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Design of Water Source Alternative Based on SWAT Model Simulation

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ABSTRACT

Water shortage problem was often happened in many places in Indonesia. Water availability is very important not only for domestic needs, but also for other activities particularly for agricultural activities. To solve water shortage problem, this study aimed to design a water source alternative. The rain is a free water source and collecting rain in the small dam or reservoir is one of the effective rainwater harvesting technique that can increase water availability. This research was conducted at Sekaran Village and the analysis had done using SWAT (Soil and Water Assessment Tools) model. The planned rainfall and discharge were analysed by 5 years return period to calculate the water potential for reservoir charging. The results of this study indicated that the location of the reservoir was planned in a forest area with a slope of 8-25%, on coordinates 111º38'11.39"E and 7º6'14.22"S and has a storage volume of 13737 m3. The reservoir has 4356 m2 surface area with a depth of 3 m. Based on the SWAT model simulation, the highest average discharge potential occured in February with a discharge of 0.312 m3/s and the lowest average discharge occured in October with a discharge of 0.044 m3/s. The total volume of potential annual water that can fill the reservoir is 61.166 m3/s per year based on a planned rainfall of 115.38 mm and a planned flood discharge of 2.54 m3/s with a return period of 5 years. The reservoir construction required a cost of IDR 1,200,747,000.

1. INTRODUCTION

Drought is an annual disaster phenomenon that often occurs in many places Indonesia, so it interferes with the community activities in an area. One of the reason of the drought problems is land conversion. Land use changed caused infiltration rata decreased and surface runoff increased (Utamahadi *et al*., 2018).

One of the fastest and simple way and the results are effective for dealing with drought is to make a dam. A reservoir is an effective water harvesting technique to control surface runoff and increase soil water content in the root zone of plants so that it can meet water needs (Surdianto *et al.,* 2012). Other research conducted by Nurlaila (2019), stated that the reservoir can reduce runoff discharge and reduce the potential for flooding in the downstream area. It can be said that the reservoir is one of the water and soil conservation techniques by applying the civil-technical method to reduce the existing flowrate ratio of 216.66 m^3/year to 22.27 m^3/year in the Cibaliung watershed. In addition, other study conducted by Park *et al*. (2022) showed that water stockage in dams or reservoirs are very effective in preventing groundwater level decline during the dry season. According to Tarigan (2008), on average one small agricultural reservoir with dimensions of 8x2x2 m can supply irrigation water for 100 m^2 of horticultural crops, during the planting period in Cikakak Sukabumi. The reservoirs with water source is rainwater are relatively cleaner and the water is more suitable for domestic needs (Setiawan *et al*., 2016). Regarding the importance of the role and benefits of the reservoirs, this study aimed to design a reservoir as an alternative of the water source in Sekaran Village, Bojonegoro Regency, using a rainwater harvesting technique, to increase water availability.

2. MATERIALS AND METHODS

This study was conducted in Sekaran Village, Kasiman District, Bojonegoro Regency, East Java Province (Figure 1). Sekaran Village is located in the Bengawan Solo Hilir Sub-watershed and experienced drought every year. The drought pattern in Bojonegoro is classified as very dry. The duration of drought pattern occurred in 2014 with a drought duration of 22 months (Sutanhaji *et al*., 2016). According to the Bojonegoro Regional Disaster Management Agency (BPBD) in Halil (2018) as many as 17 sub-districts were hit by drought, especially during the dry season. One of them is Kasiman District.

