Water Regulation in Tidal Peatland Agriculture using Wetland Water Level Control Simulator

By

Satyanto Krido Saptomo[1], Budi Indra Setiawan[1], Yoshisuke Nakano[2]

[1]Department of Agricultural Engineering. Bogor Agricultural University, PO BOX 220, Bogor 16002, Indonesia.
E-mail : ddody@telkom.net, budindra@ipb.ac.id

[2]Faculty of Agriculture, Kyushu University, 6-10-1 Hakozaki, Higashi-ku, Fukuoka-shi, 812-8581, Japan.
E-mail : ynakano@agr.kyushu-u.ac.jp

Abstract.
The study has the main objective to develop an environmentally sound water management to be applied in peat land agriculture. The output of this study is water level controller software that incorporates fuzzy controller with taking into account the soil physical properties of peat soil under consideration and its hydrological conditions. This paper presents the simulation part of the study which is used to find the optimum design of the land. The simulation incorporates two dimensional equation of water flow in saturated soil and tidal fluctuation as natural disturbance. This simulator can be used as a tool for obtaining appropriate size of specific peat land agriculture within the capability of water management when the control system is to be applied. Hopefully, this system can be used as a valuable assistance in designing an agricultural plot converted from peat land and enables the determination of operation cost of water management in a field scale.
Keywords. Peat land agriculture, groundwater, and fuzzy control.

INTRODUCTION

The utilization of peat land for agriculture activity requires water regulation particularly for avoiding uncontrolled decrease of groundwater, which could cause land subsidence. In general, due to loose structure, a natural peat soil would experience volumetric deformation if subjected to significant changes of groundwater. In the field, along with seepage evapotranspiration are the main factors directly effecting the diurnal changes of groundwater level (Takahashi et.al., 2000). During the process of decreasing water level, the surface soil would experience water deficit, and in subsequent, reduce its bulk density. Changes of bulk density are considered the main factor that effected the decreasing of infiltration capacity of the natural peat soils (Sumawijaya, 2000).

Deformation in peat soil can cause the change in physical properties; among others are specific gravity, porosity, and available water. This deformation among others has the implication on the water movement in the peat land. Significant changes of soil properties due to different land uses in which land use change from paddy field to upland field has created caves with the formation rate between 1~6.5 cm/year (Imoto et.al (1998). These changes obviously will affect the hydraulic properties such as water retention and hydraulics conductivity. Irreversible deformation is believed to occur when the water level lasts long exceeding a certain level under the soil surface. Setiawan et.al., 2001 reported a permanent soil surface decrease if the condition of the groundwater surface is greater than 20 cm and a subsidence of land surface of 15 cm occurs due to the irreversible deformation in soft soil. These facts shows that the regulation of water in peat soil needs to consider the deformation property of the related soil and the occurrence of irreversible deformation is prevented.

This research is the computer simulation part of the research that was presented by Setiawan et.al (2002), aiming on developing and testing the control system for water regulation in peatland agriculture which is influenced by tide fluctuation.

MATERIAL AND METHOD

Simulation Flow

Data input of field and on-farm canal dimension are prepared to be used internally by the program. This data contains various field dimensions to be simulated for performance evaluation of each field setting. Manual input of simulation time and setpoint are needed to determine when the simulation should be started and finished, and at what level the water should be controlled. The simulation time is related to the calculation of other natural influence to the field, which is the tide in this case. Figure 1 shows the flow of the simulation.

Tide fluctuation is calculated on timely basis, based on a year observation of water level fluctuation, in a canal which was affected by tide in South Sumatra, Indonesia, reported by Susanto and Muslimi (1997). The approximated interpolation is arranged as 3rd order polynomial piece-wise.

$$hi(t) = ai + bit + cit^2 + dit^3 \qquad (1)$$

with a, b, c and d are constants of piece-wise polynomial and h is water level at i^{th} sampling point at the boundary. The tides fluctuation affects the groundwater in the field. The calculation of groundwater is approached using 2 dimensional groundwater flow equation. In order to keep water groundwater level at the desired level or setpoint, Fuzzy Logic Controller will work to operate water pump(s) properly. Amount of water will be charged to or discharged from the on-farm canal to keep the water level at the setpoint. These calculations will be repeated until the simulation is over. When the simulation finished, the simulation will be started again with different field dimension.

