Paper 1

by Nilna Amal

VARIABILITY OF WATER TABLE ELEVATION AND FLOW RESPONSE OF TROPICAL PEATLAND CASE STUDY AT PULAU PADANG RIAU PROVINCE OF INDONESIA

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Abstract

Peatland is a type of soil that characterized by high water content. Using peatlands for plantation is accompanied by the presence of a channel. It caused water table decreasing to a certain depth that increases the risk of fire. The study aims to observe characteristics of water table level in order to reveal the peatlands hydrology transformation. The study was conducted in Pulau Padang Riau Province of Indonesia, which is a drained peatland that has been developed for industrial crop cultivation. The land is managed by different two groups, which are those maintained by the local community and by private companies. The analysis was carried out by using a balance of water budget on peatland. The results showed that there are correlations between water management with the state of water table elevation, especially the way and the presence of the channels. The decrease in the water table in local community areas is higher than that in companies' land with a variety in the value is higher. This phenomenon occurs because there are no canal blocks on the peatland, which is managed by the local community so that the rise and fall of the water surface occur naturally..

Keywords: *peatlands, water table depth, channelization, rainfall, direct runoff*

1. Introduction

Deforestation, especially peat forests, has received serious intention from researchers. Some of the articles cover the forest point of view, such as the quantity area of forest loss (Page 1997; Curran, 2004), the amount of carbon and its balance in peatland (Suzuki et al. 1999; Tuittila et al. 1999) relationship between vegetation and water table especially in the drained peatland (Tuittila et al. 1999; Breeuwer et al, 2007; Potvin 2015; Ruseckas 2015) and the reduced number of specific plants (Curran et al.1999; Haapalehto et al. 2010). Other presents hydrodynamics of hydrology characteristics. Those such as alteration in hydraulic conductivity and interaction between peatland hydrodynamics, climate and carbon sink (Curran et al. 1999; Komulainen et al. 1999; Curran et al. 2004; Briggs et al. 2007; Wösten et al. 2013; Harenda et al. 2018), . The significant roles of peat, including swamp, are its ability to store carbon stocks (Vitt 2008; Harenda et al. 2018), a major factor for runoff production (Bay 1969; Holden et al., 2011). Others are as a source of water and even as an alternative to decreasing floods (Holden 2005; Acreman and Holden 2013) triggers it to be an essential research object. The analysis is needed to manage peat soils to provide benefits that are greater than the losses incurred due to the converting function.

The total peat area is estimated to reach 2.84% of all the world's land (Xu et al. 2018) with tropical peat is 11% of the global peat area (Page et al. 2011). Peatlands contain soil carbon stock reach to 20%. The volume of tropical peat carbon 15%-19% of the global peat carbon that 77% of tropical peat in Southeast Asia which the biggest is in a single country i.e. Indonesia which is around 65% (Wu et al. 2010; Page et al. 2011). Indonesian peatlands become significant in order to recognize the characteristics of tropical peatland, including volume of carbon due to its dominant peatland in Southeast Asia and the differences with subtropical peatland (Murdiyarso et al. 2019; Wahyunto et al. 2016; Shimada et al. 2001).

Management of peatlands requires drainage to achieve a water table level that is appropriate for plants. Peatland, which is saturated or even flooded, will need special treatment before it can be used as plantation or agriculture. Those need drainage to prepare them so that those have a water content that is following the types and the function of plants to be planted (Mitsch and Gosselink 2015; Breeuwer et al. 2009; Potvin et al. 2015). Drainage systems on peatland have caused various effects. Those are the differentiation between the top layer and down layer, altering the composition of acrotelm-catotelm, changing in groundwater level, and altering in the fluctuation of overflow and carbon reduction. (Grand-Clement et al. 2015; Daniels et al. 2008, Holden et al. 2006; Holden 2005).

