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# Effectiveness Analysis of Canal Blocking in Sub-peatland Hydrological Unit 5 and 6 Kahayan Sebangau, Central Kalimantan, Indonesia

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**Highlights:**

- Methods for quantifying the effectiveness of canal blocking were developed using Freewat software.
- Dry conditions on peatland can be solved by canal blocking with the height depending on the canal's distance.
- A chart was developed to make it easy for site engineers to calculate the groundwater table rise and the time needed for re-wetting peatland.

**Abstract.** The height of canal blocking has a significant influence on re-wetting peatland, depending on the canal's distance. An effective canal in good condition has to raise the groundwater table to -0.4 m below ground level according to the Indonesian Ministry of Environment and Forestry (*MENLHK*). The effectiveness of different canal blockings was modeled by Freewat software with variation of canal distance (200 m, 250 m, 300 m, 350 m, and 400 m) and blocking height (0.2 m, 0.3 m, 0.4 m, 0.5 m, 0.6 m). This simulation was carried out using recharge and evapotranspiration data covering 20 years. The input of the conductivity value was done using 50 m/day according to the calibration. From the modeling, 0.6 m high canal blockings give a satisfactory result at every canal distance. The study took place during the annual dry season, when recharge was almost zero and average evapotranspiration was 6 mm/day. Adjusting the canal blocking to a maximum of 0.6 m and the canal distance to 400 m, the groundwater table slowly rose 0.38 m and it took 30 days to reach full-re-wetting capacity. This study revealed that the effectiveness of canal blocking is directly related to evapotranspiration and recharge, which has a positive correlation with the groundwater rise and the re-wetting period.

**Keywords**: *canal blocking; groundwater; peatland; restoration; re-wetting.*

## 1 Introduction

Peatland is a wetland/swamp ecosystem formed by the accumulation of organic material on the surface of used soil from the vegetation above over a period of

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thousands of years. The vegetation decomposes and forms new layers on top of the soil surface. This accumulation occurs because the rate of decomposition is slower than the rate of deposition of organic matter on the surface of the soil. Physically, peatland consist of organosol soil or histosol soil, which are generally always saturated with water or submerged throughout the year unless drained. Peat is generally defined as the accumulation of plant remains found under stagnant, acidic conditions; being in the soil causes incomplete decomposition [1]. Peatland management is an important topic of international research. The latest research explains that the presence of tropical peatland is a crucial factor in the water cycle, carbon emissions, and climate change [2]. The degradation of tropical peatland environments leads to increasing carbon emissions and other hazards and disasters, including subsidence [3], fires [4], floods [5], and climate change [6].

The research problem in this study concerned the creation of canals in the Peat Hydrology Area in Central Kalimantan province, Indonesia for the development of agricultural area. This causes the availability of water in the peatland to decrease, causing subsidence, damaging the peatland ecosystem and making it much more vulnerable to fire, especially during the dry season. This condition becomes worse when there are several canals in the peatland. The general uses of canals are drainage, transportation and reducing the groundwater level when it causes problems in the peatland. Canal blockings need to be built [7] so that the groundwater level can be kept at about -40 cm for wildfire prevention [8].

Hydrological restoration (re-wetting) is a way to restore the damaged hydrological function of peatland by water management [9]. Alternative solutions offered for peatland engineering are re-wetting and building reservoir ponds so that the water level in the dry season can be maintained at -0.4 m according to the Ministry of Environment’s Decree No. 16 of 2017 [10]. Other government regulations involving peatland include the new Government Regulation 71/2014 concerning Protection and Management of Peat Ecosystems [11], Law 32/2009 concerning Environmental Protection and Management, and the 1945 Constitution [12].

The aquifer in peatland is unconfined. With numerical modeling, the effectiveness of canals applied to peatland can be predicted. In this study, modeling based on data covering a period of 20 years was expected to provide an overview of water level fluctuations. Various channel scenarios and dimensions were modeled. The effects on the peatland were modeled in order to support appropriate planning, considering the conditions on the ground. The researchers analyzed the effectiveness of different channel blockings by varying of the distance of the canal in the field (200 m, 250 m, 300 m, 350 m, and 400 m) in Sub-peatland Hydrological Unit (Sub-PHU) 5 and 6 of Kahayan Sebangau.

