Current Condition in Lowland Irrigation Area Tahai: Challenges and Solutions

Zachlul Zelvi[1] Istiarto[2,*] Lestari Rahayu Waluyati[3]

[1] *Master Student, Department of Civil and Environmental Engineering, Universitas Gadjah Mada, Indonesia*
[2] *Department of Civil and Environmental Engineering, Universitas Gadjah Mada, Indonesia*
[3] *Department of Social Agricultural Economics, Universitas Gadjah Mada, Indonesia*
[*] *Corresponding author. Email: istiarto@ugm.ac.id*

ABSTRACT

The Tahai lowland irrigation area is one of the on-going lowland development national projects. This channel network consists of the primary channel and a number of secondary channels on its left and right banks at regular distances. This is known as comb (*sisir*) system. The primary channel starts at Kahayan River and ends at an upstream pond. Farmers currently do not use the water in the channels for irrigation. Channels are used to drain water from paddy fields. The upstream pond is no longer functioning because it is filled with sedimentation and has been covered by vegetation. In the past two years, dredging was carried out on a 7 km primary channel calculated from the upstream of the channel. Before dredging, the sediment had formed a mound in the center of the primary channel. Meanwhile, sedimentation in the secondary channel is left unchecked, resulting in reduced channel capacity. The poor drainage ability of the channel resulted in poor water circulation. Observations of water quality in the spring and neap tide periods have been carried out as a first step in proving this problem. Field observations were completed to obtain an overview of the existing condition of the channel network. An overview of the issues was also obtained from discussions with observers of the irrigation areas and local farmers. The development plan is discussed in this paper as a proposal for solving these problems. The plan is based on the results of the study and the discussions with farmers. It is expected that water from the land and channels can discharge into rivers at low tide and freshwater can flow into channels at high tide. The latter serves as the water supply for the paddy fields.

Keywords: *Lowland Irrigation Problem, Water Management, Tahai.*

1. INTRODUCTION

The Tahai lowland irrigation area or Pangkoh IV is derived from the Kahayan River. Pangkoh IV is Ex-peatland project (PLG) of Block D working area. The Pangkoh IV reclamation network was built periodically from 1979 to 1981. Transmigrants started this area in 1980-1982 [1]. The goal of reclamation is to create drier and more mature soil to make it appropriate for agriculture. In fact, the reclamation phase takes a very long time. The reclamation process in time and management terms must be enhanced so that the lowland can genuinely develop into a paddy production source [2].

In lowland tidal areas, acid sulfate soils are often found with low fertility and are unfavorable. Pyrite oxidation is one of the factors in the reclamation process. Pyrite content in acid sulfate soils is a severe problem for rice growth [3]. This idea is also revealed by Noor in [2], where some chemical characteristics of tidal lowland soil are low content of macronutrients and micronutrients and have a layer of pyrite (FeS2). Under anaerobic conditions or reduction, the pyrite component in the soil is still stable. However, under aerobic conditions, pyrite undergoes oxidation which releases sulfuric acid and dissolved iron. Aerobic conditions occur when the groundwater level decreases. The decrease may result from deep construction of the channel. Water from acid sulfate soils implicates the transfer of toxic from the root layer to the environment and surface water [4].

Another problem that usually occurs in lowland irrigation areas is sedimentation in the channel. Sediment can reduce channel capacity both when supplying and

A. D. Saputro et al. (Eds.): ICOSEAT 2022, ABSR 26, pp. 113–120, 2023.
https://doi.org/10.2991/978-94-6463-086-2_16

when draining water [6]. The poor drainage ability of the channel also results in acid water being retained [5].

In water management, the water supply aims to leach acid water and maintain potential acid sulfate soils in a reductive condition to avoid excessive oxidation [3]. Another statement supports this function that some of the main objectives of water management are disposing of excess water, supplying irrigation water, preventing groundwater table subsidence, leaching and flushing acid in rice fields and channels. A one-way flow system is better for leaching and flushing processes [6]. Therefore, the proper water management system determines the success of using tidal lowlands to become agricultural land [3].

