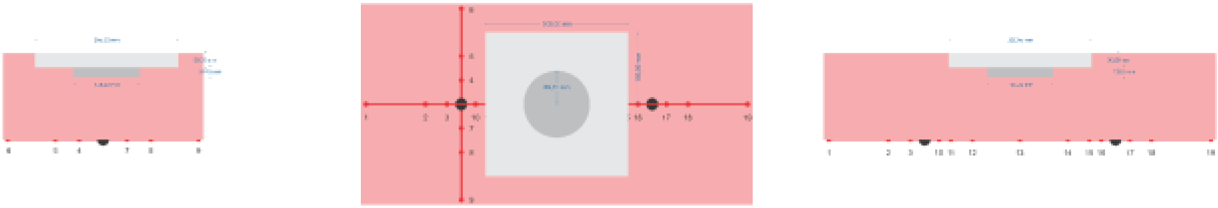

Fig. 4. Shaft pit experiment setting.

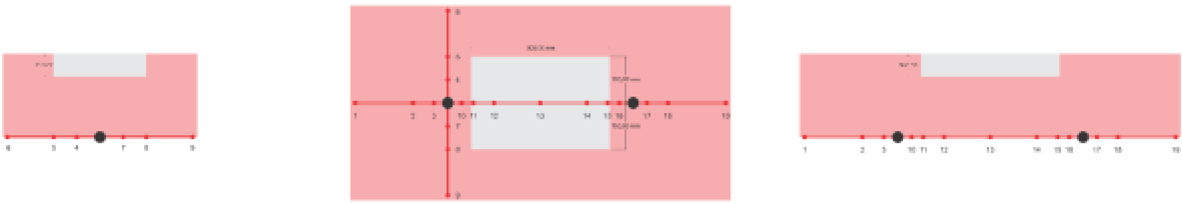

Fig. 5. Percolation pond experiment setting.

F. Volume Total

Volume total defined as total volume where both soil and water are saturated as a respond of recharge. Water table height differ for each observation point. Equation used to calculate total volume on this research are:

$$V(t) = Ht - H0 = \int_0^1 (ht - h0)dx \qquad (8)$$

Where

V(t)	=	Volume total on f(t)	(l)
x	=	Distance of observation point from starting point	(cm)
l	=	Total length of Groundwater Abstraction	(l)
ht	=	Height of water table on observation point at t	(cm)
h0	=	Height of water table on observation point at t-1	(cm)

III. Result and Discussion

A. Artificial Recharge Dimension

TABLE I Artificial recharge dimension.

		Artificial Recharge			
		Percolation Pond	Recharge Well	Shaft Pits	
Total Depth	5 cm	Length 30 cm Width 20 cm Depth 5 cm	Radius 13 cm Depth 5 cm	Shaft Length 30 cm Width 20 cm Depth 3 cm	Pits Radius 7.5 Depth 2 cm
	10 cm	Length 30 cm Width 20 cm Depth 10 cm	Radius 13 cm Depth 10 cm	Shaft Length 30 cm Width 20 cm Depth 6 cm	Pits Radius 7.5 Depth 4 cm
	15 cm	Length 30 cm Width 20 cm Depth 15 cm	Radius 13 cm Depth 15 cm	Shaft Length 30 cm Width 20 cm Depth 9 cm	Pits Radius 7.5 Depth 6 cm

B. Soil & Aquifer Properties

1. *Particle size distribution*

Average of the soil that used on this research is coarse sand. As seen on the grain diameter diagram, most of the soil content is sand with few percent of them are silt.

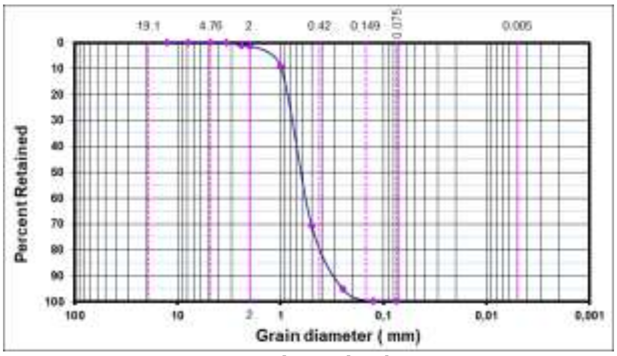

Fig. 6. Particle size distribution.

