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MATHEMATICAL MODELLING ON THE OPERATION OF WATER CONTROL STRUCTURES IN A SECONDARY BLOCK CASE STUDY: DELTA SALEH, SOUTH SUMATRA

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ABSTRACT The project Land and Water Management of Tidal Lowlands (LWMTL) was set forth in Indonesia to reclaim vast areas of waterlogged tidal land for agricultural exploitation. The objective of this study was to simulate water management systems near the farmers' field by controlling flap gate culverts in secondary canals (SDU) and stop logs in tertiary canals under different scenarios of irrigation, drainage and flushing. Based on data (hydraulic and hydrometric) collected during a field survey in August 2005, a 1D mathematical model (DUFLOW) for the canal system was developed and calibrated. For boundary conditions of the model, tidal water level fluctuations in the primary canals were used. Different rainfall intensities (10 mm/day, 30 mm/day and 80 mm/day) and evaporation of 3 mm/day were modelled in order to evaluate the hydraulic response of the system. Water normally flows from the secondary canals to the tertiary canals. Water level is kept and maintained as high as possible. The model shows that water level in the tertiary canals increases in time; the level also depends on tidal water level outside and rainfall intensity. In the case of 80 mm/day rainfall, water level in tertiary canals will reach around 2.00 m above median sea level (+MSL, more or less the ground surface elevation) after one day. At this level, water can be utilized for agricultural production. Flushing can be done by operating the culverts and water can flow out from SDU to the primary canal. Water in the tertiary canal can be set at low elevation +1.30 m +MSL for flushing to the SDU and primary canal. Based on the hydraulic performance of the mathematical model, water level can be controlled to improve the hydro-topographical conditions of the area which can change from C/D to A/B category. A one way flow system can be realized where the flow will start from the SDU to tertiary canal and to the field. During low water, drainage can also be regulated from field to the tertiary canal and to the SDU. Finally, related to the water management system in this secondary block some suggestions can be presented. In the future this temporary dam in the SDU should be replaced by a permanent control structure and culverts should be completed with a flap gate. Based on the water level in the SDU (behind the dam), operational rules of the tertiary water control structures have to be derived and used by the farmers.

Keywords: Tidal lowlands, Water management zoning, Modelling, Operation and maintenance.

INTRODUCTION Indonesia avails over large lowland areas with an estimated area of about 33.4 million ha, out of which about 20 million ha is tidal lowland. Almost 4 million ha of tidal lowlands have been reclaimed, partly by spontaneous settlers (more than 2.5 million ha) and partly by government Schemes (about 1.3 million ha). The reclaimed areas in South Sumatra province cover about 450,000 ha. They have been reclaimed more than 20 years ago and consist mainly of fertile clay soils in the upper layers. The project Land and Water Management Tidal Lowlands (LWMTL) aimed at the improvement of existing agricultural exploitation, among others by establishing water user associations, upgrading of the hydraulic infrastructure, improvement of agricultural practices and post harvest activities, transfer of knowledge and manpower development. As one of the pilot areas, a secondary block between primary canals P10 and P11 in the Delta Saleh water management scheme in South Sumatra, Indonesia has been chosen. The area belongs to C/D hydro-topography category. The location of P10-Saleh is presented in Figure 1.

HYDRO-TOPOGRAPHY Hydro-topographical conditions are defined as the field elevation in comparison to river, or canal water levels in the nearest open water system. Four hydro-topographic classes are generally distinguished (Figure 2) (Land and Water Management for Tidal Lowlands (LWMTL), 2006):

- *category A (tidal irrigated areas).* The fields can be flooded by the tides at least 4 or 5 times during a 14-day neap-spring tidal cycle in both the wet and the dry season.
- These areas are situated mostly in depressions, or close to river mouths;

