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Pengembangan Embung untuk Penyediaan Air Pabrik Kelapa Sawit Berbasis Soil Water Assessment Tools

Embung Development for Palm Oil Industry Water Supply Based on Soil Water Assessment Tools

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Abstract

The water supply at the IPB Education and Research Garden Jonggol is generally sourced from rainfall. This can lead to water shortage during certain periods, so building a water storage structure such as a small reservoir (embung) is necessary. The embung can provide a more stable water supply by storing rainwater and river inflow. This research aims to design an embung at the IPB Education and Research Garden Jonggol, and to analyze the water balance of the planned embung. This study presents the application of SWAT-based dependable discharge analysis for small-scale industrial reservoirs in tropical regions. The findings support sustainable water management and enhance enhance agro-industrial resilience, particularly in regions dependent on rainfall. The planned embung is designed for the palm oil processing plant with a total water requirement of 8,786 m^3 in the dry season. Dependable discharge analysis is conducted using Soil Water Assessment Tool (SWAT), while flood discharge analysis uses the rational method. Embung capacity design is based on water availability, water requirement, sediment volume, and total evaporation. The planned embung will be located at coordinates 107° 2' 10.53" E and 6° 28' 17.60" S. It features a normal water surface area of 7,737.19 m^2, a normal water depth of 3 m, and a total storage volume of 9,947.76 m^3. The design includes essential components such as an overflow channel, an outlet channel, and an embankment. The water balance indicates that the embung will begin filling in February and remain full from March to May. Subsequently, the water balance is expected to repeat its cycle consistently, ensuring that the embung can meet the water demand at the location.

Keywords: *dependable flow, embung design, palm oil, rainwater harvesting, SWAT*

Abstrak

Kebutuhan air di Kebun Penelitian dan Pendidikan IPB Jonggol pada umumnya dipenuhi dari air hujan. Hal ini dapat menyebabkan kekurangan air pada periode tertentu, sehingga diperlukan pembangunan struktur penyimpanan air seperti embung. Embung dapat menyediakan pasokan air yang lebih stabil dengan menyimpan air hasil pemanenan air hujan dan aliran sungai. Penelitian ini bertujuan untuk merancang embung pada Kebun Penelitian dan Pendidikan IPB Jonggol serta menganalisis neraca air embung yang direncanakan. Penelitian ini menerapkan analisis debit andalan berbasis SWAT untuk embung industri skala kecil di wilayah tropis. Temuan penelitian ini mendukung pengelolaan air yang berkelanjutan dan meningkatkan ketahanan agroindustri, terutama di wilayah yang bergantung pada curah hujan. Embung yang direncanakan ditujukan bagi pabrik pengolahan kelapa sawit dengan total kebutuhan air sebesar 8.786 m^3 selama musim kemarau. Analisis debit andalan dilakukan menggunakan Soil Water Assessment Tool (SWAT), sedangkan analisis debit banjir dengan metode rasional. Perhitungan kapasitas embung sebagai cadangan air permukaan didasarkan pada ketersediaan air, kebutuhan air, volume sedimen, serta total penguapan. Embung direncanakan berlokasi pada koordinat 107° 2' 10,53" BT dan 6° 28' 17,60" LS dengan luas permukaan muka air normal sebesar 7.737,19 m^2, kedalaman muka air normal 3 m serta volume tampungan sebesar 9.947,76 m^3. Desain embung meliputi saluran pelimpah, saluran keluaran, dan tanggul. Neraca air menunjukkan bahwa embung akan mulai terisi bulan Februari dan penuh mulai bulan Maret hingga Mei. Setelah itu, siklus ketersediaan air akan berulang secara konsisten sehingga embung mampu memenuhi kebutuhan air pada lokasi.

Kata Kunci*: debit andalan, desain embung, kelapa sawit, pemanenan air hujan SWAT*

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INTRODUCTION

In the IPB Jonggol Education and Research Garden area, as shown in Figure 2 ongoing periodic development is taking place, including the construction of livestock, plantation, and industrial areas. The Education and Research Garden of IPB in Jonggol covers an area of 268.66 hectares (Pejabat Pengelola Informasi dan Dokumentasi IPB, 2023). This area is divided into two blocks: the western block is used for livestock, and the eastern block is used for cassava, fruit, and oil palm plantations. Development in an area will inevitably increase its water needs (Heidari et al., 2021). The water supply for these needs is sourced from rainfall, both directly collected as rainwater and as runoff. One sector that requires a significant amount of water in the IPB Jonggol Education and Research Garden is the industrial sector, specifically the palm oil processing plant. This plant requires 40 m^3/day of water to produce 40 tons/day of crude palm oil. Additionally, the dry season in this area can last from 3-5 months (Badan Pusat Statistik Kabupaten Bogor, 2023).

