WATER MANAGEMENT FOR PEAT SWAMP REHABILITATION IN SEI AHAS, CENTRAL KALIMANTAN, INDONESIA

MANAJEMEN AIR UNTUK REHABILITASI RAWA GAMBUT DI SEI AHAS, KALIMANTAN TENGAH, INDONESIA

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ABSTRAK

Di Kalimantan Tengah, pembangunan jaringan saluran secara besar-besaran dan sangat kompleks menyebabkan kerusakan dan degradasi yang intensif terhadap kondisi gambut dan rawa gambut yang ditandai dengan perubahan tutupan lahan, penurunan muka air tanah, kebakaran, beberapa bencana kekeringan, penurunan tanah, dan lain sebagainya. Salah satu langkah untuk mengatasi kondisi tersebut adalah dengan mengatur kondisi hidrologi di area tersebut. Duflow digunakan untuk mensimulasi tinggi muka air di saluran dan Modflow digunakan untuk mencari distribusi dan karakteristik dari muka air tanah di lapangan. Berdasarkan simulasi dari 2 model tersebut, kondisi eksisting (musim kering), area studi mengalami kekeringan karena muka air tanah turun lebih dari 1 m dibawah permukaan tanah. Hasil yang diperoleh, usaha untuk merehabilitasi rawa gambut dengan mengatur muka air tanah mendekati elevasi permukaan tanah melalui 2 skenario (canal blocking and pemasangan bendung bertingkat) di musim kering tidak sepenuhnya menyelesaikan semua masalah di area itu. Meskipun hasilnya akan berbeda, jika itu disimulasikan di musim basah ketika pengaruh air hujan dimasukkan ke dalam perhitungan, beberapa langkah lain seharusnya di diterapkan seperti pendekatan manajemen air lainnya dan program silvikultur. Dalam pendekatan silvikultur, beberapa teknik dan prosedur seharusnya dilakukan untuk meningkatkan kualitas dan kuantitas tutupan lahan guna mendukung fungsi hidrologi secara alamiah. Penanaman kembali secara intensif semestinya dilakukan di lapangan melalui sistem jalur. Jadi, dengan 2 pendekatan yang terintegrasi tersebut, tingkat kesuksesan dalam rehabilitasi rawa gambut akan dapat dioptimalkan.

***Kata Kunci**: Manajemen air, rehabilitasi rawa gambut, budaya tanam, Duflow, Modflow*

ABSTRACT

In Central Kalimantan, the construction of huge and complex drainage canals networks causes intensive damages and degraded conditions of peatlands and peat swamps that indicated by land cover changing, lowering groundwater table, fire, several drought accidents, land subsidence, etc. One of the measures that can be chosen to deal with those conditions is managing of the hydrological condition surrounding the area. Duflow had been utilized to simulate the surface water level in the canals and Modflow model had been used to find the distribution and the characteristics of the groundwater table in the field. Based on the simulation of those two models, in the existing condition (dry season), study area is suffered in drought because groundwater table drops more than 1 m below the surface level. According to the result, effort of peat swamp rehabilitation by managing (ground) water level remain near surface level through two scenarios (canal blocking and cascade weirs installation) in the dry season is not totally solved all problems in the area. Even though the result will be different, if it simulates in wet season when recharge from rainfall taken into account, some other measures should be applied such as other water management approach and silviculture programmes. In silviculture approach, some appropriate procedures and techniques should be applied to improve land cover quality and quantity that support its natural hydrological function. Intensive planting should be applied in the field through lane planting system. Finally, by integrating those two approaches, success factors of peat swamp rehabilitation would be optimized.

***Keywords**: Water management, peat swamp rehabilitation, silviculture, Duflow, Modflow.*

INTRODUCTION

Peat swamp as part of peatland ecosystem is unique ecosystem which has complex interrelationships that provides a wide range of important natural functions and environmental services, such as supporting biodiversity of flora and fauna species, providing water catchment and control function for much people daily utilization (Page & Waldes, 2007), stabilizing landscape through decreasing landscape erosion and flood in downstream area (J.O. Rieley, Ahmad-Shah, & Brady, 1996) and also storing a large amounts of carbon and essential information of the ancient times climates (Rieley & Page, 2008).

Over-drainage canal networks cause worse condition that indicated by increasing bare land area, peatland fire, several drought accidents, land subsidence, etc. Fire occurrences increase as an impact of application of huge and complex drainage canal networks that cause the drop of groundwater table. Fire, as cited from Page et al. (2009), has close relationship between peatland subsidence, surface flooding during wet season and vegetation succession. Human intervention has major impacts on peatland hydrology through rapid transformation of landscape structure and function unless appropriate water management is implemented (Hooijer, 2005a).

In degraded peat swamp area, rehabilitation trials should be supported an adequate water management that controls the hydrological system which determines soil and plant factors. Furthermore, rehabilitation method in peat swamp area needs an integrated approach that includes appropriate water management strategy that hinges on effectiveness of holding water scenarios to create optimal condition for tree planting, and good implementation of silviculture method. Through sufficient understanding of peat swamp as a unique ecosystem and its complex interrelationship, the failure of rehabilitation of peat swamp area can be avoided.

Study objectives of this researches are to understand the existing hydrological condition in study area, to analyze possibility application of water control structure in study area and and to propose an appropriate silviculture approach regarding to fire and land subsidence issues.

The study area is located in Sei Ahas (zone 50 S between 212,717 – 217,349 m East and 9,744,973 – 9,742,353 m South), Block A of Ex Mega Rice Project with total area around 1,000 ha, and part of upstream area of Kapuas river basin in Central Kalimantan. The area has peat dome shape which the thickness is ranging from 2.00 - 12.00 m. Topography of study area is relatively flat with surface slope ranging between 0 - 8 %. The contour is ranging from 3 - 8 m +MSL as decribed in Figure 1.

Drainage network systems surrounding the area cause severely decreasing water table of peatland and damaging natural habitat of endemic peat swamp flora and fauna. Meanwhile, agricultural activities and other productive purposes that were expected by opening that area are totally failed. All the remaining land use in the area is the bare land in some parts as former logging area dominated by shrubs and ferns, land burnt caused by fire accident few years ago, and rubber plantation owned by surrounding people that are not in well maintained condition. Fires and drought due to over-drained become potential threaten for its existence. Moreover, there are no measures to control ground water table fluctuation in that area.