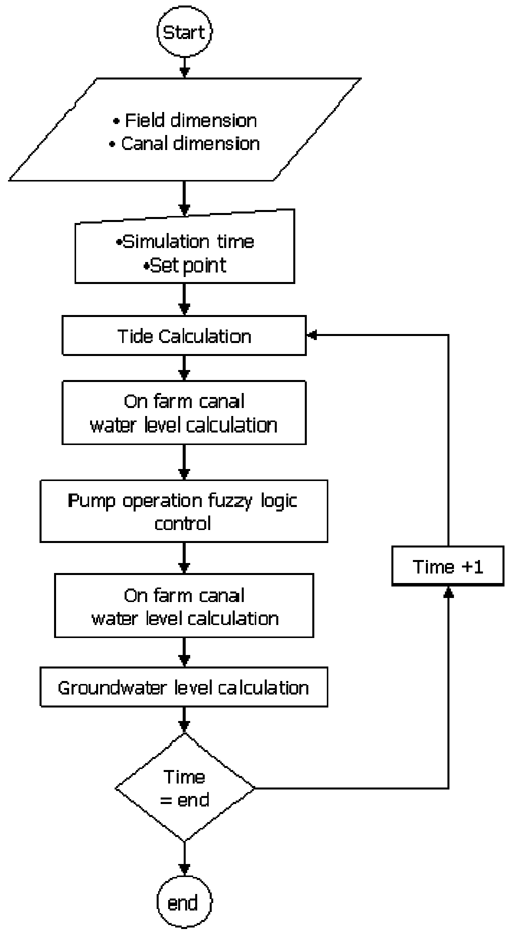

Figure 1 Simulations flow

Water Flow in The Field

Groundwater flow in peat soils is simplified in such a way to follow saturated water flow equation in inert porous media under isothermal and isotropic conditions (Bear and Verruijt, 1986), which is applied in one dimension by Setiawan and Saptomo (1997). The equation in two dimensions is written

$$S\frac{\partial h}{\partial t} = \frac{\partial}{\partial x}\left(T\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(T\frac{\partial h}{\partial y}\right) + Q \qquad (2)$$

where S is storability, T is transmissivity (m^2/d), h is water pressure head (m), Q is charge and/or discharge rates (m/d), respectively, x is distance (m) and t is time (d). Actually, equation 1 will only work for soil that does not experience volume changes when its water content changes. This is the assumption that is used in our simulation. T is taken as a product of k times h of each x, y, and t. The equation is solved using Alternate Directing Implicit, finite-difference method, Newton method with Jacobian Matrices, Thomas Algorithm/Crout Reduction Methods/ALU and algorithm for convergence and error testing.

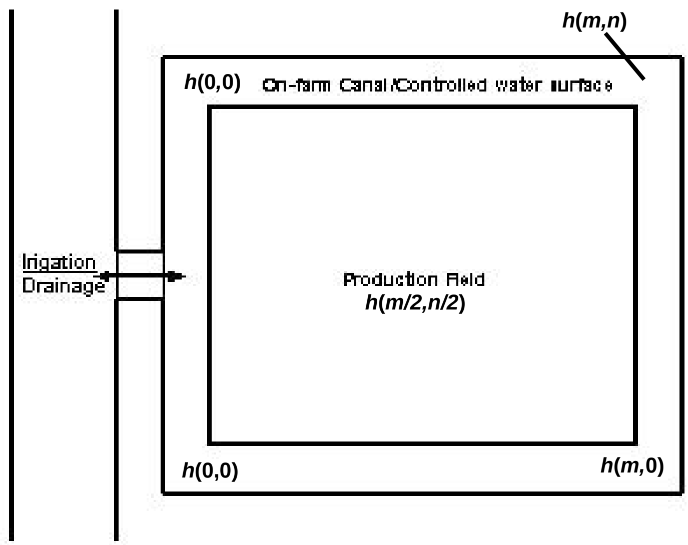

Figure 2. Field setting

The field is surrounded by on-farm canal, as shown in figure 2, where water level $h_{canal}(t)$ directly affects the ground water level at boundary of the field. On the other hand, the water level of the surrounding on-farm canal is influenced by the fluctuation of tides. Thus, the boundary condition can be expressed as follows:

$$h_{(0,j,t)} = h_{(i,0,t)} = h_{(m,0,t)} = h_{(0,n,t)} = h_{canal}(t) + q_t \quad (2)$$

where q is charge (positive) or discharge (negative) in m/d, i, j are index y (i=1..m) and x (j=1..n) direction; and t time.

