International Seminar

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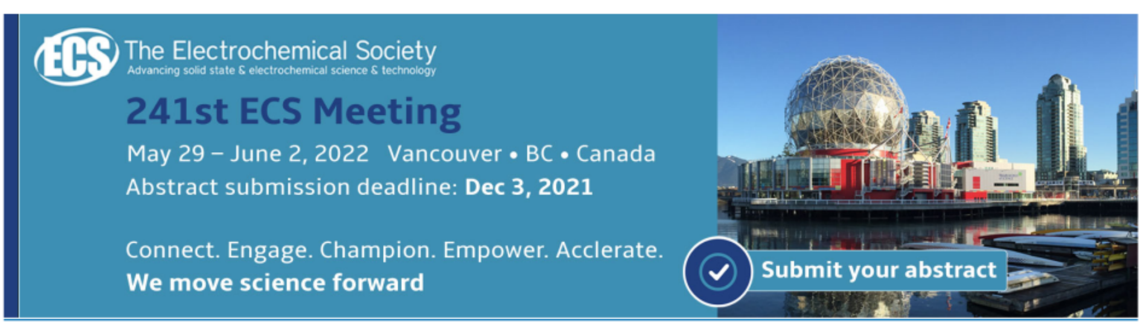
To cite this article: M S Imanudin *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **871** 012035



IOP Conf. Series: Earth and Environmental Science **871** (2021) 012035 doi:10.1088/1755-1315/871/1/012035

Integrated Duflow-Drainmod model for planning of water management operation in tidal lowland reclamation areas

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Abstract. The research objective was to develop field operational model to control water table level at reclaimed area of tidal lowland for food crop cultivation. DUFLOW computer model was used to evaluate the perfomance of water management network at secondary and tertiary levels, whereas DRAINMOD computer model is used to evaluate soil water status at tertiary block. Results of DUFLOW model simulation can be used to improve water management by passing the Secondary Irrigation Chanel (SPD) and Secondary Drainage Chanel (SDU) through tertiary channels, water gate installation of stop-log type and weir construction in Drainage Secondary Channel (SDU). The weir construction has function as long storage and capable to control or maintain soil water level in land not quickly drawdown. Drainmod simulation model is acceptable, this is indicated by the results of statistical analysis where the correlation coefficient value reaches 0.89. Analysis of DUFLOW-DRAINMOD computer model software showed mutually supportive results in which DUFLOW simulation results can provide water potential information in channel for supply purpose. This water level condition is an important part in DRAINMOD model because it has effect on soil water level dynamics as targeted on tertiary block as well as on capacity to applied drainage operation system.

1. Introduction

In General the tidal lowland reclaimed area in Indonesia to date is could not optimally function in controlling water status. This condition is proved by the variety of water status and land productivity although located on the same land typology [1]. The existing design system is made with the same concept without considering land hydro-topography resulting in excessive soil water level drawdown on one side and excessive water (logged condition) on other side [2]. Therefore, evaluation of the existing drainage system is urgently needed to obtain proper information related to how and where the proper system design that is still suitable for agricultural purpose, especially for food crops cultivation [3]. Operation of drainage in wet land is mainly to control soil water level in order to create soil water depth condition that capable to supply crop water requirement which in turns reduce the irrigation water requirement [4][5].

Water management is one of the most important factors in managing agricultural land at tidal lowland area. The objective of this water management is not only to reduce or add surface water availability, but also to decrease soil acidity, prevent soil acidity due to oxidized pyrite layer, to prevent salinity and flooding hazards as well as to leach toxic elements accumulated in crop root zone [6][7]. In order to achieve the above objectives, water management operation is directed to aspect of soil water level detention that should be always kept above pyrite layer and land leaching through controlled drainage system [8][9]. Therefore, effort of water level control is important in management of tidal lowland area. The expected condition water level is highly depend on crop types, soil and hydrological condition of local area [10][11].

The computer model had been made and developed in order to examine drainage system effectiveness at micro level. This model is well known as DRAINMOD [12][13]. It was developed to evaluate water balance at shallow soil water level so that it is very acceptable to be used in tidal lowland area. This model can also be adapted to variety of land characteristics in accordance with local agro-climate characteristics Model had successfully tested in some states such as America [14]; Australia [15]; Europe [16]; China [17], and Indonesia [18][19].