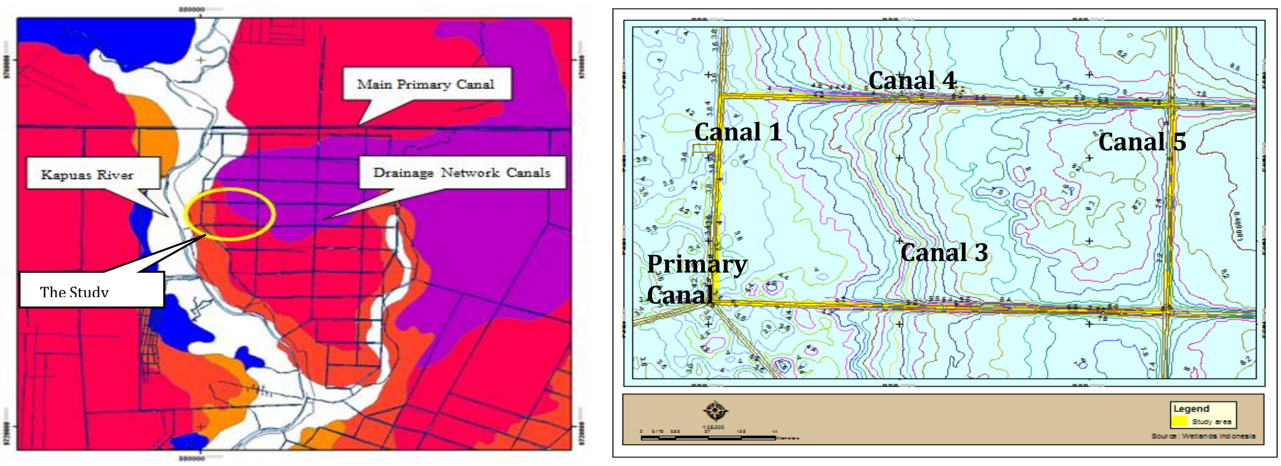


Figure 1 Map of location and topographical condition of Sei Ahas

LITERATURE STUDY

Duflow Modelling

Duflow (Dutch Flow) program is designed to simulate some applications related to flow and quality aspects of surface water by using one-dimensional approach such as calculating unsteady flows in canal networks, rivers, and channels; simulating the transport substances in free-surface flow and performing flood modelling; and water quality and flow processes can also be simulated. The basic equation which used in this program is the mathematical translation of the laws of conservation of mass and of momentum as follows (STOWA, 2004):

$$\frac{\partial B}{\partial} + \frac{\partial Q}{\partial x} = 0 \qquad 1)$$

$$\frac{\partial Q}{\partial t} + gA\frac{\partial H}{\partial x} + \frac{\partial(\alpha Qv)}{\partial x} + gA\frac{g|Q|Q}{C^2AR} = \alpha\gamma w^2\cos(\Phi - \emptyset) \qquad 2)$$

where:

t	:	time (s)
x	:	distance (m)
H(x, t)	:	water level (m)
v(x, t)	:	mean velocity over a cross section (m/s)
Q(x, t)	:	discharge (m^3/s)
R(x, H)	:	hydraulic radius of cross-section (m)
A(x, H)	:	cross-sectional flow width (m)
b(x, H)	:	cross-sectional storage width (m)
B(x, H)	:	cross-sectional storage area (m^2)
G	:	acceleration due to gravity (m/s^2)
C(x, H)	:	Chezy coefficient ($m^{1/2}/s$)
w(t)	:	wind velocity (m/s)
Φ(t)	:	wind direction (degrees)
Ø(x)	:	direction of channel axis (degrees)
γ(x)	:	wind conversion coefficient
α	:	correction factor for non-uniformity of the velocity distribution in the advection term

Modflow Modelling

Processing Modflow is a simulation system for modelling the groundwater flow. Modflow is belonging to United States Geological Survey (USGS) program. Even though the Processing Modflow was originally developed for a remediation project of a disposal site in the coastal region of Northern Germany, when at the beginning of the work the code was designed as a pre- and postprocessor for the groundwater flow model Modflow, but now there is a Windows-version of Processing Modflow with the goal of bringing various codes together in a complete simulation system by US Geological Survey (USGS). Modflow, nowadays, is the most popular groundwater flow model used by government agencies and consulting fins. Modflow solves the partial differential equation as describing in Equation 3 that the three-dimensional movement of groundwater of constant density through porous material (Harbaugh et al., 2000) :

$$\frac{\partial}{\partial x}\left(Kxx\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(Kyy\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial z}\left(Kzz\frac{\partial h}{\partial z}\right) - W = Ss\frac{\partial h}{\partial t} \qquad 3)$$

where:

Kx	:	hydraulic conductivity along the x axis (L/T)
Ky	:	hydraulic conductivity along the y axis (L/T)
Kz	:	hydraulic conductivity along the z axis (L/T)
h	:	potentiometric head (L)
W	:	volumetric flux per unit volume (1/T)
Ss	:	specific storage (1/L)
t	:	time (T)

Peat swamp rehabilitation

1) Water Management

Peat swamp ecosystem plays an important environmental and natural resource functions such as biodiversity pool, water pool, and carbon sequestration (Andriesse, 1988). Hydrology is key factor in maintaining its support functions, so water table fluctuation control is needed. Takahashi et al. (2002) as cited by Ritzema & Jaya (2007) shows that if the groundwater table in peat swamp forest drops about 0.40 m below the surface level, the susceptible to fire level raises extensively. The drop of groundwater table will be followed by land subsidence. According to that relationship, in order to avoid risk fire and land subsidence, each of land use types requires its specific depth of the ground water table.

The multipurpose of water management system should perform in different functions that depend on the seasons, such as removing excessive water during the wet season, and conserving water in dry season. Moreover, water table control is also one of the purposes of the water management system in order to create suitable condition for the plant and avoiding the risk of fire (H. P. Ritzema & Jaya, 2007). In natural condition, peat dome situation which the mainly source of water is from the precipitation around the area, the dome can be played as a natural water storage in the wet season that can be maintained the level of the water surrounding the area by conveying water during the dry season.