Water table level state is the core for understanding the changes that occur in drained peatlands (Daniels et al. 2008; Wosten et al. 2008; Erwin 2009; Postila et al. 2015; Howie SA and van Meerveld 2013; Ruseckas et al. 2015). The relationship between water table elevation and peatlands hydrology is investigated to determine its potential against fire threats (Novitasari et al. 2019). The study about the relationship between water table elevation and peatland conditions was carried out by Wosten et al. 2008. It resembled the actual term by using the hydropedology model. SIMGRO (Simulation of groundwater flow and surface water levels) model was used to assume water level state. The study was conducted in Kalimantan and produced a map. It describes peatland vulnerability with an estimated groundwater level based on the characteristics of hydraulic conductivity and soil moisture content.

Peatlands in Indonesia as part of tropical type has been a concern and subject of research for a long time (Brady 1997; Curran et al. 1999; Shimada et al. 2001; Page et al. 2002; Miettinen and Liew 2010; Ritzema 2014; Uda et al, 2017). Peatlands distributed in Sumatra Island, Kalimantan Island, and a little in Papua Island (KMLH 2019;). Sumatra peatlands as in Kalimantan are deep in-depth and have undergone drainage, but the level of research is not as much as research on Kalimantan peatlands (Page et al. 2002), one of them is research on Pulau Padang (Brady, 1997). Some of them are intended to provide recommendations for other tropical countries that have not yet converted much of their peatlands such as Peru and the Republic of Congo (Murdiyarso et al., 2019); others are to see what influence is dominant once forest loss occurs in Kalimantan (Curran et al., 2004; Miettinen and Liew 2010) or the amount of carbon released by peatlands in the fires that occurred during 1997 (Page, et al., 2002).

The approach to characterize swamp hydrology, including peatland other than water table elevation, is carried out through the water balance analysis (Holden 2005; Mitsch dan Gosselink 2015, Grundling et al. 2015; Gracz et al. 2015; Edom et al. 2010). The hydrological and hydraulic state of peatlands can be identified by changing the water table level, altering hydraulic conductivity and fluctuating flow rate in the channel. (Postila et al. 2015; Holden et al. 2006,; Edom et al 2010).

Study of runoff on peatlands (Stewart and Lance, 1991; Evans et al., 1999; Holden and Burt, 2002a,b, 2003a,b, Gracz et al 2015) shows that at the location of the intact peat layer, the flow rate usually starts occurring where the groundwater level is in the upper layer which is about 50 mm below from the peat surface, namely in the acrotelm layer and at that point time the saturation or excess flowing stars to flow.

Research on peatland areas in the tropics such as Indonesia has differences with the other four-season countries, such as very thick peat depths of up to more than 12 meters like those on the Pulau Padang Riau Province (Brady 1997; Page et al. 2011). Pulau Padang is a deep peatland that has been restrained and converted into a variety of plantations (Karyanto, 2000). Research in a particular area with detailed and local scaled is needed to understand how peatlands transform during managing (Curran et al. 2000; Shimada et al. 2001, Whitfield 2009). In addition to land that has experienced canalization such as Pulau Padang, the necessity is more significant. Studies will be done to investigate whether hydrological characteristics change will be found after the use of peatland for plantation or agriculture.

Two different characteristics are available in Pulau Padang i.e area is managed by the corporate, and the community manages it. The study aims to: 1) to compare the state of the water table level on both of the characteristics, 2) to describes the process of runoff channel showed a response of peatlands to rainfall and 3) to analyze the state of the groundwater by frequency of occurrence.

2. Material dan Methods.

The study was conducted on one of the drained tropical peatlands in Riau Province and carried out for two months, from November to December 2017 and arranged it at two location points representing community-managed land and the company's concession area. The more explanations are in the description below.