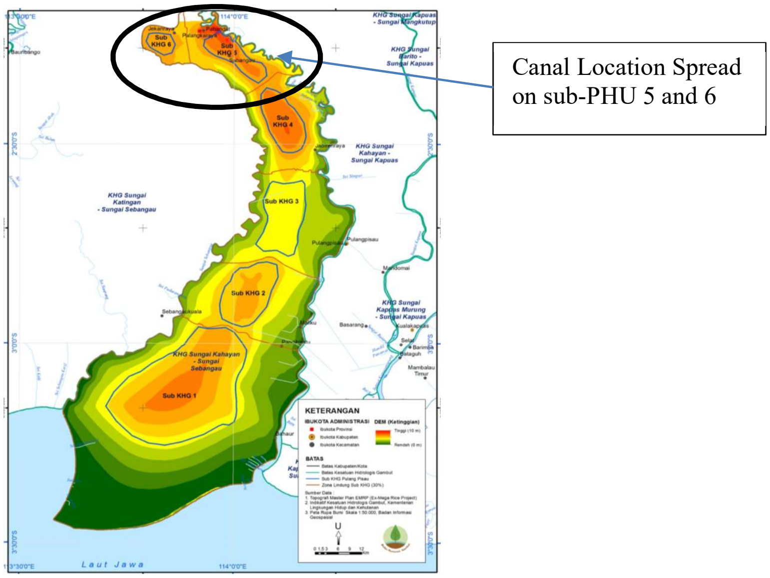
Channel effectiveness was also analyzed based on variation of canal blocking height (0.3 m, 0.4 m, 0.5 m, 0.6 m).

Rainfall (recharge) and evapotranspiration (discharge) data were used as input for the Freewat modeling system. The researchers also noted the increase in the groundwater level when canal blocking was applied under various combinations of recharge and discharge/evapotranspiration. A graph was made to simulate the fluctuations of the groundwater level. In the next section, we will discuss how long the re-wetting process takes with different input variations, which is useful for determining a best scenario for canal blocking.

## 2 Methodology

### 2.1 Study Location

The location of this study was limited to Sub-PHU 5 and Sub-PHU 6 Kahayan Sebangau, Central Kalimantan Province, Indonesia. A PHU is a water zone for peatland, which consists of two rivers and some peat-domes, while a sub-PHU is a hydrological system for one peat dome. The sites are hydrological peat units in Palangkaraya city, Pulang Pisau district, Central Kalimantan. The peatland in the area is passed by two rivers (Kahayan River and Sebangau River).



Canal Location Spread on sub-PHU 5 and 6

**Figure 1** Study Area [13].

## 2.2 Freewat Modeling

Freewat is a joint plugin for the GIS open-source desktop software, QGIS. The reference version chosen from QGIS is the latest long-term release as a combined plugin. Freewat is designed as a modular ensemble of different tools, some of which can be used independently, while some modules require initial execution of other tools. This modeling framework is based on differences in groundwater flow and related codes known throughout the world [14] by integrating Modflow-2005.

Modflow aims to simulate the dynamics of groundwater flow in saturated and unsaturated zones. The numerical settlement method uses the groundwater flow equation. The formula is as follows:

$$\frac{\partial}{\partial x}\left(T_X\frac{\partial H}{\partial x}\right)+\frac{\partial}{\partial y}\left(T_y\frac{\partial H}{\partial y}\right)\pm Q(x,y,t)= S_s\frac{\partial H}{\partial t} \tag{1}$$

H = water level until the surface is free [L]
Tx, Tx = pseudo transmissivity [L/T]
Ss = storage coefficient (1/L].
Q = discharge per unit volume of aquifer added (injection/positive) or subtracted (pumping/negative) from the groundwater system

## 2.3 Numerical Modeling of Groundwater Flow

In the case of peatland, there can be several canal models with different distances and heights. This makes it difficult to determine the groundwater level. The canals in Sub-peatland Hydrological Unit 5 and 6 have different distances, therefore canals with a distance of 200, 250, 300, 350, and 400 m were investigated in the simulations. The increase in groundwater level was calculated with the groundwater flow equation.