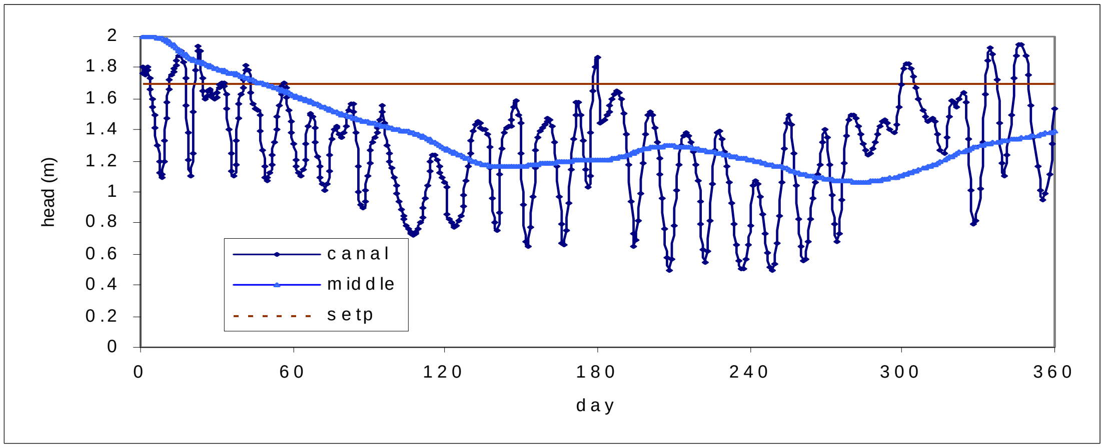

Figure 3 The simulated tide fluctuation and uncontrolled water level at the middle of the field for one year.

The fluctuation of tide in the canal and uncontrolled groundwater level simulated for 5 m x 5 m field size are shown in Fig. 3. The tide (*canal*) fluctuates as the result of the tidal fluctuation function, affects the water head at the boundary and the water level in every point of the field. Uncontrolled water head in the center point shown in this figure (*middle*) seems to be a trendline for the tide fluctuation during the simulation. When the control is activated, the water is set at 0.3 m below the soil surface, shown as a straight line in this figure (*setp*).

Water Control Strategy

The important things to be considered in water management of peat land agriculture are to maintain save level of groundwater and prevent water from being discharged more rapidly than the soil permeability. A recent experiment in South Sumatera where peat soil exists showed that volumetric deformation would occur even though the peat soil was still in water-saturated condition, particularly when the water level was below the threshold value under the soil surface for some period of time (Setiawan et.al, 2001).

A save water level is the threshold value which does not cause irreversible deformation of soil structure and expose of pyrite layer, under the influence of water balance’s natural components, artificial irrigation, and drainage channel. In this case the save level of groundwater must be determined beforehand through experiment or experience for a specified location. After the threshold value is determined, an effective technique must be implemented in order to maintain the save groundwater level. For this purpose, an automatic water level controller based on fuzzy algorithm was developed. The prototype system was tested in wetland area in South Sumatera (Setiawan et.al, 2002). Figure 4 shows the scheme of this control system in experimental plot.

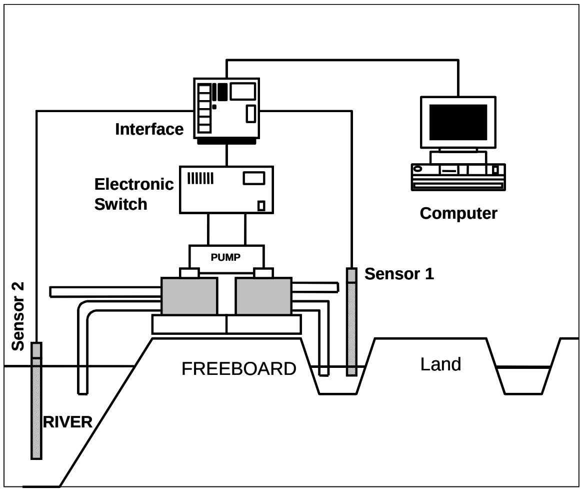

Figure 4 Scheme of water control in experimental plot.

