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Research Article

Assessing the effects of water flow patterns on dam construction in degraded tropical peatlands

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Abstract

Tropical peat swamp forest becomes degraded through forest removal and drainage, usually followed by land use change and fire. Restoration of the degraded peatland requires rewetting, which involves canal blocking and water level management. The purpose of canal blocking is to rewet the peat so that peat-forming trees can re-establish or crops be grown with minimal greenhouse gas emissions and peat subsidence. In addition, wet peat is more fire resistant than degraded dry peat. Canal construction faces several technical problems, including stress that causes bending, water seepage under the dam, and erosion of peat by water forcing its way around the sides when the water level upstream exceeds the dam height. This research examined the behaviour of water flows in canals in peatland in Central Kalimantan after blocking with dams of different designs. This study used a survey method and hydraulic physical model test with a horizontal scale of 1:30 and a vertical scale of 1:10. Field measurements were carried out on the primary canal of the former Mega Rice Project (MRP) Block C to build a physical model test prototype for laboratory research, includes measurement of cross-sections, canal length and water flow for a distance of 100 metres upstream and downstream of the construction. The test included three types of the physical model, reviewed for the effect of flow patterns caused by flood discharge frequencies of 5, 25, 50 and 100 years. The effects of flow patterns on canal dam construction in peatland were obtained from the physical model test.

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Introduction

Peatlands occupy only 3% of the global terrestrial surface (Vitt and Short, 2020) and are characterised by the accumulation of organic matter from dead and decaying plant debris under water-saturated conditions. Of the world's total peatland area of around 441 Mha (Rieley and Page, 2016), as much as 36-44 Mha or 8-11% is located in tropical regions (Page et al., 2011), and more than half (24.8 Mha or 56%) of this is in Southeast Asia, mostly in Indonesia and Malaysia. Due to the considerable thickness (mean >5 m) of peatlands in these two countries, they contain 77% of the carbon stored in tropical peat globally (Page et al., 2011).

Amongst these countries, Indonesia contains the largest area (around 13.43 Mha) of tropical peatland (Page et al., 2011; Anda et al., 2021), located mainly on the islands of Sumatra, Kalimantan (Borneo) and Papua (Purnomo et al., 2019). These peatlands contain as much as 57 Gt of carbon, or about 65% of the world's peat carbon (Page et al., 2011) and 7% of the 861 GtC of global forest-based carbon stocks (Pan et al., 2013).

Tropical peatlands are important ecosystems for biodiversity conservation, climate regulation (Joosten, 2015) and human well-being (Wildayana, 2017; Xu et al., 2018). Besides being important carbon stores, they have high value for biodiversity because there are endemic and rare species with high conservation value, such as orangutans and tigers (Morrogh-Bernard et al., 2003; Posa et al., 2011; Sunarto et al., 2012). They are also a source of livelihood for local people (Anshari et al., 2005; Silvius and Diemont, 2007; Suyanto et al., 2009).

Indeed, peatlands in Indonesia have been widely used by people. Poor peatland management can lead to land degradation and forest and land fires. In Southeast Asia, conversion of around 10 Mha of peatland results in additional CO_2 emissions of 355-855 Mt yr^{-1} from peat oxidation (Canadell et al., 2007) while the increased incidence of peat and forest fires not only adds substantially to global greenhouse gas emissions but also threatens public health and livelihoods locally (Marlier et al., 2013; Miettinen et al., 2017). Additionally, loss of peat through oxidation and fire results in land subsidence and increased risk of flooding (Hooijer et al., 2012; Evers et al., 2016; Evans et al., 2019) and risks exposing underlying sulphuric acid soils (Wösten et al., 2006), causing extremely low pH of water and soils. In such conditions, only certain types of biota can develop, including decreases of fish population (Moiseenko, 2005), while low soil pH is an obstacle to plant growth (Noyaa et al., 2014).

Following Indonesia's major forest and peatland fires in 2015, the Government of the Republic of Indonesia established the Peatland Restoration Agency (*Badan Restorasi Gambut*; BRG) with the main objective to carry out peatland restoration based on rewetting (R1), revegetating (R2) and revitalising community economy (R3). Peat rewetting through blocking of canals used for farmland and plantation drainage, transport and/or timber removal from forests is therefore a key component of Indonesia's peatland restoration strategy (Dohong et al., 2017). Almost all studies report that surface and groundwater levels rise immediately after rewetting by blocking canals (Suryadiputra et al., 2005; Limin et al., 2007; Dohong and Lilia, 2008; Orangutan Project, 2010; Panda et al., 2012; Ritzema et al., 2014).

Proper dam design is key to peatland wetting, to effectively raise and hold water levels along blocked canals and nearby locations. The dam design must be able to adapt and meet the main requirements of dam construction on tropical peatlands, such as low bearing capacity, high porosity, high permeability and high hydraulic conductivity (Page et al., 2009; Kelly et al., 2014; Ritzema et al., 2014;). The design should be able to raise and maintain the desired water level as high as possible, especially during periods of poor rainfall and high evaporation. Dam design depends on drain size, water volume and water velocity. Some of the technical problems encountered in the construction of canal water level control structures (dams) include: a) bending of transversely positioned wooden poles, especially in the middle of the bulkhead; b) erosion / seepage of water around the side of the bulkhead when water discharge is high during wet seasons, causing erosion of the surrounding peat forming a new canal for water to flow into the canal below; c) water seepage underneath the dam owing to the swelling of the sacks of peat used as dam foundation and the remains of tree branches and logs that form gaps in the peat underneath (Suryadiputra et al., 2005). Research in the former Mega Rice Project (MRP) Block C in Central Kalimantan (Indonesia) by Ritzema et al. (2014) found that dams became damaged due to scouring, which creates depressions in the peatland surface, leading to interception of overland flow and interflow, and increased risk of overtopping of dams during extreme rainfall events.