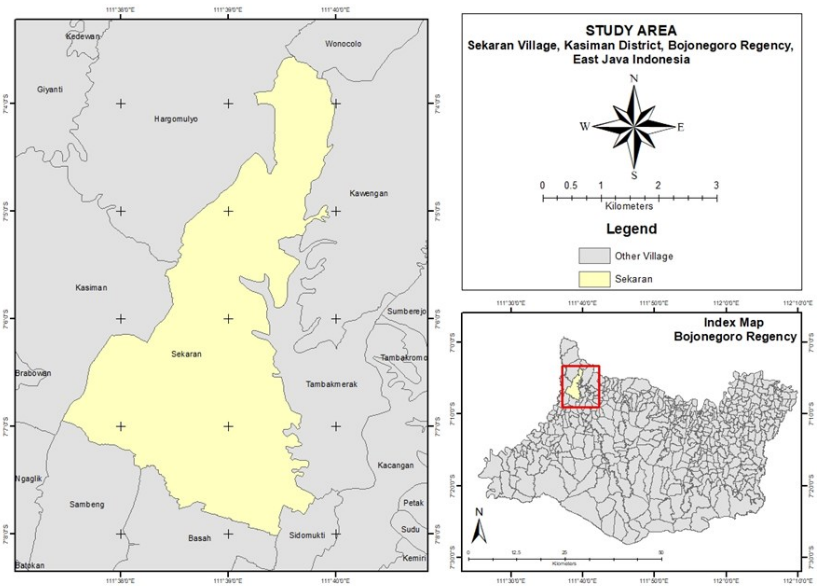

Figure 1. Study area for design a reservoir as an alternative of the water source in Sekaran Village, Bojonegoro Regency

Drought problems that occur in Sekaran Village were low river discharge, low rainfall, and minimal groundwater potential (Pandjaitan *et al*., 2021). Previous research conducted by Pandjaitan *et al*. (2021) stated that the potential for water during the dry season is very low. River discharge it is only 1.43 liters/s and groundwater potential is less than 1 liter/s. According to Pandjaitan *et al*. (2018) the low groundwater potential in Sekaran Village can be caused by the varying directions of groundwater flow caused by the lithological arrangement.

Data collection in this study was carried out from August to September 2020. The data used in this study were digital elevation model (DEM), soil type data sourced from BPSDLP, Bengawan Solo watershed land cover data sourced from LAPAN, geological maps, and climate data sourced from the Padangan rain post of BBWS Bengawan Solo, East Java Province. The stages of analysis in this study consisted of determining the potential location for the reservoir, hydrological analysis, and designing the reservoir.

2.1. Determining the Location of the Reservoir

The data used in determining the location of the reservoir were soil type maps, geological maps, slope maps, topographic maps, and land cover maps. All the maps were combined or overlaid with the weighted overlay data analysis method by converting shapefile data into raster form and each criterion was given a weight and criteria score (Hermawan, 2019). The weight criteria are divided into several numerical classes. The largest value is the value that is very suitable to be used as a potential reservoir location. It is interpreted using Arcgis software to determine the planned location and the water catchment areas in the prospective reservoir along with the level of land suitability.

2.2. Hydrological Analysis

The hydrological analysis in this study aimed to determine the hydrological conditions of the catchment area and the potential sources of runoff water that can be stored in the reservoir. Hydrological analysis using a SWAT model (soil and water assessment tool) was integrated into the ArcSWAT plug-in software Arcgis 10.6. The stages in making the SWAT model are:

1. Delineation of the catchment area

The watershed data delineation process is formed from DEM input and river network data. By making the outlet point and the location of the reservoir, it is possible to know the area of the catchment area in the planned location of the reservoir. The watershed delineation process was carried out automatically by the SWAT program by determining the outlet point as the location of the reservoir, the water catchment area will be delineated automatically. However, one of the drawbacks of DEM for making watershed delineation is that it cannot identify drainage, especially man-made structures, so manual digitization of streams is required (Almendiger & Ulrich, 2010).

2. Hydrological Response Unit (HRU)

The HRU can be used to analyze the effect of hydrology on the area being analyzed (Susanto *et al*., 2017). The HRU analysis at this stage is to include land use maps, soil maps and slopes to be overlaid so that a hydrological response unit is formed. The HRU is spread out in each subbasin which can describe the biophysical condition of each subbasin by combining (overlaying) areas that have the same soil type, slope and land use into a single response unit (Nugroho, 2017). The formation of HRU on land cover is adjusted to the SWAT code for each type of land cover. The SWAT code used for each type of land cover is described in Table 1.

Table 1. SWAT code for land use classification

Land use classification	SWAT code
Field	AGRL
Rice field	RICE
Urban	URMD
Plantation	ORCD
Forest	FRST

The slope class in the formation of the HRU was divided into 5 classes: flat slope 0-8%, gentle slope 8-15%, wavy slope 15-25%, steep slope 25-45%, and very steep slope >45% (Pranoto *et al*., 2016). Meanwhile the soil class in the formation of HRU was adjusted to the FAO parameter.

3. Merging HRU with Climate Data
The formation of HRU in the model uses the threshold by percentage method, namely by entering the percentage value on each land use map, soil map, and slope (Susanto, 2015). Threshold by percentage in this study is 0% which means that all variables of land cover, soil type, and slope have no limits in the formation of HRU (Purwitaningsih & Pamungkas, 2017). The process of combining HRU with climate data aims to see the output value of the discharge generated from the simulation model.