Nowadays, the local people are farming, raising livestock, trading and doing other non-agricultural activities for their daily livelihood. Even so, most of the population in DIR *(Daerah Irigasi Rawa)* Tahai still work in their paddy fields to earn daily income. The local farmers plant rice twice a year using high-yielding varieties [1]. The yields still rely on rainwater sources. This paper will explain farmers' problems that make them depend on rainwater as the main water source. Other problems will elaborate on the description of the existing condition of the observation location. Development plans that need to be carried out to solve these problems are also presented in this paper.

2. MATERIAL AND METHOD

Currently, the lowland Tahai irrigation area is still being cultivated for agriculture and plantations. The lowland Tahai Irrigation Area is located in Tahai Jaya and Tahai Baru Villages, Maliku District, Pulang Pisau Regency, Central Kalimantan Province. DIR *(Daerah Irigasi Rawa)* Tahai is located in the southeast of Palangkaraya City and Sebangau National Park. Although it is included in the province of Central Kalimantan, this location is closer to the city of Banjarmasin.

The water system at DIR *(Daerah Irigasi Rawa)* Tahai applies the *sisir* type system. The length of the primary channel is 10.45 km beginning from the Kahayan River and heading south. At the end of the primary channel, there is a pond with a size of 400 m x 500 m. This pond controls the flow in the channel and accommodates the results of acidity leaching that cannot come out into the river [7]. Secondary channels are formed perpendicular to the primary channels with 200 m intervals between channels. The number of right secondary channels is 49, about 1900 m. On the other hand, the left secondary channel is 48, with a length of 2100 m. The right secondary channel 49 connects the side of the pond with the right collector channel. Likewise, the left secondary channel 48 also connects the side of the pond with the left collector channel.

The area of Tahai's irrigation area is 3517 hectares where 1522 hectares of it is the paddy field. Some parts are used by villagers for housing and plantations. Only a small part is in the form of shrubs [8].

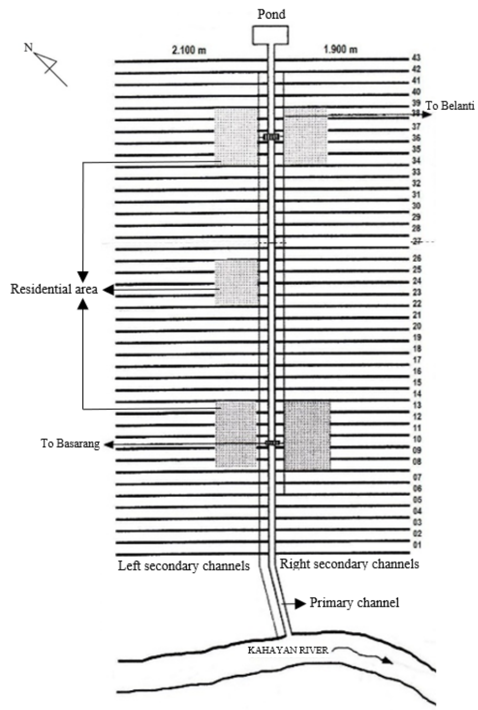

Figure 1 Schematic of DIR *(Daerah Irigasi Rawa)* Tahai (*Departemen PU,*1997).

This paper presents the observations and facts in the area. Periodic observations were carried out from February to March 2022 to describe the existing conditions of the research site. Water quality testing was carried out in primary and secondary channels to determine the level of water quality, such as acidity. The quality test location points were determined using satellite image maps. Tests were carried out on 28 February 2022 at low tide and 15 March 2022 at high tide. The next test was soil testing. Soil testing was aimed to determine the type of soil and identify the depth of pyrite. Soil sampling locations were at two points, each representing the left and right land of the primary channel.

An overview of the problems was also obtained from discussions with water observers, farmers and gardeners. Their expectations will be stated in the development plan as a proposed solution to the problem. Secondary data is also collected. Secondary data comes from *Balai Wilayah Sungai (BWS) Kalimantan II* in the form of a design investigation survey (SID) of the rehabilitation and improvement of the irrigation network in the Block D working area at the DIR *(Daerah Irigasi Rawa)* Unit Tahai in 2020.