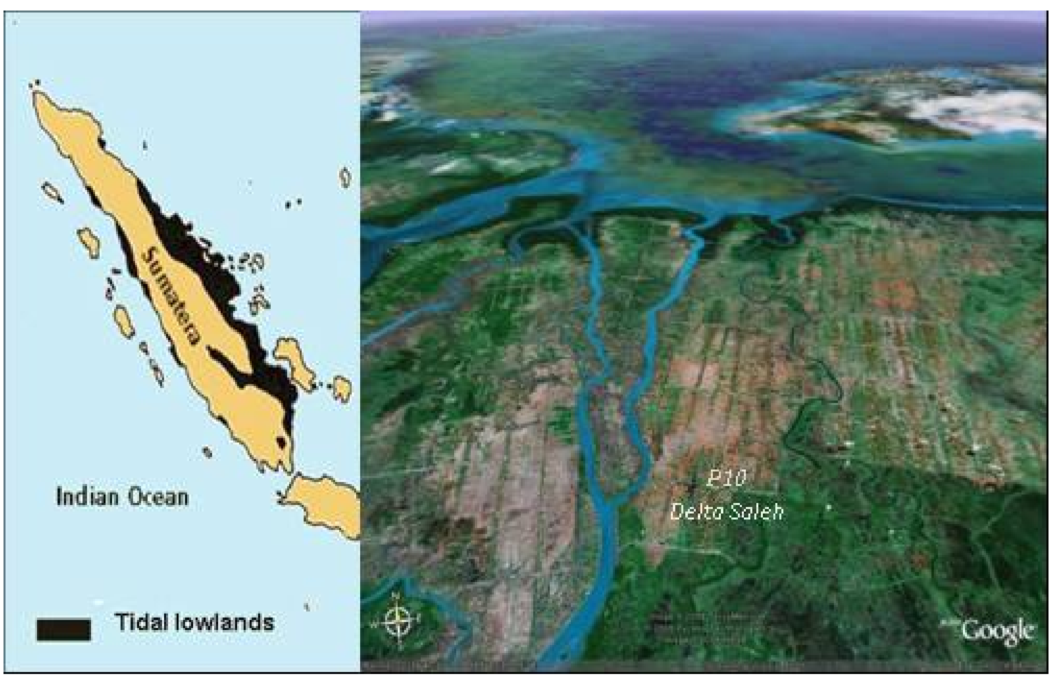

Figure 1 Delta Saleh, South Sumatra

– *category B (periodically tidal irrigated areas).* The fields can be flooded by the tides at least 4 or 5 times during a 14-day neap-spring tidal cycle in the wet season only;
– *category C (areas just above tidal high water).* The fields cannot be regularly flooded during high tide. The groundwater table may still be influenced by the tides. The relatively high elevation may cause significant percolation losses, making it difficult, or impossible to keep a water layer on the field for rice cultivation. Therefore, dry food crops and tree crops can better be grown on such lowlands;
– *category D (area50 cm above tidal high water s).* The fields are entirely above tidal influence. Dry food crops and tree crops are best suited to these areas. Except for areas receiving extra water from bordering uplands and/or peat domes which are used usually for wetland rice.

The secondary block in the case study area is located in the Saleh area along Primary Canal 10 is a category C/D hydro-topography (no tidal flooding potential) and covers an area of about 250 ha. The area is provided with hydraulic structures at secondary and tertiary canals.

PROBLEM DEFINITION The cultivation of a second crop in the tidal lowlands of South Sumatra still meets major challenges to be successful. Although the yields of the second crop are still mostly low, observing the performance of the second crop in 2005 yielded important knowledge of the problems encountered. For the cropping season of 2005/2006 this knowledge has been used to determine the inputs for the annual cropping plan. These inputs are related to water management, land preparation techniques, required machinery/pumps/post-harvest equipment and various agronomic inputs. Examples are applied for drought resistant rice crops and upland crops such as maize, depending on local conditions and farmers interests. Trials were conducted for the second rice crop in cooperation with the farmers and two main problems were noted (LWMTL, 2006):

- insufficient decomposition in the soil surface layers of the green organic material of first crop when the second crop is planted;
- relatively dry conditions during the growth period of the second crop.