Model analysis of the groundwater level is affected by recharge and evapotranspiration. The groundwater table can be calculated using the equilibrium mass balance with an inhomogeneous anisotropic homogeneous aquifer [13].

$$\frac{\partial}{\partial x}\left(K_x h\frac{\partial h}{\partial x}+K_y h\frac{\partial h}{\partial y}\right)+N\ (x,y,t)=S_s\frac{\partial h}{\partial t} \tag{2}$$

The above equation is derived into the linear equation

$$\frac{\partial^2 h^2}{\partial x^2}+\frac{\partial^2 h^2}{\partial y^2}+\frac{2N(x,y,t)}{K}=\frac{S_s}{Kh}\text{ x }\frac{\partial h^2}{\partial t} \tag{3}$$

using the Crank-Nicholson scheme [16].

$$\frac{\partial^2 h}{\partial x^2}=\frac{1}{2}\text{ x }\left[\frac{h_{i+1,t}-2h_{I,t}+h_{i-1,t}}{(\Delta x)^2}+\frac{h_{i+1,t-1}-2h_{I,t-1}+h_{i-1,t-1}}{(\Delta x)^2}\right] \tag{4}$$

The linear equation is simplified as follows:

$$\frac{\partial^2 h^2}{\partial x^2}+\frac{2N(x)}{K}=\frac{S_s}{Kh}\,x\,\frac{\partial h^2}{\partial t} \tag{5}$$

Note: to make the calculations easier, $h^2 = W$.

h = initial condition (m)
K = hydraulic coefficient (m/day)
N = input loading
Ss = specific storage
x = distance (m)

## 2.4 Data Collection

Data were collected from relevant agencies, journals and other literature based on title. This study used data from the agencies listed in Table 1.

**Table 1** Data collection.

| Data | Data Sources | Decision |
|---|---|---|
| Topography data (DEM) | USGS,<br>DEMNAS | Input Modflow and initial boundaries |
| Rainfall data | Research and Development Center for Water Resources (PUSAIR) | Calculate precipitation |
| Climatological data | | Evapotranspiration |
| Observed water level data | Peatland Restoration Agency (BRG) | Initial heads/input Modflow |
| Aquifer geometry data | | Input Modflow |
| Canal data | PT LAPI ITB | Input Modflow |
| General data | Journal and report data | Location data |

## 2.5 Flowchart Modeling

Figure 2 presents a flowchart of this study. A literature study was conducted to collect the latest studies. Hydrological and climatological data were used to simulate groundwater levels. Based on the modeling, the channel blocking was optimized with various channel distances and blocking heights.

This research was completed by determining the best scenarios (alternative solutions) for the distance of the channels.