3. RESULTS AND DISCUSSION

3.1. Current Condition in DIR (Daerah Irigasi Rawa) *Tahai*

3.1.1. Current Land Use and Hydro-topography

Knowledge related to land use is needed in water development planning. The local people use the area in Tahai for housing, plantation and paddy fields. In Figure 1 of the DIR *(Daerah Irigasi Rawa)* Tahai scheme, the housing location is indicated by the shaded part. The housing area is divided into Block A that is closer to the downstream channel, the middle of the primary channel and Block B which is closer to the pond. The paddy fields are on the right side of the primary channel which spreads from secondary channel 1 to 47. While on the left side of the area, the paddy field starts on the left secondary channel 39 to secondary 46. As it is known, this rice field is a productive land that local farmers cultivate. The land to the left of the primary channel is mostly plantations. Unused land is only 3.9% of the total land in the form of shrubs.

The hydro-topography of the land shows the relationship between the water tide level and the surface elevation of the land. Category/type A (land always overflowing) is land lower than the spring tide level and is always flooded or inundated every full moon cycle a minimum of 4-5 times in the rainy and dry seasons [9].

Category B (land overflowed during the rainy season) is land that is still lower than the spring tide level. However, it is flooded or inundated every full moon cycle during the rainy season for a minimum of 4-5 times. Category C (land higher than the spring tide level) is a relatively high elevation area and is not flooded with spring tide all the time. However, the spring tide still affects groundwater. Category D (dry land) is lowland that is higher and drier, so it is not at all affected by tides [9].

The hydro-topography of this area has three categories/types, namely type A (the land is always overflowing), type B (land overflows during the rainy season) and C (land higher than the spring tide level). The percentage of each type is 3.5%, 41.1% and 55.4% respectively [8]. As shown in the data, the percentage of type A is extremely lower compared to the other two types. Based on the SID DIR *(Daerah Irigasi Rawa)* Tahai hydro-topography map, type A land is located between the left secondary channel 5 and the left secondary 10. Regarding the land use map, this area belongs to the plantation area.

In the area, observation of the left secondary channel 8 has been carried out to see the function of the land. In Figure 2, the land at the observation point functions as a rubber plantation.

Figure 2 Typical condition of left secondary channel 8.

In terms of tidal overflow, the channel observations were carried out again in the spring tide period. At 16:20 on 15 March 2022, the water level reached 0.76 m. However, the water level in this channel has not yet reached the land. One hour later, the water level peaked at 0.9 m, probably only close to the land surface elevation, as shown in Figure 2.

Rubber plantations already have a production value that is hard to turn back into paddy fields. The scope of this research is rice field farming. So, based on the hydro-topography map of the Tahai, the hydro-topography types in paddy fields are type B (land overflows during the rainy season) and C (land higher than the spring tide level). The challenge for these two types of hydro-topography is that tides do not always flood the land. During the rainy season, type C land (land higher than the spring tide level) uses rainwater as a water supply. In the dry season, the land has the potential to experience lack of water.

3.1.2. The Existing Water System

The flow system at DIR *(Daerah Irigasi Rawa)* Tahai is a two-way flow system. The water in the collector channel returns to secondary channel 1 and then flows into the primary channel. However, in reality, the water management system only works to remove water from the paddy fields.

The primary channel was dredged for approximately 7 km from the end to the center of the channel in 2020. However, the secondary channel is still silting and overgrown with plants (Figure 3 (1)). This will reduce the volume of water in the channel and the land at high tide.

In addition, the pond was full of sediment and vegetation (Figure 3 (2)). The dimension of the pond is 400 x 500 m whose depth is 2 m – 3 m. The sediment volume is around 400,000 m^3. Sediment and toxicity have accumulated for years in pond and will be a new problem if an excavation is done. The problem is that these substances will diffuse and contaminate the primary channel. If the sediment still shows high acidity,