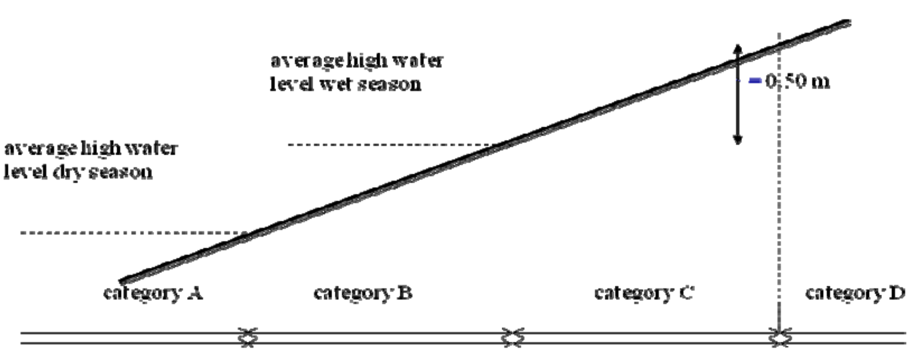

Figure 2 Hydro-topographic classification

Water management in the tidal lowlands in Indonesia aims first of all at realising optimal agricultural yields. Especially for hydro-topography C area, most of the cases are only rice crop during wet season. In order to improve the utilization of the C area, water management system has to be improved properly based on the require crop environment. Principally, the objectives of water management system are:

- to provide a suitable conditions for rice crop during wet season;
- to provide also a suitable conditions for rice crop and dry land crops during dry seasons.

In Pilot Area II the main problem was the relatively high agricultural ground elevation in comparison with the tidal high water levels. Here the rice is completely depending on rainfall in one hand, and in other hand subsurface flow of groundwater to the adjoining secondary canals caused relatively high water losses. LWMTL proposed, in consultation with the farmers, the construction of two dams with culverts having movable flap gates and made by the farmers. See Figure 3.

These dams are located at the mouth of the secondary canals near the primary canals. During the field campaign in April 2006, some observations have been carried out and presented in Figure 4. These dams in the secondary canal have been repaired by *Proyek Irigasi Andalan* (PIRA) (Department of Public Works at Provincial Level). PIRA also conducted a number of improvements in the water control infrastructure in Pilot Area II based on proposals prepared by LWMTL in 2004 and 2005. These improvements of the water control infrastructure and the construction of the dams resulted in a substantial increase in the rice yields of 50-100% this year. PIRA is now planning for 2006 to install similar dams in other similar high areas and will improve the dams made by the farmers in Pilot Area II, based on designs prepared by the LWMTL team.

In order to achieve these objectives, first the tertiary canal and secondary canal and its water control structures have to function properly.

Figure 3. Dam structure completed with culverts (flow to downstream direction)

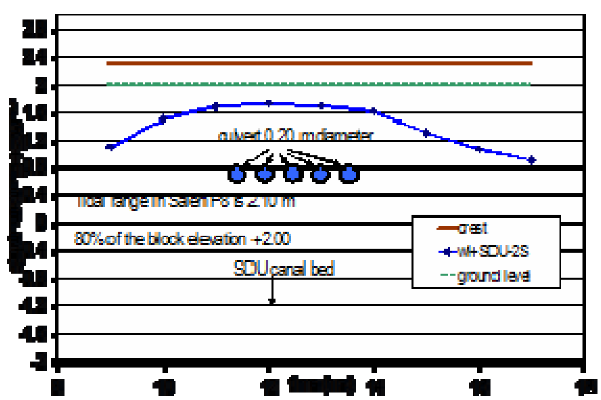

Figure 4. Water level and ground elevation at the Dam location P102S, Saleh

MATHEMATICAL MODELING In this case a 1D hydro dynamic modelling DUFLOW (DUtch FLOW) package was used where the basic St. Venant equations for unsteady flow was applied. The mathematical modelling will cover Village Secondary Canal or Saluran Sekunder Pedesaan (SPD) and Main Secondary Drainage Canal or Saluran Sekunder Drainasi Utama (SDU) and tertiary canals in P10, Saleh area. The ground elevation is around +2.00+MSL. The basic data were collected during the measuring campaign in the Pilot Areas in April 2006. Based on this campaign the DUFLOW model was set up in order to evaluate the hydraulic performance of the water management system in Pilot Area II. The schematization of the model is presented in Figure 5.