The effect of relying solely on rainfall is the possibility of water shortage during certain period, so building water structures such as small dams or embungs is necessary (Wang et al., 2025). An Embung is a pond-shaped structure that can provide a more stable water supply by harvested rainwater and by utilizing river flow (Ananda et al., 2023; Kementerian Pertanian, 2020). Several studies, such as those conducted by Pandjaitan et al., (2022), have shown that embung can enhance water availability through rainwater harvesting techniques. Embung is also significantly effective in preventing a decline of the groundwater level during the irrigation season (Park et al., 2022). According to Gayuh & Mayasari (2021), an embung with dimensions of 300 x 200 x 4 meters can supply irrigation water for 183.6 ha of horticultural crops in Desa Karangsambigalih. Furthermore, embung that obtain water through rainfall harvesting are relatively cleaner and more suitable for domestic needs (Tenebe et al., 2022).

The use of embung to meet water needs has already been implemented in the IPB Jonggol Education and Research Garden, both in the west and east blocks. However, the embungs in the east block are considered less optimal in meeting the water needs of the palm oil processing plant in the area. Of the five embungs built in the east block, only three are functioning, while the remaining two are non-functional due to leaks and inability to store water. The total capacity of the three functional embungs is 1,847.5 m^3. The dry conditions of the embung were caused by broken embankments and water gates, and several embungs have been planted with trees, which means they needed rearrangement (Badan Pengembangan Kampus Berkelanjutan IPB, 2023).

In the event of a drought during the dry season, these existing embungs can only meet the water needs of the palm oil processing plant for 1-2 months, after which a water shortage will occur. The embung is considered functioning optimally if it can fulfill its purpose, which is to meet the water needs of the palm oil processing plant during the dry season. This can be achieved by calculating the optimum storage volume based on water requirement and water availability (Andawayanti et al., 2020).

Given the increasing water demand due to ongoing development in the IPB Jonggol Education and Research Garden as well as the limited reliability of rainfall as the primary water source, this study aims to design an optimized embung system to ensure water availability for the palm oil processing plant during the dry season. The research analyzes water balance, storage capacity, and operational feasibility to improve the efficiency of existing facilities and support sustainable water resource management in the site. Therefore, the objective of this study is to design an embung and analyse its water balance using SWAT to ensure a reliable water supply for palm oil processing.

METHODS

The research was conducted from December 2023 to August 2024 at the IPB Jonggol Education and Research Garden, specifically in the East Block. Data processing and analysis were carried out at the Department of Civil and Environmental Engineering, Faculty of Agricultural Technology, IPB University. The study utilized both primary and secondary data processed using several analytical tools. Microsoft Excel was used for numerical data processing, ArcGIS for spatial analysis of satellite imagery, and AutoCAD 2020 for drafting the technical design of the embung. The data collected comprised Digital Elevation Model (DEM) data from the Badan Informasi Geospasial (BIG) website, landuse maps from Badan Pengembangan Kampus Berkelanjutan (BPKB), soil type maps from Balai Besar Sumberdaya Lahan Pertanian (BBSDLP), and climate data from Badan Meteorologi Klimatologi dan Geofisika (BMKG).

The research procedure is illustrated in Figure 1. The research process consisted of four main stages: literature review, data collection, data processing, and report drafting. Data processing involved three analyses: (1) embung site selection,

(2) hydrological analysis, and (3) capacity and design analysis. Site selection considered soil characteristics, topography, land cover, proximity to water sources, and accessibility to the service area. The hydrological analysis comprised reliable discharge and flood discharge. Reliable discharge was analyzed using the SWAT plugin in QGIS, while flood discharge was analyzed using the Rational Method.

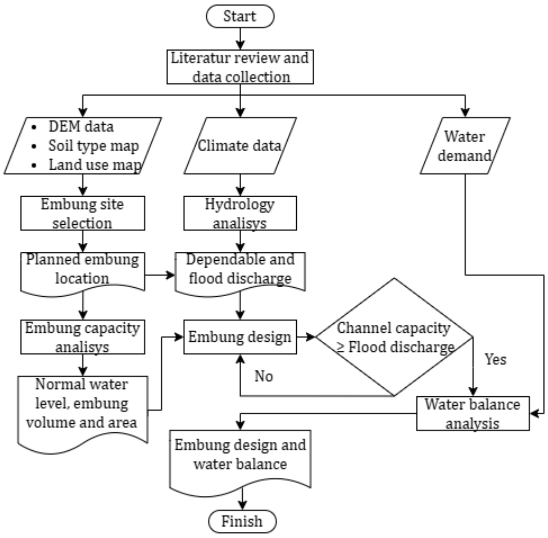

Figure 1 Flow diagram for this research

The water balance analysis was based on water availability, water requirement, sediment storage, evaporation volume, and infiltration rate. The water balance was calculated from the difference between water availability at the study site and the water requirement (Niu et al., 2025). The embung design was based on the topographic shape, which is basin-like, and the existing conditions. The embung design was created using AutoCAD 2020, producing 2-D design drawings.