2) Silviculture approach

Silviculture is the art and science to build and maintain the forest ecosystem functions by controlling the establishment, growth, composition and quality through various treatments and integrating the ecological and economic concepts to become more productive and achieve forest management purposes in sustainable manner (Nyland, 2002). Peat swamps rehabilitation in silviculture approach means that the efforts to improve the degraded condition in the fields through planting activities (Wibisono, Siboro, & Suryadiputra, 2005).

METHODOLOGY

In order to manage the hydrological factors in the area, the analyses and modelling software's are prepared to deal with the problems; Duflow would be utilized to simulate the surface water level in the canals; and Modflow model will be prepared to find the distribution and the characteristics of the groundwater table in the field. In this study, the inter-relationship between application of Duflow and Modflow can be easily described in Figure 2.

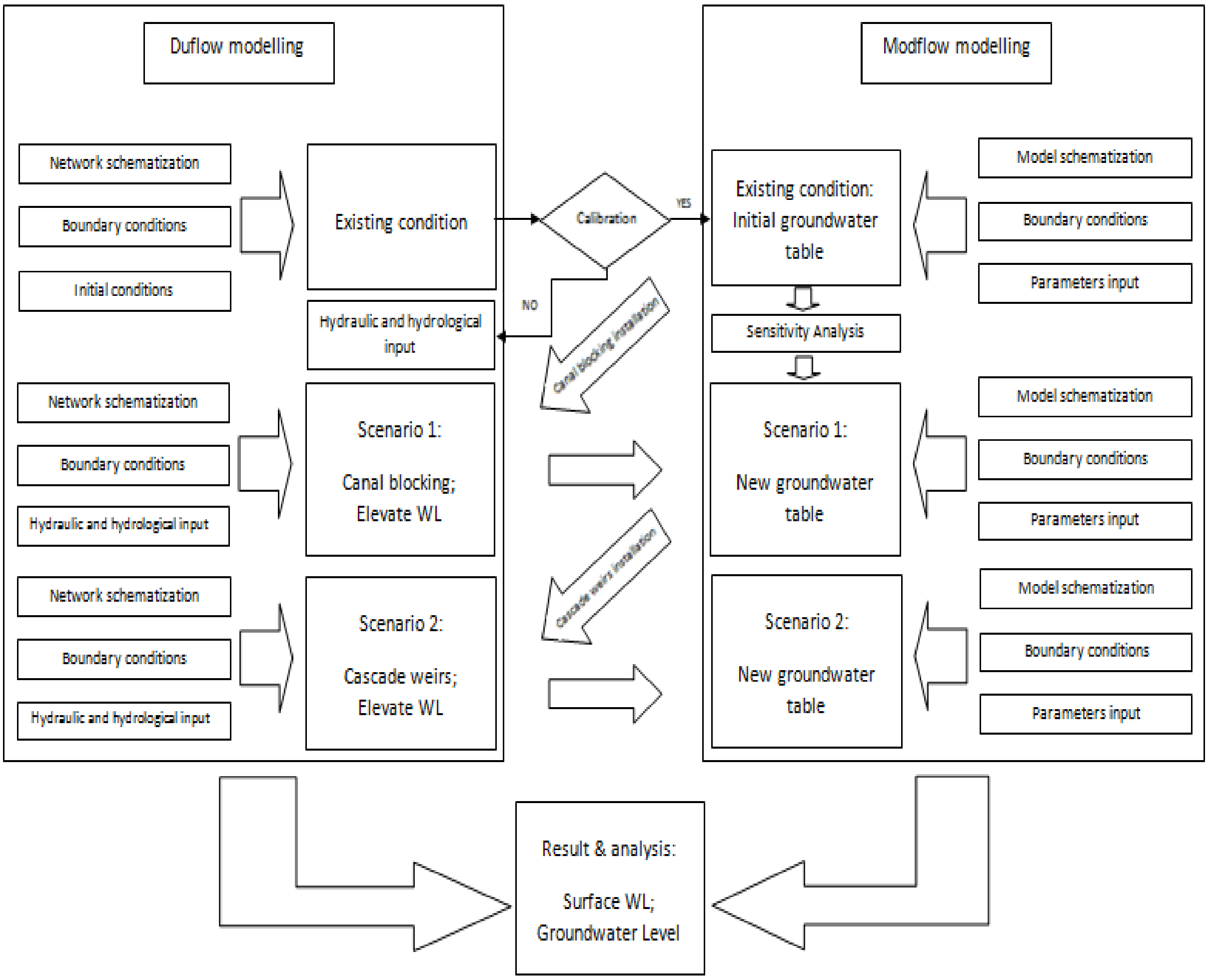


Figure 2 Duflow - Modflow inter-relationship model

In this study, two scenarios are prepared as follow:

1 Scenario 1: Canal blocking located in the end (downstream) of Secondary Canal 3 and Canal 4. This scenario simulates the existing condition of study area and finds the difference both condition related to the water level condition in canals. The analysis will be developed by comparing the water level before and after installation of structure canal blocking. One of the considerations of this scenario is that nowadays the canal blocking has been constructed in the end (downstream) of Secondary Canal 3.

2 Scenario 2: Cascade weirs along Secondary Canal 3 and Canal 4 (Figure 3). The idea of this scenario is to hold smaller difference head level in each section along Secondary Canal 3 and Canal 4. By holding the level difference smaller, run-off could be controlled and groundwater table in the field keeps in the safe level for tree planting rehabilitation therefore free from fire risk.