To address and help develop solutions to these issues, we assessed the effects of water flow patterns on dam construction using hydraulic physical testing. This was done using a scale model, with the results of field measurements for the conduit conditions informing the development of a physical model in the laboratory. This research aimed to understand the behaviour of water flow in peatland canals after canal blocking.

Methods

The research stages included the initial activities up to the measurements and observations made, as presented in Figure 1.

Field measurement and hydrological characteristics of canal

Field measurements were carried out in the vicinity of a dam created on one of the canals in Block C of the ex-MRP (Figure 2), as a measure for hydrological restoration of degraded peat. The length of the canal measured in this study is 100 m. Measurement was made using the Theodolite tool with a distance interval of 10 m until a typical cross-sectional and elongated cross-sectional shape. While the measurements of canal discharge were made with a current meter with a distance of 10 m to the longitudinal direction of the canal and 2 m intervals to the transverse direction of the canal (Figure 3). Field measurements were carried out following the Indonesian National Standard (Boiten, 2003; SNI 3409, 2008; SNI 3410, 2008; SNI 3411, 2008; SNI 3965, 2008; SNI 1724.2015; SNI 8066, 2015; SNI 2415, 2016), and included namely: a) measurement of canal discharge using a current meter with a distance of 10 m to the longitudinal direction of the canal and 2 m intervals to the transverse direction of the canal; b) measurement of the canal dimensions using the Theodolite with an interval of 10 m; c) measurement of the depth of peat to the mineral soil layer using peat borer (or from secondary data).

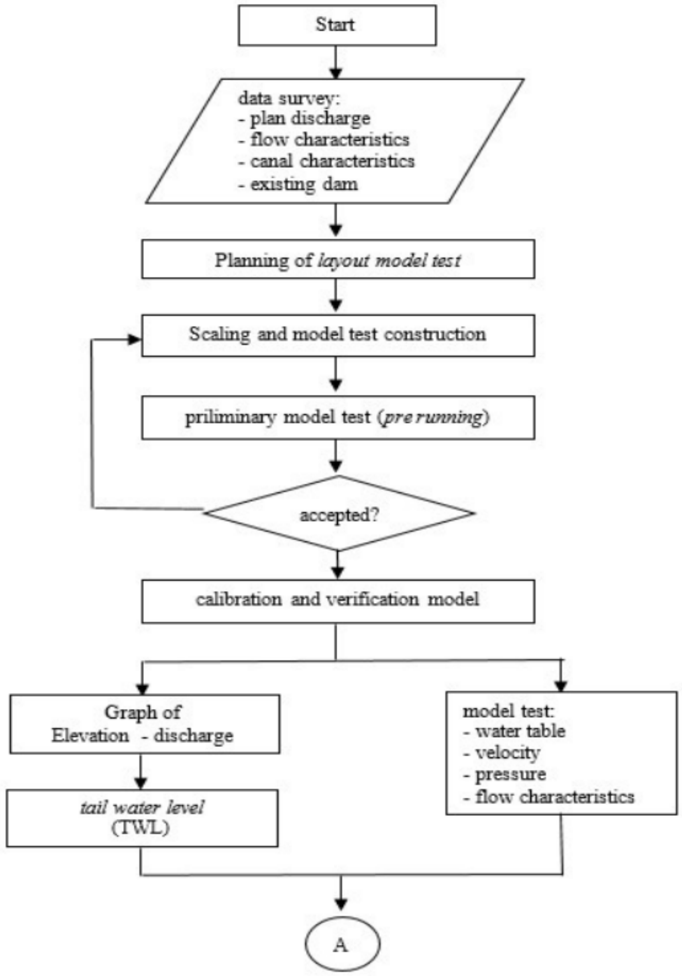


Figure 1. Flowchart of model test.

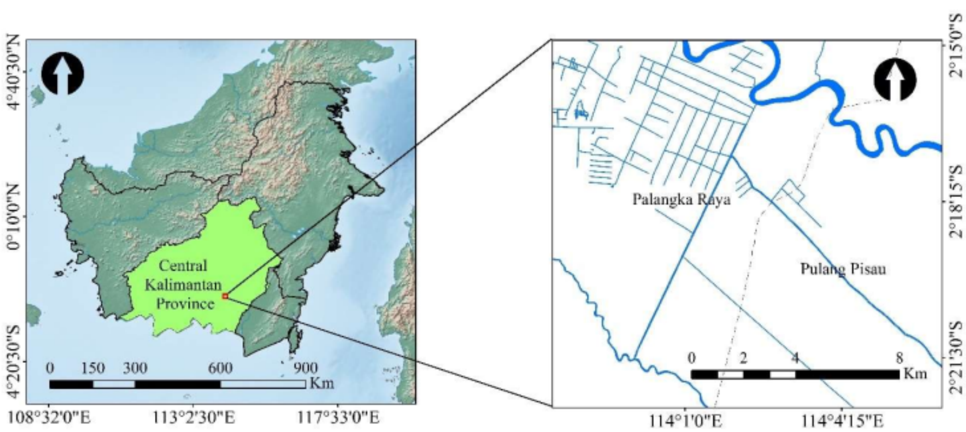


Figure 2. Location of measurement of the characteristics of the canal for the physical model (blue line is a water body, the red line is a road).