RESULTS AND DISCUSSIONS

Research Location

Land cover in the IPB Jonggol Garden is dominated by open land covering 202.94 ha and oil palm plantations covering 57.34 ha. In addition, there are fruit plantations covering 2.92 ha, embung covering 2.87 ha, cassava plantations covering 1.45 ha, and several supporting buildings covering 1.13 ha. The access roads are mostly unpaved. The topography of the Education and Research Garden of IPB in Jonggol is undulating, forming hills, basins, and valleys. The elevation of the research area ranges from 60 to 130 meters above mean sea level (mamsl), while the land slope varies from gentle (8-15%) to steep (up to 40%). Geologically, the soil is predominantly latosol. According to Subardja et al. (2016), latosol soils develop from volcanic material, have clay content ≥ 40%, feature a crumbly and loose homogeneous structure, and have a deep soil profile. This soil type also has very low infiltration and high runoff potential (Sifundza & Beckedahl, 2025).

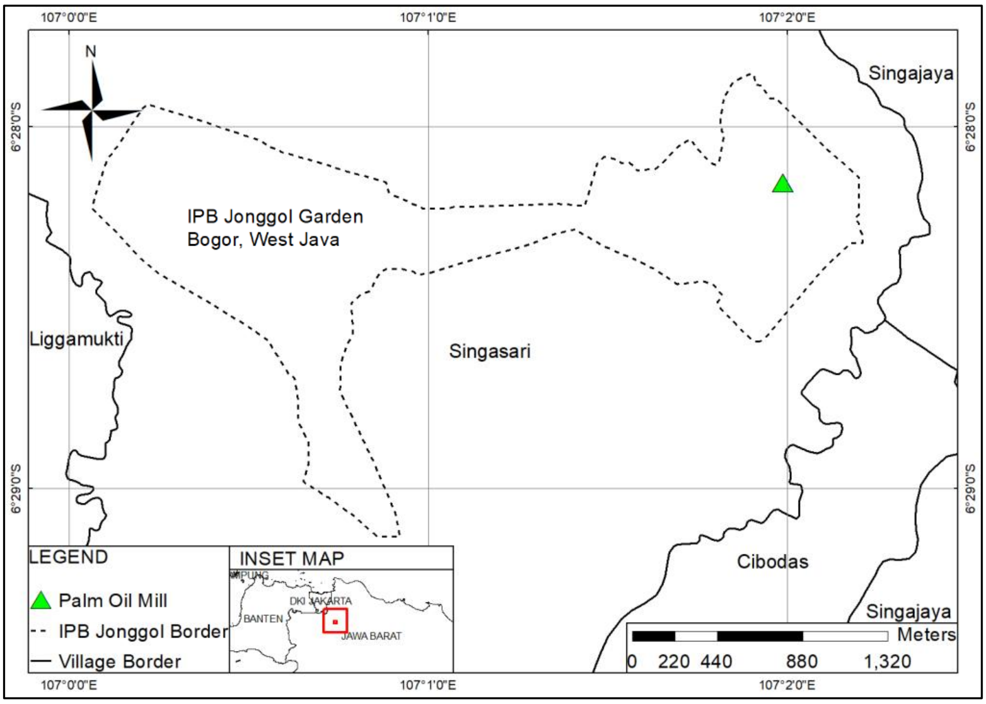

Figure 2 Location of the Education and Research Garden of IPB in Jonggol

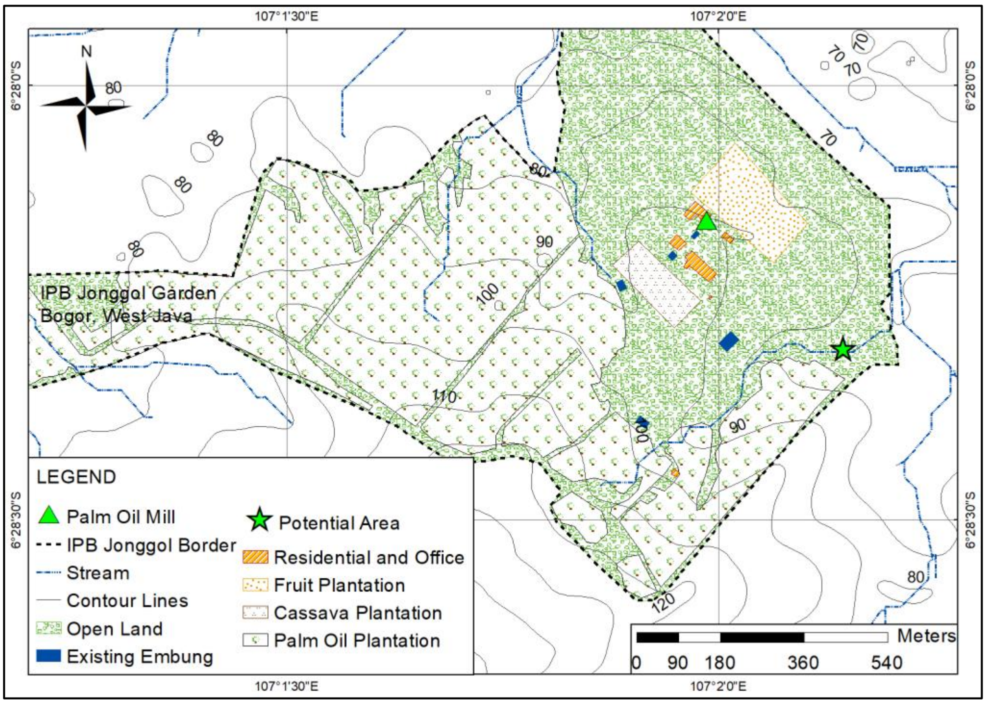

Figure 3 Potential area for embung

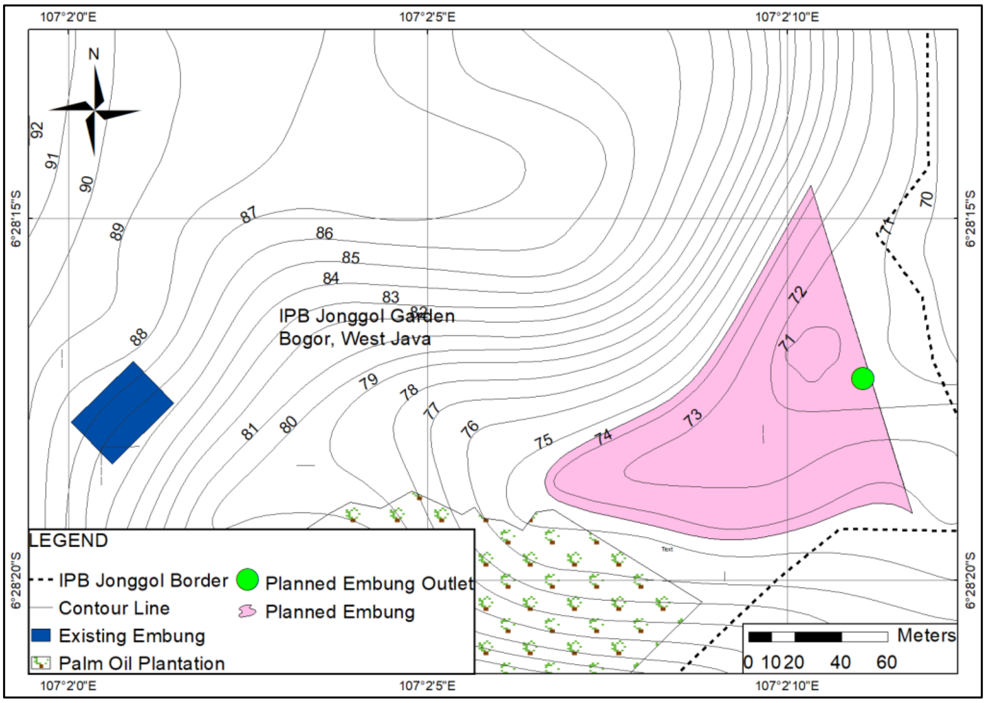

Figure 4 Planned embung locations

Embung construction is feasible across all potential locations due to the uniform latosol soil type. Regarding land cover, vegetation areas are more favorable for rainwater harvesting and planning an embung on open land will also be easier, with minimal disturbance to surrounding land cover (Suni et al., 2023). Topographically, the embung location should ideally be selected within a large basin and low slope area to