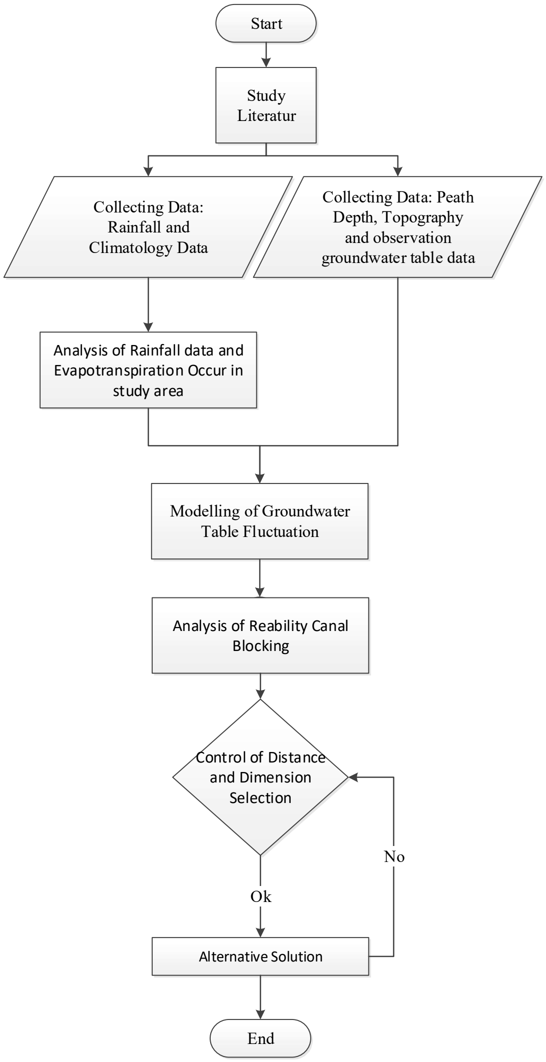


**Figure 2** Flow chart modeling.

# 3 Result and Discussion

## 3.1 Calibration of Conductivity Value

Groundwater level data measured near a canal were used for calibration of the model in our research. The canal had a width of about 10 m. The peat had various depths, from around 4 to 8 m. The calibration used data covering 30 days with 8 observation points within 50 meters. Here, we show well number 7. We quantified the hydraulic conductivity with a trial-and-error simulation, making comparisons based on the groundwater level in the field. The simulations were carried out by input recharge and evapotranspiration of plants that occur in the field for model calibration. After trying out several conductivity values, the best value (with the highest NSE and correlation) was 50 m/day or 5.78 x 10-4 m/s.

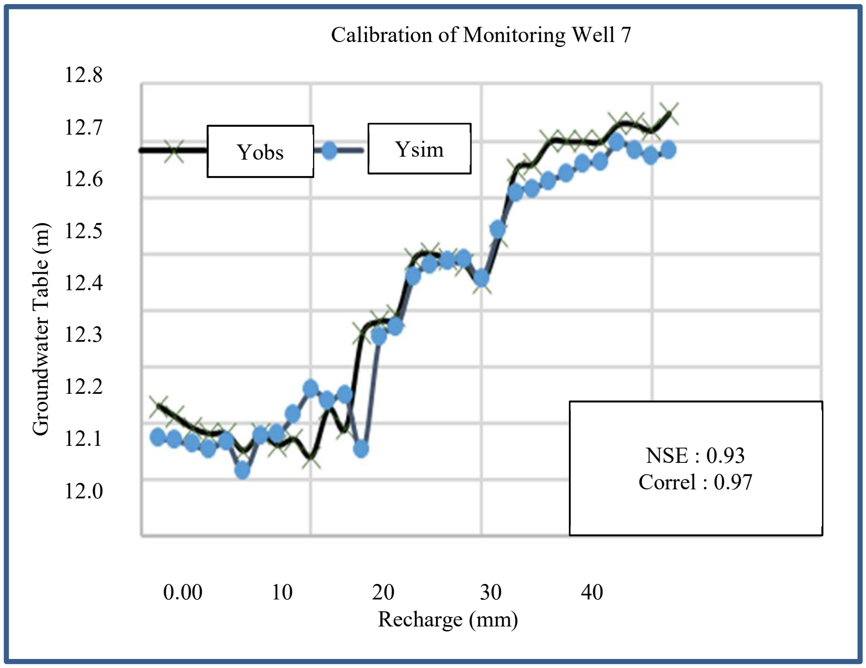


**Figure 3** Calibration value (groundwater table from local level) [17].

**Table 2** Calibration table.

| Observation Well Name | NSE | Correlation | Conductivity Value (m/day) |
|---|---|---|---|
| Well 7 | 0.93 | 0.97 | 50 |
| Well 6 | 0.95 | 0.98 | 50 |
| Well 5 | 0.81 | 0.95 | 50 |
| Well 4 | 0.89 | 0.97 | 50 |
| Well 3 | 0.73 | 0.95 | 50 |