4. Simulation Model
Running a SWAT model simulation is carried out if the data that has been entered is judged to be appropriate to minimize the occurrence of simulation failures to see the results of the model that has been created. The equation used in the SWAT simulation to predict runoff discharge is the SCS Curve Number method (Rau *et al*., 2015).

5. Rainfall and planned discharge
The design rainfall and the planned flood discharge were analyzed and would be used to calculate the potential annual discharge of the prospective reservoir location. Design rainfall and planned flood discharge were calculated by the log Pearson III method using a 5-year return period and a statistical approach. The log Pearson III method was choosen based on the analysis results of the distribution method selection.

The purpose of calculating the design rainfall and planned flood discharge were to analyze the capacity of the rainwater supply and to determine the characteristics of the flood discharge based on the duration of the flood in its repetition period. According to the definition of the reservoir as a medium for harvesting rainwater, the main water source for reservoirs is the rain and the surface runoff from rainwater.

2.3. Reservoir Planning

The design reservoir was designed based on topographical forms. In addition, the topographical form which is limited by contour lines will also provide an overview of the volume of the reservoir. Then the design of the reservoir was calculated to know the work volume for each type of work. After obtaining the value of the total volume of work, then the total costs needed to make the reservoir could be calculated. The cost analysis was conducted based on the list of work price unit analysis standard, work wages and building material prices in 2021 in Bojonegoro Regency.

3. RESULTS AND DISCUSSION

The planning for the location of the prospective reservoir in Sekaran Village was analyzed based on the analysis of land cover maps, soil type maps, topographic maps, geological maps, and slope maps which were overlayed and given weighted criteria using the weighted overlay method. The weighted overlay method could be used to analyze land suitability for potential reservoir locations by classifying classes 1,2,3 and 4 on each shapefile data based on the level of suitability. The greater the classification value, the more suitable the location to be used for potential reservoir locations and vice versa. The output of the weighted overlay method in the spatial analysis of potential reservoir locations was classified based on 4 classes, namely not suitable, quite suitable, suitable, and very suitable. The location of the prospective reservoir was planned in an area with a concave contour based on the topographic map, located on a high elevation and had a basin. Those criteria were based on the consideration that a higher location has a greater potential to capture runoff water and in its distribution, can rely on gravity. So, the water can irrigate rice fields around the reservoir location and does not require a pump in its distribution.

The determination of the location was analyzed using a 1:50,000 scale map to portray the suitability of the location to the standard of planning for the reservoir. After merging the map/overlay, the next step was to establish a classification based on the level of land suitability based on the suitability level score. Based on the results of the classification of scores against the results of the combined map, it was found that one potential reservoir location was in Jar Kulon Hamlet with a reservoir area of 4356 m^2, presented in Table 2.

Table 2. Characteristics of the prospective reservoir

Factor	Results
Location	111º38’11.39”E ; 7º6’14.22”S
Land use	Forest
Slope	8-25 %
Soil type	Mediteran
Geological type	Formasi Tambak Romo
Elevation	49 masl
Distribution access	10 m to rice field 5 m to plantation area
Watershed	318 Ha

The potential reservoir area had a flat slope with a surface area of 4356 m^2 and a depth of 3 m. The potential reservoir location was the water collection point in the creation of a SWAT model for hydrological analysis.

The hydrological analysis in this study used a SWAT plug-in program. Hydrological analysis was carried out on the prospective location of the reservoir which was used as an outlet point. The SWAT model was used in the hydrological analysis because the basis for SWAT calculations was the water balance (Hidayat *et al.*, 2017) with the output of the hydrological condition performance model in the catchment area in the form of discharge, erosion, and transported sediment. Based on the simulation results of the SWAT model for the reservoir, the catchment area of the reservoir was 318 Ha.

Based on the SWAT model simulation, the biophysical conditions in the catchment area of the prospective reservoir had 237 HRU with a threshold formation of 0 % on land cover, soil type, and slope. Land cover in the catchment area is dominated by forest land and rice fields (Table 3). The soil unit in the catchment area of the prospective reservoir had 2 types of soil, namely vertisol with an area distribution of 144.7 Ha and alluvial with a surface of 173.2 Ha.