minimize construction cost (Haddad et al., 2024). Considering access to water sources and distribution, the embung will be more efficient if located near surface runoff paths and close to the palm oil processing plant (Asif et al., 2024; Faisal & Abdaki, 2021). After evaluating these factors, the green star in Figure 3 was identified as the most suitable proposed location for the planned embung. This location is located at 107° 2' 10.53" E and 6° 28' 17.60" S.

Figure 4 illustrates the design of the planned embung, developed based on contour lines at 0.5-meter intervals around the potential embung area. The planned embung is situated in the natural flow path with the lowest elevation at 71 mamsl. This positioning is expected to minimize earthwork and energy requirements for conveying water to the mill due to the elevation difference (Hassan et al., 2025). The potential inundation depth values were calculated from topographic elevation differences, ranging from 71 to 74.5 mamsl.

Embung Capacity

The water requirement at this location is intended for the palm oil processing plant. The plant consumes approximately 1 m^3 of water per ton of processed palm oil. With a production target of 40 tons per day, the water requirement amounts to 40 m^3 per day. This demand is critical during the dry season, which typically lasts approximately five months based on regional climatological data, requiring a total of 6,120 m^3. After determining the total water requirement, sediment accumulation and evaporation losses were estimated using standard volumetric and climatological approaches (306 m^3 and 2,717 m^3, respectively). Therefore, the total reservoir capacity required is 9,143.76 m^3.