Meanwhile, DUFLOW computer model had been developed to evaluate condition of water management network in the capacity as supply and drain [20][21]. This model is capable to predict how far the the reach of high tidal water that can be utilized for water supply. This model can also be adapted to variety of land conditions in accordance with local agro-climate characteristics and water level of low tidal effect for drainage potential [22]. Simulation results DUFLOW model can provide practical recommendation for effort of water network improvement and operational system of water management [23][24][25]. Integration of the DUFLOW-DRAINMOD models are expected capable to answer the problem of water level control from tertiary block to water network level so that operational design of water level control can be developed to provide condition of soil water status as required by crops. DRAINMOD model is very good to be used to predict the depth of soil water level [26][27]. Estimation value of soil water level prediction resulting from simulation and modelling was $r^2 = 0.93$ [27].

Research aimed to develop field operational model of water management on tertiary block in effort to control water level in accordance with water requirement for corn and rice. The use of DUFLOW-DRAINMOD computer model should be tested as auxiliary equipment in operational plan composing of water level control at tidal lowland area.

2. Methodology

2.1. Place and Time

This reserach was conducted at tidal lowland reclaimed area of Delta Saleh, South Sumatra Province. Two tertiary blocks were chosen as representative (1 in the end and 1 in the middle) within one secondary block for each sample locations. Sample location of adaptation model was located at primer 10 Delta Saleh (Figure 1). The observation period (ground water level monitoring) was carried out from November 2008-2009. For model simulation required, field data has been used since 2005 to 2016.

2.2 Material and Equipment

The equipments used in this study were consisted of soil samples, corn seeds, rice seeds, fertilizers, pesticides, plant protection plastic and chemical materials for soil analysis in laboratory. Materials used in this study were consisted of piezometer, wells (perforated paralon pipe), metering board, water pass, tape measure, soil augers, disposal tube (*bailer*), stopwatch, GPS (*Global Positioning System*), digital camera and farm equipments. Computer simulation was conducted by using DRAINMOD 5.1 software [28]) to evaluate water status at tertiary block. DUFLOW software [29] was used to analyze water network perfomance..

2.3. Method

Some stages are required to compose the recommended design for water level control at each land hydro-topography class. The first stage is primary data compilation to conduct physical characteristics identification of land environment and scenario composing of water management. The second stage is design testing (simulation model) and field testing (model validation). The third stage is composing of the recommended management for each sample areas and the last stage is information presentation of management operation at micro level.

IOP Conf. Series: Earth and Environmental Science **871** (2021) 012035 doi:10.1088/1755-1315/871/1/012035

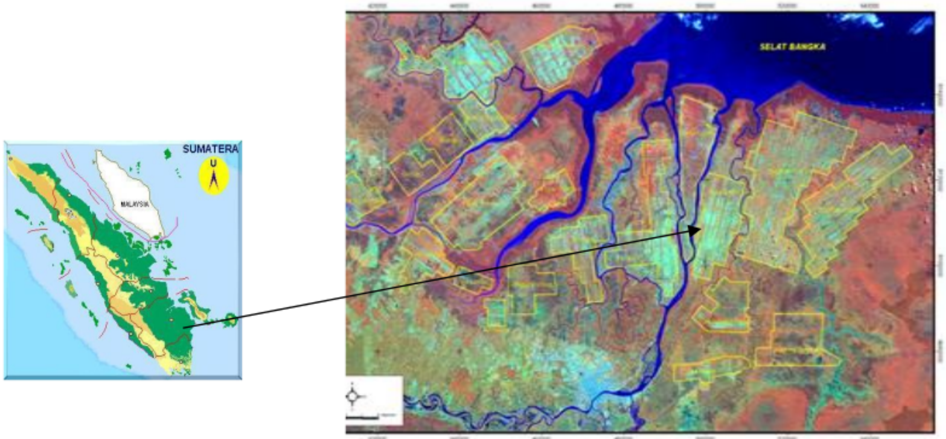

Figure 1 Research area situation map at Delta Saleh of South Sumatera Indonesia

Operational design of water management that will be developed in model adaptation of water management at tertiary block is as follows:

- Water disposal concept *(drainage)* and soil leaching
- Controlled drainage concept (*control drainage)*
- Channel water seepage concept *(sub irrigation),* and
- Tidal irrigation concept *(tidal irrigation),*

For simulation of computer model, one unit of water management system is taken as the boundary condition, i.e. one secondary block consisting of 17 tertiary channels. Tie points for borderline of modelling is estuary of supply and drainage secondary channels at upstream and downstream sites. Tertiary block is used as monitoring block for validation.

The scenarios to be developed for water network improvement at Delta Saleh Area with land typology C/D (dry) are as follows:

- Scenario 1: Tertiary network of grid system, connected in two directions toward village secondary channel (SPD) and drainage secondary channel (SDU), channels are equipped with valve gates and secondary water gates only available at SPD level ,
- Scenario 2: Tertiary network of grid system, connected in two directions toward village secondary channel (SPD) and drainage secondary channel (SDU), channels are equipped with stop-log gates, secondary water gates are available at SPD level and weir is built at drainage secondary channel (SDU).
- These two scenarios will be combined with objective to be used for rice and corn crops with variation of dry, normal and wet rainfall conditions (probability of 20, 50 and 100%).

DRAINMOD model simulation is conducted to determine soil water status as a results of water operation in tertiary channel. There are three management scenario plans consisting of controlled drainage through water retention combined with land leaching, maximum water disposal as long as crop is unavailable in order to leach hazardous substances, and pump irrigation opportunity for short live plants.

Condition of tidal water and daily rainfall will also be analyzed to obtain opportunity of planting pattern that probably be implemented at two types of land. Meanwhle, value of water level status will be related to availablity of acid sulphate layer in order to determine how long the land experience oxidation and when land leaching operation can be implemented. These combination will be used as a basis for composing of water management scenario.

Calibration will be conducted by using DRAINMOD computer model prior to evaluation of some scenarios of selected water management. Some data input farticularly soil and drainage system parameters will be simulated in order to obtain simulation results data that is close to field measurement data [30]. If this condition is met, then DRAINMOD computer model can be used as a means to evaluate the perfomance from each selected scenarios and it is already proven that model results can be adapted to field condition [31] [32]. Data input that should be available for the purpose of calibration and DRAINMOD computer model simulation can be seen in Table 1.

Table 1 Main Data input for DRAINMOD simulation model

Input Data of DRAINMOD model	**Unit (dimension)**
Soil characteristics	
• Saturated Water Content	Cm3 Cm-3
• Wilting Point Water Content	Cm3 Cm-3
• Bulk dencity	gr cm-3
• Organic matter	%
• Hydroulic conductivity (lateral)	m hari-1
At soil depth (30-100) cm	
(100-200) cm	
Drainage system parameter	
• Drainage depth	m
• Drain spancing	m
• Impermeable layer	m
• Efective Drain Radius	m
• Surface Storage	mm
Contro Drainage Parameter	
• Rainy season : gate setting at 40 cm	cm
• Dry season: gate setting at 50 cm	cm
Crop parameter	
• Planting time purposed	Juni
• Crop planting period	7 hari
• Crop growing period	90 hari
• Maximum Rooting depth	130 cm
• Fertilizer input	150 kg/ha

Source: [20]

Adaptation model of water management for each scenarios was conducted through expermental plot in the field with farmers group. The main observation indicator is monitoring of daily water level fluctuation and crop growth performance. Field water management operation model covers tertiary water gate operation and develop of micro water management network. Illustration of water table control operation in tertiary canal through water gate operation can be seen in Figure 2.