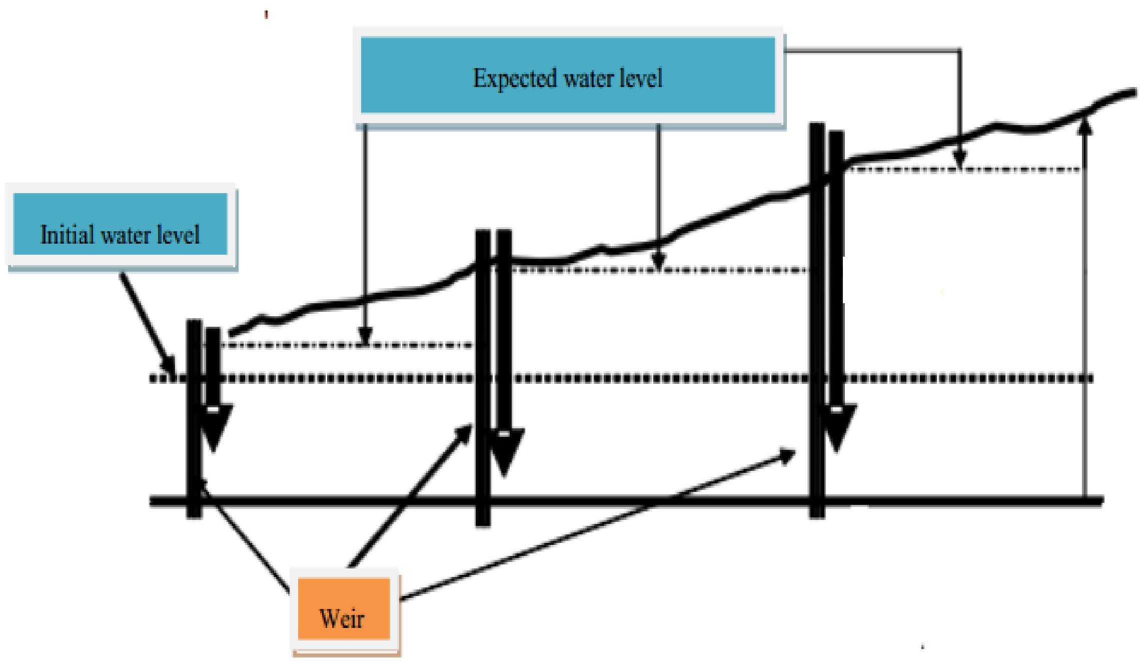
There are two major data in this research, primary and secondary data. Primary data was taken from measurement in the field level such as water level measurement in surrounding canals, canal dimension and area measurement, peat depth and soil sampling. Secondary data was collected from several agencies or institutions that have data related the research matters such as rainfall data, spatial data and information, profile geometry data of surrounding canals, and literature review.

RESULT AND DISCUSSION

1) Rainfall analysis

Rainfall analysis had been done by calculating frequency analysis to get the extreme minimum rainfall in some return periods. This rainfall analysis design based on considerations that the real problem in peat swamps area which proposed as rehabilitation area is in the drier months, when the groundwater drop far below surface level and bring the area into highly fire risk and failure tree planting rehabilitation.

Based on the calculation of Gumbel probability distribution, the selected extreme minimum daily rainfall is the return period of 2 years (50% probability of occurrence) which is 0.1 mm/day which mean close to zero, and it will be used as an input of rainfall design value in Duflow model. In Duflow model, a zero value of rainfall is simulated to get similar condition of the extreme dry condition.



Adopted from: Stoneman and Brooks (1997) in Suryadiputra et al. (2005)

Figure 3 Cascade weirs profile

2) Modelling analysis

a) Existing conditions

i. Duflow modelling

A simple network is prepared according to the real condition of study area. The study area is bordered by four secondary canals that play a role as a drainage system. All those secondary canals are drained into one primary canal that connected to Kapuas River. The model network that represents the real condition of study area is shown in Figure 4. The length of primary canal in study area is about 1,613 m and average canal width is 25 m. Secondary Canal 1 has length and average width for about 2,552 m and 25 m respectively. Secondary Canal 3 has 4,774 m length and average canal width for about 25 m. Secondary Canal 4 has 4,666 m with average width for about 25 m.

In this network, model calibration was done to calibrate water level measurement on some observation points compared to water level results which calculated by Duflow model. Based on model calibration result in Figure 5, computed water level in two observation points has a similar pattern with observed data from the field. There are small gap value (0.05 - 0.1 m) between the field measurement data and the model. It can be happen because of overestimating measurement in the field level or some different input of roughness coefficient that used in the model. The 0.1 m gap is considerably accepted and realistic enough.