The results of the inundation potential analysis for the embung are detailed in Table 1. The embung capacity was selected based on the volume that most closely matched and meets the requirements. Consequently, the highest elevation of the embung was set at 74 mamsl, with a storage capacity of 9,947.76 m^3. A depth of 3 meters was established as the normal water level of the embung. The 74 mamsl elevation was designated as the spillway crest level, which is designed to safely discharge excess inflow beyond the storage capacity.

Table 1 Potential area and volume of inundation at each elevation change

No	Elevation (mamsl)	Surface Area (m^2)	Volume (m^3)
1	71.0	416.35	0.00
2	71.5	829.91	305.68
3	72.0	1,769.49	940.88
4	72.5	2,448.95	1,990.90
5	73.0	4,788.03	3,767.78
6	73.5	6,126.72	6,489.60
7	74.0	7,737.19	9,947.76
8	74.5	8,115.95	13,910.66

Hydrology Conditions

The hydrological analysis commenced with delineation of the contributing catchment area for the planned embung. The input data for this delineation included the DEMNAS (Indonesia National DEM, 8.25–arcsecond resolution) and designated outlet points of the planned embung site. The results of the catchment delineation at the planned embung site are shown in Figure 4. The catchment area map indicates the catchment area for the planned embung, which is 37.35 hectares.

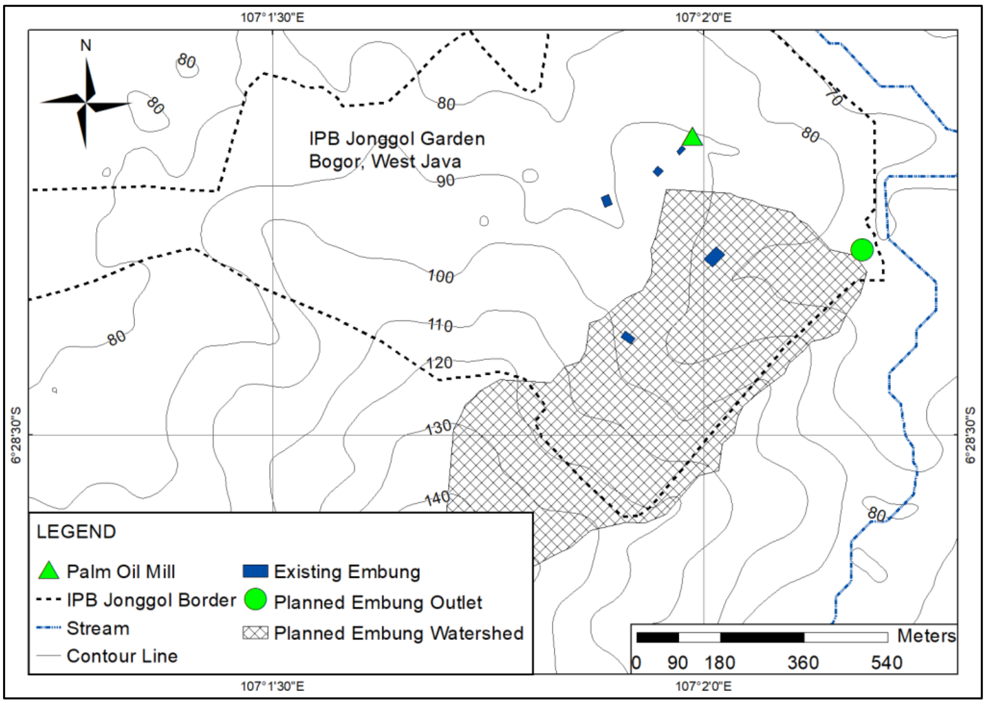

Figure 5 The catchment area for embung location

Table 2 Flood discharge using rational method

No	Return Period (year)	Rainfall (mm)	Concentration Time (hour)	Rainfall Intensity (mm/hour)	Overflow Coefficient	Catchment Area (km²)	Flood Discharge (m³/s)
1	2	91.56	1.84	21.14	0.40	0.373	0.877
2	5	120.47	1.84	27.82	0.40	0.373	1.155
3	10	142.92	1.84	33.01	0.40	0.373	1.370
4	25	175.19	1.84	40.46	0.40	0.373	1.679
5	50	202.41	1.84	46.74	0.40	0.373	1.940