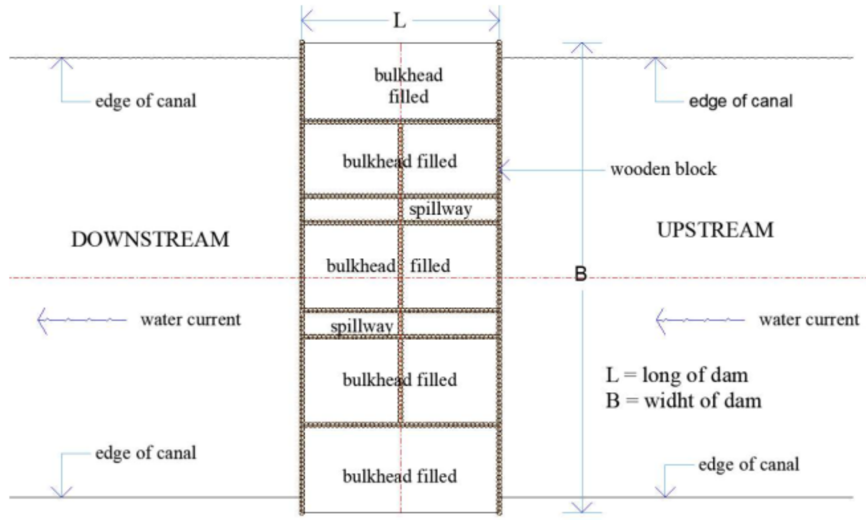


Figure 3. Sketch of the position of canal discharge measurement.

Physical modelling

The scale of the physical model used in this study was based on several considerations: the purpose of the test, the expected accuracy, the available facilities, the time and cost required. There are two possible approaches to scaling a hydraulic physical model, namely: 1) undistorted model, in which the horizontal and vertical scales are the same; and 2) distorted model, in which the horizontal and vertical scales are not the same, i.e. there is a horizontal or vertical exaggeration. A distorted model was employed in this research. Modelling research was conducted at the Hydraulics Laboratory, Faculty of Engineering, Palangka Raya University, Indonesia. To support the implementation of the physical model test in this study, tools and equipment were used, including a water storage pool, water pump, discharge measurement building, measuring the water level, flow velocity measuring device and the peat soil from around the dam location, for making the physical model of the canal. Several parts of the prototype were imitated in the model using the type and size of the specified scale value, namely: a) the main canal is made of soil taken from the location of the canal blocking with changes to spillway construction; b) typical canal cross-sections are made based on the longitudinal and transverse field measurements; and c) the canal bulkhead model construction is made of round profile wood.

In testing the hydraulic flow behaviour and bulkhead stability, several models were tested, namely: a) Model Series 0 based on the field prototype; b) Model Series 1 based on a modified field prototype with an overflow in the middle of the construction; and c) Model Series 2 based on the results of the previous model, with changes to spillway construction (Figures 4, 5 and 6). The above model was tested for variations in the flood discharge plan with return periods of 5, 25, 50 and 100 years. In order to get the planned rainfall, the rainfall data in this study used the Tjilik Riwut Palangka Raya airport station data approach for the period 2006-2015. The method used to calculate the planned rainfall was the statistical method or distribution method of the maximum average daily rainfall by using several types of distribution, namely Normal Distribution, Log Normal Distribution, 3 Parameters Normal Log Distribution, Type III Log Pearson Distribution and Gumbel Distribution.

Types of observation, measurement and analysis

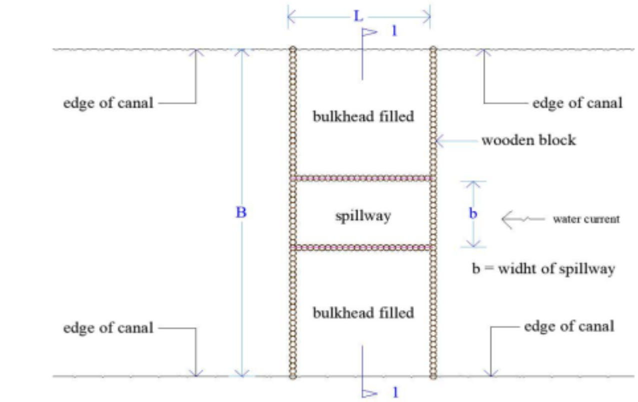
During the process of testing the physical model for various discharge variations, observations and measurements were made at predetermined sections, including:

a. measurement of water depth in both upstream and downstream canals and the spillway;
b. measurement of water flow velocity in canals and overflows; and
c. observation of water flow behaviour around the canal blocking construction model.

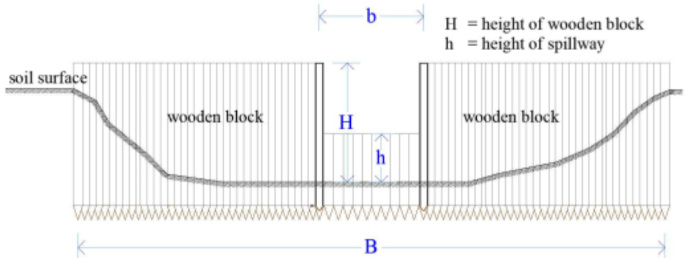
The field measurements obtained were then used as test variables, as shown in Table 1.

Calculation of planned flood discharge

A planned flood discharge is the maximum discharge from a river or canal, the amount of which is based/related to a specified return period (SNI 2415, 2016). The calculation of the planned flood discharge was used to determine the canal capacity and water level based on the flood discharge for a certain period. The planned flood discharge is a discharge with a certain return period, which is a parameter of water-building planning.

