Developing water management objective on tropical peatlands under oil palm cultivation

M S Imanudin¹, M E Armanto¹, E Wildayana¹, Bakri¹ and H Junedi²

¹ Faculty of Agriculture, Sriwijaya University, Indonesia.
² Faculty of Agriculture Jambi University, Indonesia.

E-mail: momonsodikimanudin@fp.unsri.ac.id

Abstract. Less attention to peatlands for various economic development activities have led to the emergence of serious environmental problems. The problems are floods in the rainy season, fires in the dry season and increased carbon emissions. This paper aimed to examine physical and hydrological characteristics to develop land management plans. The research was conducted on peatlands used for oil palm plantations. The study concluded that the available drainage system generally indicates excess discharge (over drainage). Water retention efforts proved effective in secondary channels and are able to raise the water level of 20-30 cm higher than the uncultivated peatlands (no water retention). Fluctuations in groundwater levels in the period from August to September on the cultivated peatlands showed that the groundwater is deeper than the uncultivated peatlands. It determined greater value of evapotranspiration of oil palm plantation. If the floodgates do not exist, then the groundwater becomes deeper than the cultivated peatlands. In the January-February period of the groundwater in the cultivated peatlands can be increased to 20-30 cm under the soil surface, but on the uncultivated peatlands without controlling the water level drops at the position 40-50 cm below the soil surface. Thus the concept of water retention became the main purpose for water management in peatlands.

1. Introduction

Approximately 20 million ha of peatlands, which is equivalent to half of the tropical peatlands in the world, are in Indonesia [1]. Therefore, Indonesia has an important value and strategic views of biodiversity and ecological functions. Peatland is generally located between two rivers; thus, it hydrologically formed a unique island-shaped "dome". Depth variability of peats greatly affect the carrying capacity of peats to store water, vegetation, and management policies. On the other hand, land clearing for oil palm plantations and industrial plants are still ongoing [2].

In the long dry conditions (more than three months) in the absence of added water containment efforts then drying peat is becoming increasingly widespread, even to areas that have not been opened. It is therefore important to do a field study to find peatland management options for the creation of conditions of the ground water level that meet the needs for plant growth and prevent forest fires. Approach to land capability should be involved in the preparation of management plans on peatlands [3]. During this time, many companies only see from the ground surface; the depth of peat is the key factor often overlooked. Often found in the cultivation of plants is done on the peat depth more than 3.0 m deep or even more [4]. The business world should count carefully because cultivation in peatlands is costly. To increase one-two units of pH values required 10-30 tons of dolomite [5].
Cultivating wetlands and peatlands for oil palm plantation and acacia industrial plantation (HTI) in South Sumatra has been started since 1990, which have brought serious impacts to environmental issues such as among others degradation of peat quality, decreasing water level, increasing decomposition rate of peat leading to carbon emissions, peat subsidence, changing of peat characteristics, losing ability to store water, hydrology, land and forest fires [6]. Several efforts should be done to increase ground water table. Installing the canal blocking has significant effect to increase water table [7].

Water management in peatlands are unique compared to that of mineral soils, since the peatlands have high ability to absorb a lot of water (hydrophilic), and if peatlands are over drained their ability to absorb water will dramatically decrease (hydrophobic). The condition occurs because the peats occur irreversible drying process (irreversible drying), especially if peats experience very long (extreme drying condition. Therefore peat land drainage process is not simply boast drain the excess water or land, but how to create the conditions so that the water level could support evapotranspiration needs of plants, and water movement of capillarity humidity can still maintain that peat soil surface soil from drying out [8]. Therefore, the process of peat land drainage is not only to throw excessive water or drain the land, but how to create the conditions where the water level in order to support the needs of crop evapotranspiration, and the movement of capillary water can still maintain soil moisture on the soil surface, so that peats are not experiencing totally dry [9].

Water regulation in peatlands has also to consider the impact on the rate of decomposition of peat. There is a linear relationship between the depth of the ground water level in the channel and the water level in the plot of land. Decreased water level will be followed by an increase in carbon emissions. There is a very strong correlation with less value of regression ($R^2 = 0.71$), which is expressed in $CO_2$ emissions = $0.91 \times$ depth of groundwater [10].