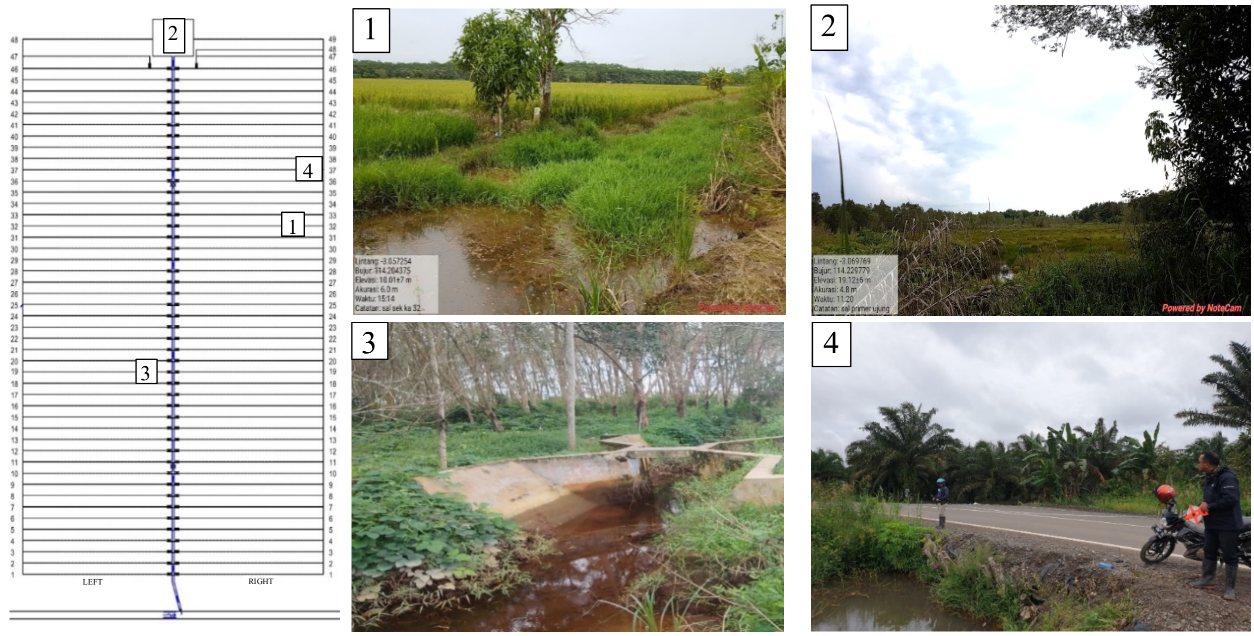

Figure 3 The condition of the water system network and location in scheme. (1) Sediment and vegetation in secondary channel. (2) The pond was covered by sediment and vegetation. (3) The gate was damaged. (4) Road over the channel without a culvert.

excavation will cause the spreading of acidity to channels and fields. This situation will have an impact on decreasing agricultural yields [7].

The sluice gates in the secondary channel were damaged due to a lack of maintenance (Figure 3 (3)). The operation has not been carried out following the established standards. The sluice gates play a significant role in regulating water circulation.

The collector channel is just like a belt surrounding the DIR *(Daerah Irigasi Rawa)* Tahai. Many secondary channels are not connected to the collector channel. Road construction has also resulted in the right collector channel being cut off due to road embankment. The road embankment location is near the right secondary channel 37 (Figure 3 (4)).

Farmers use a pipe to drain water from the land to the channel. The pipe is connected from paddy fields to the channel via embankment. The pipe in the field can open one segment when draining water. Pipe segments are refitted and initiated vertically when retaining water in the field or preventing water from channels to fields.

Siltation in the channel, unoperated sluice gates and unconnected channels are challenges that need to be resolved in the future.

3.1.3. The Acidity of Water in Channels

Farmers have planted twice (2 plant seasons) using superior rice varieties. Production results based on observer information are 5 tons/ha. The results obtained turned out to only utilize the supply of rainwater. Water quality testing is carried out to identify the cause of this condition.

Tests were carried out using a multi-parameter tool (pH, EC, TDS and salinity) to obtain water quality conditions in the channel. The test result that needs to be analyzed for the acidity indicator is the pH value. In addition, by visual observation, there is still *purun* grass in the secondary channel, which is a natural indicator of water acidity. Then, the yellow color on the walls of the channel is also shown as the effect of pyrite oxidation. The results of the acidity test (pH) can be seen in the following table.