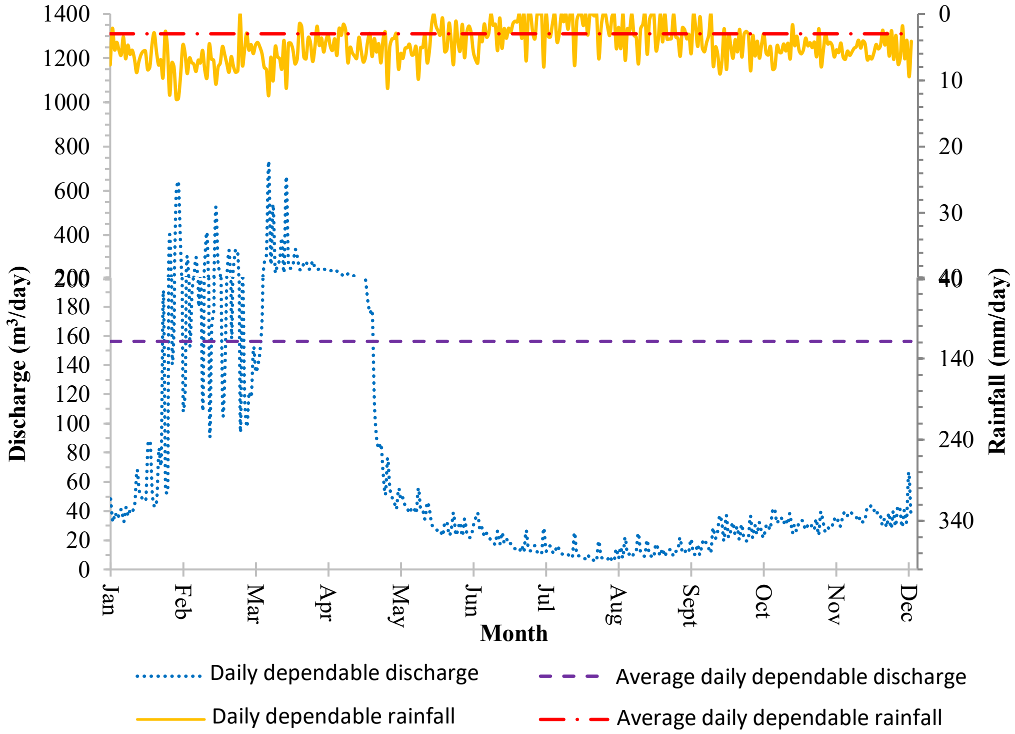

Figure 6 Daily dependable discharge SWAT simulation results

Rainfall data were obtained from the nearest station, Klapanunggal (BMKG), which provided daily maximum rainfall records from 2002–2021. The distribution method applied was the Log Pearson Type III, with 2, 5, 10, 25, and 50-year return periods. Design flood discharge was then estimated using the rational method. The results are presented in **Error! Reference source not found.**. According to Pusat Pendidikan dan Pelatihan Sumber Daya Air dan Konstruksi (2017a), the spillway design is typically based on 25-year return period. Therefore, the design flood discharge was determined to be 1.679 m^3/s.

Dependable discharge was analyzed using the SWAT plugin in QGIS. SWAT was selected due to its water balance-based approach, enabling simulation of discharge, erosion, and sediment transport (Wang et al., 2024). The analysis was conducted in several stages: delineation of the catchment area, identification of hydrological response units (HRU), climate data input, and simulation. The catchment delineation process follows the same procedure used to obtain the previous catchment map. HRU analysis identified 166 units using a 0% threshold for land cover, soil type, and slope classification.

The climate data used for the simulation includes daily data from Klapanunggal Station, covering a period from 2002 to 2021. This 20-year dataset was used to calculate the dependability, specifically an 80% probability using the Log-Pearson Type III method. The potential dependable discharge was simulated on a daily basis for 2025–2026. Figure 5 displays the results of the SWAT simulation for reliable discharge at the planned site with an average reliable discharge of 156.27 m^3/day. The maximum reliable discharge recorded was 735 m^3/day on March 13, 2025, while the minimum was 5.8 m^3/day on August 10, 2025.

During the dry season, the embung receives a relatively low amount of water from July to September. In contrast, between October and January, the incoming water volume increases significantly. The estimated reliable discharge flowing into the embung reaches 31,110.32 m^3 per year. Calibration and validation were not carried out due to the absence of observed discharge data. To mitigate this limitation, model inputs such as land cover, vegetation, soil, and climate parameters were aligned with field observations to ensure representativeness.

Embung Design

The embung design utilizes the natural soil depression, which is 71 to 74.5 mamsl. An embankment will be constructed at the outlet point to retain water within the embung. The planned embung covers an area of 8,115.95 m^2, with a normal water surface area of 7,737.19 m^2 and a normal water depth of 3 meters. Classified as a medium-sized embung, it has a storage capacity of 9,947.76 m^3. The embung structure includes an overflow, outlet, and embankment. A geomembrane layer will be installed at the embung base to prevent water seepage. The results of the embung design are shown in Figure 7.

The embankment slope is designed to ensure stability against potential landslides. It is constructed as a fill-type embankment, utilizing soil sourced from the vicinity of the proposed embung site. According to regulations from the Pusat Pendidikan dan Pelatihan Sumber Daya Air dan Konstruksi (2017b), the maximum height of the embankment is 10 m, and the minimum height must exceed the normal water level by at least 0.5 meters. Consequently, the embankment is designed with a height of 3.5 meters and a width of 2 meters. Additionally, the foundation will be constructed to a depth of 0.5 meters and a width of 5 meters. The length of the embankment is 138.6 m, which is adjusted to in the embung construction process. Cross-section lines of the embankment are labeled T1 and T2, shown in Figure 8, with the detailed cross-section for embankment T2 illustrated in Figure 9.