Table 3. Watershed land use area

No	Landuse	SWAT code	Area	
			(Ha)	(%)
1	Field	AGRL	68.8	21.66
2	Rice field	RICE	69.7	21.93
3	Urban	URML	22.1	6.95
4	Forest	FRST	156.9	49.35
5	Plantation	ORCD	0.3	0.11
	Total		**317.8**	**100.00**

The slope class in the catchment area of the reservoir had 4 classes with a class division of 0-8 % (169 Ha), 8-15 % (127 Ha), 15-25 % (21 Ha), and 25-45% (0.8 Ha). So the catchment area at the prospective reservoir was dominated by slopes between 0-8%, and can be categorized as a sloping area. After obtaining the results of the formation of the HRU, the simulation of the model was carried out for a period of 11 years to get the hydrological conditions in the catchment area of the prospective reservoir.

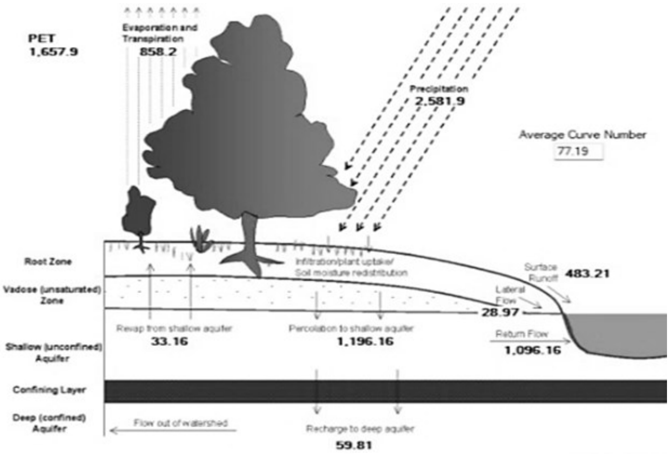

Figure 2. The simulation result of the model (all units in mm)

The simulation results in Figure 2 showed that 62% of the total rainfall (2581.9 mm) became streamflow and was collected at the outlet point of 1608.18 mm. The value of river flow was formed from the rain that entered the river directly and also from surface runoff, lateral flow and base flow. The total value of surface runoff in the prospective reservoir was 483.21 mm/year with an average CN value of 77.19. The surface runoff is very dependent on the rainfall, and the magnitude of the runoff value greatly affects the potential for water filling discharge at the prospective reservoir location. The potential discharge at the prospective reservoir location can be seen in the daily simulation results for a period of 11 years (Figure 3).

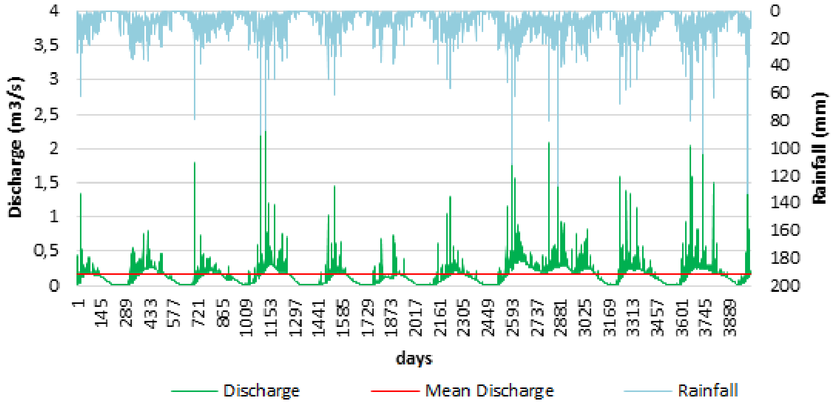

Figure 3. Fluctuation of discharge and rainfall of prospective reservoir

The maximum discharge value for the prospective reservoir was 3.76 m^3/s with an average discharge of 0.1675 m^3/s. The maximum discharge at the prospective reservoir location is influenced by the high intensity of the rain that occurs, which is 133 mm. The average discharge in the simulation results is used to know the potential discharge that can fill water in the prospective reservoir.

Based on Figure 4, the potential monthly discharge of the prospective reservoir had the highest discharge in February with a discharge of 0.312 m^3/s and the lowest discharge was in October of 0.044 m^3/s. From June to October was a dry season, so the discharge entering the reservoir area will be very small and lower due to the lack of rainfall. From December to May there will be an increase in rainfall so that the reservoir is able to accommodate more water and can increase the water availability.