Table 1. Acidity testing 28 February 2022, in the spring tide period with sunny weather at low tide

No	Test Location	pH
1	Downstream primary channel	4.10
2	Primary near secondary channel 11	2.93
3	Primary near secondary channel 23	2.91
4	Primary near secondary channel 36	2.88
5	Right secondary channel 8	3.16
6	Left secondary channel 19	2.98
7	Left collector channel	2.48
8	Right collector channel	3.06

In the table above, in the water system, the pH results obtained are in the range of 3. As seen from the data, the primary channel at the downstream, middle and upstream show even less than 3. This test was carried out during low tide and sunny weather. Information from villagers stated that the location had not rained for more than three days.

From the table above, it is clear that the left collector channel shows the most acidic pH. It happened due to the water supply from oil palm plantations in the East of the Tahai area. So, it can be concluded that when there is no supply from the river and no rain falls, the pH in the channel ranges from 2.48 to 3.16 (acidic conditions).

The pH test was then carried out under different conditions, namely during high tide. This test is carried out to determine changes in pH that occur when river water enters the primary channel. The test results can be seen in table 2.

Table 2. Acidity testing 15 march 2022, in the spring tide period with cloudy weather nearing the peak

No	Test Location	pH
1	Primary near secondary channel 11	4.06
2	Right secondary channel 8	3.91
3	Left secondary channel 8	3.39
4	Primary near secondary channel 36	3.00

Water sampling was carried out at 16.00 up to 17.00 WIB on 15 March 2022. If compared with tidal observations at that hour, the water level elevation was approaching the peak. The elevation read on *peilschaal* 1 was between 0.72 to 0.86 meters. Tests in the primary channel near the secondary 11 obtained a pH value of 4.06. However, in the primary channel near the secondary 36, the test results showed a pH value of 3.

Based on observations of water levels in the spring tide period, high tide lasts for approximately 7 hours and the rest is low tide. At low tide, the water in the primary channel is acidic. Meanwhile, in high tide conditions, the end of the primary channel is still classified as acidic. It means that the pH test results show that the acid water in the primary channel is not completely drained when it recedes. The trapping of acidic water in the channel indicates that the process of leaching acid substances into the river is not current.

Then, acidic water also indicates acid sulfate soil. Acid sulfate soils are mineral soils that contain pyrite (FeS2) of more than 2%. The oxidation process breaks down pyrite into ferrous and high acid sulfide content [7]. Therefore, an approach must be taken to facilitate the acid washing process.

3.1.4. Soil Type and Existence of Pyrite

Mineral soils and peat soils are two types of soil found in the lowland area. In terms of soil conditions (pyrite depth, salt content and peat thickness), lowland is divided into 14 types [10]. Testing the depth of pyrite and soil type needs to be done to find out. The location chosen is land that was no longer planted with rice and has become shrubs. Soil testing was carried out on land near left secondary 19 and near right secondary 23. This consideration is to find out whether there is a relation with the existence of pyrite so that farmers do not manage to plant the rice successfully.

This soil test used hand boring. The soil from the test results is clay mineral soil (clay). As for checking pyrite, the soil sample was dripped with a liquid that will react (bubble and foam) if it meets pyrite. The liquid is Hydrogen Peroxide / H_2O_2. The results of the left-field test indicated the presence of pyrite, which was deep and safe for the paddy root zone. The pyrite layer at the first location was found at 110 cm. Based on this condition, the land belongs to the SMA-3 type (Actual acid sulfate in deep pyrite) [10].

In the field near the right secondary channel 23, pyrite has been found at a depth of less than 50 cm. This land condition belongs to the SMP-1 type (shallow pyrite potential acid sulfate) [10]. Pyrite was in the root zone of 25-30 cm, inhibiting rice growth. The existence of shallow pyrite indicated that the reclamation process was still on-going. At low tide, the potential for sulfuric acid soil to oxidize and become one of the factors causing the water in the channel to become acidic. The reclamation of lowland on sulfuric acid soils caused pyrite oxidation, acidification and toxicity. These elements inhibit agricultural activities on the land [11]. Therefore, an approach is needed to maintain the potential acid sulfate soil in the reduction phase.