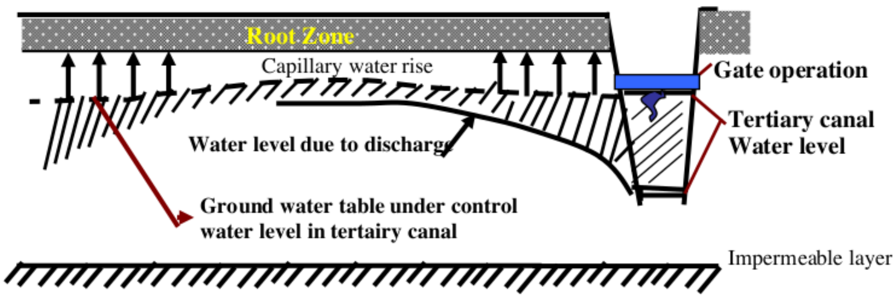

Figure 2 Water table profile between two tertiary channels due to water gate operation

3. Results and Discussion

3.1. Water Management Objective

Water management aims to fulfill crop water requirement at tertiary block. Suplay water in tidal lowland is highly affeted by crop growth phase, and rainfall [33]. This condition cause different water management objective plan on respective phase and land type (Tabel 2). For second crop such as corn, the main objective in water management on farm land area is retained water in tertiary canal and maintened ground water table control by gete operation..

Water management objective is also highly depend on land hydro-topography classes. For tidal lowland area with C-type (high tide water is unable to enter the land), then water management aims to retain rainfall water and to maintain water level in tertiary channel at depth of 40-50 cm below the canal dike [34]. Water pump sometimes is still needed for crops during long dry season [35] It was commonly famer done in generatif growing phase on July-August-September period.

Table 2 Water management objective for rice and corn cultivation at tidal lowland for each crop growth phases

Phases	Rice	Corn
Crop growth phase	Water management objective for rice crop	Water management objective for corn crop
Land tillage	Plowing: soil is below field saturation capacity Flooding: puddle 0 – 5 cm Levelling: puddle 5 cm	Water table elevation is dropped up to 40-50 cm so that soil is in field capacity condition which suitable for land tillage operation
Seedling	Water saturated soil/no flooding	Water table elevation control at depth of 30-40 cm. Soil should be at field capacity, not in saturation condition.
Vegetative growth	Puddle 5 – 10 cm, water replacement, drain water during fertilizing time	Water table elevation is dropped up to 40-50 cm, except for area in which phyrite layer is located below 50 cm
Reproductive growth	puddle 5 – 10 cm, water replacement, drain water during fertilizing time	Water table elevation is dropped up to 40-50 cm
Maturing phase	Soil in saturation condition up to field capacity.	Water table elevation control is not neccessary, it will dropped naturally

Source: [20].

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3.2. DUFLOW Model Adaptation in Composing Operation and Improvement of Water Management Network at Tidal Lowland Area with Dry Land Typology(C/D Type).

Analysis of wáter network perfomance is also conducted for dry área of C/D land tipology. As borderline within computer simulation model, one secondary block is used as simulation borderline (boundary condition). Some basic data of measurement used in this simulation are average soil surface level of 2.07 m (msl), average tidal water level of 1.7 m (msl). Crop evapotranspiration is made constant with average value of 5-7 mm/day [36] and rainfall condition is divided into three categories of dry (0 mm), normal (50 mm) and extremely wet (100 mm).

Scenario which is composed in DUFLOW simulation at the study area can be seen in Table 3. Variation of rainfall condition with and without waterworks at tertiary level is observed at this dry tipology land as well as water gate construction to maintain water level in SDU channel. The choice of waterworks at tertiary level is water gate of stoplog type and water level control is conducted by setting water gate height. Water retention with height of 50-60 cm in tertiary channel will capable to keep the ground water table under 40-50 cm below soil surface. [34].

DUFLOW simulation as water supply and water retention is an effort to maintain stable soil water level in order to prevent quick water losses into tertiary channel which subsequently wasted into secondary channel. This can be done by installing water gate of simple stoplog type and by restraining water with weir in drainage secondary channel (SDU). The objective of restraining water with weir in drainage secondary channel (SDU) is to obtain fixed water level in drainage secondary channel (SDU) which in turn can maintain water level in tertiary channel. Drainage channel has function as long storage in order to prevent drop of soil water level because there is strong correlation between fluctuation of water level in channel and soil water level [37].

Table 3 Scenario of DUFLOW program simulation for land type of C/D.