Triangular fuzzy membership function is used in this study (Figure 5). The control program used fuzzy logic with 3 labels of membership which are Negative (NEG), Zero (NIL), and Positive (POS) for each membership function of Error and Gradient of Error. Error is defined as the difference between the actual water level and the setpoint and the Gradient of Error was the first derivative of Error. Control strategy was made in the form of decision matrix as presented in Table 1. The decisions are categorized into five, i.e., Negative (NEG), Medium Negative (MNEG), Zero (NIL), Medium Positive (MPOS), and Positive (POS). Singular method was used for the justification process and weighing method used for the defuzzification process.

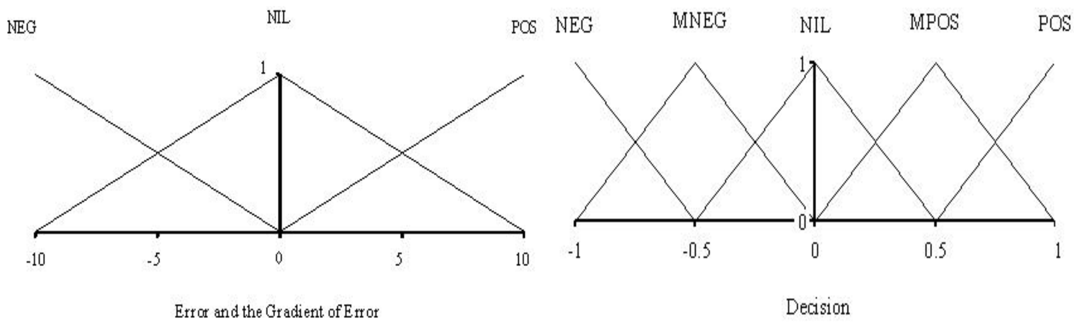

Figure 5. Fuzzy triangular membership function

Table 1. Decision Matrix

Decision Matrix		Error		
		NEG	NIL	POS
Error Gradient	NEG	-1	-0.5	0
	NIL	-0.5	0	0.5
	POS	0	0.5	1

In order to maintain groundwater level stable in a set point Sp, the surrounding on-farm canal is used as water level reference for controlling water level inside the field. If the water head was higher and/or had the tendency of increasing, the water would be discharged from the field. Conversely, if the water head is lower and/or had the tendency of decreasing, the field will be irigated properly. In the field experiment, this was done by using both drainage and irrigation pumps, that were operated with electronic relays controlled by the computer as presented by Setiawan et.al. 2002.

It is likely that there will be difference or Error between the desired water level and the actual one. The error is recorded and calculated, and used for evaluation and analyzing the system performance. The error sum is calculated for the boundary (0,0), the center point of the field (*m*/2, *n*/2) and the accumulation of all nodes in the finite difference scheme of the field (0,0)...(*m*,*n*) for each time *t* from beginning to the end of simulation (360 days), as expressed in these equations.

$$\sum \xi_{0,0} = \sum_{t=0}^{360} \left| h_{0,0,t} - S_p \right| \qquad (4)$$

$$\sum \xi_{\frac{m}{2},\frac{n}{2}} = \sum_{t=0}^{360} \left| h_{\frac{m}{2},\frac{n}{2},t} - S_p \right| \qquad (5)$$

$$\sum \xi = \sum_{j=0}^{n} \sum_{i=0}^{m} \sum_{t=0}^{360} \left| h_{i,j,t} - S_p \right| \qquad (6)$$

RESULT AND DISCUSSION

The simulation was conducted for various sizes of fields having initial water level of 1.5 m (0.5 m depth from the surface), with bottom of 2.0 m depth from the surface, and set point of 1.8 m (0.2 m depth from the surface. The value of S is 0.75, which is also the value of the effective porosity of the soil. The soil permeability is 4 cm/h. On-farm canal having width of 0.5 m is used as the boundary of the field where the water level is controlled using pumps. The finite differences are 0.5 m both for Δx and Δy.