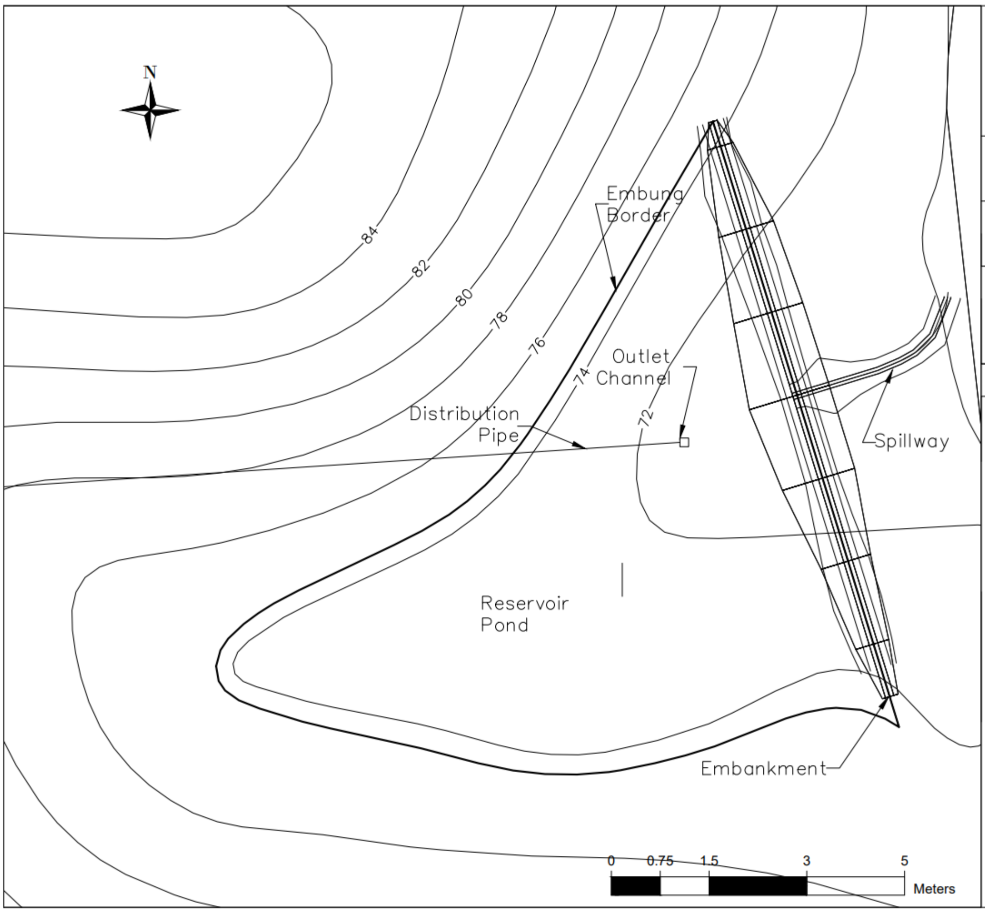

Figure 7 Embung design layout

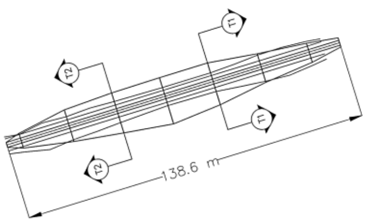

Figure 8 Top view of embankment design

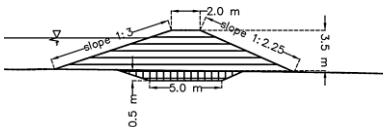

Figure 9 Cross-section of embankment design (T2-T2)

Embankments with a homogeneous type must consider the slope gradient. The slope gradient is the ratio between vertical and horizontal dimensions of the slope. It typically ranges from 2:1 to 3:1 depending on soil characteristics (Salmasi et al., 2020). Homogeneous embankments constructed using fat clay, lean clay, clayey sand, clayey gravel, silty gravel, and silty sand generally use a 1:3 ratio for the upstream slope and a 1:2.25 ratio for the downstream slope (Pusat Penelitian dan Pengembangan Sumber Daya Air, 2013). The embankment slope is formed by following the reference to be stable enough against the possibility of landslides. The upstream slope is designed gentler than that of the downstream slope to withstand hydrostatic pressure from the reservoir water exerted by stored water.