2. *Soil moisture*
   Based on each experiment soil moisture measurement, average of soil moisture is 0.1482 within range 0.13-0.1.65.
3. *Bulk density*
   Based on each experiment bulk density is around 1.1-1.3 with average value 1.2.
4. *Porosity*
   Based on measurement of laboratory sand box aquifer porosity, porosity value is around 44%.
5. *Specific yield*
   Based on aquifer drawdown of porosity testing, specific yield value of laboratory sandbox aquifer 20,7%
6. *Specific retention*
   Based on amount of water retained on aquifer during aquifer drawdown, value of specific retention is 19,3 %.
7. *Hydraulic conductivity*
   Based on hydraulic conductivity testing of laboratory sandbox aquifer is 0,000534539 m/s.

C. Water Table Level

As seen on Fig. 7, Fig. 8 and Fig. 9, water table height fluctuation on each observation point plotted into water table fluctuation graph. Within depth variation, each of its experiment has to maintain the same recharge area.

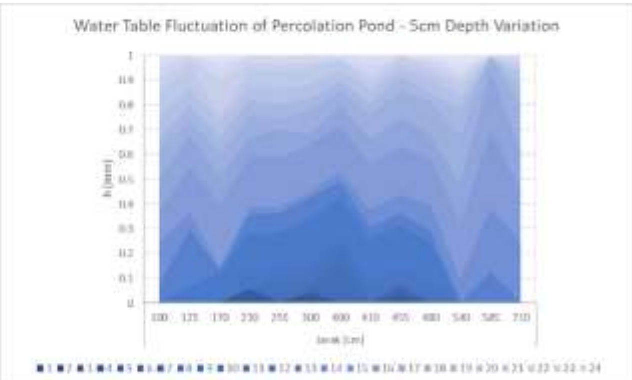

Fig. 7. Percolation pond water table fluctuation.

Water table increase in percolation pond at Fig. 4, has an even distribution form compared to the other two methods. The increase in groundwater level at 13 observation points does not have any point that has a more dominant increase. The spread tends to occur horizontally.

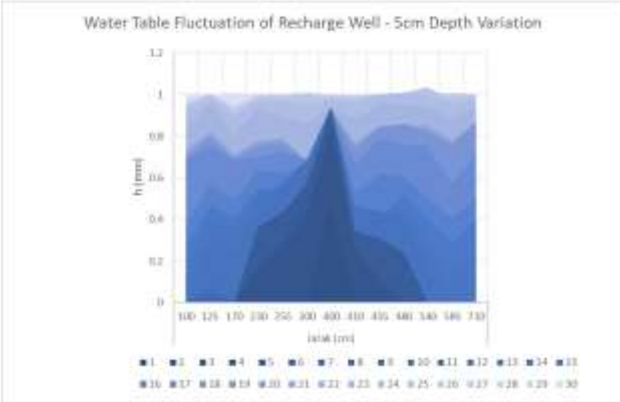

Fig. 8. Recharge well water table fluctuation.

Compared to the other two methods, recharge well has a point where the increase occurs predominantly compared to 13 other observation points right in the middle of the well. The spread tends to occur vertically compared to horizontally.

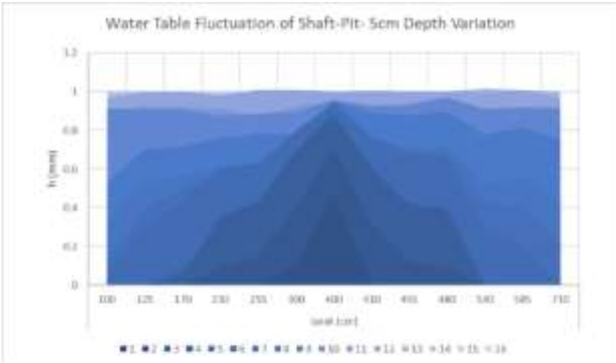

Fig. 9 Shaft pit water table fluctuation.