### 3.2 Modeling Groundwater Table Fluctuation

The Freewat software was used to test the effectiveness of several canal distances by using rainfall and evapotranspiration data. The input conductivity value was set to 50 m/day or 1.78 x 104 m/s based on the calibration. The peat thickness was 4 to 5 m according to the peat thickness map. We made a table of accident failure from data covering 20 years with different canal distances and canal heights. The data consisted of rainfall and evapotranspiration, which were used as input for the modeling system. We applied various canal distances, i.e. 200 m, 250 m, 300 m, 350 m, and 400 m. We simulated the groundwater level higher to determine the reliability level of canal blocking under fairly fluctuating recharge and discharge conditions. The results are represented in Table 3.

**Table 3** Canal blocking reliability (%).

| Canal Distance (m) | Height of Canal Blocking (m) | | | | |
|---|---|---|---|---|---|
| | **0.2** | **0.3** | **0.4** | **0.5** | **0.6** |
| 200 | 83.33 | 90.42 | 100 | 100 | 100 |
| 250 | 80.42 | 86.25 | 98.33 | 100 | 100 |
| 300 | 78.33 | 84.58 | 92.50 | 100 | 100 |
| 350 | 75.42 | 82.50 | 87.50 | 100 | 100 |
| 400 | 72.08 | 78.33 | 84.58 | 91.67 | 100 |

The longer the distance to the channel, the lower the height of the blocking channel should be. This is because when the channel is closer, the re-wetting process occurs faster while a longer distance causes a prolonged re-wetting time, especially after an extremely dry period.

The longest channel distance was chosen to represent all scenarios. In this research, a recharge and discharge relationship graph was created that can be used by site engineers to determine the appropriate canal blocking height as a quick assessment is needed to determine the most suitable height for re-wetting. Based on our modeling, 0.6 m of canal blocking is the best height, while 15.6 m is the minimum requirement for an effective groundwater table level according to the existing site conditions. The results are depicted in Figure 4.

Figure 4 shows a simulation of all canal distances for a canal blocking height of 0.6 m. From the graph above it can be concluded that the longer the distance to the canal, the longer re-wetting process takes, which causes lower groundwater levels. The canal blocking must be higher when the channel distance is longer, in order to speed up the re-wetting process.

