Implementation of Zero Run-Off (ZEO) system on Cocoa land to increase watershed performance

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Abstract. One indicator of the decline in watershed performance is the increase in the ratio of maximum discharge to minimal discharge due to major surface runoff when rain occurs. Land use for cocoa cultivation can increase surface runoff by 389% compared to forest land. For this reason, it is necessary to implement a zero run-off system technology that can minimize surface runoff through increasing groundwater recharge. Groundwater recharge in the Zero runoff system (ZRO) was determined using Darcy's approach. This approach requires hydraulic gradient data obtained through measurements of groundwater levels around the ZRO system using two monitoring wells and hydraulic conductivity data of saturated soil. Groundwater levels are measured interactively using an aqua plumb liquid level sensor with data logger recording. The saturated hydraulic conductivity was determined using the falling head approach. Based on the result of the research, the hydraulic gradient in one of the ZRO system in the research location is 0.4, and the saturated hydraulic conductivity of 2.61×10^{-5} m/s shows that the soil in the research location is moderately coarse or loamy textured. Thus, the velocity of water entering the subsurface is 1.04×10^{-5} m/s, so that discharge of the groundwater recharge for one ZRO system is 4.16×10^{-5} m^3/s with the cross-sectional area of the ZRO system is 4 m^2.

1. Introduction

The impact of cocoa cultivation on the hydrological function of a watershed can be seen regarding the elementary flow in the river network. A watershed is declared good if the ratio between maximum discharges to minimum discharge is small. This ratio uses the ratio between peak flow (maximum discharge) to base flow (minimum discharge) [1].

Efforts to minimize the maximum discharge ratio to the minimum discharge is to reduce the maximum discharge (minimize surface flow) and or increase the minimum discharge by increasing groundwater recharge. Both of these efforts can be carried out by maximizing the inclusion of surface flows into the soil as groundwater recharge. However, with the conversion of natural forest functions into a cocoa land, it can increase surface flow by up to 389% for young plants, while in adult cocoa plants by 284% [2]. Efforts to improve watershed performance on cocoa land are implementing the Zero Run-Off system (ZRO). This technology can minimize surface flow [3] so that it can provide a worthy response to the environment [4] and provide environmental and economic benefits [5]. The primary function of the ZRO System is to reduce surface flow so that the research knows the function of the system to groundwater recharge as an effort to improve the watershed performance of the cocoa land.

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2. Methods

2.1. Groundwater recharge

The ZRO system analysis of groundwater recharge using Darcy's approach. Groundwater recharge is calculated using data on groundwater level differences. The velocity of groundwater input is calculated based on the saturated hydraulic conductivity of the soil using Darcy's law [6] which explains that the flow of water entering the soil has a linear relationship between differences in pressure and flow rate [7]. Thus, the calculation of groundwater recharge using equation:

$$Q = K.i.A \tag{1}$$

Where Q = Earth debit (m3 / day), K = Hydraulic conductivity (m/day), i = Hydraulic gradient, A = sectional area of flow (m2).

The hydraulic gradient is the ratio between the difference in groundwater level and the distance between the monitoring wells. The cross-sectional area is assumed to be the same as the area of the wall of the wet building, whose value depends on the dimensions of the ZRO system.

2.2. Saturated hydraulic conductivity

Measurement of Hydraulic conductivity with falling head method using [8]:

$$\ln\left(\frac{h}{h_c}\right) = \frac{A}{a}t \tag{2}$$

Where h_0 = the initial water level in the manometer pipe above the water surface (m), h = water level in the manometer pipe at time t (m), A = sample surface area (m^2), a = cross-sectional area of manometer pipe (m^2), L = average sample thickness (m), Ks = saturated hydraulic conductivity (m / s), t = time (s).

3. Result and Discussion

3.1. Saturated hydraulic conductivity

Saturated soil hydraulic conductivity is a function of the flow of water coming out of the ZRO system. The hydraulic conductivity is measured by the falling head method. Soil samples were taken using a sample ring, so that the soil sample has the same consistency as when it was in the field, therefore the ability of the soil to pass water with the infiltration process is close to the conductivity value that measured. Data for determining soil conductivity are presented in table 1.

