A Proposed Improvement of Belanti II Tidal Irrigation Scheme, Kalimantan, to Support Leaching of Acid Sulphate Soil Reclamation.

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Abstract. The reclamation process of acid sulphate soil of the Belanti II tidal irrigation scheme remains unfinished. During ebb tide, the upstream acidic drainage water retains and settles in the irrigation canals. During high tide, the acidic water flows back into some parts of the agricultural land and reduces rice productivity. The measured pH is about 2.5 ~ 3.5 and the measured electric conductivity is about 0.25 ~ 0.35 mS/cm. Sedimentation in the middle to the end of the primary, secondary, and collector canals and tidal pond at the upstream end of the primary canal, preventing the leaching process of sulfuric acid soil. Primary canal normalization as an alternative solution to increase the capability of acidity leaching is proposed. Leaching the acidic soil of Belanti II irrigated area of 3.976 ha requires 500 m³/ha/day of freshwater, equivalent to 1.998.000 m³/day. The one-dimensional HEC RAS mathematical model is used to evaluate the hydraulics performance to support the leaching process. The hydraulic analysis was carried out using two tidal cycles on the existing channel and the normalized channel. Channel normalization has succeeded in reducing the water supply deficit to support the leaching process from 39% to 9%.

keywords:

1. Introduction
The development of swamp areas began when local settlers and migrants came spontaneously to exploit the riverbanks and swamps affected by the tides during the 1920s and 1930s for agriculture purposes. They make a channel from the river into the swamp, which is then called handil. This handil serves to reduce inundation and transportation. This development of swampland for agriculture was followed by government-sponsored transmigration of swamp areas in the 1970s and 1980s. A study in 1984 concluded that only some parts are still suitable for development, especially areas with mineral soils. However, other parts of the area consist of thick peat, which is not suitable for development [9].

The development of the tidal swampland in Kalimantan was carried out to support the transmigration program initiated in 1969 through the Tidal Rice Field Development Project (P4S) in the 1970s. In 1995, the Peatland Development Project (PLG) of one million ha for food crop agriculture in Central Kalimantan. The area is located between the Sebangau, Kahayan, Kapuas, Kapuas Murung, and Barito rivers. The area is located in the administrative area of Kapuas Regency and Pulang Pisau Regency. The
PLG area covers the area served by the Kapuas River up to 150 km, the Kahayan River 125 km, and the Barito River 158 km upstream [1,2]. The PLG project started by constructing an irrigation network that cuts through the peat dome and connects the Sebangau River, Kahayan River, Kapuas River, Barito River, and tributaries. The water management system developed in the Ex-PLG Area is planned as a closed water system. The water entering and leaving the water system can be controlled for optimization of the leaching process. This closed water system is equipped with embankments and sluice gates.

The soil in the ex-PLG area is peat soil with varying depths from shallow to very deep (Histosols). The distribution of thick peat (>3 m) is dominant in Block C, partly in Block B and Block A. Because it is less productive and endangers the environment, the thick peat area is then directed as a protected area and needs to be conserved. In addition, acid sulfate soils were found in the working area of the PLG Project, especially in Block D, which is the largest one. The main problem of swampland is the acidity of soil and water due to the oxidation of pyrite and peat. When iron oxide, sulfate ions, and organic matter are reduced, iron sulfide will eventually form pyrite compounds.

Belanti II Scheme is a tidal swamp area located in Pulang Pisau Regency, Central Kalimantan Province, built in the 1980s as part of the Tidal Rice Field Development Project (P4S) and Block D Peatland Development Project (PLG). Currently, Belanti II Scheme is one of the irrigation areas included in the national strategic program. Its been decided by the Ministry of Public Works and Public Housing to support food security programs in Central Kalimantan Province [3].

![Figure 1. Location of Belanti II Scheme [3]](image-url)

The Belanti II Scheme is located between The Kahayan River in the west and the Kapuas River in the east (Figure 1). The source of tidal water comes from the Kahayan River, which enters through primary and handil channels and collector channels at the border area. The Belanti II irrigation network was initially equipped with a tidal pond with an area of 12 ha. Furthermore, Its have a primary canal with a length of 8.70 km and a width of 45 m, 100 secondary channels (41 channels on the right side with a length between 0.40 ~2.70 km and 59 channels on the left with a length between 2.0 ~ 2.80 km), the collector channel is 14.22 km long and 6 m wide, with a width of 5.6 m. The distance between the secondary canals is 200 m serving ± 3976 Ha of irrigation area. The water flow system is a two-way open channel system, where river water flows into the system at high tide and returns to the river at low tide. Since being used until now, there has been a reclamation process. Currently, some of the existing
networks and channels have reduced their function in water management. Many channels are overgrown with shrubs and siltation due to sedimentation, which causes a decrease in water quality and quantity and causes a reduction in agricultural productivity.