3.2. Proposed Solution

3.2.1. One-way Flow System

The research area had a characteristic where the river water source was only from one location. There was no water source from the upstream of the primary channel. Sediment brought in when tide through the primary channel will be left at the end of the channel. Water from the land also carries sediment and enters the secondary and primary channels. It was predicted that these factors might lead to silting of the pond and mounds. The mounds occurred in the middle along the primary channel. This condition continued until dredging (normalization) was carried out in 2020.

Currently, normalization still needs to be continued, especially for secondary and collector channels. This approach is essential to restore the channel's ability to drain water. After the normalization of the primary channel, the problem of low water quality remains unresolved. During the two-way flow system, the problem of water acidity will still occur. A one-way water system is recommended to avoid retaining of acid water at the end of the channel [12].

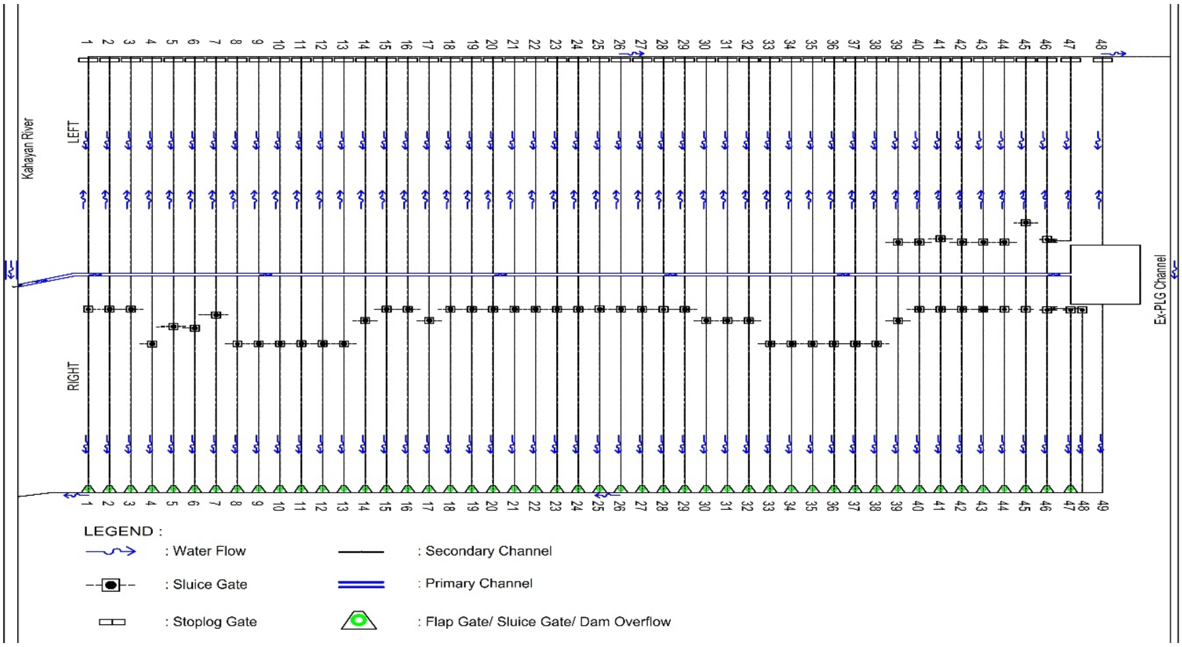

Figure 4 Schematic development plan of DIR *(Daerah Irigasi Rawa)* Tahai.

The change of water system to one direction needs to be simulated to find out the effective scenario to be implemented. Suggestion obtained from the farmer can be part of the development plan. The suggestion is to make the right collector channel connected to the river. The goal is that the water does not flow back into the primary channel but is directly discharged into the river. The distance from the right collector channel to the river is about 600 meters (see figure 4).

Another important thing is the construction of a culvert under the road will reconnect the right collector channel. Secondary channels that have been cut off due to hoarding also need to be reconnected with collector channels.