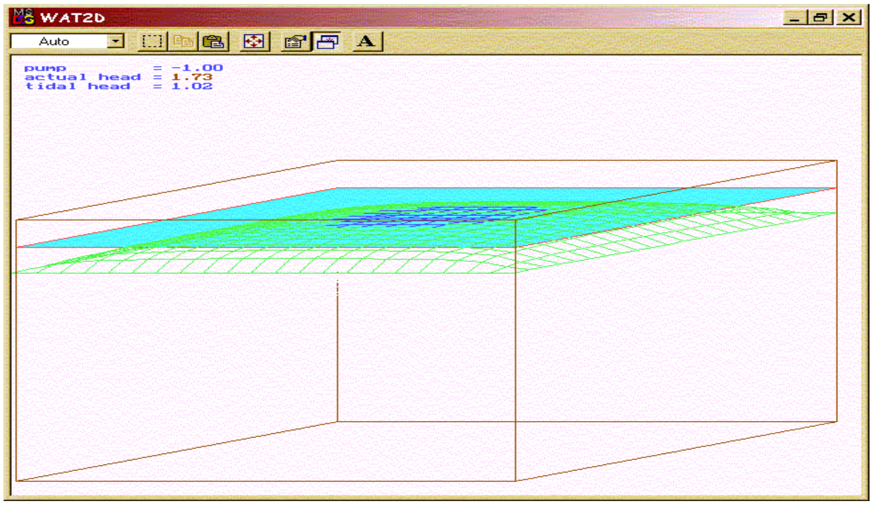

Figure 6 Computer screen capture of ground water distribution

Figure 6 shows a screen shot of the simulator. The transparent cubic shape represents the bulk of the simulated field, rectangular fishnet represents the actual groundwater distribution, and rectangular plane represents the set point plane. The shape of the fishnet changes due to the fluctuating boundary water level. This figure is the visualization of groundwater distribution during simulation, generated using customized graphics procedures of Turbo Pascal.

The simulation was run for uncontrolled condition and controlled conditions. In the controlled condition, the simulation was repeated with different combination of control rule. The higher value of the resulted error means inadequate performance, while the lower value resulted from combination denotes better performance (Fig. 7).

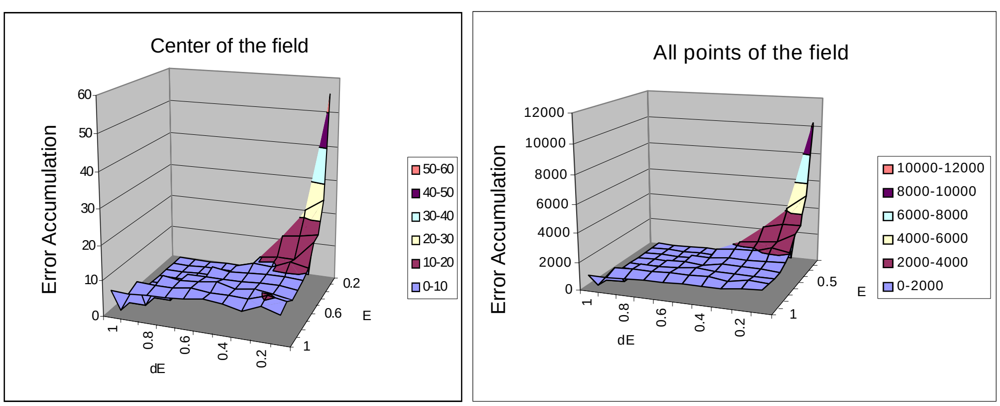

Figure 7 Cumulative error of h at middle of simulated field and cumulative Error of *h* at all *x*, *y*, *t*; using combinations of control rules Error (*E*) and change in Error. (d*E*)

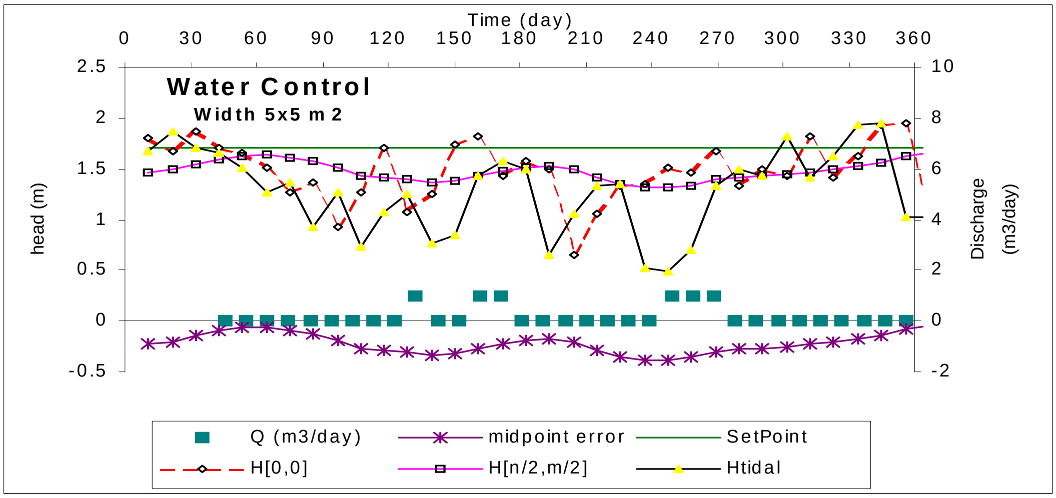

Figure 8 Simulation of 5x5 m^2 size field.