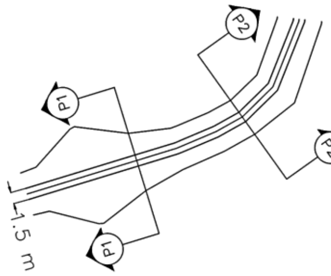

Figure 10 Top view of spillway design

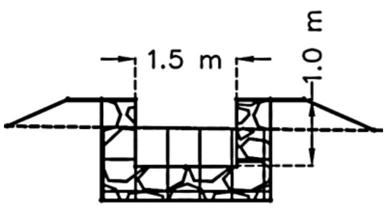

Figure 11 Cross-section of spillway design (P2-P2)

The design of the spillway channel is based on the computed flood discharge. Using the rational method, the design flood discharge for a 25-year return period was determined to be 1.679 m^3/s. The spillway channel's inlet point was set at an elevation of 74 m amsl to direct excess water away from the embung. The channel cross-section is a rectangle, constructed using river stone materials. This design helps minimize sediment transport. Detailed specifications can be found in

Figure 10, including cross-section lines of the spillway channel marked P1 and P2 in Figure 11.

According to the Kementrian Pekerjaan Umum dan Perumahan Rakyat (2018), the minimum freeboard is 0.5 m, with a slope of 1:1. The channel is designed with a freeboard height of 0.5 meters, resulting in a total channel height of 1 meter. The channel is rectangular with a planned width of 1.5 m. The channel is designed to accommodate a water discharge of 2.33 m^3/s, which is higher than the calculated flood discharge of 1.679 m^3/s. This ensures that the channel can safely manage floodwaters.

Water Balance Condition

The water balance analysis aimed to evaluate the ability of the embung to meet operational water demand throughout the hydrological year. The water balance is determined by calculating the difference between inflow and outflow, and storage. The inflow was derived from the reliable daily discharge entering the embung, while the outflow consisted of water withdrawal, sediment storage, and evaporation losses. Sedimentation was assumed as 5% of the reliable daily discharge entering the embung, while evaporation was calculated based on evapotranspiration at the embung surface. The initial storage assumed that the embung was empty initially.

The fluctuations of the embung water balance, as shown in Figure 11, indicate that the embung would start filling in February and be full from March to May. After that, the water balance would repeat a cycle consistently so that the embung can satisfy the required water demand. The storage increases when the inflow exceeds the water requirement from February to May. The reliable inflow entering the embung is 31,110.32 m^3 per year. However, this entire volume cannot be stored due to the embung's capacity limit of 9,947.76 m^3, resulting in excess water flowing through the spillway. This overflow, estimated at 9,910.51 m^3 per year, is essential to maintain the local ecosystem-health. The water storage elevation in the embung would fluctuate in response to the amount of water stored.

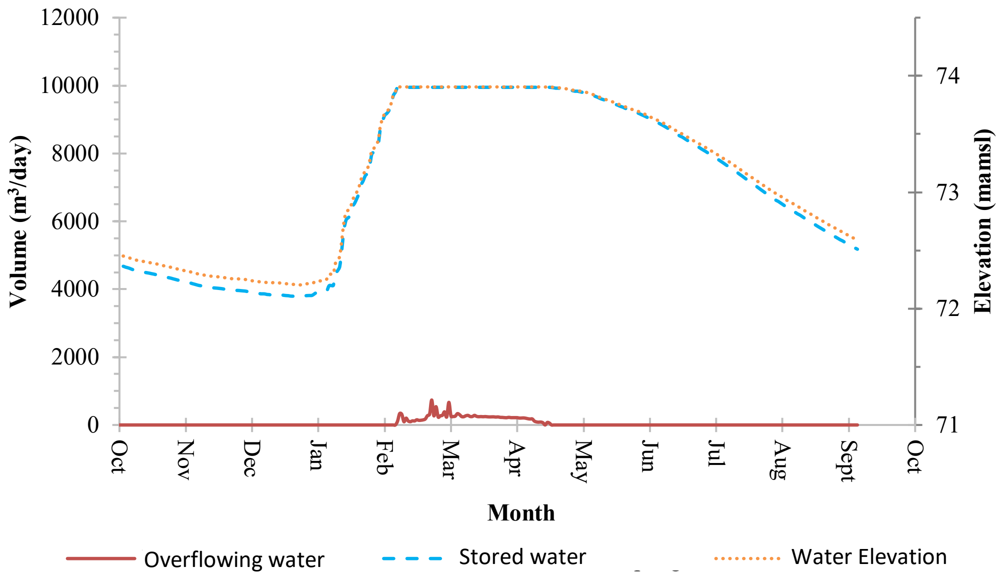

Figure 11 The fluctuation of water volume

CONCLUSIONS

The planned embung is located at coordinates 107° 2' 10.53" E and 6° 28' 17.60" S. The structure has a normal water surface area of 7,737.19 m^2, a normal water level depth of 3 meters, and a total storage capacity of 9,947.76 m^3. These design parameters are determined based on contour analysis and inundation potential mapping of the site. The embung design incorporates essential components, including an overflow channel, an outlet channel, and an earthen embankment constructed following medium-sized embung standards.

A monthly water balance simulation indicates that the embung starts filling in February and reached full capacity form March to May. During this period, excess water flows out through the spillway. The storage volume is sufficient to meet the dry-season water demand of approximately 8,786 m^3 for the palm oil processing plant, indicating that the embung can maintain a stable water supply throughout the operational cycle.

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