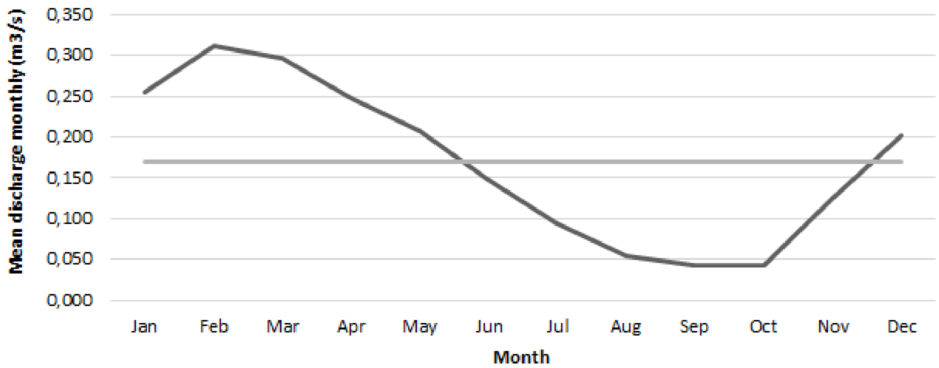

Figure 4. Fluctuation of average discharge in prospective reservoir

The average volume of potential surface water discharge that can fill the reservoir was 61.166 m^3/s annually. Besides, the reservoir also has an additional source of water from rainwater that directly falls into the reservoir and could increase the availability of water in the reservoir. The volume of water that enters the reservoir can later be used if there is a water shortage in Jar Kulon Hamlet, Sekaran Village, especially during the dry season. The location of the reservoir was at an elevation of 49 -44 masl (Figure 5).

The reservoir was designed to follow a concave contour line to minimize costly excavation work. Rainfall and planned discharge for reservoir were analysed using 5-year return period and the result showed that the planned rainfall value was 115.38 mm, while the flood discharge value was 2.54 m^3/s.

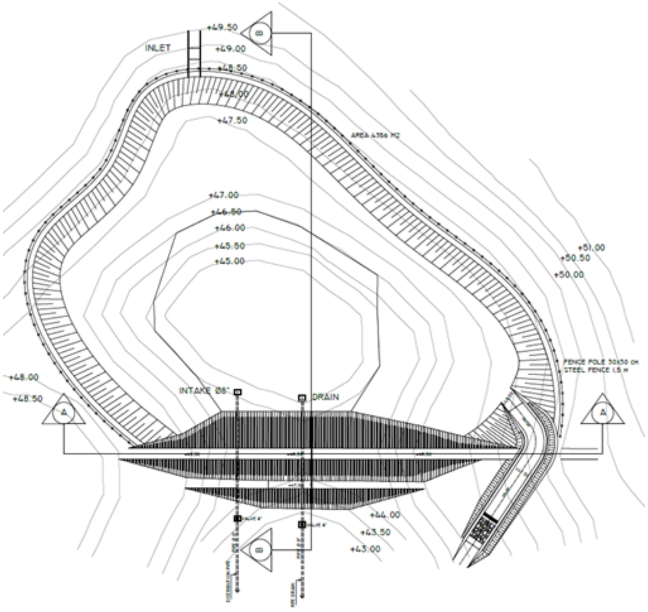

Figure 5. The reservoir design

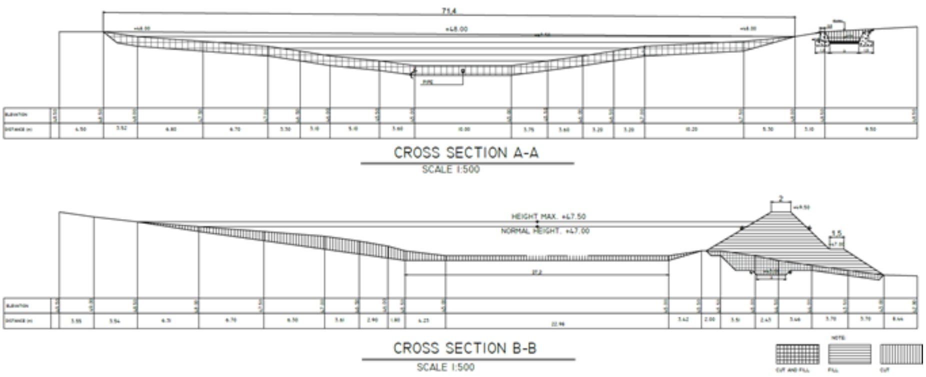

Figure 6. Section A-A and B-B

The spillway area and the reservoir body were at an elevation of 44 masl. The reservoir body had a height of 5 m (Figure 6) with a composite reservoir body type, was made with a combination of concrete and earth fill. The application of the combination of soil and concrete fill made the concrete can withstand water seepage so that there is no failure of the reservoir body construction in the form of cracks and landslides.