Water management scenario	Simulation treatment
Current condition evaluation, no water gate in secondary channel Networking improvement evaluation with wáter retention in drainage secondary channel (SDU) through wáter gate installation	• Dry rainfall (0) mm • Normal rainfall (50) mm • Wet rainfall (100) mm

Simulation results of computer model in which secondary channel is retained with weir and land had normal raifall (50mm) are presented as initial phase. Duflow gives an overview that water retention in secondary channel is capable to increase water level in tertiary channel (Figure 3). Water level in tertiary channel during initial water intake is relatively high close to 2 m msl, but subsequently drop and water level in the middle of tertiary channel is close to 1.5 m msl. Application of water retention in tertiary channel is difficult to be applied on the last period of wet season or dry season due to high soil porosity. Thus, effort to develop drainage secondary channel as long storage is highly appropriate so that water losses can be reduced.

DUFLOW model is incapable to respond the effect of high hydraulic conductivity of soil in the field. DUFLOW only capable to evaluate flow capacity of channel as supply and disposal. The increase of water level in tertiary channel as results of weir development effect in SDU ca be seen in Figure 4. This is due to the increase of water level in secondary channel which capable to supply water for tertiary channel. Water level in tertiary channel has increase and finally can be maintained at height of 1.5 m msl. It means that tertiary channel receive constant water supply at height of 50-60 cm from soil surface. But what is more important is that the available of water level in tertiary channel is to maintain soil water balance at tertiary block so that water is not quickly drop.

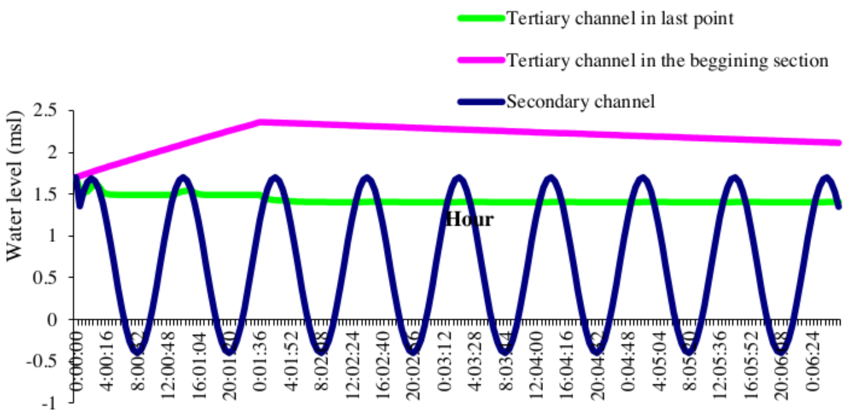

Figure 3 The effect of supply operation combined with water retention in tertiary channel at minimum rainfall condition

If water depth in tertiary depth is maintained at 50-60 cm height, then soil water level at tertiary block is still at safe level for rice crop or it is above 15 cm zone. Water level condition at depth of 10-15 cm for long period can significantly reduce production [38]. This condition is similar to study result by [39] which show that rice crop will experience water stress if soil water depth is drop below 20 cm zone. Optimum water depth for rice crop is 5 cm above soil surface [40]. According to [41] production of 1 kg rice requires 1,432 liter water to fulfill crop evapotranspiration requirement.

According to [25] DUFLOW computer model is very good to evaluate the flow and disposal potential at network system of tidal lowland. This condition corresponds to the study result in which Duflow computer model capable to give an overview of water level rise due to waterworks operation. One of important operation that should be conducted is channel flushing to dispose poor water quality due to water retention for long time in secondary and tertiary channels. The increase of water level in SDU can be flown into tertiary channel and to dispose water from tertiary channel into SPD which is subsequently flown into primary channel. This water operation can also be arranged based on simulation of DUFLOW and one of them is used to decrease sedimentation effect in channel [42].