As boundary conditions water level fluctuations at SPD and SDU are used. The semi diurnal tides with 1.05 m tidal amplitude. First, rainfall of 20 mm/day is used as internal boundary conditions. After that rainfall of 10, 30 and 80 mm/day have also been used in order to check and evaluate the hydraulic performance of the water management system.

DISCUSSION AND EVALUATION In the present conditions there is no or hardly operated tertiary and secondary structures. From the field visit in 2005 and 2006 showed that tertiary canals in Saleh area (type C/D) only small parts were cleaned by the farmers. The quality of the water control structures in general are in poor conditions and can not be operated properly. In most of tertiary canals, acidity or pH of water is still low. It was around 4.0 and stagnant water is the reason for that. Farmers cultivated rainfed rice or

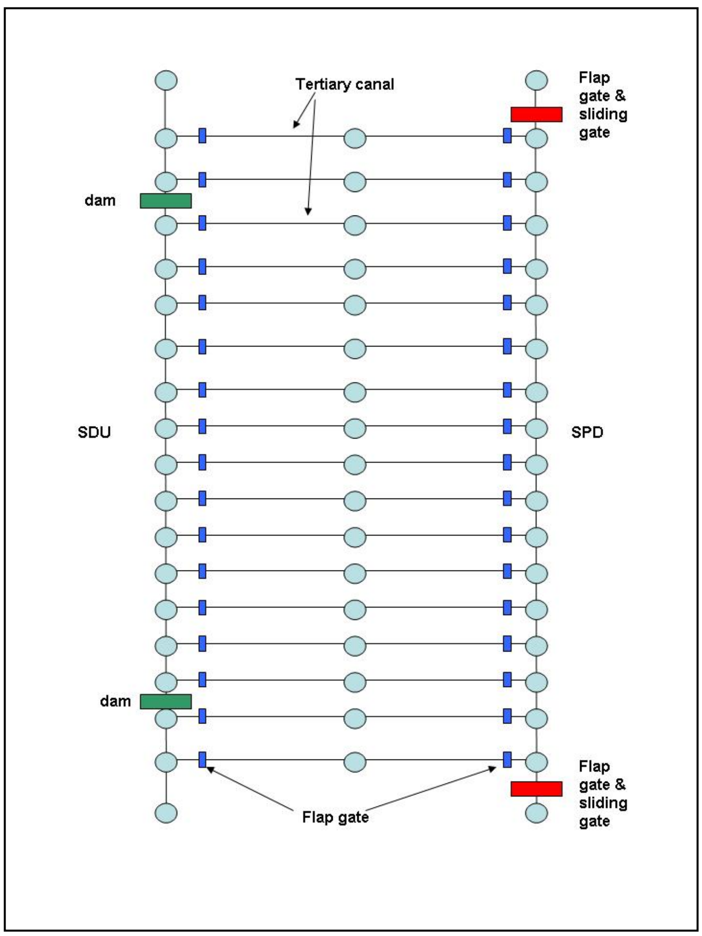

Figure 5. Model schematization of P10-Saleh

maize during wet season. Farmers blocked the tertiary canals with sand bags in order to maintain the soil moisture content in the rootzone by retaining the water in the tertiary canals. In case the water quality in tertiary canals are too acid, the farmers simply removed the sand bags and take out the flap gates in order to flush water in tertiary canals. See Figure 6 and Figure 7. It is showed in Figure 5 that the flap gate is blocked by concrete and can not be operated as a flap gate but it functions as a stop log or a wall. In Figure 6, it is clear that dry land crops (in this case maize) can grow properly in this area. As water control structures, flap gates are not needed here. Instead of that stop logs will be better to be used as water control structure in this hydro-topo category. From practical point of view and the interviews with the farmers there, in the future water control structures (stop logs) can be operated weekly or two weekly (flushing) in order to maintain a proper water quality in the canal system.

In 2005 dams which are completed with flap gate culverts were constructed in the SDU canal. The purpose of these dams is to have a high water level in the SDU between the dams. This high water level can be achieved from the primary canal during high tides (through culverts) and also rain water.