The spillway (Figure 7) was planned to use a retaining wall cantilever with a structure that can withstand the backfill. The retaining wall used concrete material with K350 standard. The use of a retaining wall cantilever was considered safe against stand shear forces, slopes, and subgrade bearing forces with a safety factor of 1.62; 1.55; 2.16 on a relatively steep slope on the Padang Road section (Alzahri *et al.*, 2020).

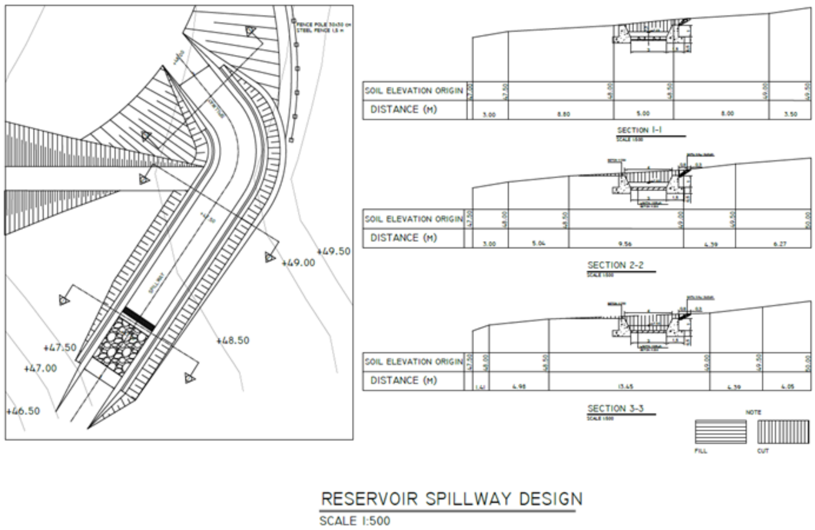

Figure 7. The spillway design

In addition, cantilever walls had an economic value and were suitable for handling soil stability that has unstable loads and pressures (Sadat *et al*., 2018). The reservoir outlet was designed using a valve pipe with a diameter of 8 inches. This outlet will later become a water distribution channel to the rice fields and plantations around the reservoir.

The reservoir body was designed with a homogeneous type which was a composition of backfill. Construction mitigation to reduce seepage and cracks in the reservoir body was added with crushed stone aggregate and coated with 0.5 mm geomembrane covering the reservoir storage area. The total cost needed to build the reservoir was IDR 1,200,747,000 (Table 4).

Table 4. Watershed land use area

Part	Jobs	Cost (IDR)
A	Preparatory	66,644,700.00
B	Soil Jobs	168,507,790.00
C	Pond construction	748,111,855.00
D	Outlet construction	28,643,000.00
E	Finishing	79,680,500.00
	Total	**1,091,587,845.00**
	Tax 10%	**109,158,784.00**
	Total cost	**1,200,746,629.00**
	Rounding	**1,200,747,000.00**

For the reservoir body on the front and back sides, there were differences in the outer layer of the reservoir body, namely the addition of K300 concrete as a reinforcement material for the reservoir to prevent seepage and cracking of the reservoir body due to the force of water pushing. The description of the work in the construction of the reservoir was divided into several sub-jobs, namely preparatory work, earthwork, pool work (geomembrane), concrete work, drain work, outlets, and complementary / finishing work.

4. CONCLUSIONS

The results of the analysis by combining map data (overlays) obtained potential reservoir locations in Sekaran Village. The reservoir location was in the Jar Kulon Hamlet at 111º38'11.39"E and 7º6'14.22"S with a reservoir area of 4356 m^2 at an elevation of 49-44 masl and a storage volume of 13,737 m^3. The potential average discharge of the reservoir had the highest discharge in February with a discharge 0.312 m^3/s and the lowest discharge in October with a discharge 0.044 m^3/s. The average volume of potential water that enters the reservoir was 61.166 m^3/year with a planned rainfall of 115.38 mm and a planned flood discharge of 2.54 m^3/s. The total cost needed to make a reservoir with a depth of 3 m was IDR1,200,747,000.

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