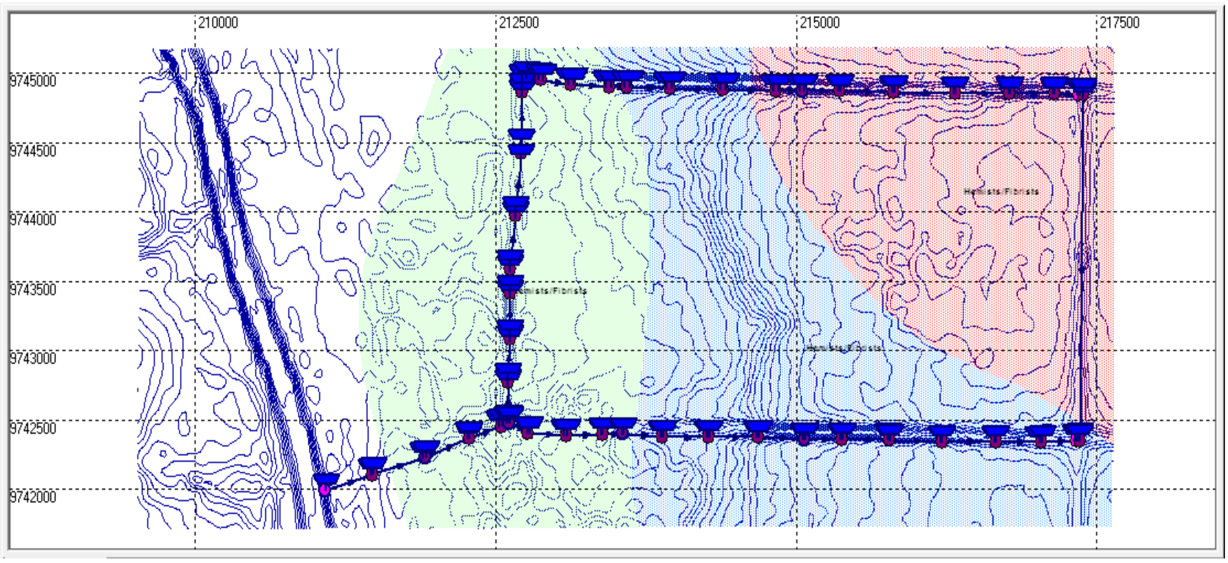


Figure 4 Network schematization

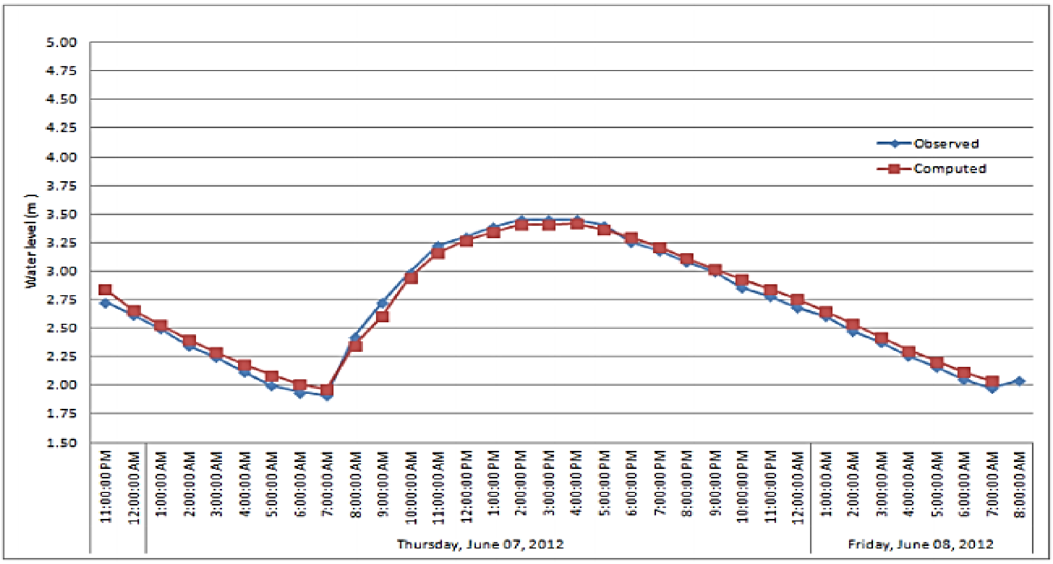


Figure 5 Model calibration at CP2 (Secondary Canal 1)

ii. Modflow modelling

The existing water level in surrounding canals that was already simulated in Duflow model plays as a boundary condition in the existing condition of Modflow model. The field area for about 1,170 ha was represented by 100 x 100 m of cells consist 25 of rows and 47 of columns. The area was schematized as one layer with the impervious mineral subsoil layer that set at mean sea level as the bottom boundary. Simulation type use transient flow simulation that tried to represent the dry condition with no rainfall occurred and the evapotranspiration is set to 0.004 m/day. The top layer was the surface rough elevation of the peat based on provided elevation map. The groundwater level simulation in the existing condition is shown in Figure 5. Based on Figure 6, it can be identified that after 1 week simulation during dry season, groundwater table in the field is follow the contour line pattern. The groundwater table level is below the surface level that occurred in all parts of the study area.

To check the sensitivity of the model parameters, the sensitivity analysis was conducted. The hydraulic conductivity parameter was conducted to verify the response of the model due to the changing of those parameters. The values of hydraulic conductivity that used were 30 m/day and 50 m/day. According to the sensitivity analysis result, the change of hydraulic conductivity parameters did not give any significant change to the simulation water table in the field. By changing the value of hydraulic conductivity, the groundwater table in the field is relatively remained the same.

iii. Groundwater condition

The result of application of two models shows that in dry season, study area is suffered in drought because groundwater table drops more than 1 m below the surface and varies from 1.2 m in the downstream part to 2.7 m in the upper part of the study area (see Figure 7). This condition should be taken into account that some measures should be done in order to control the groundwater table that should not drop too far from the surface level. One of measures that can be done is related to water management in surrounding canals of the study area. The purpose is to keep the water level in canals high as possible in order to elevate or hold groundwater table. Two scenarios are prepared to deal with those conditions.