The form of water table rising at recharge using shaft pit is like a combination of two other methods. The shaft pit itself has the shape of a centered water level on one point and has a more even distribution.

Main difference of percolation pond, recharge well and shaft pit is its shape of water table increasement. Shaft pits has the earliest and biggest water table increase, shaped right on the middle of the pits. Difference of each methods are summarized on Table II.

TABLE II. Artificial recharge water table fluctuation.

Type	Depth (cm)	Initial Increase Time (minutes)	Increase Point	Constant Time (minutes)
Percolation Pond	5	4	12	21
Recharge Well	5	10	10 to 11	31
Shaft Pit	5	1	12 to 13	10
Percolation Pond	10	1	12 to 15	17
Recharge Well	10	2	13	21
Shaft Pit	10	1	10 to 14	9
Percolation Pond	15	1	12 to 15	12
Recharge Well	15	2	10 to 15	16
Shaft Pit	15	1	11, 14 to 15	8

From each depth variation, the slowest to respond the recharge is recharge well with 10 minutes in depth of 5 cm, and 2 minutes on two other depths. From Table II, we could see that recharge well takes the longest time from recharge started until the manometer show the increase of water table. In terms of initial increase are from what the observation point show, the narrowest water table increase is recharge well. On the other hands the largest one is both shaft pit and percolation pond. All of the experiment above controlled under the same affecting factor and area.

D. Total Volume

Of each increasement of water table, we could calculate the total volume of submerged water and soil on laboratory sandbox aquifer using Eq. 8 as shown on Table III.

TABLE III. Total volume.

Type	Depth (cm)	Total Volume (Liter)
Percolation Pond	5	53.45
Recharge Well	5	53.16
Shaft Pit	5	54.37
Percolation Pond	10	48.45
Recharge Well	10	53.46
Shaft Pit	10	52.59
Percolation Pond	15	43.35
Recharge Well	15	53.46
Shaft Pit	15	55.26

From this total volume of each experiment, there's difference from each experiment on the same depth where actually it has to be the same. The difference occurred within observation of water level that used to calculate total volume. This difference happened as the side effect of the manometer's hose. There's a quite sediment that got into the flow of drawdown flow then settled on the bottom of the hose. Therefore it resist the flow of water that will go up.

E. Effective Storage Capacity

Value of effective storage capacity below, is the value that obtained from observation data that then calculated using Eq. 7. Effective Storage Capacity that presented on the Fig. 10, Fig. 11, and Fig. 12 showed the total increasing of water contented on laboratory sandbox aquifer during recharge period. Each of its value observed and calculated by minutes basis.

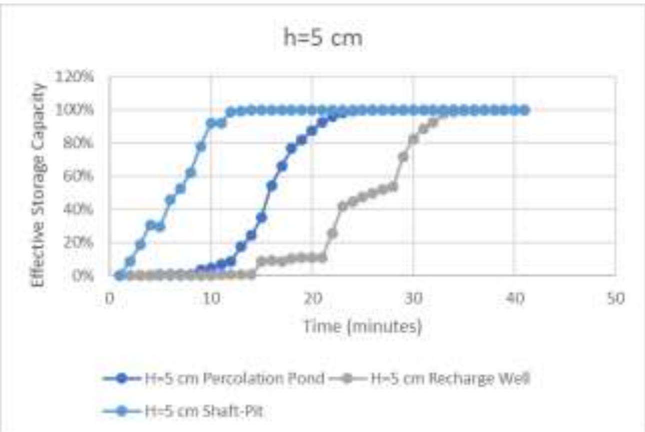

Fig. 10. Effective storage capacity of artificial recharge with 5 cm depth.

From Fig. 10 above we could conclude that the increasement of water table will reach 100% by the end of the observation time. There's some lag time between this three to respond to recharge. Between the three methods of artificial recharge with 5 cm depth, the one that start to respond to recharge and reach the 100% first is shaft pit, the second is percolation pond and recharge well respond the latest.