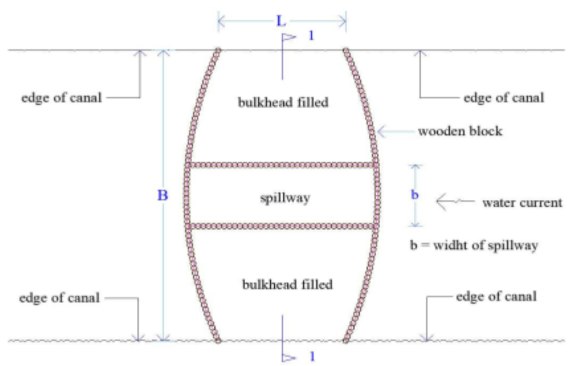


(a) sketch

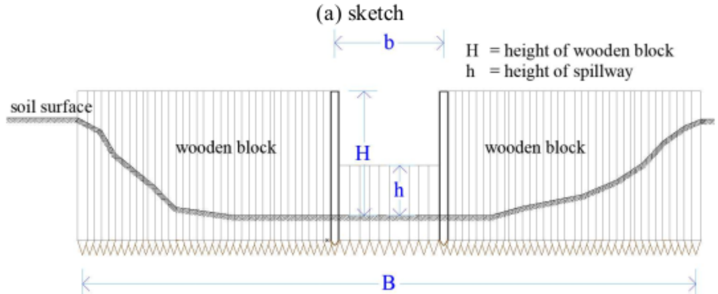


(b) cross section 1-1

Figure 4. Sketch of physical test of model series 0 (original design/prototype).

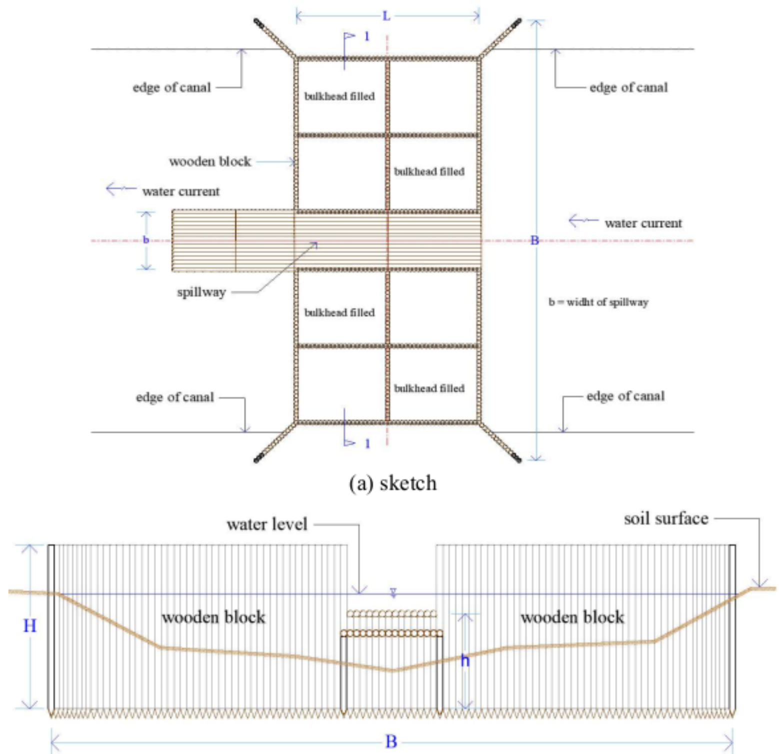


(a) sketch



(b) cross section 1-1

Figure 5. Sketch of physical test of model series 1 (alternative).



(a) sketch

(b) cross section 1-1

Figure 6. Sketch of physical test of model series 2 (final design).

Table 1. Parameter of model test

Parameter			**Type**
Description	**Symbol**	**Unit**	
- Canal capacity	Q	$m^3 sec^{-1}$	Water depth
- Spillway capacity	Q_s	$m^3 sec^{-1}$	
Flow characteristics:			
- Upstream and downstream of the canal		Flow depth	
- Spillway		Flow velocity	
- Around construction		Flow direction	

Because the flow data in question was not available, several methods were used in calculating the flood discharge (Kamiana, 2010), namely:

Rational method

Rainfall intensity (I, mm hour^{-1}) was calculated as:

$$I = \frac{R_{24}}{24} x \left[\frac{24}{T}\right]^{2/3} \quad \text{.....................................[1]}$$

where R_{24} is daily rainfall (mm) and T = time concentration (hour) = $\frac{L}{W'}$, L = canal length (km), W' = flow velocity (km hour^{-1})

Then:

$$Q_r = \frac{C.I.A}{3.6} = 0.278\, C.I.A \quad \text{............................[2]}$$

where Q_r = peak discharge (cfs), C = runoff coefficient, A = catchment area (km^2).

Wedumen method

Equation: $Q_n = \alpha\, \beta\, q_n\, A$ .... [3]

$$\alpha = 1 - \frac{4{,}1}{\beta\, q + 7} ; \qquad \beta = \frac{120 + [(t+1).(t+9)].A}{120 + A} ;$$

$$q_n = \frac{R_n}{240} . \frac{67{,}65}{t + 1{,}45}$$

where Qn is peak discharge (cfs), t = time concentration (hour), Rn = rainfall plan (mm), A = catchment area (km^2).

Hasper method

Equation: $Q_n = \alpha\, \beta\, q_n\, A$ .... [4]

$$\alpha = \frac{1+0{,}012.A^{0{,}7}}{1+0{,}075.A^{0{,}7}} \;;\; \frac{1}{\beta} = 1 + \frac{t+3{,}70x10^{-0{,}4t}}{t^2+15} . \frac{A^{0{,}75}}{12} \;;$$

$$q_n = \frac{R_n}{3{,}6\,t} \qquad t = 0{,}10\,.\,L^{0{,}80}.\,S^{-0{,}3}$$

where *Qn* is *peak discharge* (cfs), t = time concentration (hour), *Rn* = rainfall plan (mm), *A* = catchment area (km^2), L = canal length (km) and S = canel slope (%).

Results

Rainfall analysis

The type of distribution used was the one that met the requirements as in Table 2, which showed that from the tests carried out above, the type of distribution that met the requirements is Log Pearson III. The results of this distribution were used to calculate the planned rain intensity according to the specified period, as presented in Table 3. Tables 2 and 3 show that from the tests carried out the type of distribution that meets the requirements is Log Pearson III.