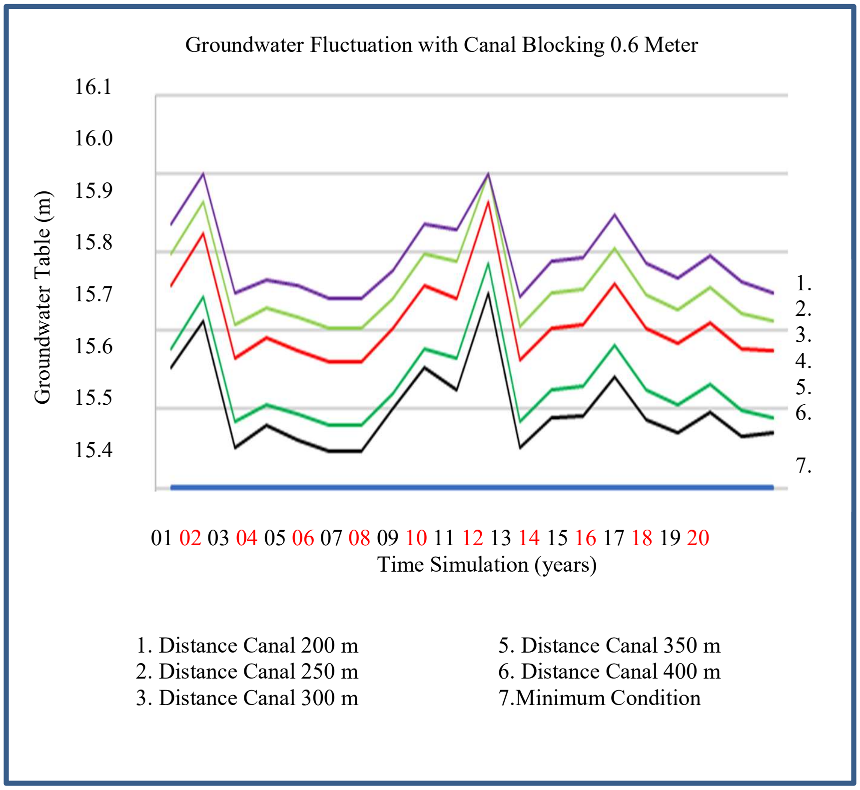


**Figure 4** Fluctuation of the groundwater table, 1997-2016.

## 3.3 Time of Rising Groundwater Table

Canal blocking is planned for peatland when the groundwater table is higher than -0.4 m from the ground level. The depth of the aquifer is 5 m and a suitable groundwater table level is higher than 15.6 m. With this assumption, during several months of the year canal blocking is required. A canal blocking height of 0.6 m was chosen to anticipate dry conditions. The unsteady unconfined aquifer formula was applied to make a graph of the relationship between rain, evapotranspiration and groundwater table rise, as shown in Figure 5.

Looking at the graph of the canal blocking height of 0.6 m, it is concluded that in dry conditions with an evapotranspiration of 6 mm/day and no rainfall, the groundwater rises only 0.38 m. The possibility of wildfire in the dry season is higher, so that this condition is highlighted in the simulation.

Raising the groundwater table is important but the time needed for the re-wetting process has to be calculated. The next graph is to know how much time raising the groundwater level takes after creating a canal blocking. The time was quantified using a numerical method, i.e. the unsteady unconfined aquifer formula. Some evapotranspiration conditions decreased by precipitation, changing the time required for the re-wetting process.

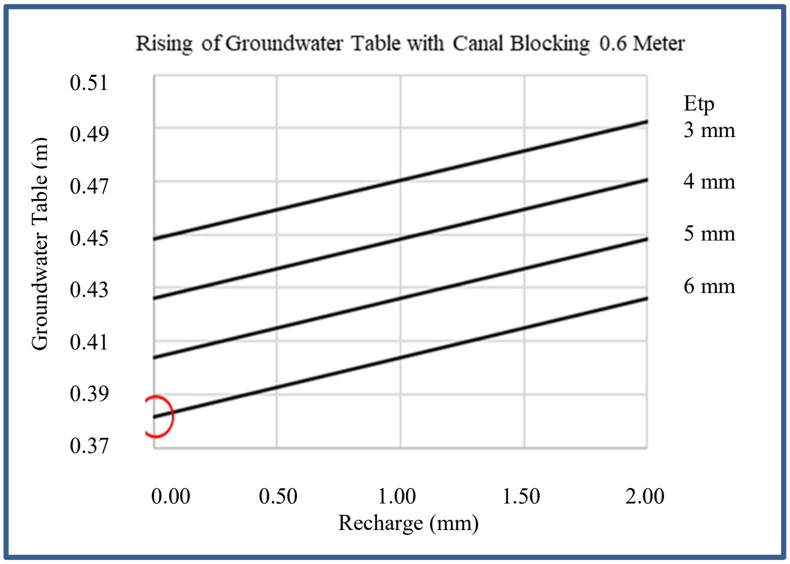


**Figure 5** Rising groundwater graph.

The figure shows the correlation between time and groundwater rise. The dry conditions in Figure 5 cause a groundwater rise of up to 0.38 m, where the re-wetting process takes 30 days according to Figure 6. The figure is able to help site engineers to control the time it takes to reach the groundwater level for plant needs.

Figures 5 and 6 can help site engineers in the field to decide the height of the canal blocking infrastructure based on the variability of climate conditions and groundwater level requirements for plant needs. The quick assessment method that was developed in this research provides a simple way to understand the correlation between recharge and discharge below the ground, based on which the most suitable re-wetting infrastructure can be chosen.