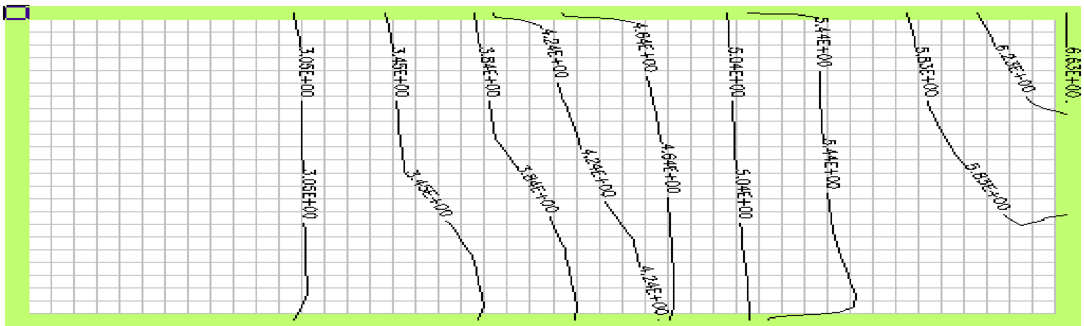


Figure 6 Groundwater table simulation after 1 week

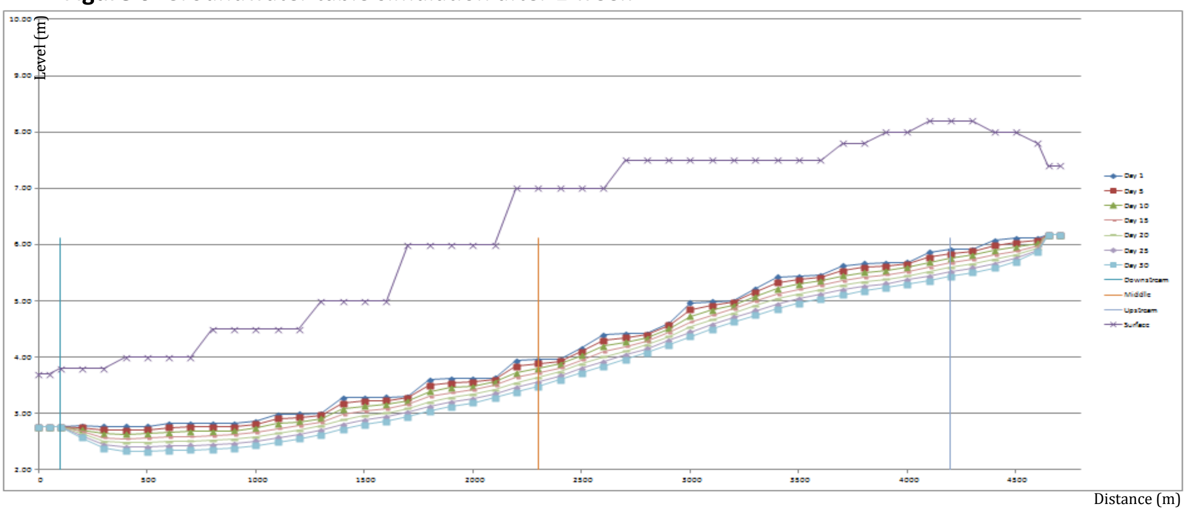


Figure 7 Groundwater table in dry season

b) Scenario 1 (canal blocking)

Based on the result of Duflow modelling in Secondary Canal 3, the effect of canal blocking installation is only give the rise of water level along canal for about 2,500 m from the downstream part, meanwhile the rest distances canal is remain the same. The similar pattern is also occurred in Secondary Canal 4. The rise of water level do not give significant effect to the upstream part of the area. By setting 3.7 m height of the canal blocking in the end of Secondary Canal 4, the affect has only influence up to 2,000 m from the structure installation.

Scenario 1 that applied canal blocking installation at downstream part of Secondary Canal 3 and Canal 4 shows that the rise of groundwater table near the structure can reach at 0.40 m below the surface and after 15 days with no-rain condition, level drop to 0.50 m below surface level. Middle and upper part of study area are still having gaps difference that have varies gaps ranging from 2.0 m to 3.0 m below surface level (see Figure 8).

In order to expand the effect of the structure installation in the canal that can elevate groundwater table in the field, Scenario 2 is proposed. Cascade weirs installation is the idea of the Scenario 2.

c) Scenario 2 (cascade weirs)

The idea of scenario 2 is to hold smaller difference head level in each section along Secondary Canal 3 and Canal 4. By holding the head difference smaller, run-off could be controlled and groundwater table in the field keeps in the safe threshold for tree planting rehabilitation therefore free from fire risk. In this scenario, the total weir structures were 10 and 9 weirs in Secondary Canal 3 and Canal 4 respectively, with different height and distance within the weirs that depend on the desired water table in the canal and surface level conditions.

Based on Duflow modelling result showed in Figure 9, Secondary Canal 3 shows that the distance within 2 weirs is varied from 200 m up to 500 m. Moreover, one of the important things in cascading weirs installation is that the head difference should be in smaller difference. In this simulation, head differences were set into some varied range from 0.20 m to 0.50 m. The effect of cascade weirs shows that water level in the canal can be elevated into near the surface level. Furthermore, in Secondary Canal 4 showed in Figure 10 which has been also installed some weirs show almost the similar result as in Secondary Canal 3. The head difference was set varied from 0.30 m to 0.50 m. The space between weirs is varied from 200 m to 600 m.

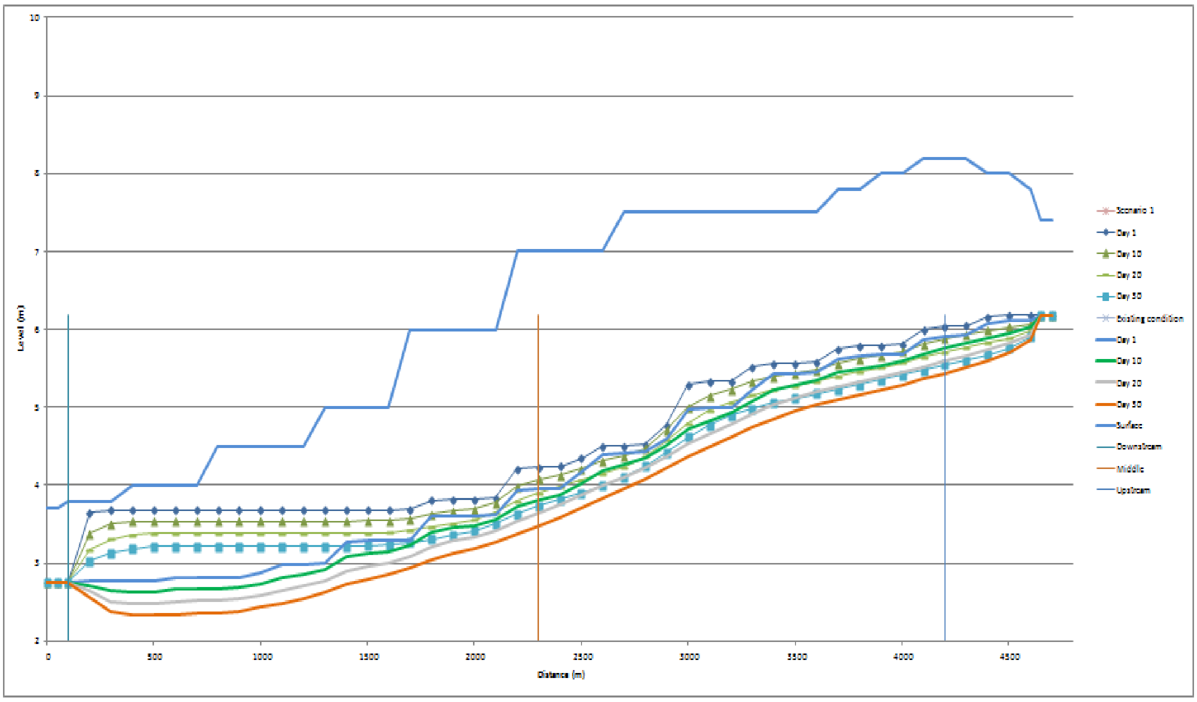


Figure 8 Compared groundwater level condition between existing and Scenario 1 condition