The depth of drainage for the ideal oil palm is between 50-70 cm and rubber plants ranging from 20-40 cm, while the sago palm plants do not require drainage but still require water circulation as well as rice. In general criteria for good water acacia management (HTI) in peat land among which the depth of soil water at planting about 20 cm, and after the age of 1 year was lowered to 30 cm, for further lowered by 10 cm for each year of the aging of the plant. Finally, at the age of 6-8 years of ground water depth was maintained at approximately 80 cm below the soil surface. According to [11] land use for agroforestry systems allows groundwater to be maintained at a depth of 40 cm. Because it aims to meet the needs water requirement. This paper aimed to examine physical and hydrological characteristics to develop land management plans.

2. Materials and methods

The study was conducted in peatlands cultivated with oil palm and some areas not been planted. The research was conducted in the beginning of August to December 2016. Tools and materials used included peat driller, ring samples, measuring instruments of soil conductivity (permeameter) and the well to measure groundwater levels. The research work was divided into field and laboratory works. Filed activities were to perform network of water system, land use, measuring peat depths, making the soil profiles, and monitoring of water levels and daily rainfall.

The excess water was calculated in the root zone of 30-50 cm. Rated value of 30 cm was determined as the minimum condition of the ground water level, which was received by the crops not to experience water stress in wet condition, while the excess water of more 50 cm in the rooting zone is the tolerable limit for oil palm.

Water status on each plot of farmers can vary due to differences in humidity and depth of the groundwater levels. The excess amount of water (excess surplus water) at a depth of less than a certain depth SEW-30, for example, gives a measure of the condition of excessive soil moisture deficiency during infancy, which can inhibit plant growth. These conditions indicated when water falls below 30 cm soil, plants will suffer from water stress.

Calculating the excess water in the root zone of 40 cm can be used for the majority of non-rice crops, and also meets the regulatory criteria by the government, which states that utilizing peatlands
has to maintain the water level at a depth of 40 cm below the soil surface. An excess amount of water in the upper 40 cm can be calculated to predict excessive soil moisture for crop growth period. The formula is as follows:

\[ \text{SEW} - 40 = \sum_{i=1}^{n} (40 - x_i) \]  \hspace{1cm} (1)

where \( x_i \) is the groundwater table on day \( i \), where \( i \) is the first day and \( n \) is the number of days during plant growth. Model Drainmod calculate the value of SEW-30 cm per hour, rather than calculate the daily value, therefore the calculation of the value of SEW-30 is more accurate and defined by the following equation:

\[ \text{SEW} - 40 = \frac{\sum_{j=1}^{m} (40 - x_j)}{24} \]  \hspace{1cm} (2)

where \( x_j \) is the ground water level by the end of each hour and \( m \) is the total hours during the period of plant growth.

The position of the water table to the critical limit of 30 cm is done with consideration of the figure of 30 cm below the soil surface taken as not most crops will suffer physiological disorders when the ground water level drops at a point 30 cm or otherwise increase from the figure of 30 cm of the soil surface. This means that when the ground water getting away from the boundary figure of 30 cm or closer to the ground, there will be excess water (excess water).

### 3. Results and discussions

3.1. Existing condition of water system network

Figure 1 shows the arrangement of the network system in the research area. Secondary channel (2) also serves to open access roads, because this channel is parallel to the road. Perpendicular to the secondary channel in the wake of the tertiary channels, these channels have a surface width dimension of 2.5-3.0 m, on bottom width of 1.5-2.0 m. This channel is only connected next to the secondary channel, while the other part (closed end). Tertiary channel length is approximately 1000 m (Figure 1).

![Figure 1. The network system of water management in peat land areas. (1) Secondary channel; (2) tertiary channel; and (3) main road.](image-url)
Oil palm cultivation especially for large plantation in peatlands is mainly restricted by intensive inundation (poor drainage). Oil palm requires ground water level of 60-70 cm below the soil surface. Thus, land reclamation efforts were carried out by making primary channels, secondary and tertiary channels to remove excess water. The research area is classified as peatlands with average peat depth of 5 m. Oil palm has been cultivated by establishing an open channel water system (open channel) for the initial phase, and then developed with a closed folder system where there is an effort to make water retention (water containment).

