THE ROLE OF DRAINAGE IN THE WISE USE OF TROPICAL PEATLANDS

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SUMMARY

The Indonesian Government has identified the coastal zones of Borneo as a major region for agricultural development. Owing to a scarcity of agricultural land, there is an increasing interest to invest in the development of lowland peat swamps. Drainage is needed to make these waterlogged peat swamps suitable for agriculture or other land use. As soon as the peat swamps are drained the process of irreversible subsidence commences. This subsidence is a well-known and hard-to-overcome constraint to the development and use of tropical peatlands. Drainage and fires associated with the agricultural development and logging release increasing amounts of carbon to the atmosphere. The dilemma is how to strike a balance between two contrasting needs, namely, intensive drainage in order to produce more food and less intensive drainage to avoid irreversible damage to these fragile eco-systems. In this paper, a new water management strategy for the sustainable use of tropical peatland is proposed. In this strategy, emphasis shifts from drainage to water control. The challenge therefore is to strive for a balance between water levels allowing optimal crop production and water levels minimising peat subsidence. Under the new system, water levels in the drainage system will be maintained at the highest feasible level. These high levels have implications for the design, implementation and operation of the water management system. It will result in a water management system with narrowly spaced shallow drains in combination with an intensive network of control structures. It should be remembered, however, that subsidence cannot be completely arrested; it is the price one has to pay for utilising lowland peat swamps.

Keywords: tropical peat, hydrology, drainage, water management, Indonesia

INTRODUCTION

To be able to feed the growing world population and to banish hunger, food production needs to be doubled in the next 25 years. In south-east Asia, where fertile land has become scarce, agriculture development more and more focuses on marginal soils such as peatlands, acid sulphate soils, and steep land. Peatlands in south-east Asia cover about 27.1 Mha, or about 10% of the total land area (Hooijer *et al.*, 2006). About one quarter of the world's tropical peatlands (11 million hectares) occur in Borneo. These peatlands, which are waterlogged most time of the year, are dome-shaped. It should be realised that because of the dome-shape topography, peat domes cannot be irrigated by gravity from the surrounding rivers. The only source of water is rainfall. The rainfall is not distributed evenly over the year (Ritzema & Wösten, 2002). The average dry season (monthly rainfall <100 mm) can last for 3 to 4 months. Under these conditions the water table depth can fall to one metre or more below the peat surface (Takahashi *et al.*, 2002). Without water conservation, this can lead to severe and persistent moisture deficits in the surface peat layer and thus to increased oxidation and risk of fire.

The Indonesian Government has identified the coastal zones of Borneo as a major region for agricultural development. The lowland peat swamps of Borneo are purely rain-fed and waterlogged most times of the year. Drainage is needed to make these waterlogged lands suitable for agriculture or other land uses. Many development projects on tropical peatlands have failed through a lack of understanding of the natural functions of these complex ecosystems. The leading principle of the existing water management practice is based on fulfilling the drainage requirements, namely, avoiding flooding by the evacuation of excess rainfall within a certain period of time. Furthermore, it is assumed that this excess rainfall is mainly removed by surface runoff. Thus, the design principles for drainage of peatlands are similar to those for mineral soils, although the soil and hydrological characteristics differ greatly. Compared to mineral soils, peat has a much higher infiltration capacity, drainable pore space and hydraulic conductivity, but a lower capillary rise, bulk density and plant-available water (Wösten *et al.*, 2003). Another major difference is the subsidence behaviour of peat; it is partly caused by oxidation and is never-ending. Oxidation leads to CO_2 emission, which under Borneo conditions, is estimated to be in the order of 26 tonnes per hectare per year. In addition to the loss of peat by oxidation, the excessive subsidence rates result in a pronounced drop in the elevation of the land reducing the efficiency of the drainage system. To avoid flooding and waterlogging problems during the monsoon season, frequent deepening of the system is required (Figure 1). The resulting progressive lowering of water levels triggers off increased subsidence and so on. In Western Johore, Peninsular Malaysia, for example, it is estimated that the low water levels in the drainage system, caused by uncontrolled drainage, increase the overall subsidence by approximately 30 per cent (DID and LAWOO, 1996). The mineral substratum under peat soils is often sulphidic. Once the peat has disappeared, the mineral subsoil, which are often sulphidic, will surface. The available pyrite will oxidise and acid sulphate soils with very low pH values will form (Kselik *et al*., 1993). This continual subsidence process threatens the sustainable use of peat areas (Rieley *et al.*, 2002). To sustain the use of lowland peat swamps a new approach in water management, based on controlled drainage, is proposed. In this paper, the hydrology of the tropical peat swamps of Borneo is discussed and, based on the specific characteristics of this peatland hydrology, a new water management approach is presented. The paper is based on experiences obtained in the utilisation of peatlands in Malaysia (DID, 2001, Ritzema *et al.*, 2003), The Netherlands (Ven, 1996) and other parts of the world (de Bakker and van den Berg, 1982).

