Evaluation of Life Cycle Benefits of Zero-Runoff Campus Strategies

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Abstract— **The green campus concept represents a dedicated endeavor to establish environmentally responsible campus infrastructure. A sustainable campus integrates innovative solutions for energy efficiency, waste reduction, and natural resources conservation. In sustainable development, the drainage paradigm has shifted from quickly removing stormwater to sustainable designs that enable water conservation with cost-effective solutions. In this study, an evaluation of a sustainable drainage system in a middle scale campus in Malang Indonesia is presented. Drainage facilities for the water conservation system include retention ponds, infiltration chamber, rainwater harvesting, and bio-absorption holes. Decisions are made based on criteria relating to reduced runoff, water infiltration, and extended flood time concentration brought to life cycle-costs of the system. From the analysis results it can be concluded that the proposed drainage system is hydrologically and financially feasible in terms of reduction in runoff. The analysis provides evidence that the Net Present Value (NPV) amounts to IDR 78,267,092, and the Benefit-to-Cost (B/C) ratio is 1.99. Technically, the rate of flood reduction is 51.8%.**

Keywords—component; zero runoff; green campus; life-cycle benefit; sustainable drainage

I. Introduction

Sustainable development offers a way to balance the needs of people and nature, ultimately contributing to a better quality of life for everyone while safeguarding the earth's ecosystems and resources. It also emphasizes that any development must achieve a harmonious equilibrium among economic, social, and environmental factors[1]. The idea of a green campus signifies a determined effort to create campus infrastructure that prioritizes environmental responsibility. A sustainable campus incorporates inventive strategies aimed at enhancing energy efficiency, reducing waste, and conserving natural resources. By promoting a culture of sustainability and implementing cutting-edge practices, sustainable campuses would inspire the next generation of environmental leaders[2].

Zero runoff refers to a sustainable urban drainage approach aimed at minimizing or completely eliminating the discharge of rainwater runoff into stormwater drainage systems, rivers, or other bodies of water. Instead of channeling rainwater away rapidly, zero runoff focuses on managing precipitation on-site through various techniques to reduce the burden on conventional drainage infrastructure and promote sustainability[3][4].

Investigating the value of facilities and issue of the investment are continuing concerns within the creation of environmentally responsible built infrastructure[5][6]. In recent years, there has been an increasing interest in comprehensive assessments that evaluate the practicality and viability of implementing sustainable infrastructure projects[7][8]. Runoff reduction, water quality, amenity, public willingness to pay, life-cycle cost are some criteria represent a holistic approach to evaluating the effectiveness and sustainability of sustainable drainage projects in urban area[9][10]. By considering these factors, planners and stakeholders can make informed decisions about the implementation and design of stormwater management systems that benefit both the environment and the community. However, lack of the studies regarding the consideration of intangible benefit has existed that can indeed lead to infeasible investments and incomplete project evaluations. The research to date has tended to focus on monetary benefit rather than perceived value. These benefits often extend beyond financial gains[11].

The purpose of this paper is to review the performance of sustainable cutting-edge practices or eco-drainage in a campus. The objectives of this research are to determine whether the facilities are feasible in multi-criteria approach. The tangible economic factors include cost of investment, cost of operation and maintenance, reduced runoff, ground water recharge volume, and recycled water volume. In this study, intangible benefits are taken into account, including the campus community's perception of amenity, the value associated with having a green campus, and the promotional benefits for the campus. The concept is applied in Polinema campus, a mid-sized campus situated in Malang City. The central question in this study asks how the zero-runoff campus is feasible technically and financially. This research offers an exciting chance to enhance our understanding of how to promote a sustainable and environmentally friendly campus.

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II. Research Methodology

A. Study Area

Planning was carried out in Polinema campus, Lowokwaru District, which is in the north of Malang City, precisely on the border with Brantas River mainstream. The campus has an area of 138,305 m². Figure 1 shows the location map, topographical map, land use, and some visualization of the study area. The data collected directly in the location is soil permeability through Guelph Permeameter test and infiltration rate through absorption test. The result of permeability and infiltration rate is 0.00821 m/dt and 0.000002 m³/s respectively. In addition, a sondir test with a maximum depth of 4.6 meters was conducted. Solid layer with a cone penetration of up to 250 kg/cm2 at a depth of more than 4 meters. At depths between 0.00 m and 3.80 m, sandy and clay soils with conus penetration (qc) values between 11 and 26 kg/cm2 are discovered.

Figure 2 is the procedure of primary data surveying. The secondary data required are daily rainfall data (mm/day) in Sta. Ciliwung, Tajinan, Jabung year of 2013-2022 which is obtained from Dinas Pekerjaan Umum Kota Malang.