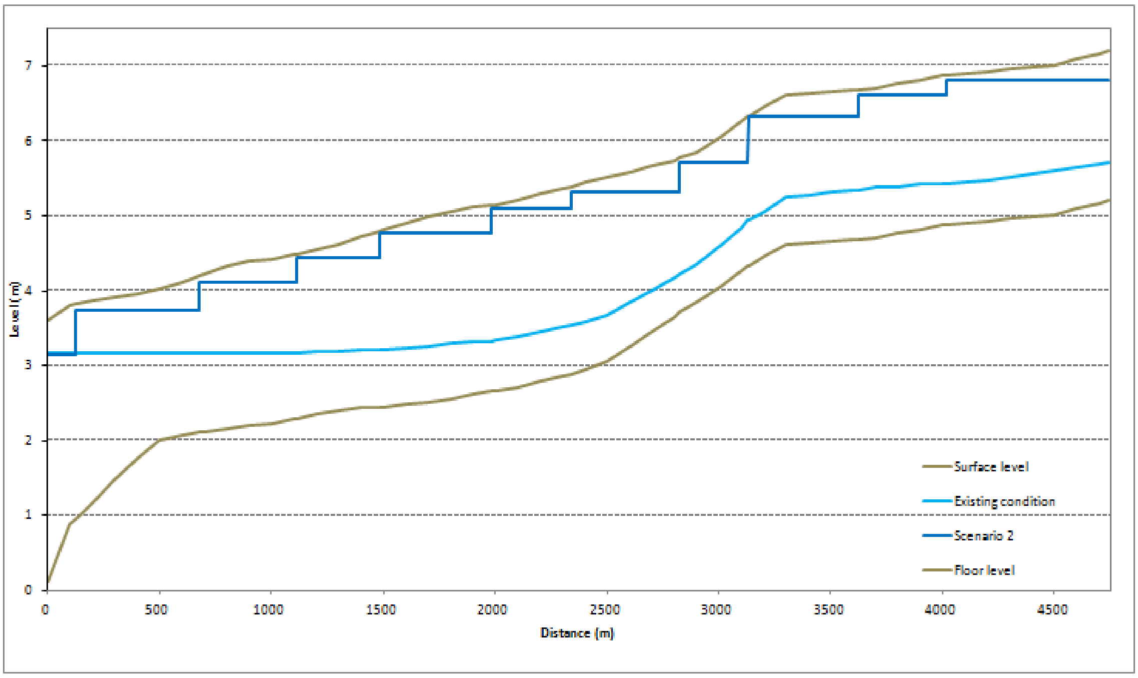


Figure 9 The effect of cascade weirs in Secondary Canal 3

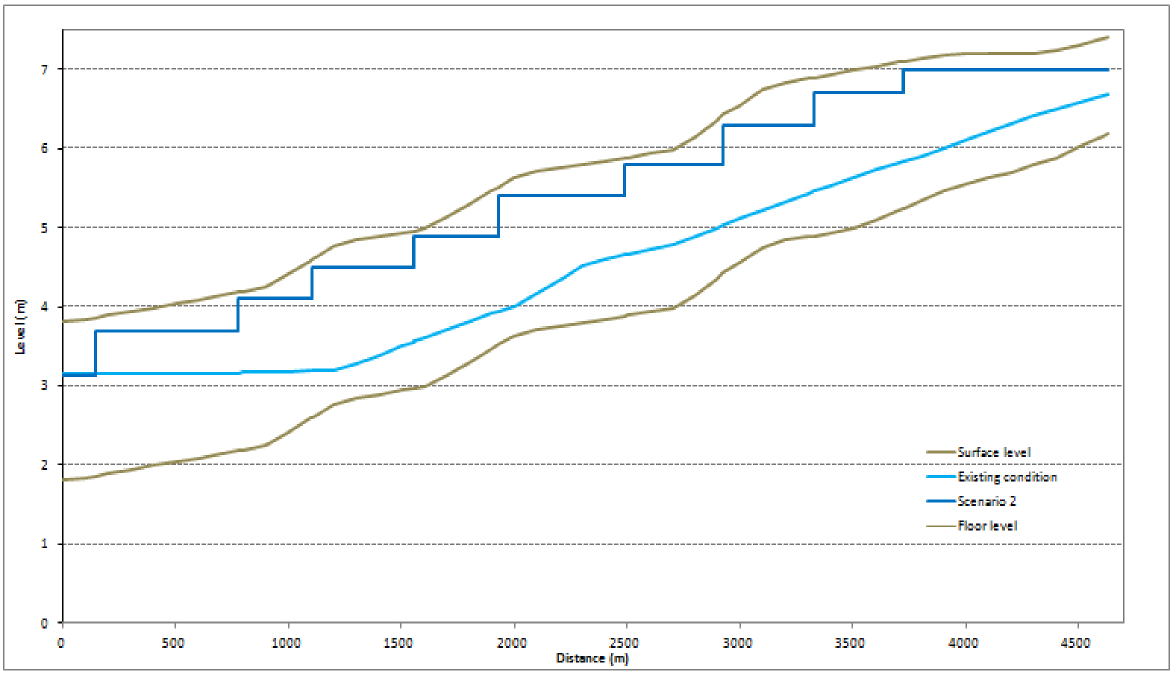


Figure 10 The effect of cascade weirs in Secondary Canal 4

Based on Modflow modelling result, groundwater table can be elevated in each section when cascade weirs installed. However, this increment has not totally solved the far down groundwater table in the deeper peat more than 5 m +MSL. By installing cascade weirs, groundwater table can be elevated up to near surface level in downstream part; 1.30 m in middle part, and 0.70 m in upper part (see Figure 11).