Then high water from SDU canal can flow easily to tertiary canals and to the agriculture fields. For this purpose the water quality from the SDU canal has to be checked. The dam and the water level in the SDU in the present conditions are presented in Figure 8 and Figure 9. In the present conditions, the stability and workability of the dams and its flap gate culverts are not really good. It is proposed that to replace these temporary dams with permanent structures.

Besides irrigation possibility, drainage conditions have also to be improved in C/D area in this secondary block. This can be done by doing an operation strategy and maintenance of the water control structures in the secondary and tertiary canals. The dam and its flap gate culverts have to be operated in such a way in order to optimize its function for the agricultural development of the area. When the water quality in the SDU is relatively bad (low pH), flap gate culverts have to be opened during low tides and water in the SDU can be flushed out to the primary canal.

Figure 6. Tertiary water control structure.

Figure 7 Field conditions P10 Delta Saleh.

Figure 8. Dam in SDU

Figure 9. Water level upstream of the dam

Expected conditions by improving water management system and their water control structures This operation strategy has been modelled and the results of the model simulation are presented in Figure 10 and Figure 11.

Besides that water control structures in tertiary canals have to be improved. By having a high water level in the SDU canal, water can be regulated in the tertiary canals and irrigation or water control structures can be managed in relation to the crop requirement at the field level. By considering the hydro-topographical condition of the area (C/D categories) and the water level in the SDU and SPD canals, it is clear that sliding gates or stop logs will be more suitable and applicable than flap gates to be functioned as water control structures in tertiary canals.

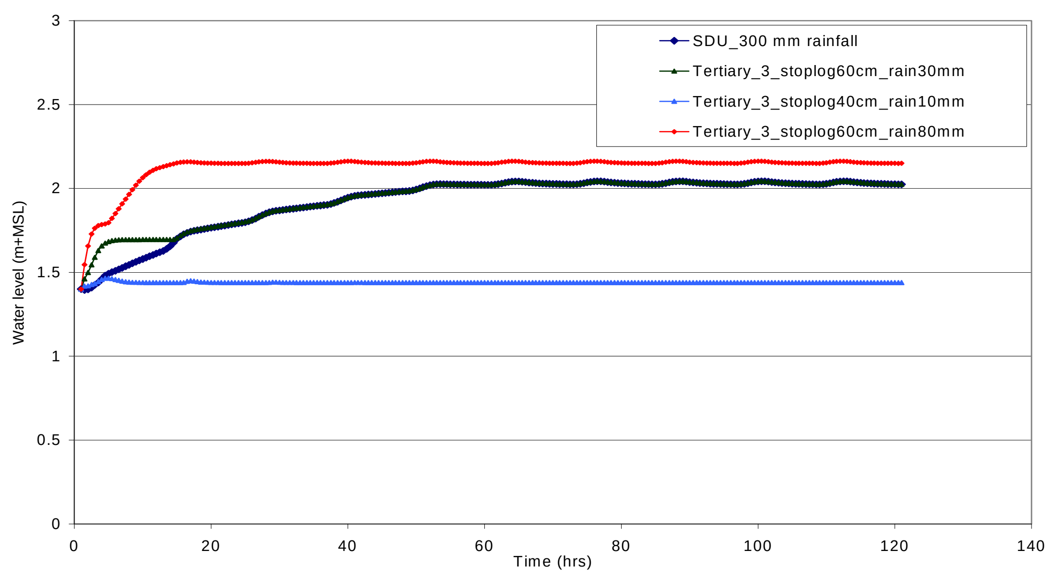

Figure 10. Model simulation results

Different rainfall intensities (10mm/day, 30 mm/day and 80 mm/day) and evaporation of 3 mm/day have been simulated in order to see the hydraulic response of the system. In these simulations, tertiary stop logs at SDU side are set at +1.60 m+MSL and stop logs at SPD side are set at +2.00 m+MSL. It is expected that water will flow from the SDU and in tertiary canals, water will be kept and maintained as high as possible. In fact, from Figure 10, it shows that water level in tertiary canal will increase in time and this increase is very much depends on the rainfall intensity. In case the rainfall is 80 mm/day and only during one day, water level in tertiary canal will reach around +2.00 m+MSL after one day. It means that with this water level, water can be utilized for the agriculture development. Besides that, the quality of the water has to be checked where if pH is quite low, water has to be flushed out from the system.