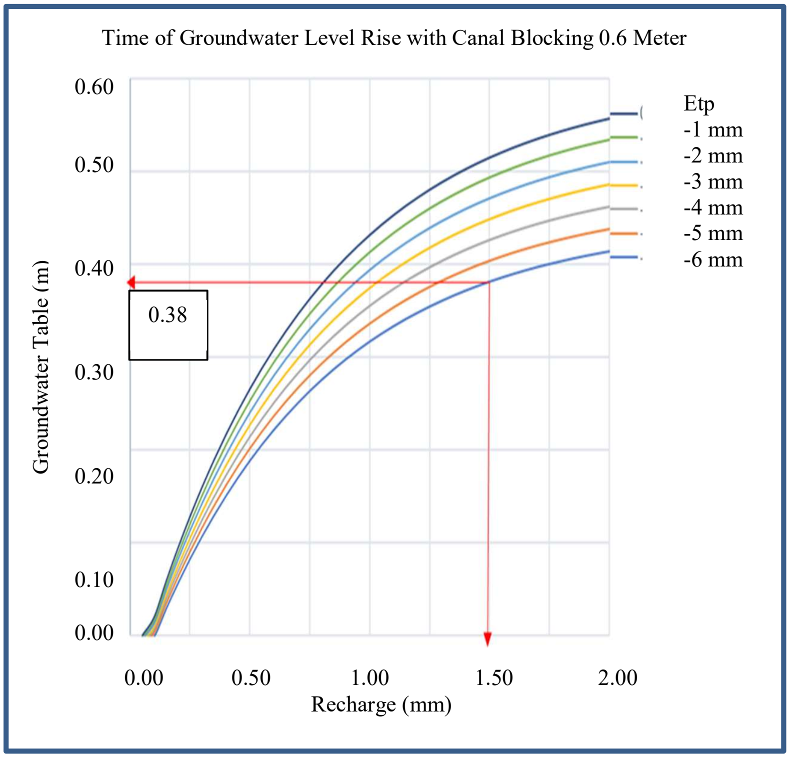


**Figure 6** Time of rising groundwater chart.

## 4 Conclusion

The effectiveness of canal blocking was quantified by Freewat modeling based on data covering 20 years (1997-2016). Drainage canals with different canal blockings were observed to find their correlation with the groundwater level. The simulation scenarios consisted of a combination of different canal distances and canal blocking heights. The input recharge and discharge were simulated and the conductivity value was 50 m/day according to the calibration, which had an NSE of more than 0.8 and a correlation value of more than 0.9. Failures occur every year, so we offer the solution of canal blocking. A number of canal blocking height scenarios were simulated. The best canal blocking height is 0.6 m, which is able to increase the water level by 0.38 m in a maximum of 30 days for the required raise of the groundwater table.

The effectiveness of the canal blocking depends on various combinations of canal distance and canal blocking height. The groundwater rise and time required for the re-wetting process are important to be calculated, so the graphs in Figures 5 and 6 were developed. The graphs can be used by site engineers to choose the most suitable canal blocking height for peatland re-wetting. Without making any calculations, the site engineer can find which the most suitable canal blocking height is. This research showed that the larger the canal distance, the higher the canal blocking that must be applied to raise the groundwater table, which extends the time required for the re-wetting process.

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## References

[1] Rydin, H. & Jeglum, J.K., *The Biology of Peatlands.* Ebooks Corporation, Oxford University Press, Oxford, United Kingdom, 2013.

[2] Ōsaki, M. & Tsuji, N., *Tropical Peatland Ecosystems*, Tokyo Heidelberg New York Dordrecht London: Springer, 2016.