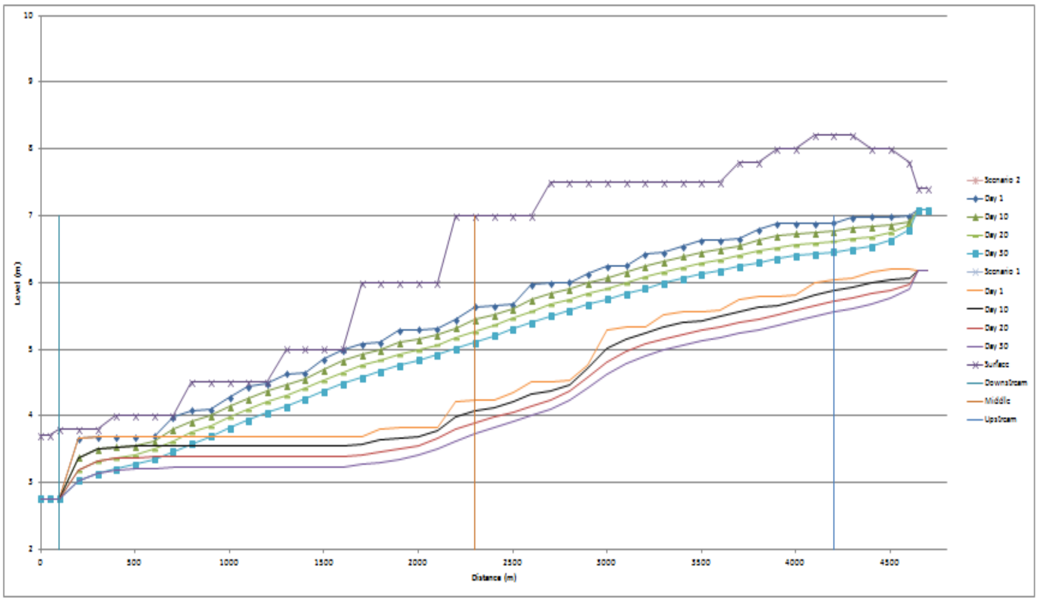


Figure 11 Compared groundwater level condition between Scenario 1 and Scenario 2 condition

According to all simulation, Scenario 2 had been succeed to raise the surface level in the canal and the groundwater level in the field, but it is still remain the problem due to the deeper groundwater level more than 1 m particularly in some parts of the field which has the peat depth higher than 5 m +MSL. It should be realized that in this study dry season condition was simulated. The result will be different when the wet season is simulated, when the recharge from the rainfall is taken as an input to the model. Scenario 2 could be solved the problem when amount of precipitation store and fulfill the gaps level of groundwater table.

3) Integrated peat swamp rehabilitation

According to the water management result in dry season, effort of peat swamp rehabilitation by managing (ground) water level remain near surface level through two scenarios is not totally solved all problems in the area. Some other measures should be combined such as other water management approaches and silviculture programmes.

a) Water management

Water management is firstly prior measures to be done in peat swamp rehabilitation. In the relation to the planting activities, water management through elevating water level in some parts in the field is fully necessary particularly when the season is in no rain charging conditions. It should be done to make sure that the seedling and/or plant can survive in severe conditions. In integrated approach perspective, water management is not only about constructing water control structures, moreover it could support natural regeneration and rehabilitation programme at the same time.

In this study, those two scenarios are applied that the result is not fully solved the problem to the all area. From this study, it can be proved that elevating the water level in the canal will influence the rise of the groundwater in the field. It should be completed with other measures that can be solved the problem whether in the wet and/or dry seasons. In future study, some other water management measures should be simulated such as conserving water by constructing collector drain which conveyed water to the peat dome with combination network of control structures. In this study, those measures are not discussed.

b) Silviculture approach

In silviculture approach, some appropriate procedures and techniques should be applied to improve land cover quality and quantity that support its natural hydrological function on this area. Intensive planting should be applied in the field through lane planting system. Planting fast growing species (i.e. Asam-asam (*Ploiarium alternifolium)*, Garunggang *(Cratoxylon arborescens)* and Tumih *(Combretocarpus rotundatus)*), endemic species (i.e. Belangeran (*Shorea belangeran)*, Jelutung (*Dyera lowii*), and Pulai (*Alstonia pneumatophora)*, and the plant that could be survive in severe condition, Galam *(Melaleuca cajuputi* Roxb.*)* are recommended to be planted in some parts of study area that still have problem of lower groundwater table in dry season.

Time scheduling for the rehabilitation in peat swamps area should be adjusted to the right season. Planting time is commonly started when the wet season begin. Meanwhile the land preparedness such as creating artificial mounds could be 2 - 3 month before the planting. Some shallow trenches can be also built in order to play as water control structure in the site level and as firebreaks particularly from the underground fire.

CONCLUSIONS AND RECOMMENDATIONS

Based on modelling simulation, results, analyses and discussions, some conclusions can be listed as follow:

In the dry condition simulation by using combination Duflow and Modflow model, the existing condition of the area shows the deeper groundwater table that reached range from 1.2 m in the downstream part up to 2.7 m below the surface level in the upper part of the area. This condition makes peat soil in the top layer become very dry and high risk to fire.

Canal blocking installations in the end of Secondary Canal 3 and Canal 4 show that the rise of groundwater table near the structure (downstream part) can reach at 0.40 m below the surface level and after 15 days with no-rain condition, level drop to 0.50 m below the surface level. The middle and upper part of the area are still having gaps difference that have varies gaps ranging from 2.0 m to 3.0 m below the surface level.

Cascade weirs installation along Secondary Canal 3 and Canal 4 shows the increment of surface level in the canal and groundwater level in almost each section on the field, but it is still remain the problem of gaps of groundwater level particularly in the field which has the peat depth higher than 5 m +MSL. By installing cascade weirs along the canal, the groundwater table can be elevated up to near the surface level in the downstream part; 1.30 m in the middle part, and 0.70 m in the upper part.

Silviculture approach should be applied to support water management measures that already done in order to optimize and give significant influence to the rehabilitation programme. Intensive planting should be applied in the field through lane planting system. Planting fast growing species (i.e. Asam-asam (*Ploiarium alternifolium)*, Gerunggang *(Cratoxylon arborescens)* and Tumih *(Combretocarpus rotundatus)*), endemic species (i.e. Belangeran (*Shorea belangeran)*, Jelutung (*Dyera lowii*), and Pulai (*Alstonia pneumatophora)*, and the plant that could be survive in severe condition, Galam *(Melaleuca cajuputi* Roxb.*)* are recommended to be planted in some parts of the area that still have problem of lower groundwater table in dry season.

Integrated peat swamps rehabilitation that involved of the two main aspects of hydrological measures (water management in the canal, water control structures, etc.), and reforestation (silviculture techniques and procedures) should be applied in proper way to support the rehabilitation programme.

Some recommendations to the improvement of water management for peat swamp rehabilitation are: In order to deal with the groundwater table problem in the peat dome area particularly in dry season conditions, some combination measures by constructing collector drain which conveyed water to the dome shaped and network of control structures should be considered.

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