Water level setting in the secondary canals is done by making containment dikes and to flow water in the pipe connecting with three pieces. The pipe has a diameter of 30 cm. This method aims for the water distribution system in the tertiary channel for each secondary plot. Each tertiary channel has a height difference of water surface. Thus, the water in the drainage channel has the potential gravity. If the water in the plot is full, it will overflow drain next to the next plots, so that all plots are expected to obtain the same water. Water distribution system refers to the principle of connecting vessel (Figure 2). Pipe was buried embankment near the surface (10 cm below the soil surface), it is intended to make the water in the channel to remain the lowest in the 10-20 cm from the canal banks. Swath end is usually connected with the main drain, i.e., the area or river swamp in nature (Figure 3). The water system is using the concept of excess water disposal, where the door at the main drainage valve was installed at a height above the bottom line, be in a depth of 1 m above the bottom line. Therefore, the water disposal will run when the water level in the main channel of the numbers exceed 1 m. Furthermore, when the rains come where overflow water from the river or swamp the outside of the area will go to the land, the valve door closes automatically by the encouragement of water. This condition causes the water from the outside cannot enter the land.

![Figure 2](image1.png)  
(a) ![Figure 2](image2.png)  
(b)  
**Figure 2.** A water-retaining embankment in the secondary channels; in downstream (a) and in the upstream (b) [12].

![Figure 3](image1.png)  
(a) ![Figure 3](image2.png)  
(b)  
**Figure 3.** The main drainage systems including valve door; (a) the inside; (b) the outer lead toward to free waters or disposed region (swamp).
3.2. Water status evaluation

Periods of wet months were commonly found in months of December, January, February, and March. In the four months the oil palm is be able to adapt to the wet conditions and so far, oil palm has a high tolerance to saturated soil conditions. The oil palm can tolerant fairly high on inundation if the oil palm entered its second year. On the inundation condition during four months, the oil palm can still survive. Thus, the company efforts were to implement a retention system (canal blocking), which were true to support government policy and to restore the peatlands. The initial step of the peat land ecosystem restoration is through rewetting. Channel blocking is one of the efforts to raise the groundwater level and can reduce the rate of peat subsidence.

Water loss in the peatlands is still high despite the condition of the rainy season. Data of groundwater table in January 2017 on cultivated peatlands and without the water level control indicates that the average groundwater stands at 45-58 cm below the soil surface. This showed that the danger of the land clearing by building canals and without being followed by water control (door operation). Even in the wet season conditions, the water level in the research area was approaching the critical zone (under 40 cm). But instead on the oil palm land where to control the operation of tertiary entrance is retention, the water level in the channel can be increased and the impact on groundwater levels in the area are in the safe zone, which is located at a depth of 15-30 cm below the soil surface (Figure 4). The period of water table level below 40 cm is from mid-October to Mid June. Under full retention system in the field at wet condition when the annual rainfall is above 4000 mm, ther there will be a water surplus period of 8-9 month.

![Figure 4.](image)

Looking at the critical value of fire hazard in the zone of 60 cm, then in January or during the rainy season the research area is relatively safe from fire hazards. Beside that the land is also very suitable for planting oil palm and food crops.

The water availability in the root zone of plants or critical zone of ground fire in swamp area is highly dependent on the water volume moving in the capillaries. Capillary water movement is strongly influenced by the position of the groundwater depth, texture, and soil hydraulic conductivity values. On soils with clay or clayey texture, the depth of ground water 1.5 m can meet the needs of the plant evapotranspiration, but the sand or sandy texture, soil maximum water depth of only 0.5-1 m. Our research areas are peatlands, thus determination of soil texture is very difficult to do because of the
high soil organic matter that would interfere with the determination of soil texture, which is likely to do is, to determine the soil water dynamics by maturity peat. Figure 5 shows the soil profile on peat soil-hemic sapric where groundwater at a depth of 40-50 cm is able to create conditions in the root zone moist conditions and moisture content of field capacity, so the land is relatively safe against fires.