2.1. Site description.

Pulau Padang is one of a series of four main islands within the Kepulauan Meranti Regency, Riau Province. Pulau Padang is a Peatland Hydrological Unity (Kesatuan Hidrologi Gambut KHG) with the entire area is 1.114,04 km2. Geographically Kepulauan Meranti district is located 0° 42' 30"- 1° 28' 0" N dan 102° 12' 0"- 103° 10' 0" E. The climate in Pulau Padang as well as in the Kepulauan Meranti district region is temperate with maximum air temperatures ranging from 25°C – 32°C (BPS Kepulauan Meranti District, 2017). Figure 1 below shows the area of the study (LKFT, 2017).

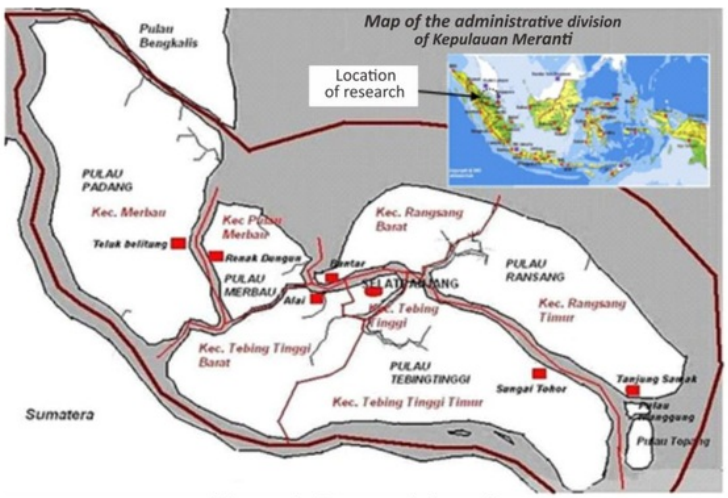

Figure 1. Research location

Pulau Padang has a flat topography with a maximum height of 15 m above mean sea level (MSL). The Thickness of peat on Pulau Padang, like others in Indonesia peatland such as Kalimantan, tends to be more than three meters. Figure 2 shows that the primary type on Pulau Padang is 6 meters or more in-depth so that it can be categorized as deep peat, depth of groundwater tends to be more stable than shallow peat (Brady, 1997).

2.2. Field Measurements

Hydrological data needed are rainfall data, flow data, and water table elevation (WTE) data. Data collected is daily rainfall measured using automatic rain gauge (ARR) for 10 minutes series. The two sets of equipment are installed in Sei Hiu village and Bagan Melibur village. The installation of the pieces of equipment in the sketch can be seen in Figure 2 below. Figure 2 describes that water table elevation measurement installed at the center of the area and automatic water elevation and rainfall settled at the edge of the zone. The arrangement of materials is needed to observe the state of the groundwater level condition and its relationship to the water level in the channel.

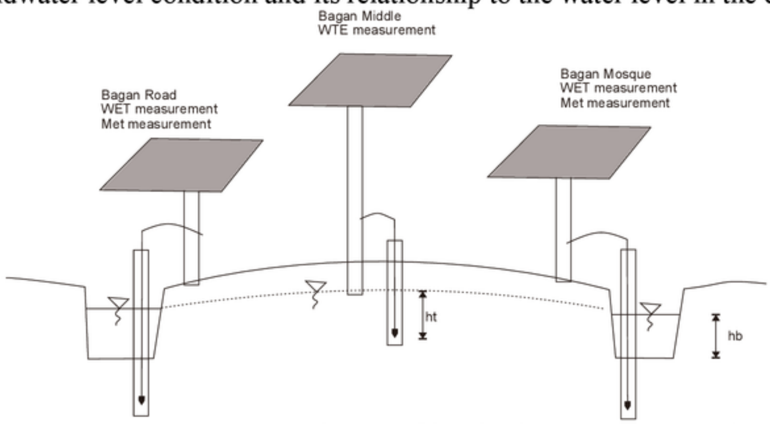

Figure 2. Sketch of measurement equipments

2.3 Secondary Data

There are two kinds of water table elevation (WTE) information. Those come from the results of measurements called primary data. Others comes from monitoring that have done by Riau Andalan Pulp Paper (RAPP) as secondary data. Secondary data covers the RAPP area which consists of industrial plantations (IP) which are presented in three stations, namely PPD1, PPD2, and PPD9; three natural forests (NF) not yet planted namely PPD3, PPD4 and PPD 10 and one buffer zone (BF) area (PPD 8). Data covers 2015 to 2017 at intervals of one hour. Even though data was started from 2015 but not all of them are complete, so the analysis will have its limitation here.