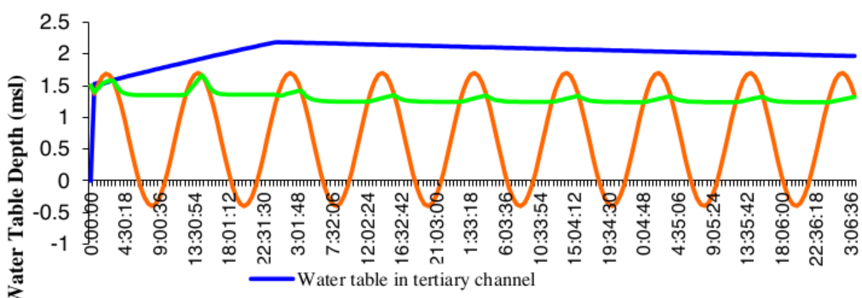

Figure 4 Results of DUFLOW simulation at SDU (main drainage channel) condition as longstorage and water table elevation in tertiary channel is elevated at 70 cm

Leaching and flushing activties can only be done at the end of rainy season after rice planting. Water in tertiary channel can be disposed into secondary channel which subsequently flow into primary channel. Observation of soil water level at tertiary channel before and after the existence of waterworks at SDU secondary channel can be seen in Figure 5.

Figure 5 shows that there is an increase of ground water table during the growing period (MT1) of rice crop. Soil water level never drop beyond -30 cm so that soil water status stays in saturation condition. Meanwhile, previously soil water level drop to -60 cm resulting in water stress experience by rice crop, especially during initial period of the flowering stage.

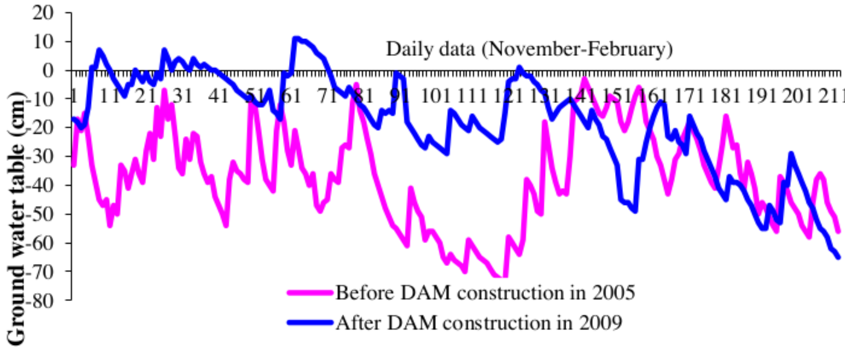

Figure 5 Water table elevation at tertiary block for first planting season 2005 before and after weir construction in 2008-2009 at P10-2S delta Saleh

The disadvantage of weir construction in SDU is the difficulty in water management system operation because it is not equipped with operational water gate. At least a culvert is needed in combination with fiberglass flap gate.

3.3. DRAINMOD Model Adaptation for constructing field operation model

DRAINMOD simulation had been done at dry land (Saleh). This simulation use several assumptions such as *steady state condition,* crop water requirement use empirical approach in which potential evapotranspiration is calculated by using Thornwhite equation [43]. The drainage system had distance between channel of 200 m and the depth of impermeable layer is located 1.5 m below soil surface.

Water management scenario is based on land utilization pattern potential and farmer socioecomic aspect in which the proposed planting pattern is rice-corn. Based on water status in land, the main objective of water management at Saleh area is water retention and water leaching.

The results of statistical analysis of the DRAINMOD simulation using one year of data (rainy and dry conditions) showed good performance where the results of modeling and observations had the same trend of water level fluctuation patterns. This means the model is acceptable, with high reliability. This condition is strengthened from the results of statistical analysis where the correlation coefficient value reaches 0.89; the efficiency model has a positive value and is close to one, namely 0.97, and the root mean error (Root Mean Square Error) is 1.45 cm. With these results, it can be concluded that the performance of the model is said to be very good, and the DRAINMOD model can be used to evaluate the status of shallow groundwater levels.

The recommended water management scenario is to cultivate land with planting pattern system of rice-corn in which rice is planted at first planting season of November-January/February and corn is planted at April up to June/July. The problem for corn cultivation is that soil is still in water saturation condition in February, March and April so that drainage is required. Entering the month of May, soil water level drops below 30 cm so that corn crop experience water stress. Water retention in channel is required during this condition and whenever possible irrigation can also be given. Water level dynamics resulting from DRAINMOD simulation can be seen in Figure 6.