Figure 8 shows the result of simulation for 5x5 m^2 size field, which shows the fluctuation of water head in the boundary, the center of field, and the tide. The chart shows the pump operation (*Q*) which value can be used to calculate the capacity and energy requirement. Irrigation dominates the pump operation, indicated by the positive value of *Q*. When the water level tends to decrease, irrigation pump operates as the effort to avoid water level from dropping below the save water level.

Surface graphs shown in Fig. 9 are the groundwater level at the end of simulation. The first graph shows the water level when control system is operating and the other is not controlled. Water level in the uncontrolled field dropped deeper than 1 m below the soil surface while with control operation the water can be hold about 0.5 m below soil surface. This shows that the control system has succeeded in controlling the water from decreasing below the desired level.

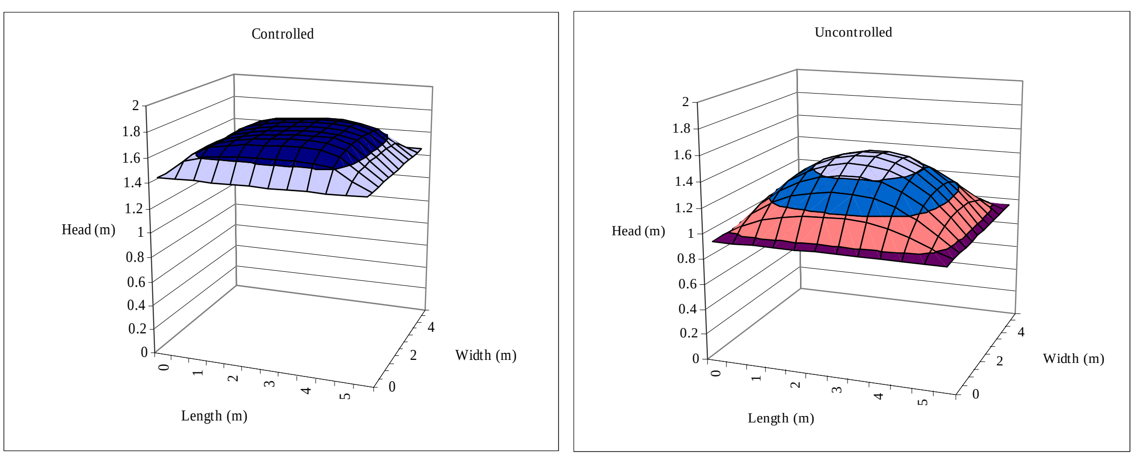

Figure 9. Controlled and uncontrolled head distribution at the end of simulation (day 360) of 5x5 m^2 size field