3. **Literature Review**

3.1. Water Balance Equations on Peatlands and Debit Analysis on Channels.

Water table elevation data change can be used to study the influence of the presence of channels and land cover on groundwater fluctuations. The water balance equation can analyze alteration in the groundwater level. The formulation will be different for drained peatlands with network systems than that are still intact. It happens because the presence of canals will significantly influence the groundwater fluctuations that are affected by the rate of groundwater wear by the process of subsurface runoff.

The general equation of water balance in peatlands is in a rain state just before the canal network is based on the hydrometeorological cycle as follows:

$$\Delta S = P - ET - RO - I \tag{1}$$

where:

- P : rainfall (mm/day),
- ET : evapotranspiration (mm/day),
- RO : surface flow (mm/day),
- I : infiltration (mm/day),
- ΔS : water storage change (mm/day).

The discharge that occurs for each rain event is calculated as the description below. The total runoff volume leading to the canal (VRO) is equal to the above-ground runoff volume (SRO) coupled with the subsurface runoff volume (SSRO) and changes in groundwater storage can be stated as follows.

$$\Delta S = \sum I - \sum O \quad (2)$$

$$\Delta S = VP - (VRO + VET) \quad (3)$$

where:

ΔS : change in water storage volume (m^3),
$\sum I$: total of *inflow* = volume of rainfall (m^3),
$\sum O$: total of *outflow* = *runoff* + evapotranspiration (m^3),
VP : rainfall in volume (m^3),
VET : evapotranspiration in volume (m^3),
VRO : volume of total direct runoff total flow to canal (m^3).

4. Results and Discussion

Peatland management carried out by two large groups will distinguish the peat hydrological states that have been managed. It maintained by the community have simple characteristics, have not implemented a regular system, and have almost no canal blocking. On the other hand, the land runs by the company have higher network density characteristics and regularity of the channel system including the presence of canal blocking.

4.1. Analysis of changes in water table elevation to water management

The secondary data was examined by using the percentage of secondary data presentation of WTE events. Canal with regularly monitoring by cooperate staff surrounds all the space, including the natural forest and the buffer zone. The IP has the main channel with width and id-channel between the block.

The results of the analysis showed that there is a wide variation between the lowest and highest water table elevations (WTE). Some value exceed the government requirements that is 0.4 m below the surface (RI 2014) following the graph presented in Figure 4 below.

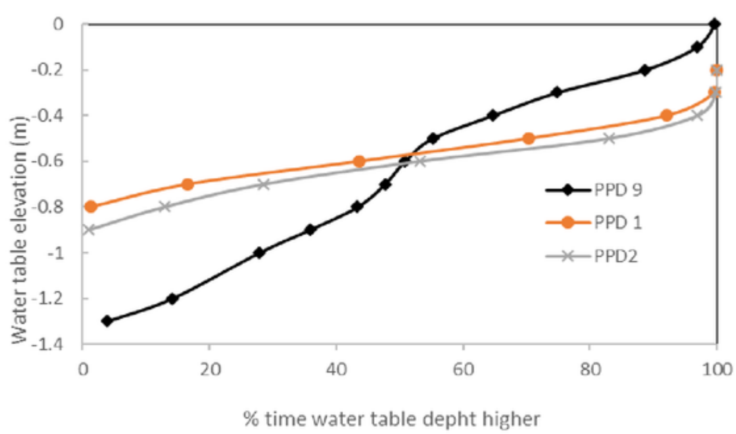

Figure 3. Water table frequency curves for area of IP

From Figure 3, it can be seen that, in general, the groundwater level is almost always outside of the allowed level. PPD 9, a state higher than -0.4, reaches around 60%, which is the best. 80% of the value of PPD 1 and PPD 2 are higher than the allowable limit. Therefore it can be concluded that water table elevation at most of the time of the study is in a position that is not recommended. It can be analyzed that the chance of a fire associated with the groundwater level will be higher. For another region, the trend can be explained by the graph below.