![Soil profile under oil palm](a)
![Soil profile in uncultivated peatlands (bush)](b)

**Figure 5.** Condition of peat soil profile at a depth of 40-50 cm soil water condition.

The depth of the ground water greatly affected the value of water capillary and soil moisture status. Computer calculations up flow models for soil hydraulic conductivity value of 8 m day$^{-1}$ water show capillary 5 mm day$^{-1}$ are at a fixed value ranging in groundwater found at a depth of -120 cm to -60 cm. This means the plant has not requiring irrigation for the purposes of evapotranspiration 5 mm day$^{-1}$ until the position of ground water in the depths of -120 cm of the soil surface. Avoiding the danger of fires, the ground water should be at the level of 40-50 cm below the soil surface. The water content in these conditions is above the field capacity and is close to saturation. Water saturated condition is usually achieved when the depth of the groundwater was 30-20 cm below the ground surface. This condition is caused by the movement of water capillary in the peats, which is relatively small compared to the mineral soil even with the sandy soils.

3.3. *Water management objectives in field level*

Control of water levels in cultivated peatlands should be integrated also with land utilization plans. Experience in European countries [8] showed land used for grazing cattle. In the dry season the water of detention, so that the ground water is maintained not fall below 40 cm, and the wet season, the floodgates were opened and the water level can be controlled below 10 cm below the soil surface. However, in some areas, in trying to conservation, then the area of stagnant water left. This condition should be adopted in the exploitation of peatlands. Often companies (both acacia timber and oil palm) to maximize all land cleared and planted with oil palm or acacia. They must allocate for the conservation of at least 20%. The areas that should be conserved are peatlands. The areas will also be balancing the ecosystem and to replenish the groundwater in the dry season.

![Multi-store block technique](1)
![Secondary channel blocking](2)
![Control overflow](3)

**Figure 6.** The multi-store block technique (photos 1 and 2: [12]); (3) the secondary channel blocking in an oil palm plantation and control overflow.

Local wisdom in managing water in the peatlands is also an important think to be applied. In West and South Kalimantan, farmers control water level with multi-store block technique, meaning that
farmers have done water conservation efforts. Multi-store block technique was done along the tertiary channels. Figure 6 shows multi-store block technique in tertiary canal level. With this technique, the ground water level in the plot of land can be maintained (not easy to drop), so that the soil moisture content is safe from fire hazards. This system inspired canal blocking technique in the research area with the upper dam system is equipped with a discharge pipe or overflow.

In the field operations, a monthly operation schedule is required. Table 4 shows the monthly canal blocking operations based on climatic condition. The experience of cases in South Sumatra in 2015 and 2019, the annual rainfall is in the range of 4000 mm, and this condition has resulted in severe fires. Meanwhile in 2016 and 2020 where the rainfall was above 4500 mm, there were no land fires. Therefore based on differences in rainfall conditions, a canal blocking operation model can be prepared in the field (Table 1).

| Blocking canal operation | Operation period |
|--------------------------|------------------|
| Over flow 10 cm          | January-March    |
| Permanently closed       | April-December   |

4. Conclusions
Based on results and discussion of research data, thus it can be taken some conclusions as follows:
1) The drainage system is open system with the primary channel (4 m wide and 2 m deep), perpendicular to the primary channel is secondary channels (2 m wide and 2 m deep) and distance between the secondary channels is 250 m. The channel dimensions are too wide and deep, so that when there is no water retention, excess discharge will occur in the dry season
2) Water control with a multi-store block system shows the evident influence in increasing water level in the land plots. Detention in the dry season can raise the water level at a safe level (40-50 cm). In the uncultivated land there is no water, thus water level down to the level of 70-80 cm. Water control in the rainy season is able to raise the water level at the level of 20-30 cm, while without the water control the water level down to the level of 40-50 cm. For the safety, the water detention policy since the rainy season is the right step to keep track so that the water is at a safe zone.
3) Excess water analysis in zones 30 cm and 40 cm at a time of water retention in the channel, show that in the period from August to September groundwater conditions at the level below normal (-), but due to the movement of water capillarity then when the ground water at depths up to the limit 50-60 cm, they can create soil conditions valleys on the surface, making it safe against fire.
4) The availability of surface water reserves in the oil palm plantation is also very dependent on the conservation of forest area, however forest area was already burnt, so it must be done immediately peat forest restoration around the plantation area
5) The model of peat management should integrate ecological and economic objective, rewetting efforts must be followed by food crops, which can increase the income of farmers. Intercropping patterns with pineapple, watermelon and others will help create environmental conditions remain moist area, and free land of fires.

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