This study tries to evaluate the reliability of the canal network in supporting the reclamation process and increasing agricultural productivity. The hydraulic simulation uses HEC-RAS software to simulate the phenomenon of tidal flow and the cumulative volume of water entering the primary channel to dilute toxic materials.

2. Material and Methods
Poor water management, stagnant water conditions, and the behaviors of acid sulphate soils are the main problems in the Ex-PLG area. The problem of unfavorable water and soil quality dominates all aspects. The development of tidal land requires a comprehensive approach strategy in its management. An essential strategy in land and water management in swamps (affected by tides) is the ability of water management infrastructure to maintain proper water and soil quality through drainage, flushing, and controlled removal of acids and toxic materials (leaching). Good soil drainage will promote soil ripening, preventing persistent anaerobic conditions, and stimulate oxidation and loss of organic matter. If soil maturation has not been completed, it is necessary to have good drainage. Good drainage is essential to control the decrease in groundwater level during the dry season, flushing channels during high tides, acid and toxic leaching in the rainy season [4,5,6].

Most of the reclaimed tidal marshes have more or less matured in the early stages. Although in the second stage, there were some changes in physical and chemical properties, which among other things, depended on the type of water management in the area. After reclamation, the tidal swampland undergoes a maturation process. Soil maturation occurs due to a reduction in water content and pore volume (increase in bulk density), a reduction in organic matter content, and changes in soil structure and exchangeable cations. The high permeability in raw soils makes it difficult to maintain a waterlogged layer.

In contrast, proper submergence of the soil is impossible. Most of the clay soils in the tidal lowlands contain pyrite or sulfuric acid soil material at some depth below the surface. As long as this pyritic material remains submerged, it does not pose a danger to plants. After reclamation and better drainage, this pyritic material begins to oxidize, causing low pH and high Fe 2+ and Al 3+ toxicity [7].

![Figure 2. Soil type. [3]](image)

The result from the soil survey shows that the surface area of agricultural land is 3976 ha (Figure 2). It consists of pyrite mineral soil (shallow pyrite) of 12.5%, non-pyrite mineral (pyrite below 100 cm) of 72.5%, thin peat soil of 3.3%, and peat soil of 11.7%. Figure 3 shows the peat thickness area. Which
consists of the area has a thickness of $<15$ cm is 85.1%, the area with a thickness of $15~50$ cm is 3.3%,
the area with a thickness of $50~100$ is 7.6%, and the area with a thickness of $>100$ cm is 4%.

**Figure 3.** Peat soil depth. [3]

Rapid soil testing in the survey area was carried out using peroxide ($H_2O_2; 20\%$), which identified the
danger of sulfidic materials (pyrite) at a depth of less than 100 cm below the soil surface. Figure 4 shows
that the depth of pyrite $>100$ cm has an area of 87.4%, a depth of $75~100$ cm with an area of 9.4%, and
a depth of $50~75$ cm with an area of 3.1%.

**Figure 4.** Acid sulphate soil depth. [3]

Based on the type of land unit, is divided into three criteria, namely 95.1% land unit type I, 4% land
unit type VI, and 0.9% land unit type IX. The area and criteria for each land unit can be seen in Figure
5.

2.1. Water management.
A two-way channel system that allows a supply of fresh water at high tide and drainage at low tide was
introduced by Gadjah Mada University in the early 1970s. This system is to overcome the leaching
process of sulfuric acid soil. This channel system is equipped with a tidal pond at the end of the channel, which is used to maintain the flow and store the acid suspension pushed back by the backflow at high tide [5]. Like other tidal swamp Schemes, the Belanti II Scheme also has a tidal pond at the end of the channel. The results of field observations found that the tidal pond at the end of the primary channel was no longer functioning due to sedimentation and was overgrown with shrubs, the middle of the primary channel to the end of the channel, the secondary channel, and the collector channel were silting up, thus hampering the leaching and reclamation of sulfuric acid soil. The leaching of acid sulfate soil carried by rain runoff and drainage water during low tide is partially retained and settles in the channel. Some acidic water is pushed back into agricultural land during high tide and poisons crops in downstream irrigated areas leading to a decline in rice productivity. This situation explains that the volume of fresh water at high tide is not enough to dilute the acidity in the channel. Water quality with pH 2.5 ~ 3.5 and salinity 0.25 ~ 0.35 mS/cm was found in the middle to the end of the channel. The efficiency of reclamation measures is determined based on water management balances, including maximum pollution coefficients estimation [8].