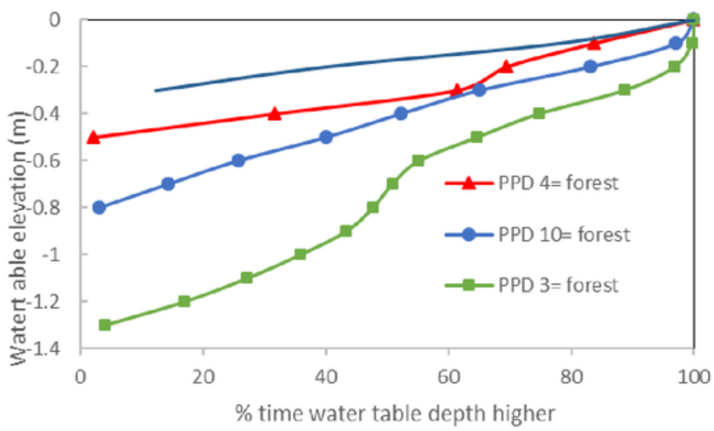

Figure 4. Water table frequency curves for natural forest and buffer zone

The buffer zone in Figure 4. shows as the most stable state of water table level. Forests (PPD3, PPD4 and PPD 10) that should have more stable groundwater depths were nor found not which areas where groundwater depths reached -1.3 m. In addition more than 80% of the depth is at an insecure depth that exceeds the recommended value of 0.4) as can be seen in Figure 4. IP area and the buffer zone have Acasia Crasicarpa as the homogenous area, whilst forest has more Melaleuca cajuputi (gelam in local language) rather than other plants. In fact that the type of land management and the type of plants do not determine to water table elevation condition, therefore it is needed to recognized another factor that can be a determiner.

The main difference between the three areas other than the type of plants is the management of water. On the IP land, the water system is built by the main canal and middle canal. The main canal lay in the boundary between the blocks whilst the middle canal is located in the center of the block. There is only the main canal in the buffer zone and there is no canal system in natural forest but a little ditch.

The large canals regulate all inflow and outflow enter and out of the area and can even hold or allow flow to other areas. Whilst mid canal regulates water intern the block so that it can be assured the plants will never be flood. It can be understood why in the buffer zone where there is no mid canal, water level elevations always are at higher than 0.4 m even more, and sometimes it flooded which is not a perfect condition for the plants.

The analysis used rainfall data from automatic rain gauges and water table level data from automatic water level recorder. The following is a graph obtained from the two pieces of equipment. Analysis of water table level and presentation of events is shown in Figure 5 below. Figure 5 shows the condition of water table elevations at the two locations where data was taken during the study. The noticeable difference is the antecedent of the groundwater wherein Bagan Melibur reaches a depth of -1.9 m while the Sei Hiu is only -0.7 m.

The graph in Figure 5 shows that there are differences in the trend of changes in the water table level in the two areas. Bagan Melibur tends to have a high level of variability, namely the water level from -0.6 m to -1.9 m while it in Sei Hiu only ranges between -0.4 to -0.6. Compared to government regulations it can be concluded that Sei Hiu is still within safe limits while Bagan Melibur into hazardous areas even tends to be risky because at the beginning of the wet season it reaches up to -1.9 m.