Fig. 1. Study Area (Source: Hirfi Studio, Malang Topograhical Line Map 2003)

B. Designed Rainfall and Flood

Log-Pearson III Distribution is applied to analyze the designed rainfall. The return period used is 2 years.

$$logX = \overline{logX} + G \cdot S_{logX} \quad (1)$$

Where X is designed rainfall (mm/day), G is coefficient, S is standard deviation. The rational method can be used to analyze storm drain design, especially for relatively small drainage regions of less than 100 hectares[12]. The following formula is used to compute the peak runoff discharge:

$$Q_T = kCi_TA \quad (2)$$

Where Q_T is the designed flood for a time return interval of T years (m^3/s), K is conversion factor (0.00278), C is the runoff coefficient, i_T is designed rainfall (cm/hr) with return period of T years in a specific time concentration, and A is catchment area (ha). Time concentration is calculated as follows:

$$t_c = t_0 + t_d \quad (3)$$

$$t_0 = \left[\frac{2}{3} x 3{,}28 x L_0 x \frac{n}{\sqrt{s}}\right]^{0{,}167} \quad (4)$$

Fig. 2. Permeability and Infiltraton Test

$$t_d = \frac{Ld}{60xV} \qquad (5)$$

Where t_c is time concentration (min), t_0 is floodplain travel time (min), t_d is channel travel time (min), L_0 is floodplain length, n is Manning roughness coefficient of floodplain, L_d is channel length (m), V is designed flow velocity (m/s).

C. Hydrology Aspects of Eco-Drainage

The eco-drainage facilities implemented are bio-absorption hole, retention pond, infiltration chamber, and rainwater harvesting tank. Theoretical assessments of the capacity and infiltrated discharge of the infiltration chamber and bio-absorption hole can be derived through calculations using the water balance equation, in accordance with Darcy's Law[13]:

$$H = \frac{Q}{FK}\left[1 - e^{\frac{-FKT}{\pi R^2}}\right] \qquad (6)$$

Where H is chamber or well depth (m), Q is discharge (m^3/s), F is geometric factor (m), K is hydraulic conductivity (m/dt) which is assumed the same as soil permeability, T is common duration of precipitation (min), and R is chamber or well radius (m).

Rainwater harvesting is designed by calculating the availability of water or the volume of rainwater that falls on the roof of a building and is collected in a tank following this equation:

$$V = \alpha \beta A I t \qquad (7)$$

Where V is rainwater volume stored in the tank (m^3), a runoff coefficient, b is rain distribution coefficient, A is the pipe cross section area (m^2), I is rainfall intensity (mm/hour), t is rainfall duration (hour). Rainwater harvested is then utilized for building water needs.

Retention pond is a man-made structure designed to manage and control stormwater runoff in urban areas. A retention pond temporarily holds and stores excess rainwater that cannot be absorbed into the ground due to impervious surfaces like roads and buildings in campus. This helps prevent downstream flooding during heavy rainfall events. The water storage functions effectively during the rainy season. The retention pond is designed by calculating the effective storage capacity and conducting water balance simulations:

$$S_{t+1} - S_t = I + R + L - O \qquad (8)$$

Where S_{t+1} is the pond storage in t+1, S_t is the pond storage in t, I is the inflow, R is the rainfall amount above the pond, L is the water losses, O is outflow.

Prior to the hydrology calculation, it is essential to identify the catchment area of each drainage outlets in the campus. Catchment area delineation helps identify the specific area that contributes stormwater runoff to a particular drainage system. This knowledge is essential for designing sustainable urban drainage components that can effectively manage the volume and flow of stormwater from that catchment area. Some additional key considerations for placing designing sustainable urban drainage components in a green campus are ensuring that the components are designed to blend harmoniously with the campus landscape and placing some SUDS components in highly visible areas to serve as educational tools.

D. Life Cycle Cost

Before calculating the reduction in drainage discharge, the runoff discharge must first be calculated, then to determine the reduction in drainage discharge, a reduction is made between the flood discharge before the presence of the eco-drainage facilities and the additional water reserve discharge after the existence of eco-drainage facilities. To analyze the water conservation planning, the parameters needed for financial calculations namely the construction costs, maintenance costs, depreciation costs, and benefit costs from eco-drainage facilities. These costs must be adjusted with the interest rate. The benefit obtained is water absorption which can be equated with the price of water. Contingency survey is administered to gain campus people perception on the willingness to pay[14] for eco-drainage system to assess the amenity. This refers to the preferences of respondents or their readiness to accept higher living costs or property investments to avoid flooding in the housing area, measured in IDR (Indonesian Rupiah). The questionnaire also addresses inconveniences associated with the presence of such constructions and the required periodic maintenance. The survey aims to gather public opinions on WTP and is conducted among teachers, students, and staff with a sample size of 50 users chosen through simple random sampling. When all these costs have been calculated, the next step is to look for the net present value (NPV) and benefit-cost ratio BCR to find out whether the system is feasible or not.