The left collector channel will be challenging to connect to the river. The reason is that the distance is more than 3 km and the possibility of crossing plantation field. Since the land on the left of Tahai is mostly plantations, the development plan approach is more effective by arranging channels close to the rice fields, namely channels 39 to 46.

3.2.2. Gate in Water Management System

The one-way flow system will be effective with the proper placement of the gate structure and the arrangement of the gate through the water system operating system. Several types of gates that can be applied are sluice gates, flap gates, stoplog gates and dam overflow.

The sluice gate can maintain the secondary channel's elevation and retain water in the channel during the dry season. Another function is to prevent saltwater intrusion into the drain. The sluice gate is still operated manually, where the material is usually made of iron plates [9].

The flap gate has benefits in operation. The gate is made of wood or fiber with hinges on the top side. This gate can open and close automatically under different conditions of water levels. The function of this type of gate is to block the flow of water at high tide and throw water in the channel at low tide. This gate is more appropriate for draining sediment and acid from the secondary channel to the right collector channel [9].

The stoplog gate also maintains the channel's water level at a certain elevation. If the water level is higher, the runoff will occur above the stoplog. stoplog are installed in the gateway of the building by manual opening and closing operation. If wanting to open a whole block of wood, it should be done when the water in the channel is receding [9].

The arrangement of the gates is important in solving the challenges of water flow from oil palm plantations which goes through the left collector channel. As stated previously, the left collectors are not recommended to go to the river. The stoplog gate is the right type to block the flow of water from the plantation into the left collector channel. By placing this gate at the end of the left secondary channel and setting the log at a certain elevation, the water from the left collector channel is cut off and does not enter the secondary channel. The left collector channel is connected to the south's ex-PLG (Peatland Project) channel. The water in the left collection channel goes to the ex-PLG channel (see figure 4).

The following arrangement is the sluice gate building on the right secondary channels and left secondary channels 39 to 46. The position of these gates are closer to the primary channel (see Figure 4). The deposition of floating sediment becomes less when using a sluice gate. Unlike the stoplog, this gate must be opened from the top, while the sluice gate is opened from the bottom of the channel using a turning steering wheel. Flushing can be done if there is deposition in front of the gate.

The gate at the end of the right secondary channel has three gate types: flap gate, sluice gate, or overflow dam. The flap gate has the advantage of operating automatically. When receding in the right collector channel, the flap gate will open to release water. Conversely, when installed in the right collector channel, the flap gate remains closed to prevent flow in the right collector channel. However, the hydro-topography type in paddy fields B and C are unsuitable when using a flap gate. The water will be immediately discharged when it recedes. The water level in the channel and soil will decrease, which results in pyrite oxidation. Sluice gates have advantages for hydro-topography type B (land overflows during the rainy season) and C (land is higher than the spring tide level). This is because the sluice gate can still hold water at low tide, especially in the dry season.

The third type of water gate that is used is an overflow dam. This building is more suitable for type C or type D areas since its function is to save water in the channel [13]. In addition, from the discussions with farmers, it is agreed that the overflow dam is also easier to operate. The elbow system of the overflow dam can store water during the rainy season for storing in the dry season. Channels function like long storage. If the elbow pipe is enforced, the water in the channel is still stored. Conversely, the elbow pipe can be lowered so that the water in the channel flows out into the collector channel [2].

4. CONCLUSION

The factors that cause the farmers use rainwater only for water supply are the high acidity of the water in the channel and the hydro-topography of the land.

The challenges in the water management system are the condition of the existing network and the circulation is not current. Steps to respond to these challenges are channel normalization, repairs and additions to water gates. The next step is to implement a one-way flow system by using a gate arrangement. This system will reduce the occurrence of pyrite oxidation and improve the circulation of water flow so that acidic water can be discharged into rivers. The freshwater that enters the channel network does not mix with acidic water. It will improve water quality in the channel.

The current research is still on-going by modelling and simulating the development plans discussed in this paper.

AUTHORS' CONTRIBUTIONS

All authors contributed equally based on their expertise.

ACKNOWLEDGMENTS

The authors would like to thank the villagers who have helped during field observations. The authors would also like to show their gratitude to the *Balai Teknik Rawa* team for their assistance during the field testing. The meaningful input during the whole process from *BWS Kalimantan II* is highly appreciated.