In Bagan Melibur area, it can be seen that the water table elevation below 40 cm takes place less than 10%, which means that nearly 90% of the depth of the water table altitude that happens is not at the recommended level. In the Sei Hiu area, the water table level lower than 40 cm occurs more than 70% so that the water depth limit that exceeds the allowable limit occurs at a maximum of 30%.

Some of the difference between the two zones that can be mentioned as the causes of these facts is Bagan Melibur, which is a community managed area that does not yet have canal blocks. It means it does not have a scheme that can be used to hold water so that rainwater flowing as runoff directly flows to downstream and does not have time to influence the water table level change on the land.

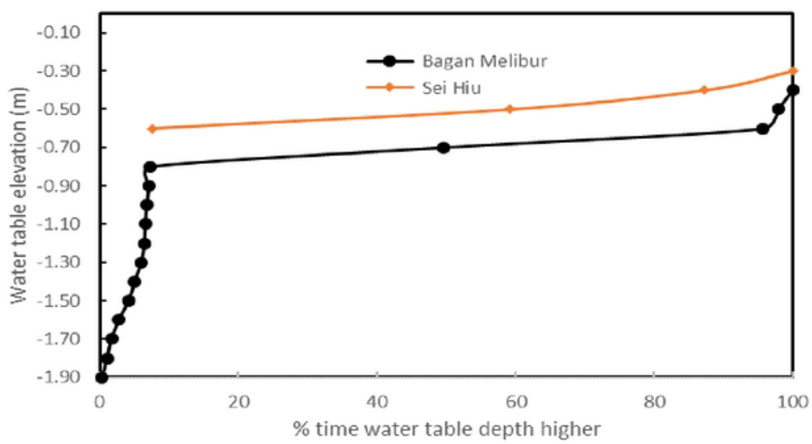

Figure 5. Water table frequency curves for Bagan Melibur dan Sei Hiu

Some of the difference between the two zones that can be mentioned as the causes of these facts is Bagan Melibur, which is a community managed area that does not yet have canal blocks. It means it does not have a scheme that can be used to hold water so that rainwater flowing as runoff directly flows to downstream and does not have time to influence the water table level change on the land. While Sei Hiu area which is located upstream has a canal block so that it has the opportunity to hold water for longer on the preferred channel section so that if the land started has begun to dry, the water is not allowed to flow downstream. This situation makes alterations in the water table level in Sei Hiu tend to be better than Bagan Melibur area. Compare to studi have done by Holden et al (2011) this research has a main difference in variability interval in WTE that are between -0.4 until -1.9 while Holde et all 2011 only between +0.1m until -0.6 m. The difference between tropical peatlands with sub tropical still need to be revealed to understand deeper each characteristic. The presence of canal blocks in research on Central Kalimantan peatlands (Ritzema et al., 2014) has raised the water level significantly to elevations above -0.4 after previously reaching below -1.22 m but unable to maintain the water level in the dry season. The trend of lower water level in the downstream area also occurred in this study.

There is a positive correlation between alteration in water table level and the presence drainage channels (Luscombe et al., 2016; Page et al., 2009) that is artificial drainage decreases the extent of the water table. In this study, both locations have a human-made channel, and the depth of the groundwater varies, but those are strongly influenced by the occurrence of rain which is consistent with research on peatlands in Kalimantan (Ritzema et al., 2014).

The hydrological response to the previous low groundwater conditions (antecedent) shows that the discharge rises rapidly while the groundwater level tends to be flat and even static (Daniels, et al., 2008). In the rainfall event December 6, 2017, the antecedent height of groundwater level at Bagan Melibur and Sei Hiu are -1.9 and -0.6 respectively. In this study, the Pulau Padang state, when rainfall fell in Bagan Melibur then water table level rose rapidly to a height of -0.8 m with antecedent height was -1.9, then it took a long time to rise to an elevation of 0.7m. When the rain prolonged the water table only rose gently until it reached a stable state at 0, 4 m so that the situation was different from Daniels' 2008 study in South Pennines, UK.