Planned flood discharge

By using rainfall data and several methods, namely the Rational method (equation 1), the Wedumen method (Equation 2) and the Hasper method (Equation 3), the planned discharge was calculated. The recapitulation of the planned flood discharge calculation is shown in Table 4 and the discharge from the Hasper method has a more conservative value and is closer to the actual condition.

Field Measurement

Cross-sectional and longitudinal cross-sectional measurements of the drainage canal

The length of the canal measured in this study is 100 m where there is a dam that has been built. Measurement using the Theodolite tool with a distance interval of 10 m until a typical cross-sectional and elongated cross-sectional shape is obtained, as shown in Figures 7 and 8.

Table 2. Requirements for selecting the type of distribution.

Distribution type	Requirement	Calculation	Note
Normal	Cs ≅ 0	Cs = 0.5088	Not accepted
	Ck ≅ 3	Ck = -0.3486	Not accepted
Log Normal	Cs ≅ Cv^3 + 3Cv = 0.1358	Cs = 0.0617	Not accepted
	Ck ≅ Cv^8 + $6Cv^6$ + $15Cv^4$ + $16Cv^2$ +3 = 3.0328	Ck = -0.3174	Not accepted
3 Parameters Normal Log Distribution	Cs = 3Cv = 0.6757	Cs = 0.0617	Not accepted
	Ck ≅ 3	Ck = -0.3174	Not accepted
Log Person III Methods	Cs ≠ 0	Cs = 0.0617	ACCEPTED
	Ck = 1.5 Cs $(\ln X)^2$ + 3 = 3.0542	Ck = -0.3174	Not accepted
Gumbel I Methods	Ck ≅ 5.4002	Ck = -0.3486	Not accepted
	Cs ≅ 1.1396	Cs = 0.5088	Not accepted

Table 3. Recapitulation of calculated rainfall plan (mm).

Period (year)	Normal	Log Normal	Log Normal 3 Parameter	Log Pearson Type III	Gumbel Type I
2	143.9900	140.7803	143.6580	140.4504	139.5956
5	171.2286	169.8865	152.2869	169.8218	178.2998
10	185.4964	187.4608	156.9935	187.8037	203.9253
25	199.3848	206.3125	159.9848	209.2725	236.3032
50	210.4651	222.7030	165.5944	224.5387	260.3230
100	219.5446	237.1001	168.7378	239.3196	284.1654

Table 4. Recapitulation of planned flood discharge calculations.

Return Period (year)	Rational Methods Q_T ($m^3\,sec^{-1}$)	Hasper Methods Q_T ($m^3\,sec^{-1}$)	Wedumen Methods Q_T ($m^3\,sec^{-1}$)
2	7.3064	15.9503	20.8944
5	8.8344	19.2858	25.2640
10	9.7698	21.3280	27.9391
25	10.8866	23.7661	31.1329

Measurement of the existing canal blocking

The prototype canal block building in the field on the ex-PLG canal in Block C, consists of Belangiran log construction with a diameter of 10 cm to 20 cm. The average length of logs is 4 m and the stakes are between 1.3 m and 1.5 m deep. The inside is given a waterproof layer (geotextile) and filled with local soil in sacks. The shape and dimensions of the canal block building are shown in Figure 9.