III. Results and Discussions

A. Green Campus Layout

Figure 3 presents the catchment area and the placement of eco-drainage facilities. The infiltration chamber is placed in the most critical areas where the eco-drainage can have the greatest impact on managing stormwater. Civil Engineering building is a building with the largest roof area of 4361 m^2. Another potential location is Chemical Engineering building with 1250 m^2 area. It is suitable to put the infiltration chamber in this position (red mark). In the city of Malang, infiltration wells have proven to be less effective due to the low permeability of the soil[15]. Therefore, rain water harvesting tanks are coupled with the chambers in this building to enhance their performance. Bio-absorption holes are planned in the inundated area. Series of survey during rainy season reports that workshop area and parking space in Civil Engineering building is frequently flooded in the high intensity rain. The holes (cyan mark) are expected to promote infiltration and diminish the inundation.

Regarding retention pond, leverage existing natural features like depressions and low-lying areas is suitable for its location. Additionally, due to the campus's proximity to the Brantas river stream, positioning the pond in close proximity to the river would have little effect on flood mitigation and water conservation. For that reason, the pond is designed in the flat area in the central park of the campus (yellow mark). Exploring multifunctional of eco-drainage, detention pond in this location could also serve as a recreational area. This pond is potential to conserve the rainwater from at least 5832 m^2 covered by 4 buildings, park, and parking lot (red hatch).

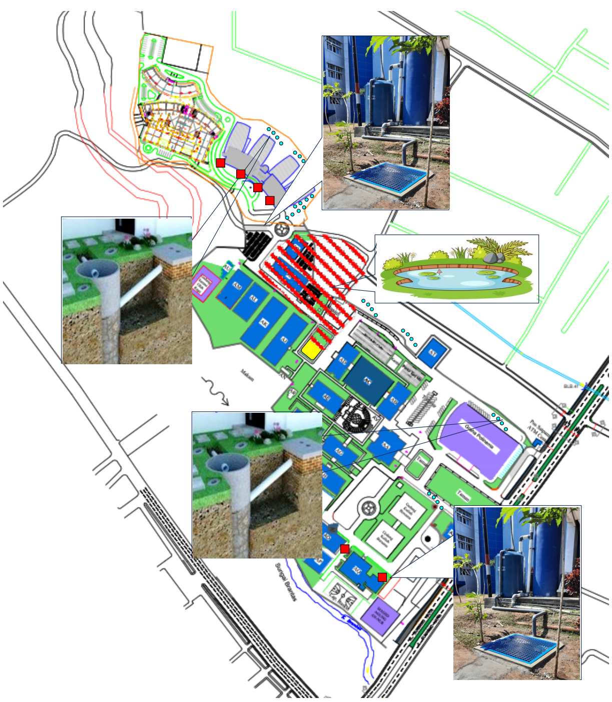

Fig. 3. Placement of Eco-Drainage Facilities

B. Sustainable Drainage Facilities

After rainfall raw data preparation, the calculations revealed that the designed rainfall is would 70.1 mm/day. The runoff coefficient for concrete roof building is 0.9. The common rainfall duration in Malang city is 6 hours. Assuming the rainfall time distribution pattern is linear, the maximum hourly rainfall is 38.6 mm/hour. Considering the landscape practice, the tank is put only 4 in 1 building. Therefore, not all rainwater would be completely stored in the tank. The overflowed water would the inflow of infiltration chamber. Frontage of Civil Engineering building (812 m^2) requires 75 m^3 water tank to save all stormwater in 1 day during rainy season. Meanwhile, the required clean water for school building is 10 l/student/day in average or equals to 20 m^3/day. Thus, the water tank could serve the demand for clean water during the wet season.

By calculating the concentration time of Civil Engineering building canal, the designed flood is found to be 0.011 m^3/s. The required chamber is 1 m diameter and 0.5 m height. The rate of infiltrated inflow is 0.003 m^3/s and the fulfillment time is 18.55 second. As for the bio-absorption holes, the designated area is Civil Engineering parking lots covered with concrete block with the area of 1656 m^2. Using the similar formulation, the absorbed stormwater for single hole is 0.0008 m^3/s. It requires 51-unit holes for completely drain up the stormwater. The hydrology procedure value is calculated in the same manner on identical facilities in other building.

The catchment area of retention pond is 5359 m^2. It results in 0.106 m3/s discharge as the inflow of the retention pond. The pond dimension is 5.5 x 5.5 x 3 m constructed from the earth material. The water balance analysis shows that the pond in saturated condition could be overflow in 10 minutes. Multiplying the infiltration rate and the area of pond bed resulting 0.00006 m3/s infiltrated water in average.