Figure 5. Type of land unit [3]

Instantaneous quality measurements confirmed this phenomenon in the primary channel (Table 1). The water quality measurements show a pH of 4.10 and an EC salinity of 0.02 mS/cm (low) in the Kahayan River, generally fresh water in the river has a pH > 5.50. This condition explains that acidic water can come out up to the Kahayan River. The water quality in the downstream irrigation area has a pH of 3.41-4.10 and an EC salinity of 0.03-0.25 mS/cm. The lowest pH occurs at the end of the right secondary channel 5, with a 50-75 cm pyrite layer depth. In different conditions in the middle irrigation area, the water quality has a pH of 2.55-3.69 (low) and an EC salinity of 0.13-0.35 mS/cm. This condition is due to sedimentation in the primary canal, which dampens the propagation of tidal flow and disrupts drainage. Meanwhile, the tip of the irrigation area that receives fresh water supply from another river (Terusan Tengah River) has better quality pH of 3.98-4.01 and EC salinity of 0.12-0.16 mS/cm.

2.2. Proposed improvement
Water management in swamp irrigation networks must fulfill at least four objectives, first is drainage of excess water during the rainy season, second is to provide irrigation water, third is to provide sufficient water for leaching and dilution of acid water, and fourth is to maintain the potency of sulfuric acid soil under flooded conditions to avoid excessive oxidation [9].
Table 1. Water quality measurements.

| River/Channel                  | pH   | EC (mS/cm) | Information                  |
|--------------------------------|------|------------|------------------------------|
| Kahayan River                  | 4.10 | 0.02       | Downstream Irrigation Area   |
| Handil                          | 4.14 | 0.03       | Downstream Irrigation Area   |
| Primary Channel Downstream     | 4.10 | 0.03       | Downstream Irrigation Area   |
| Collector Channel Downstream   | 4.00 | 0.03       | Downstream Irrigation Area   |
| Right Secondary Channel 3      | 3.98 | 0.04       | Downstream Irrigation Area   |
| Right Secondary Channel 5      | 3.41 | 0.25       | Downstream Irrigation Area   |
| Left Secondary Channel 9       | 3.47 | 0.08       | Downstream Irrigation Area   |
| Primary Channel Middle         | 3.54 | 0.13       | Middle Irrigation Area       |
| Collector Channel Middle       | 2.55 | 0.35       | Middle Irrigation Area       |
| Left Secondary Channel 20      | 3.33 | 0.25       | Middle Irrigation Area       |
| Right Secondary Channel 28     | 3.69 | 0.14       | Middle Irrigation Area       |
| Collector Channel Upstream     | 4.01 | 0.16       | Upstream Irrigation Area     |
| Primary Channel Upstream       | 4.40 | 0.12       | Upstream Irrigation Area     |
| Left Secondary Channel 56      | 3.98 | 0.16       | Upstream Irrigation Area     |
| Right Secondary Channel 38     | 3.24 | 0.12       | Upstream Irrigation Area     |

The results of a survey in 2021 on the Belanti II scheme show that after decades of reclamation, layers of pyrite at a depth of 0.50-1.0 m below the ground surface are still found in several places. The acidity of the water in the channel (pH) is around 2.55-4.40, indicating that pyrite oxidation continues. It is expected to improve proper water management to avoid excessive oxidation. Freshwater during high tides and rainwater are needed to meet the needs of irrigation water and the leaching of acid water in the channels resulting from pyrite oxidation. To overcome this, it is proposed to improve water management by increasing the capacity of the primary channel by normalization. Increasing the channel capacity will increase the amount of water to meet the needs of the dilution process. Konsten et al. [10] suggested that the need for fresh water is more than 1000 cm for 200 days, or about 5 cm/day (Table 2). The amount of fresh water needed for dilution/washing acid solution in the Belanti scheme with an irrigation area of 3976 ha is about 500 m³/day/ha water. This condition means that the collector channel must provide 1.998 million m³/day of fresh water.