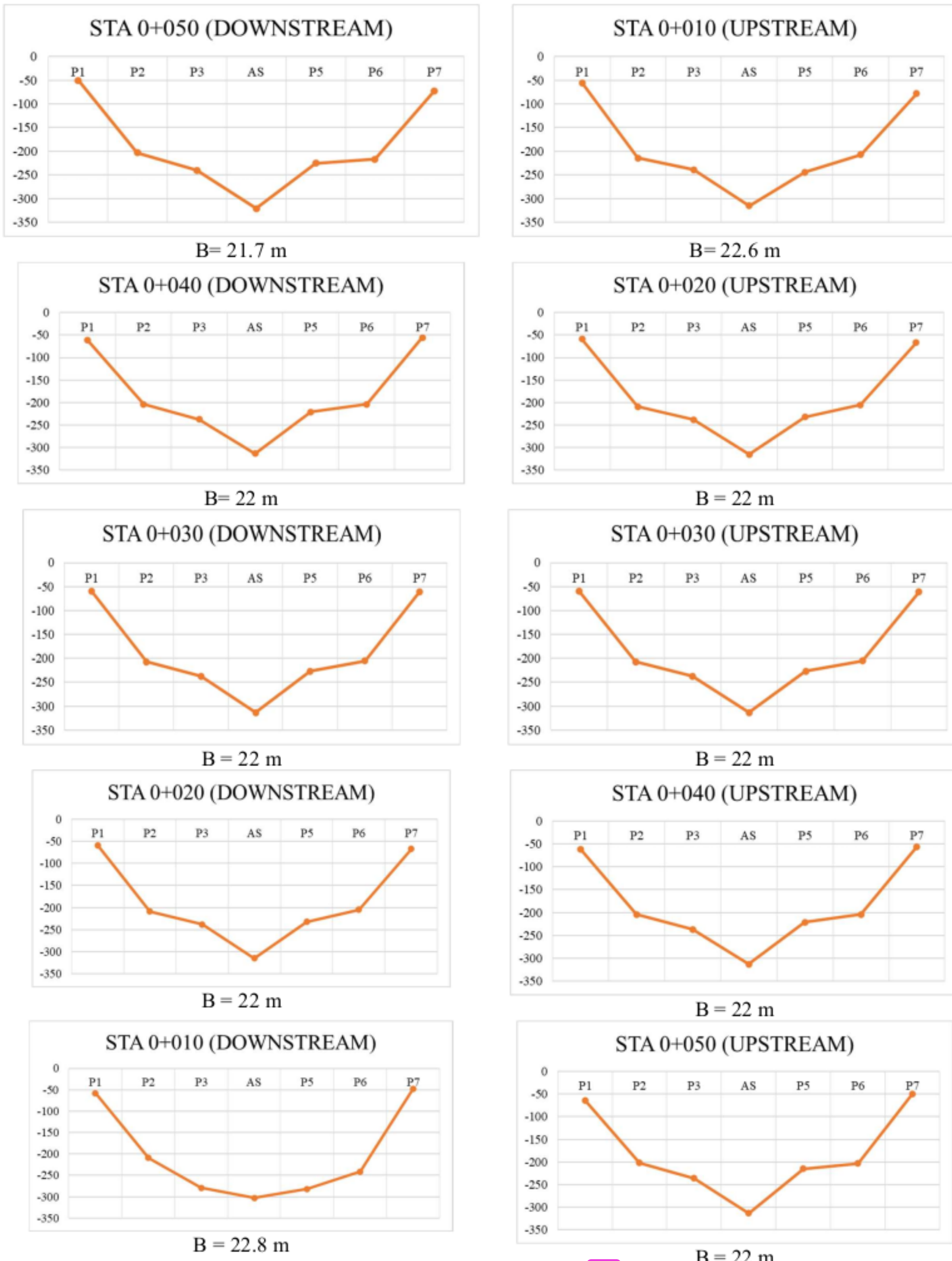


Figure 7. The results of the transverse measurement of the canal at Block C of the Mega Rice Project (MRP).

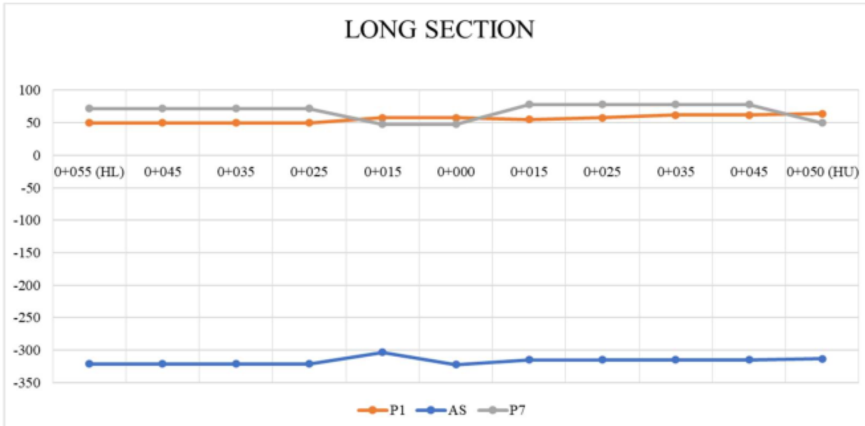


Figure 8. The longitudinal measurement results of the canal.

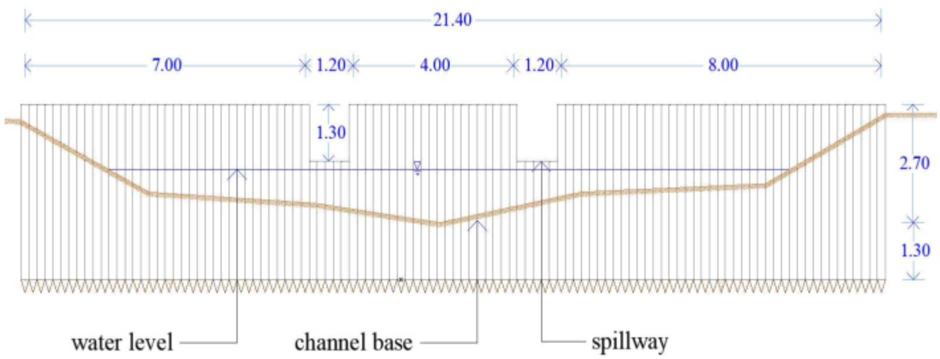


Figure 9. Cross-section of existing canal (unit in m).

Model testing

The physical model of the canal

According to the results of field measurements of the dam constructed as part of peatland rehabilitation carried out by BRG at the Blok C of the MRP (Figure 9), the physical model of the canal and bulkhead was made following the initial design in an open space with a horizontal scale of 1:30 and a vertical scale of 1:10 (Figure 10). The inside is covered with a plastic sheet and then filled with peat soil material from the research location. The drainage system is carried out by raising the water to the upper reservoir, from the upper reservoir and the discharge pump is regulated with a stop faucet, then it is flowed to the building under study and then through the drain canal it is flowed into the local drainage canal.

Canal block physical model

After the canal block's construction, the water flow pattern in the canal changes due to an increase in energy and flow turbulence, as shown in Figure 11. The flow pattern in the series 0 models produces a vortex on both sides downstream of the canal block. This results in local scouring; i.e. scouring at the bottom of the canal that occurs locally or around the building. In the series 1 model, the flow pattern that occurs is almost the same as the series 0, but there is a backflow (feedback) that tends to rotate wider on both sides of the canal block. In the series 2 model, the water flow pattern changes, with a vortex reduction observed. This is due to the existence of a floor at the bottom of the canal, which functions as a dampener for water flow energy. If this scouring is not resolved, it can result in continuous erosion of the embankment and subgrade soil at the downstream part of the bulkhead building so that, eventually, the bulkhead loses its bearing capacity and hangs.

Recapitulation of physical model test results

From the physical model test results, a recapitulation of the physical model test results on flow behaviour can be made, as presented in Table 5.