4.2. Analysis of flow response to rainfall and water table level

Drainage has a considerable influence on flow generation and groundwater spatial based (Holden et al., 2006, Wosten et al, 2008) so that on a drained peatland like Pulau Padang, it is necessary to do a spatial based flow analysis. Those are laid on different topography, i.e., Sei Hiu located upstream, and Bagan Melibur positioned in the downstream area. Some rain has occurred during the period of data collection, as follows in Figure 6 presented the relationship between rainfall events with the generated discharge flow.

Discharge data 4 s presented along with groundwater level at the same time interval and subsequently shown in the following table:

The antecedent condition of the groundwater water table level has been quite high as in the December 3 rain event (Figure 5) it can be seen that the increase in water table level still occurs but is smaller. This is due to the high antecedent groundwater level, which has reached -0.6. Later one hour after the rain with a total rainfall of 22.5 mm the groundwater level rises to -0.5 so that it can be concluded that the groundwater rise becomes smaller if compared to previous rainfall events where the groundwater level was still low because it was just starting to enter the rainy season.

Time (minutes)	Rainfall (mm)	Volume (m^3)	Discharge (m^3/det)	WTE (m)
0	0.3	0.000	0.000	-0.655
10	8.4	48.527	0.081	-0.643
20	6.6	6.066	0.010	-0.589
30	1.8	0.000	0.000	-0.555
40	2.7	18.198	0.030	-0.533
50	1.8	6.066	0.010	-0.517
60	0.3	6.066	0.010	-0.555
70	0	6.066	0.010	-0.545
80	0	6.066	0.010	-0.543
90	0.3	12.132	0.020	-0.543
100	0.3	0.000	0.000	-0.537
110	0	6.066	0.010	-0.535
120	0	0.000	0.000	-0.535
130	0	0.000	0.000	-0.536
140	0	0.000	0.000	-0.533
150	0	0.000	0.000	-0.538

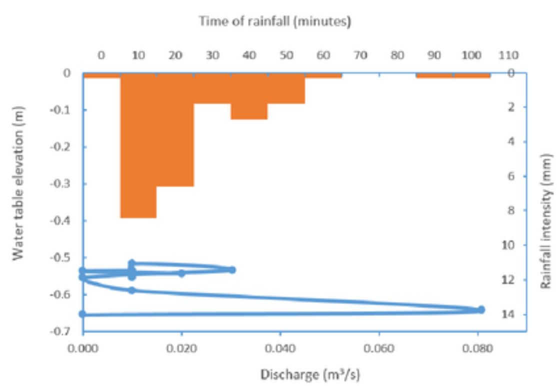

Figure 6. Discharge-water table elevation relationships at rainfall on Desember 3rd 2017

It can be seen in this study that discharges do rise rapidly (Figure 6), in contrast to Daniels et al, 2008, the ground water level rises slowly or even tends to be static. On the other hand it is rising rapidly as seen in the November 6th rain event. In this event the groundwater level was initially at position -1.2 and in the first 10 minutes with a rainfall height of 6.3 mm, there is a discharge of 0.06 m3 / sec and the water level is still in the number -1.2; then one hour later the groundwater level has become -0.8 with a total rainfall of 36.3 mm. The increase in water table level continues even though the rain begins to decrease and one hour later the water table level has reached 0.4 and after that the ground water level is relatively constant. The difference in response to the hydrological state in an area is mainly determined by the heterogeneity of the region spatially and temporally. It is included the characteristics of each peatland (Parry et al., 2914).