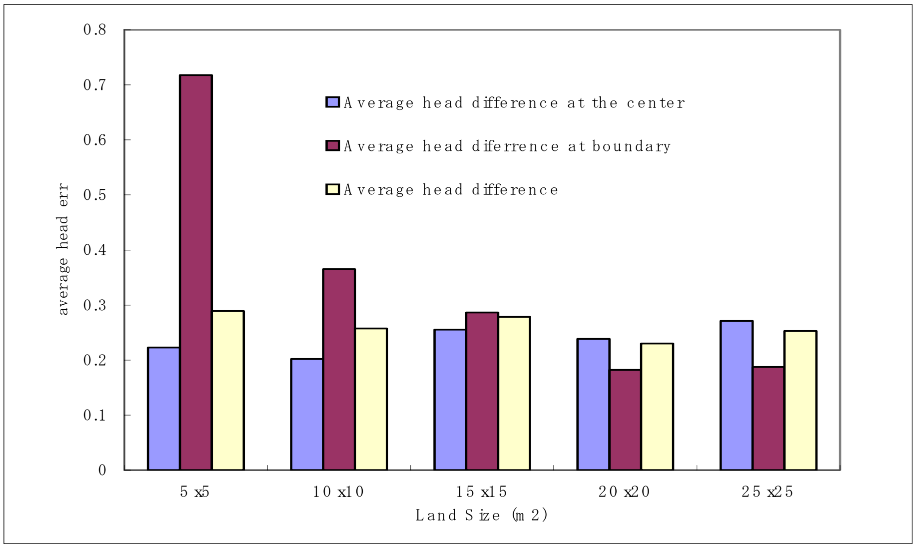

Figure 10 Performance Indexes

Figure 10 shows the head difference (error) between the setpoint and the actual level, which represents the performance index of the control system. The left bar is the average error only at the center of the field, the middle bar is the average error only at the boundary of the field, and the right bar is the average error calculated at all locations in the field. The last one was accumulated from every point in the field or the water head at every nodes of the finite difference. Based on the average head difference (error) occurs at the middle, the best performance is achieved by the field having size of 10 m x10 m. On the other hand, if the average errors at all nodes are calculated, the field of 20 m x 20 m has the smallest error value compared to others, which means the best performance is achieved with this size. If all of the average error values at the center, at the boundary and at all points in the field are compared for one design to others, the field with size of 20m x 20m seems to be the best design since it has the lowest average error.

CONCLUSION

A Simulator of water level controller has been developed that incorporates two dimensional equation of water flow in saturated soil and fuzzy logic controller with taking into account the soil physical properties and hydrological conditions. This system shows good performances when tested to maintain desired water levels in agricultural fields. This simulator might be used as an important tool for determining an appropriate area of peat land converted to an agricultural field, which is water manageable. Using the current data of tide fluctuations and soil properties implemented in the simulator, the best field size to be controlled with this system is 20 m x 20 m.

When this paper was being written, the simulator had only been only prepared to evaluate the performance of the control system by simulation with various field size, and by mean of error between the desired water level and the actual water level achieved with the control operation. The simulator has not yet improved to estimate the power consumption or cost of operation. In the near future, the simulator should have an operation cost estimation to provide the information that is useful to determine the optimum size of the field.

The simulation has not yet incorporated all components which are naturally influencing the groundwater balance. The components also include vegetation and meteorological factors. Therefore, the absent factors need to be studied and then incorporated to attempt the compliance of soil plant atmosphere continuum (SPAC) of tidal peatland area.

Acknowledgements

This research is part of the RUT VII 1999-2001 entitled *The development of automatic water regulation system for peat land agricultures.* The authors express gratitude to the *Dewan Riset Nasional* (National Research Council) of the Republic of Indonesia for the financial support in the implementation of the research.

REFERENCES

Bear, J. and A. Verruijt. 1987. Modelling Groundwater Flow and Pollution. D. Reidel Publishing Company. Holland.

Imoto, H., T. Miyazaki, H. Saito, T. Nishimura and M. Nakano. 1998. Physical properties of Bibai peat soils in forest, arable land and natural-wetland. Technical paper. The Graduate School of Agricultural and Life Sciences, The University of Tokyo, Japan.

Setiawan, B.I, Y. Sato, S.K. Saptomo and E. Saleh. 2002. Development of water control for tropical wetland agriculture. Advances in GeoEcology No. 35, Pages 259-266, Catena Verl., Reikirchen, Germany.

Setiawan, B.I., S.K. Saptomo, and Y. Sato. 2001. Irreversible deformation of tropical peat soils. Proceeding of Harmonization between development and environmental conservation in biological production. JSPS-DGHE Core University Program. Tokyo, February 21~22, 2001.

Setiawan, B.I. dan S.K. Saptomo. 1997. Water Control Simulation in Peat Soil using Fuzzy Logics. Prosiding 7th ICID International Drainage Workshop: Drainage for the 21st Century. Penang, Malaysia, 17-21 November 1997.

Sumawijaya, Ny. 2000. Infiltration test on the Palangkaraya Peat. Proceeding of the International Seminar on Tropical Peat Land. Bogor, November 22~23, 2000. Page: 349~355.

Takahashi, H., M. Kayama and S.H. Limin. 2000. The effects of environmental factors on diurnal changes of groundwater table in a tropical peat swamp forest. Proceeding of the International Seminar on Tropical Peat Land. Bogor, November 22~23, 2000. Page: 321~327.