REFERENCES

[1] Yodya Karya, “Laporan PSETK Paket Pekerjaan : Survey Investigasi Dan Desain (SID) Rehabilitasi Dan Peningkatan Jaringan Irigasi Rawa Wilayah Kerja Blok D (Paket 4),” 2020.

[2] A. Hairani and M. Noor, "Water management for increase rice production in the tidal lowlandland of Kalimantan, Indonesia: Constraints, limitedness and opportunities," IOP Conf. Ser. Earth Environ. Sci 724(1) (2021). doi: 10.1088/1755-1315/724/1/012021.

[3] W. A. Yusuf and E. Setiawati, "Overcoming constraint of tidal lowlandland with water management with one-way flow system to increase of rice growth," IOP Conf. Ser. Mater. Sci. Eng. 980(1) (2020) 1–7. doi: 10.1088/1757-899X/980/1/012072.

[4] I. G. M. Subiksa and Sukristyonubowo, "Mitigation of pyrite oxidation impact in tidal lowland management for agriculture," IOP Conf. Ser. Earth Environ. Sci. 648(1) (2021) 1–9. doi: 10.1088/1755-1315/648/1/012106.

[5] M. S. Imanudin, J. P. Satria, D. Budianta, and C. Charli, "Leaching treatment of acid sulphate soil and crop adaptation test under micro scale condition," IOP Conf. Ser. Earth Environ. Sci. 757(1) (2021) 1–13. doi: 10.1088/1755-1315/757/1/012 036.

[6] A. K. Fauzan, B. S. Wignyosukarto, and R. Jayadi, "Water Management Evaluation for Upgrading Tidal Irrigation System, Katingan, Kalimantan," IOP Conf. Ser. Earth Environ. Sci. 794(1) (2021). doi: 10.1088/1755-1315/794/1/012040.

[7] B. Wignyosukarto, “Reliabilitas Rehabilitasi Kolam Pasang pada Jaringan Irigasi Pasang Surut Unit Tabung Anen, Kalimantan Selatan,” Majalah Forum Teknik UGM, no. Vol 29, No 1 (2005). 2005, [Online]. Available:http://journal.ugm.ac.id/index.php/mft/article/view/1096.

[8] Yodya Karya, “Laporan Akhir Paket Pekerjaan : Survey Investigasi Dan Desain (SID) Rehabilitasi Dan Peningkatan Jaringan Irigasi Rawa Wilayah Kerja Blok D (Paket 4),” 2020.

[9] Peraturan Menteri Pekerjaan Umum Dan Perumahan Rakyat, “Peraturan Menteri Pekerjaan Umum Dan Perumahan Rakyat Republik Indonesia Nomor 11/PRT/M/2015 Tentang Eksploitasi dan Pemeliharaan Jaringan Reklamasi Rawa Pasang Surut.” 2015.

[10] S. Najiyati, L. Muslihat, I. Nyoman, and N. Suryadiputra, “Pengelolaan Lahan Gambut Untuk Pertanian Berkelanjutan.,” Pengelolaan Lahan Gambut Untuk Pertan. Berkelanjutan, p. 241, 2005.

[11] J. J. B. Bronswijk, J. E. Groenenberg, C. J. Ritsema, A. L. M. van Wijk, and K. Nugroho, “Evaluation of water management strategies for acid sulphate soils using a simulation model: A case study in Indonesia,” Agric. Water Manag. 27(2) (1995) 125–142. doi: 10.1016/0378-3774(95)01135-6.

[12] B. S. Wignyosukarto, "Leaching and flushing of acidity in the reclamation of acid sulphate soil, Kalimantan, Indonesia," Irrig. Drain. 62(S1) (2013) 75–81. doi: 10.1002/ird.1777.

[13] A. Hairani and M. Noor, "Water management on peatland for food crop and horticulture production: Research review in Kalimantan," IOP Conf. Ser. Earth Environ. Sci. 499(1) (2020) 1–16. doi: 10.1088/1755-1315/499/1/012006.