Flushing can be done in this case by opening the culverts and water can flow out from SDU to the primary canal. Next to that tertiary stop logs at SPD side can be set at low elevation and water can also be flushed out from tertiary canals to the SPD and finally to the primary canal. In this case, tertiary stop logs for flushing purposes are set at +1.30 m+MSL. The result of the simulation is presented in Figure 11.

It can be concluded that flushing of the water management system will not be a problem in P10-2S block. Three main points have to be considered by the farmers:

- When SDU between the dam has to be filled, the flap gate on the culverts have to be set in the supply position;
- When supply to tertiary canals is needed, stop logs control structures at SDU side have to be set at a level based on the field water requirement and stop logs at SPD side have to be set as high as possible (near the ground elevation in order to avoid water flow into SPD;
- When flushing of the secondary block water management system is needed, flap gates on the culverts have to be in the drainage position and water control structures stop logs at SPD side have to be set quite low (around 0.30 cm from the tertiary canal bed) and water will easily flow from tertiary to the SPD and finally to the primary canal.

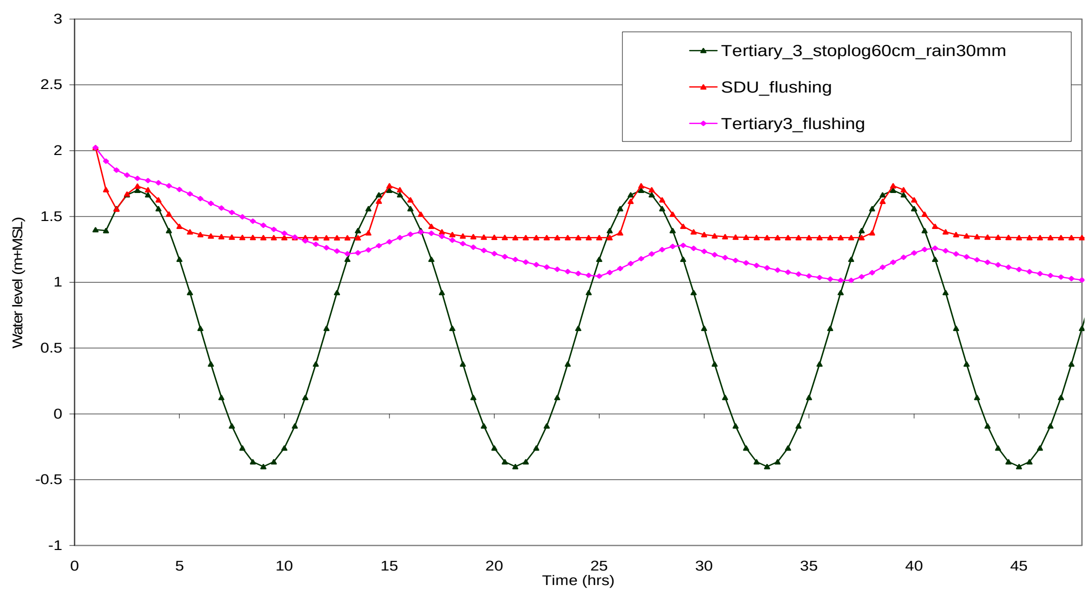

Figure 11 Model simulation for flushing

Figure 12. Field conditions P8, Telang I

Figure 13. Tertiary canal and field conditions P*, Telang I

By constructing these dams in the SDU, water level can be easier controlled and in fact the hydro-topographical conditions of the area will be changed from C/D to A/B category. In this case a one way flow system can really be realized where the flow will start from the SDU → tertiary canal →field. And during low water in the SPD canal can also be regulated from field → tertiary canal → the SPD. Besides its function for the house hold, tidal water levels in the SDU will only be important for drainage and flushing of the system (during low tides). The effect of the dams to the agricultural performance at field level is presented in Figure 12 and Figure 13.