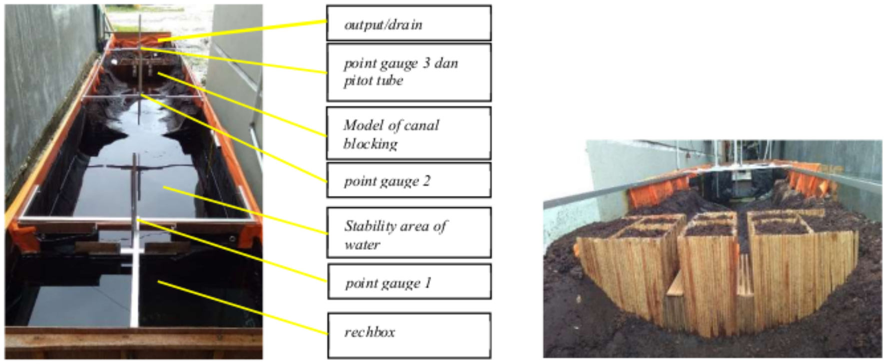
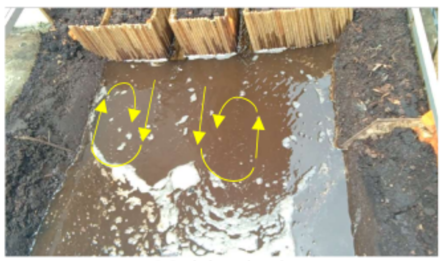
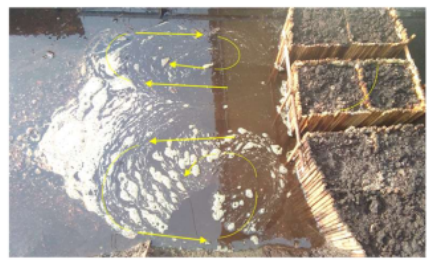


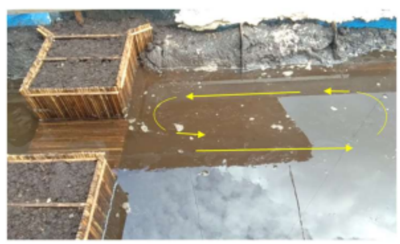
Figure 10. Physical model of the canal and measuring instrument (left) and physical model of serial 0.



Model series 0



Model series 1



Model series 2

Figure 11. Water flow pattern downstream of the model.

From the results of Table 5, it can be seen that the series 0 and 1 models with two overflow canals produce flow and scour velocities that are greater than the series 2 models. When the flood discharge occurs, the water level exceeds the bulkhead construction (runoff occurs), so it has the potential to erode the landfill and embankments at the edge of the canal bulkhead. When the planned discharge is Q5, the water level in the series 2 model does not occur in the bulkhead construction.

From Figure 12 (left), the 2 series model, the water flow rate that occurs is lower than in other models. So that the water flow that occurs has a smaller effect on the construction of canal blocking and embankments downstream. From Figure 12 (right) in the series 2 model, no scouring occurs because there is an additional floor construction upstream of the construction. The greatest scour occurs in the series 1 model, which is 9 cm or 90 cm in the actual field.

Discussion

Overall, there are simulations with various planned rain simulations carried out on the three dam models, it can be said that the presence of dams in the canal increases the water level in the upstream area of the dam. This is good for the purpose of rehabilitation of degraded areas due to the construction of canals, in particular. Ritzema et al. (2014) and Putra et al. (2021), shows the results of research that the existence of dam construction has an impact on increasing the groundwater level on the surrounding land, and of course this is good for wetting peatlands.

Table 5. Recapitulation of physical model tests on flow behaviour.

Review	Planned Flood Discharge	Model Series 0	Model Series 1	Model Series 2
Water table upstream (cm)	Q5	15.4	15.5	22.6
	Q25	16.1	16	25
	Q50	27.2	27.3	27.8
	Q100	29	29	29.4
Water table downstream (cm)	Q5	11	11.5	19.9
	Q25	13.6	13.3	23.3
	Q50	25.2	26.1	26.1
	Q100	27	27.5	27.8
Water velocity (m sec^{-1})	Q5	0.6419	0.6264	0.5775
	Q25	0.7004	0.6570	0.6419
	Q50	0.7412	0.7142	0.6718
	Q100	0.8168	0.7672	0.7412
Scour depth of upstream of the spillway (cm)	Q5	1	3	-
	Q25	3	5	-
	Q50	6	7	-
	Q100	8	9	-
Leakage discharge (m^3 sec^{-1})	Q5	0.0079	0.0079	0.0059
	Q25	0.0088	0.0088	0.0066
	Q50	0.0096	0.0096	0.0072
	Q100	0.0103	0.0103	0.0077

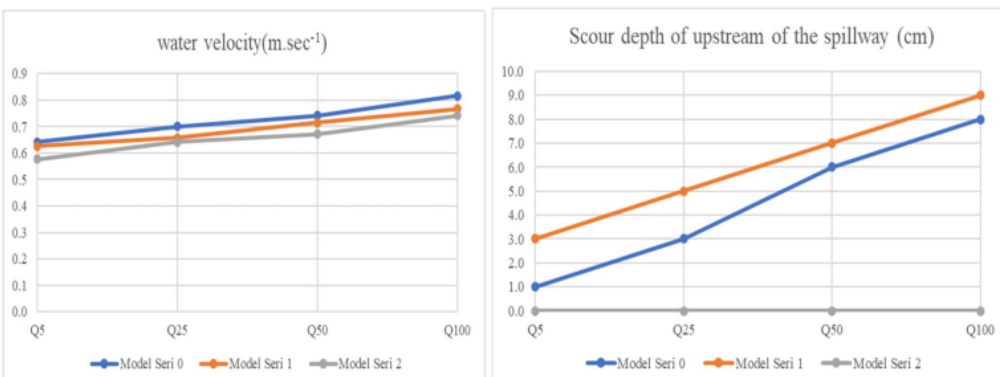


Figure 12. Flow velocity at the downstream of the series 0 model (left) and scour depth (right).

In a study in the Meranti Islands, Riau Province, Saputra et al. (2021) who conducted a study using the HEC-RAS model to determine the effectiveness of canal blocking, suggested that canal water level control can be done by calculating the spillway height in the rainy season, when the dry season the canal is closed according to the results of hydraulic calculations in the dry season, water level can be maintained to a depth of 40 cm below the surface. The increase in the average water level of the canal against the spillway building in the dry season is lower than the rainy season.