Model adaptation in the field is conducted in 2009-planting season and showed good result in which the effect of water gate retainer and water gate retainer in secondary channel showed the significant increase of soil water level (Figure 6). Soil water can be maintained due to the existence of water in tertiary channel and water can be stored in land in case of rainfall occurence. This condition causes the land to be flooded resulting in increase of production. Production for 2005 year in average is 2.5 ton/ha, whereas production is increase in average of 4 ton/ha for 2009 year.

Monthly operation of water gate according to crop growth phase can be seen in Table 4. Soil tillage for rice crop is started since November. The main objective of water management at initial soil tillage is disposal. This drainage process had been started since September- Oktober. Its objective is to leach hazardous substances and soil acidity out of the root zone of the plant. Water retention process is started since soil puddling up to seeds sowing phase. Water disposal is done at seeds sowing phase in which quarterly channel gate is opened so that water in land can be disposed through quarterly channel into tertiary channel.

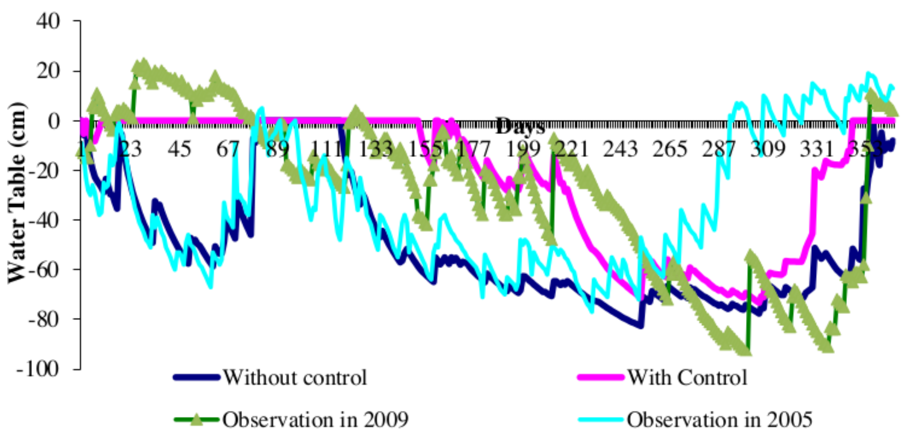

Figure 6 Daily water dynamics resulting from computer simulation of DRAINMOD model at location of P10-2S Delta Saleh

Option for water gate in tertiary channel is closed during rice crop growth in December up to February. Water gate is not fully closed at this operation, only about 40-50 cm. It is expected that suplay water is possible during high tide water and water in tertiary channel is not all discharge because it is retained by the gate at height of 40-50 cm during low tide water.

The proposed planting pattern is rice-corn based on field study and input from farmers. Gate operation is mostly in retaining condition during rice crop cultivation which is started from October-December and January-February. Water retention is done at height of 50 cm. Gate operational is by retaining water at depth of 50 cm (Table 4). It is expected that water in tertiary channel can be retained at height of 50 cm by this gate operation and water level at estuary of tertiary channel can increase to 60 cm during high tide water so that high tide water can fill tertiary channel. The entering of high tide water is also to maintain water quality.

It is obvious that without operation of water level control, water deficit will occur at Delta Saleh (Figure 7). Water level drops far beyond acid sulphate layer and land can not be cultivated for the whole year. DRAINMOD simulation results showed that ground water table is drop below root zone of 0 cm without water retention in tertiary channel although at rainy season condition. Therefore, farmers in the field are strongly agree that water retention is done during rainy season, especially during rice growing period.

Table 4 Field Operation on farm for first planting season of rice during December- February 2009) at Location of P10-2S Delta Saleh (dry type).