Table 2. Effects of leaching on aluminium concentration in soil solution at depths 20-25 cm of undisturbed severe acid sulphate soils by various authors [10].

| Authors            | Days of leaching | Water used cm | Al³⁺ in soil solution at depth 20-25 cm Before leaching mmol(+1)⁻¹ | After leaching mmol(+1)⁻¹ |
|--------------------|-----------------|--------------|---------------------------------------------------------------------|--------------------------|
| Sen 1988a          | 30              | 400 – 450    | 33                                                                  | 6 -18                    |
| Tuong et al. 1993  | 15              | 500          | 10                                                                  | 4,5                      |
|                   | 30              | 1300         | 10                                                                  | 4,5                      |
| SIWRR 1990         | 63              | 450          | 9,3                                                                 | 2,5                      |
| Konsten et al. 1991| 200             | >1000        | >20                                                                 | App 2                    |

Two simulation scenarios were used to evaluate the hydraulic performance of the scheme. By existing conditions, the first simulation begins with the model calibration process. It continues with the evaluation of the primary channel performance. The second simulation works on the normalized channel to increase the capacity of the existing channel. Channel normalization is carried out by dredging sedimentation that occurs in the middle and upstream of the primary channel.

The simulation was carried out using tidal data from measurements for two days (16 November 2020 ~ 18 November 2020) on the Kahayan River as the boundary condition of the water level. The hydraulic simulation uses the scheme as shown in Figure 6 to evaluate the channel's performance to support the leaching process using fresh water from the Kahayan river. This simulation does not evaluate the channel network on the ability of the channel during extreme rains.
3. Result and discussion.

The hydraulic simulation of the existing channel shows the attenuation of tidal fluctuations along the channel. The attenuation of tidal fluctuation in the middle of the channel is 30 cm, while in the upstream channel is 40 cm, see Figure 7. This attenuation will reduce the ability of tidal water to enter the secondary channel. The results of the hydraulic simulation on the normalized channel show the ability to overcome this tidal damping. Attenuation in the channel occurs only about 10 cm, see figure 8. Simulation of scenario one and scenario 2 calculate the incoming and the outgoing discharge at high tide and the volume of water entering and leaving the system. Figure 9 shows the hourly volume of water entering the system at the primary canal's downstream, middle and upstream parts under existing and normalized conditions. Table 3 shows the cumulative freshwater that enters during one tidal cycle. With the current leaching water demand for the whole irrigation area (1,998,000 m³), the condition of the existing system (scenario 1) cannot meet supply criteria due to a volume deficit of -38.96% of total demand.

Meanwhile, with channel normalization (scenario 2), the cumulative inflow water volume is 1.8 million m³, still a deficit of -9.21%. Although the normalization of the primary channel increases the
channel's capacity, the volume of incoming water is still not enough. The secondary channel's normalization will help increase the percentage of incoming water flow to meet the leaching criteria.

![Tidal curve in normalized channel](image)

**Figure 8.** The tidal curve in the normalized channel

**Table 3.** The volume of water entering the system

| Scenario Geometries | Water Needs (m$^3$) | Cumulative Volume (m$^3$) | Surplus/Deficit (m$^3$) | %  |
|---------------------|---------------------|--------------------------|------------------------|----|
| Scenario 1          | 1,998,000           | 1,219,554                | -778,446               | -38.96% |
| Scenario 2          | 1,813,914           |                          | -184,086               | -9.21%  |

![Water volume ratio](image)

**Figure 9.** Water volume ratio
4. Conclusion
In areas with shallow pyrite content, caution of water management is needed. Water management must ensure the leaching of acid solution resulting from pyrite oxidation and prevent continuous pyrite oxidation, in addition to drainage and irrigation criteria. Large quantities of fresh water are required for the dilution and leaching processes. This condition can be done by increasing the channel capacity. Increasing channel capacity with channel widening is better than deepening to prevent the oxidation of sulfuric acid soil. After meeting the needs of the leaching volume, it is necessary to evaluate the quality of the water in the system. Whether the tidal water movement from the river into the system can improve water quality, the next should be a water quality simulation.

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