From the results of the flow recapitulation in the laboratory experiments above, the advantages and disadvantages of each physical model are described in Table 6. The Series 2 model uses a planned flood discharge Q5 = 19.29 m^3 sec^{-1}, in the upstream canal the water level is 2.26 m (design height 2.3 m) and the embankment height is 2.5 m. Peat soils on the sides of the upstream canal can be maintained at a groundwater level of 0.2 m from the required 0.4 m. By submerging the peat soil, it is hoped that the danger of drought, which has the potential for land fires, can be minimised. Schimelpfenig et al. (2014) found that restoration through the use of dams (ditch blocking) has a positive effect on increasing groundwater levels and restoration is also beneficial in terms of CO_2 fluxes. Besides, the planned water level can be used for planting vegetation around the canal blocking buildings, both those that grow naturally and that is managed by the community. The existence of vegetation (ferns, shrubs and secondary vegetation) that grows around the canal blocking can provide an advantage, namely it can strengthen the canal bulkhead structure that is built (Sutikno et al., 2019). When the flood discharge Q50 = 25.50 m^3 sec^{-1} and Q100 = 27.18 m^3 sec^{-1} occurs, then the land to the left and right of the canal has the potential to flood because the water level is 2.94 m above the embankment height. This cannot be avoided because, topographically, the embankment height on the sides of the canal by the canal block is lower than the water level due to the flood discharge. Our suggested solution to this problem is to create a new canal (secondary canal) and increase the height of the embankment on the left and right of the canal. The series 2 model is the recommended model that can function properly and has safe stability with a planned discharge of Q5. It is important to consider that when flood discharge Q25, Q50, and Q100 occur, the bulkhead construction of the recommended model occurs, which can erode the downstream canal's subgrade.

Table 6. Description of the advantages and disadvantages of the physical test model.

Physical Test Model	Advantages	Disadvantages
Model Series 0	- round wood material is easy to obtain - the work is easier because the connecting tool is in the form of nails - more water flow leads to the spillway	- need higher blocking for Q50 and Q100 flood discharge - deformation occurs during wall construction - need a wider spillway - scouring of the bottom of canals downstream of the spillway - leakage - because there are 2 overflow canals, vortex flow occurs downstream of the bulkhead - feedback water on both sides of the spillway so that it tends to erode the embankment
Model Series 1	- round wood material is easy to obtain - the work is easier because the connecting tool is in the form of nails	- need higher blocking for Q50 and Q100 flood discharge - wall radius work is difficult - need a wider spillway - leakage - scouring of the subgrade canals downstream of the spillway - vortex flow and feedback water occur downstream of the spillway so that it tends to erode the bottom and embankments
Model Series 2	- enough height of blocking for Q50 and Q100 flood discharge - water level at upstream 2.3 m (plan discharge Q5) - wide spillway - The vortex that occurs is small and the feedback water only occurs in the middle downstream of the bulkhead	- good round wood material, wide more than 6 m - work is more difficult because the fitting tool is a bolt - more construction materials (higher costs) - scouring of the embankment as a result *of feedback water*

This condition can disrupt the bulkhead construction's stability due to the loss of the subgrade for the footing of log poles. A possible solution to this problem is to increase the depth of the log piles and increase the floor's length downstream of the bulkhead construction.

From the results of the physical model test and analysis that have been carried out on the three model designs, the followings were obtained:

1. Model 0 series is only able to accommodate the planned flood discharge Q5 and Q25. In the conditions of Q50 and Q100, the existing overflow canals are not able to drain the resulting discharge resulting in water runoff in the canal blocking construction. This condition results in scouring the soil filling the bulkhead and creating new water flows in the side embankment of the canal blocking construction. The flow pattern of water downstream of the abundance occurs vortex and return water flow. Simanungkalit et al. (2018) stated that canal blocks located in large channels (>5 m wide) such as in the former MRP area which is the research area, have a higher risk of damage than bulkheads in narrower channels.

Water currents can erode the peat layer at the edges and bottom of the bulkhead so that the wood in the semi-permanent bulkhead can be separated from the loose peat substrate.

2. The series 1 model has almost the same flow pattern behaviour as the prototype model. Downstream of the bulkhead construction, vortices occur on both sides of the spillway so that the flow pattern tends to erode the embankment cliffs. Due to the curved geometry of the model, the upstream water flow and leading to the overflow canal also tend to lead to the edge of the bulkhead construction embankment. This has eroded the embankment at the edge of the bulkhead construction. Nevertheless, this is the recommended model type for further use in tropical peatland rewetting activities because of ease regarding dam material and ease of work on dam construction. Model series 2 on flood discharge Q100 the water level inundated the embankment but there was no overtopping in the canal blocking construction. Downstream, the flow pattern tends to erode the embankment cliffs due to the backwater flow with an influence of ±20 m. The addition of floor construction downstream affects the reduced vortex, and there is no scouring at the bottom of the canal due to falling water.
3. Hydrological restoration using canal blocking is an effective way of retaining water in peat areas and in particular raising the groundwater table. Shallow groundwater caused by canal blocking can improve the peat ecosystem, especially by reducing carbon dioxide emissions. The results of the Indonesian government's efforts to carry out hydrological restoration will be very effective and this research model 1 can be applied. Dohong and Tanika (2021) stated that a typical dam design and its technical specifications are highly dependent on several factors such as the expected technical life of the dam, the size of the dam, and the availability of materials at the site.

Conclusion

Dam construction model tested has its strengths and weaknesses, but the type of model that is recommended for further use in tropical peatland wetting activities is the Model 1 series because of the ease of dam material and ease of dam construction. The results of the Indonesian government's efforts to carry out hydrological restoration will be very effective and this 1-series model can be applied.

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