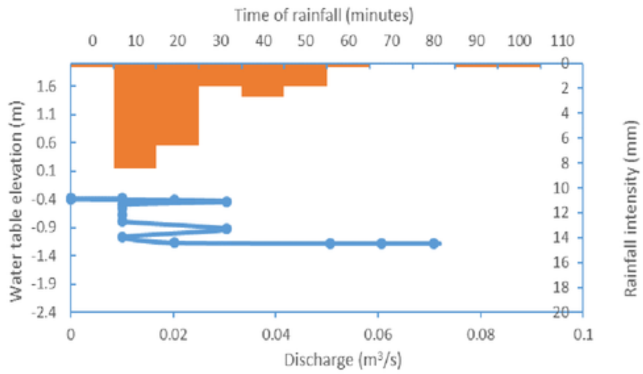

Figure 7. Profile rainfall and discharge vs water table elevation on November 6th 2017

In areas that have been drained, the profile of flow is sharper so that flow quickly reaches the peak while the intact peat with the original channel flow is longer (Holden et al., 2006). In this study, it is drained peatland that has been managed for cultivation as it can be seen that when there is the rain, the water is quickly converted into current and reaches the peak consequently there is a similar phenomenon with previous research. The graph in Figure 7 and Figure 8 below is a comparison between research in South Pennines UK by Daniels, et al., 2008 compared with this study. In low groundwater conditions, tropical peatland shows the same trend as peat which lies in sub-tropical regions.

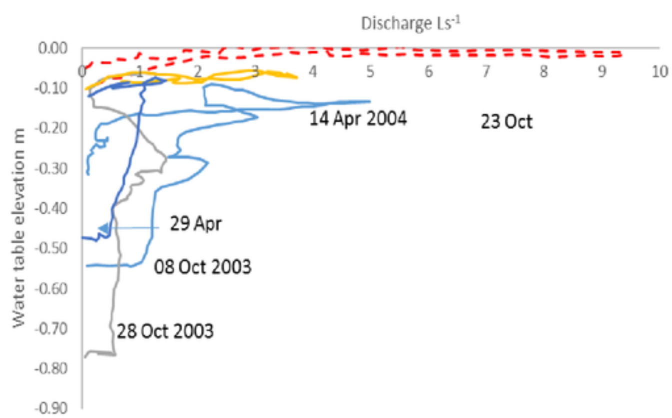

Figure 8. Graph of discharge vs water table elevation (Daniels, 2008)

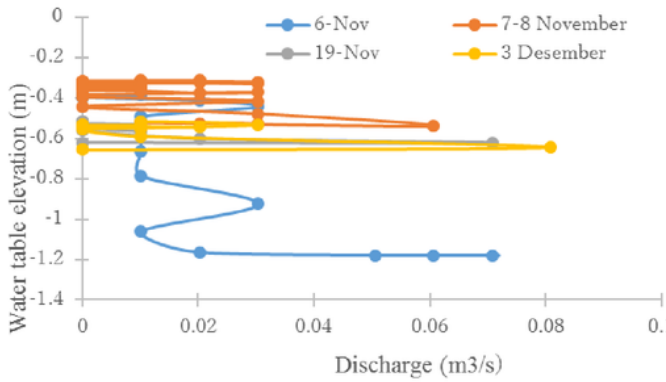

Figure 9. Graph of discharge vs water table elevation in Bagan Melibur

Conclusion:

Research on the location of Pulau Padang peatlands shows that there are significant changes in groundwater levels during the period of data collection, i.e. secondary data from 2015 until 2017 and primary data i.e. November to December 2017. There are major difference between area with the systemic channel and that with does not have. The area with the systemic canal have an opportunity to arrange the water elevation at the canal to control water elevation in order to control water table elevation. Different from that, the area without the complete canal will be determined by the season and environment itself. It will be needed advanced research about the relationship between the canal for instance dimension and density to the water table elevation.

Changes in water level are mainly determined by the incidence of rain and the condition of the initial water level at an altitude that exceeds the regulation recommended by the government, which is -0.4m. There are similarities and differences in the two locations of study. The hydrological response in the two regions, especially the flow rate in the channel looks the same only in the Sei Hiu there is no previous condition (antecedent) with an significant water table level. Further research is needed on the state of change in the dry season where the evaporation takes place and has a principal influence on the influence of thick peat on changes in land surface and flow response.

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