C. Benefit of Sustainable Drainage

The intangible benefit of the sustainable drainage is counted by the amenity score. The average of the WTP is IDR 399,000 suggests that, on average, campus people are willing to invest or pay this amount to implement inundation countermeasures and mitigate the risk of flooding in the campus area. This finding demonstrates a willingness among the surveyed population to incur additional costs for avoiding the inconveniences and potential damages associated with flooding. It also highlights the importance of flood mitigation efforts in the campus.

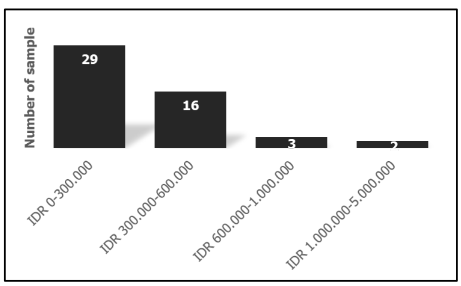

Fig. 4. Willingness to Pay For Zero-Runoff Campus (IDR)

The technical benefit of zero-runoff system is the reduction of runoff from the eco-drainage systems. The results of hydrological analysis are presented in Table 1. Further calculation shows that the rate of flood reduction is 51.8%. This insignificant value is due to less permeable ground conditions as common soil type in Malang area. Prior studies that have noted the similar results[15]. With the clean water price in Malang for public office from water authority is IDR 6500/m3, then reuse of stored water in the rainwater harvesting tank would contribute to the monetary benefit of water resources.

Table 1 Hydrological Analysis of Eco-Drainage

Source	Number	Volume (m3/s)	Volume (m3/year)
Runoff from buildings	2	0.021	667,761
Runoff from parking and green space	2	0.083	2,620,969
Runoff from central catchment	1	0.106	3,343,996
Infiltrated water from chamber	4	0.026	813,392

Infiltrated water from hole	101	0.083	2,620,969
Infiltrated water from pond	1	0.0001	1,908

D. Life-Cycle Cost Analysis

The cost of the construction is calculated for making retention pond, rainwater harvesting tank, infiltration chamber, and bio-absorption hole. The results are provided in Table 2. The operational and maintenance cost is assumed 10% of the investment cost and occurs annually. The depreciation cost follows straight line method without residual value. The economic life of the investment is 10 years. In Figure 5, the cash flow of financial feasibility study is shown. The study reveals that the investment in sustainable drainage systems would give direct benefit of reuse the water from rainwater harvesting i.e. IDR 24,124,000 per year.

Table 2 Construction Cost

Source	Vol	Unit	Unit price	Price
Infiltration chamber	4	Unit	1,868,344	7,473,375
Bio-absorption hole	101	Unit	20,250	2,045,250
Retention pond	1	Unit	31,053,640	31,053,640
Rainwater harvesting tank	4	Unit	6,217,873	24,871,493
TOTAL				**65,443,758**

These findings suggest that the project is financially viable and offers a positive return on investment. The NPV of IDR 78,267,092 indicates that the project's benefits, when discounted to present value, exceed the initial investment, further affirming its economic feasibility. Moreover, the B/C ratio of 1.99 means that for every unit of investment, the project generates nearly double the benefits, underscoring its potential profitability. This demonstrates the attractiveness of the proposed drainage system from a financial perspective, making it a sound choice for implementation in the campus.

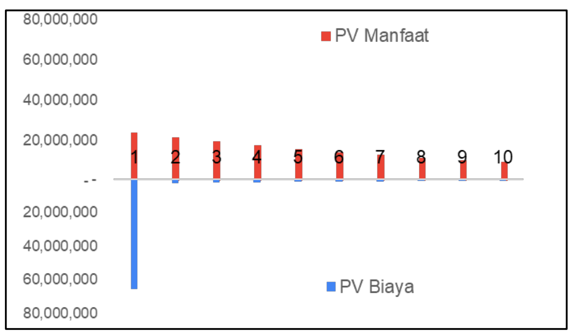

Fig. 5. Cash Flow (IDR)

IV. Conclusions

The concept of a green campus signifies a committed effort to establish environmentally responsible campus infrastructure. A sustainable campus integrates inventive solutions aimed at enhancing energy efficiency, minimizing waste, and conserving natural resources. In the context of sustainable development, there has been a shift in the approach to drainage, moving away from rapid stormwater removal to sustainable designs that enable water conservation through cost-effective solutions. This study presents an evaluation of a sustainable drainage system implemented in a medium-sized campus in Malang, Indonesia. The water conservation system includes various drainage facilities such as retention ponds, infiltration chambers, rainwater harvesting, and bio-absorption holes. Decisions regarding these facilities are based on criteria related to reducing runoff, promoting water infiltration, and extending flood time concentration while considering the life-cycle costs of the system. The analysis results indicate that the proposed drainage system is both hydrologically and financially viable in terms of reducing runoff.

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