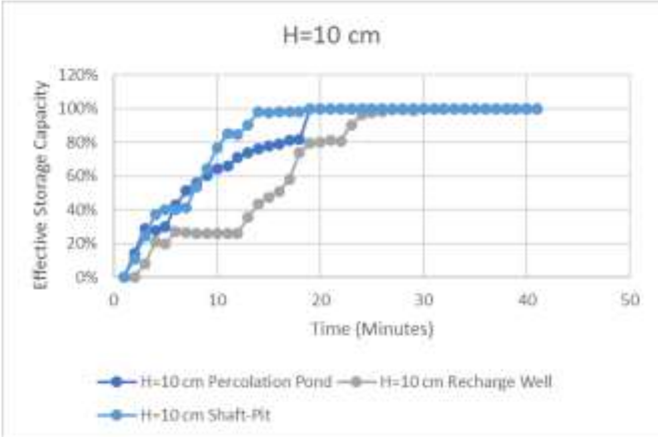

Fig. 11. Effective storage capacity of artificial recharge with 10 cm depth.

By the depth of 10 cm on the Fig. 11, the increasement on each method starts almost on similar time, but ends on 100 % marks on different time. The first method to reach 100 % is artificial recharge, the second is percolation pond and lastly is recharge well.

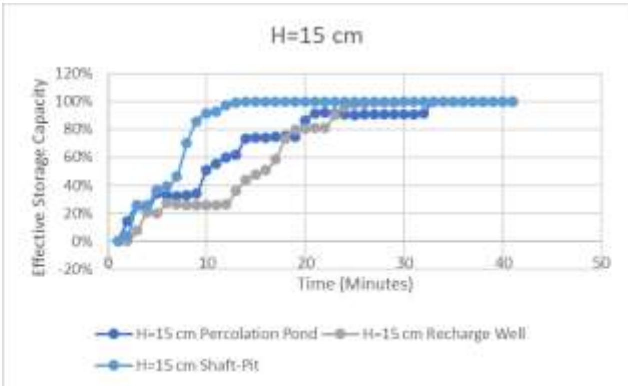

Fig. 12. Effective Storage Capacity of Artificial Recharge with 15 cm Depth.

By the depth of 15 cm on the Fig. 12, the increasement of each method also has the similar pattern with 10 cm depth. But just as the two depth before, the first one is shaft pit, the second one is percolation pond and lastly recharge well.

F. Constant Time

Fig. 13 shows comparation between each artificial recharge methods to reach 100% mark of effective storage capacity. Each of artificial recharge shows, the bigger its depth the faster it gets to reach 100 % marks. Recharge well shows the significant difference between each depth, followed by recharge well. As seen on Fig. 13, on each depth, shaft pit has the lowest time to reach 100%.

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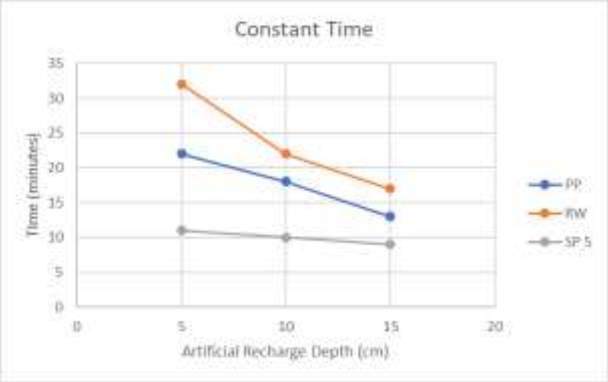

Fig. 13. Times needed by artificial recharge to reach 100% mark.

IV. Conclussion

The conclusion of this research are as follows:

1. Based on the depth variation, water table fluctuation shows the difference of each methods, percolation pond, recharge well and shaft pit. The main difference between these three methods are initial increase time (minutes) and increase point. Both shaft pit and percolation have the fastest initial increase time with 1 minutes, and the recharge well is the slowest. On the other hand, both recharge well and shaft pits has the highest initial increase.
2. Based on recharge time that defined as the time needed by artificial recharge to fully recharge the laboratory sandbox aquifer to 100 % remarks on the Effective Storage Capacity, are shaft pit with average time of 10 minutes.
3. Based on both water table fluctuation factor, and recharge time factor, shaft pit is the one that has the fastest recharge time, widest initial increase and earliest initial increase. Therefore shaft pit is the most effective artificial recharge to recharge groundwater.

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