[3] Hooijer, A., Page, S., Jauhiainen, J., Lee, W.A., Lu, X.X., Idris, A. & Anshari, G., *Subsidence and Carbon Loss in Drained Tropical Peatlands*, Biogeosciences, **9**(3), pp. 1053-1071, 2012. DOI: 10.5194/bg-9-1053-2012

[4] Wösten, J.H.M., Van Den Berg, J., Van Eijk, P., Gevers, G.J.M., Giesen, W.B.J.T., Hooijer, A. & Wibisono, I.T., *Interrelationships between Hydrology and Ecology in Fire Degraded Tropical Peat Swamp Forests*, International Journal of Water Resources Development, **22**(1), pp. 157-174, 2006. DOI: 10.1080/07900620500405973.

[5] Sumarga, E., Hein, L., Hooijer, A. & Vernimmen, R., *Hydrological and Economic Effects of Oil Palm Cultivation in Indonesian Peatlands*, Ecology and Society, **21**(2), 52, 2016. DOI: 10.5751/ES-08490-210252.

[6] Biancalani, R., Avagyan, A. & Food and Agriculture Organization of the United Nations (Eds.), *Towards Climate-responsible Peatlands Management,* Rome: Food and Agriculture Organization of the United Nations (FAO), 2014.

[7] Ritzema, Henk, Limin, S., Kusin, K., Jauhiainen, J. & Wosten, H., *Canal Blocking Strategies for Hydrological Restoration of Degraded Tropical Peatlands in Central Kalimantan*, *Indonesia*, CATENA, **114**, pp. 11-20, 2014.

[8] Indra, E.P., *The Effect of the Precipitation Pattern of the Dry Season on Peat Fire Occurrence in the Mega Rice Project Area*, Central Kalimantan, Indonesia. Tropics, **19**(4), pp. 145-56, 2011.

[9] Page, S., Hosciło, A., Wösten, H., Jauhiainen, J., Silvius, M., Rieley, J. & Limin, S., *Restoration Ecology of Lowland Tropical Peatlands in Southeast Asia: Current Knowledge and Future Research Directions*, Ecosystems, **12**(6), pp. 888-905, 2009. DOI: 10.1007/s10021-008-9216-2

[10] Ministry of Environment and Forestry of the Republic of Indonesia (KLHK), *Law No. 16 of 2017 on Technical Guidelines for Recovery Peat Ecosystem Function,* 2017.

[11] Ministry of Environment and Forestry of the Republic of Indonesia (KLHK), *Government Regulation of the R.I. No. 71 of 2014 concerning Protection and Management of Ecosystem of Peat lands*, 2014.

[12] Ministry of Environment and Forestry of the Republic of Indonesia (KLHK*), Law No. 32 of 2009 on Environmental Protection and Management*, The State Gazette of the Republic of Indonesia of 2009 number 140. Jakarta, 2009.

[13] Dohong, A., Indratmo, S., Wibisono, ITC., Maas, A., Rais, D.S., Triadi, B., Rahmadi, Aditya, T., Nasir, D., Fakhturahman, Subahani, E. & Kiki, A., *Peatland Ecosystem Restoration Plan, Pulang Pisau District, Central Kalimantan Province*, Peatland Restoration Agency (BRG), Jakarta, 2016.

[14] McDonald, Michael, G. & Harbaugh, A.W., *A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model*, US. Geological Survey, pp. 1-539, 1984.

[15] Rai S.N., *Modeling Groundwater Flow in Unconfined Aquifers*, in Basu S., Kumar N. (eds.) *Modeling and Simulation of Diffusive Processes. Simulation Foundations, Methods, and Applications*, Springer, Champ., pp. 187-210, 2014. DOI: 10.1007/978-3-319-05657-9_9.

[16] Remson, I., Hornberger, G.M. & Molz, F.J., *Numerical Methods in Subsurface Hydrology*, Wiley- Interscience, Newyork, 1971.

[17] Humam, I.A,. *Modeling of Water Balance and Groundwater Table in Peatland Hydrological Unit 5 and 6 Kahayan Sebangau, Central Kalimantan Province* in, Master Thesis, Bandung Institute of Technology, pp. 1-98, 2019.