Crop growth phase	Activity period	Tertiary canal operation system	
		Modeled by Drainmod simulation	Farmer done for model adaptation
Land preparation	September-October	Open	Open
Land tillage	October-November	Close/water retention	Close/water retention at 50 cm
Planting, direct seedling (Tabela)	November	Close/water retention	Close/water retention at 50 cm
Vegetative growth	December-January	Close/water retention at 50 cm	Close/water retention at 50 cm
Reproductive phase	January-February	Close/water retention at 50 cm	Close/water retention at 50 cm
Maturing phase	February	Close/water retention at 50 cm	Close/water retention at 50 cm

3.4. Model Adaptation in Composing Water Control Operation for Rice and Corn Crops at C/D Typology Land (Dry Condition)

In tidal lowland corn cultivation can be started if soil water drops below root zone of 30 cm. This activity can be done directly after rice harvesting. This is due to the fact that soil water level is still high so that soil layer in the root zone is still saturate with water. Therefore, water gate is totally opened at March period and at the same time flushing acid substances is done that are accumulate during water retention period at rice cultivation season. Computer simulatin of DRAINMOD had succeed in composing seasonal operational plan for water table control. The results of desired water level for corn as impact of water level control can be seen in Figure 7.

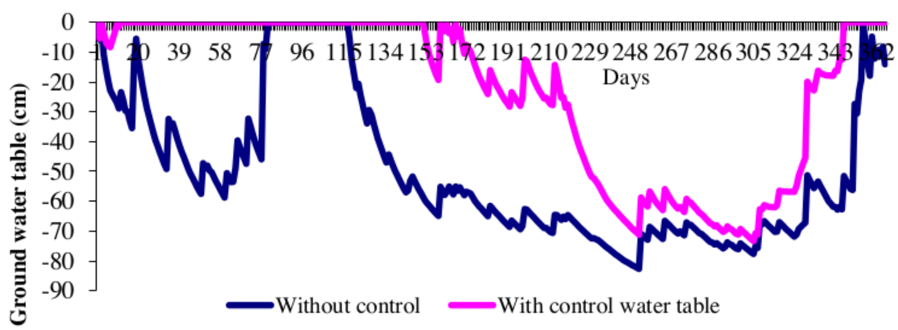

Figure 7 Simulation result of DRAINMOD under two option water management

Field operation should include water retention effort entering the dry season. Water level condition drops close to 60-70 cm below soil surface during generative phase of crop (August). This condition is vulnerable if no rainfall occurrence because crop will experience water stress [35]. Therefore, water supply from surface is needed. Water addition should be given to fulfill crop evapotraspiration requirement especially when entering the generative phase. Pump irrigation with output or discharge diameter of 8 ich can be operated with interval once in 10 days. Pump operation is done during high tide water. Gate operation after rice harvesting in March is by total disposal to flush acid substances and to lower soil water level for corn planting preparation.

4. Conclusion and recommendation

4.1. Conclusion

The best cropping patern in C typology land class of tidal lowland is rice-corn based on water availability analysis in tertiay block. Water gate construction is needed to apply water control operational system at tertiary block. Stop log type gate is the best compared to flap gate type on C typology land (dry).

Computer simulation showed good result in which soil water level dynamics from simulation result tend to be similar with field measurement results. It was stated that the root mean square value of error is 1.45 cm, model efficiency value is 0.97 and strong correlation value is 0.84.

Network improvement effort can be composed through adaptation of DUFLOW model for C typology land (dry). Network improvement is conducted by connecting tertiary channel SPD and SDU, water gate installation of stop-log type, and weir construction at drainage secondary channel (SDU).

Analysis to computer model software of DUFLOW-DRAINMOD showed the mutually supportive results in which DUFLOW simulation results can provide water potential information in channel for supply objective (irrigation)..

Field operation model of water management for corn was achieved by control drainage in which all water gates at all corn growth phase are operated as water retention and supply when salt water is not entering yet (June-July). Maximum drainage can only be conducted after finishing of rice planting and land tillage for planting preparation.

4.2. Recommendation

File operation model to maintenance the water table in tertiary block was conducting by water retention system at dry land type (C-typology). Aapplied for long time will results in water quality degradation. Therefore, water flushing and leaching in channel should be routinely operated. Maintence tertiary canal by flushing once in two weeks is sufficient to improve water quality.

Some factors to be involped in constructing the field model operation in the field are as follows: farmer instrucution should be made as simple as possible and it is socially accepted by farmers. Finally the water management operation must be done continuously although land is in uncultivated condition in order to reduce environmental damage and to accelerate the soil remediation process.

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