Table 1. Water level measurement data to determine the saturated hydraulic conductivity of the soil[9]

Water level position	Water level (m)	time (s)	ln (h/ho)
h0	0.60		
h1	0.55	5.95	0.087011
h2	0.50	12.98	0.182322
h3	0.45	19.33	0.287682
h4	0.40	26.91	0.405465
h5	0.35	35.41	0.538997
h6	0.30	45.24	0.693147
h7	0.25	57.13	0.875469
h8	0.20	71.13	1.098612
h9	0.15	90.53	1.386294

The data is plotted into the graph of the relationship between time and ln (h / ho). The results of data plotting are as in figure 1 below:

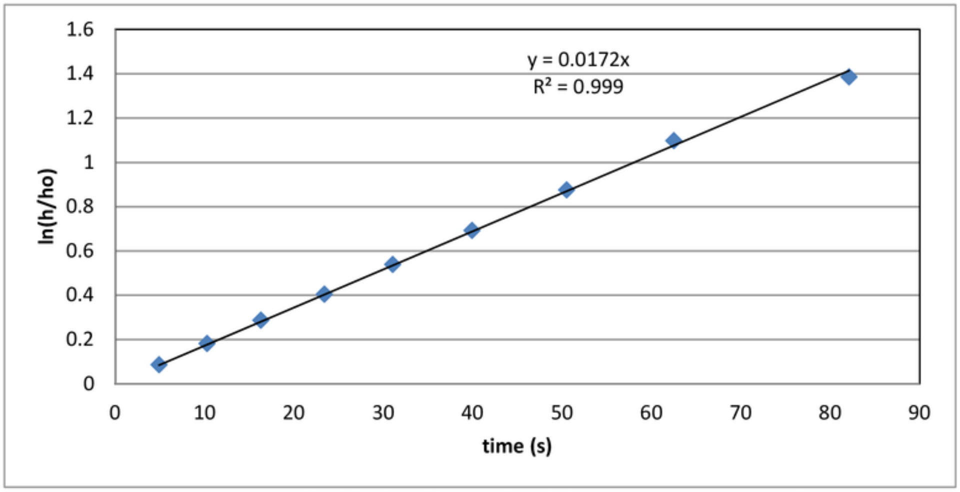

Figure 1. Soil hydraulic conductivity measurement graph.

From the graph, it is known that the value of A * Ks / a.L = 0.0172. With the measuring instrument specifications A = 0.025434 m^2, a = 0.000314m^2 and L = 0.01m so that the hydraulic conductivity is saturated at 2.61 x10^{-5} m / s. This result indicates that the soil on the cocoa field is moderately coarse or loamy textured with moderate rapid hydraulic conductivity [10] or sandy loam [11].

3.2. Groundwater recharge debit

Groundwater recharge is calculated using Darcy's approach (equation 1). The flow gradient value is determined based on the difference in groundwater level around the ZRO system. Measurements tools record water level in the ZRO system, and two monitoring wells around it. The graph in figure 2 provides the real-time water level measurement of each well.

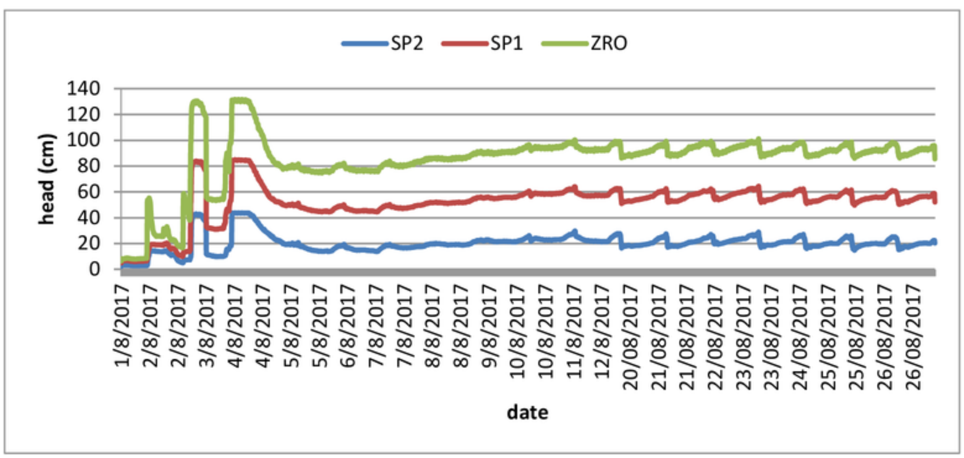

Figure 2. The water level in the zero run-off system and monitor well 1 and 2

From the data in figure 2, the average water level in the ZRO system, monitoring well 1 (SP1) and SP 2 respectively are about 20 cm. The distance between the ZRO system to SP1 and SP1 to SP2 is 50 cm each; then the hydraulic gradient is 0.40. Thus, the speed of the flow of water entering the soil is $0.40 \times 2.61 \times 10^{-5}$ m / s = 1.04×10^{-5} m / s. The wet field area of the ZRO system is 0.36 x 1 x 4 = 1.44 m^2. Thus, the surface flow debit that enters the ground for 1 unit of ZRO system is 4.16×10^{-5} m^3 / s = 3.59 m^3 / day, with a cross-sectional area of the system is 4 m^2. Increasing the dimensions of the ZRO system can increase input capacity.

4. Conclusion
The zero run-off system is effective in improving watershed performance through the inclusion of surface flows into the soil as groundwater recharge. The bigger the dimensions of the system, the bigger the groundwater recharge debit.

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