FINAL REMARKS AND RECOMMENDATIONS In general LWMTL program has to follow the irrigation reform principles of decentralization of the water sector. Farming communities, through their respective water management organizations, the P3A's, will become the driving factor in the operation of the water management systems The responsibilities of the government are decentralized to the district level. From the LWMTL program, it is clear that farmer involvement has to be done as early as possible. They will realize the positive effects of the water management strategies and the operation of the water management system to their agricultural production.

It is at this level that the farmers representatives have to link with the government on water related issues. In this Pilot area II, the design and construction of the dam in SDU has to be discussed with the District Public Works level and to replace the temporary dam to the permanent dam, besides the district level, provincial level as well as central level most probably have to be involved, especially related to the financial aspect.

Based on the water management strategy, the hydraulic performance of the water management system and the effect of the temporary dam to the agricultural system and yield, it is optimistic that a permanent dam can be expected to be built in the related SDU in the near future. Some recommendations can be listed:

a. In the future this temporary dam in the SDU should be replaced by a permanent control structure and culverts should be completed with a flap gate;
b. Stop logs or sliding gates will be more appropriate for category C area instead of flap gates;
c. Based on the water level in the SDU (behind the dam), operation of the tertiary

water control structures have to be derived.

Related to the operation of the water management system and its water control structures, supervision and guidance from the Department of Public Works and Department of Agriculture in the district level to the farmer group (P3A) are really needed.

Finally, from LWMTL program experience in P8-Telang I, post harvesting and the marketing elements have also be considered properly in order to achieve a sustainable agricultural development of the area.

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REFERENCES

Hartoyo Suprianto, Gatot Irianto Sumarjo, Robiyanto H. Susanto, F.X. Suryadi and Bart Schultz. 2006. *Potentials and Constraints of Water Management Measures for Tidal Lowlands in South Sumatra, Case study in a pilot area in Telang I.* 9th Inter-Regional Conference on Environment-Water, Delft, the Netherlands.

Hartoyo Suprianto, 2004. *Where do we stand on swamplands development, Regional Teaching Seminar on Guidelines on Tidal Lowlands*, Jakarta, Indonesia.

Land and Water Management Tidal Lowlands, 2005a. *Technical Guideline on Tidal Lowland Development. Volume I: General Aspects*, Report of the Joint Indonesian - Netherlands Working Group, Jakarta, Indonesia.

Land and Water Management Tidal Lowlands, 2005b. *Technical Guideline on Tidal Lowland Development. Volume II: Water Management*, Report of the Joint Indonesian - Netherlands Working Group, Jakarta, Indonesia.

Land and Water Management Tidal Lowlands, 2005c. *Technical Guideline on Tidal Lowland Development. Volume III: Operation and Maintenance*, Report of the Joint Indonesian - Netherlands Working Group, Jakarta, Indonesia.

Land and Water Management Tidal Lowlands, 2005d. *Training for P3A, Pilot Area P6-3N, P8-12S Telang I and P10-2S Saleh (in Indonesian language*), Palembang, Indonesia.

Land and Water Management Tidal Lowlands, 2006. *Monitoring Report February 2006, Tertiary Pilot Area T4P8- 12S Telang I (in Indonesian language),* Palembang, Indonesia.

NEDECO/Euroconsult/BIEC, 1984. *Nation wide inventory of coastal and near-coastal swampland in Sumatra, Kalimantan and Irian Jaya.* Ministry of Public Works, Indonesia.

Suryadi, F.X., 1996. *Soil and water management strategies for tidal lowlands in Indonesia.* PhD thesis, Delft University of Technology- IHE Delft. Balkema, Rotterdam, The Netherlands LWMTL, 2005. *Technical Guidance on Tidal Lowland Development. Volume 1: General*, Jakarta, Indonesia.

Suryadi, F.X. and Bart Schultz, 2001. *Effects of operation rules on water management in tidal lowlands.* In: proceedings workshop on the Agricultural based development of tidal swamps and estuaries and environmental considerations, Seoul, Korea.