THE HYDROLOGY OF THE TROPICAL PEATLANDS OF BORNEO

Hydrology is an important (if not the most important) factor in the formation and functioning of peat swamp ecosystems. The hydrology of a peat swamp depends on the climate, topographic conditions, natural subsoil, and drainage base. Any changes in the hydrology, especially those from the introduction of drainage, will have - often irreversible - effects on the functioning of these fragile ecosystems. Only a sound understanding of the hydrology of peat swamps will make it possible to develop and manage them in a more sustainable way.

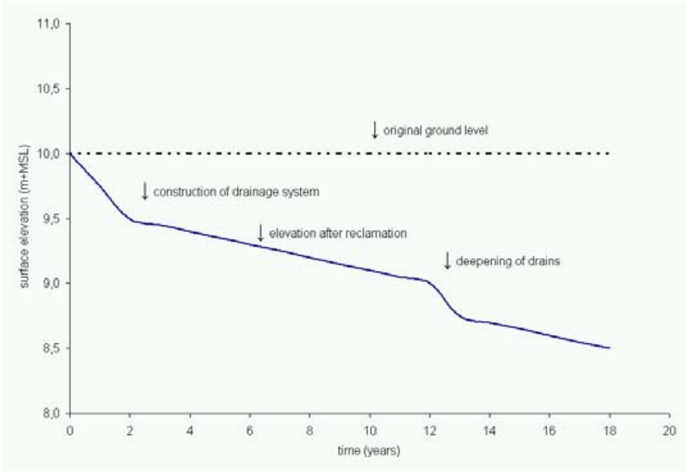

Figure 1 The everlasting subsidence results in a continuously lowering of the land surface (After Eggelsman, 1982).

Water balance in tropical peatland

The majority of the lowland tropical peat swamps are completely rain-fed. Water flow from upland areas does not enter them. The rainfall either evaporates or is transported from the swamps as near surface run-off, inter-flow, or groundwater flow. Under unsaturated conditions, almost all of the rainfall infiltrates owing to the high hydraulic conductivity (up to 30 m per day) of the surface (approximately first 1 metre) peat layer (Takahashi *et al.*, 2002). The high hydraulic conductivity, combined with a relatively low hydraulic gradient in the relatively flat peatlands, results in a rapid discharge of rainfall through the top peat layer towards the surrounding rivers or drainage channels (Figure 2).

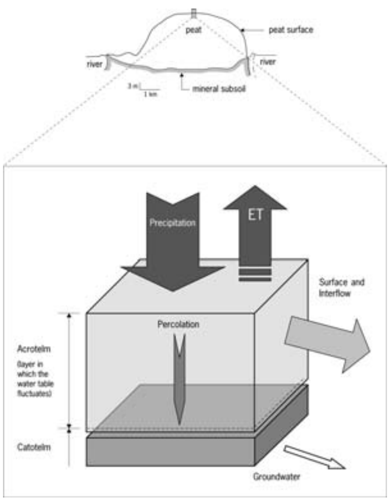

Figure 2 Water balance in a tropical peatland

The general water balance of a peat swamp can be expressed as follows:

$$P = E + Q + \Delta S$$

where:

P	total rainfall (m)
E	total evapotranspiration (m)
Q	total discharge (m)
ΔS	change in storage (m)

Under natural conditions, the water table rises with rainfall and falls as a result of evapotranspiration and the outflow of excess water. Fluctuation of water tables in a peat swamp depends mainly on rainfall because evapotranspiration and (groundwater) outflow are fairly constant. Drainable pore space, or the storage coefficient, can be as high as 0.8 (Wösten and Ritzema, 2001). In the dry season, when water levels are low, most rainfall can be stored in the surface peat layer. Even in the wettest months, the storage capacity is considerable and discharges are factors 5 to 10 times lower than in mineral soils (DID and LAWOO, 1996). During the wet season, rainfall always exceeds the combination of evapotranspiration and (ground) water run-off. Seepage through deeper peat layers is low and about 90% of the excess rainfall will run off through the top peat layer, the so-called interflow (DID, 2001). In this season, watertables will rise, creating conditions favourable for peat accumulation while, during the dry season, when rain-free periods may last for several weeks or even months, water levels often drop to a metre or more below the peat surface.

WATER MANAGEMENT

Drainability

Drainability refers to drainage by gravity, i.e. drainage without the aid of mechanical devices such as pumps. The drainage base is defined as the water level in the adjacent river or stream, below which natural drainage by gravity cannot be achieved (Figure 3). For conveyance losses an additional hydraulic head of at least 20 cm per kilometre should be added.

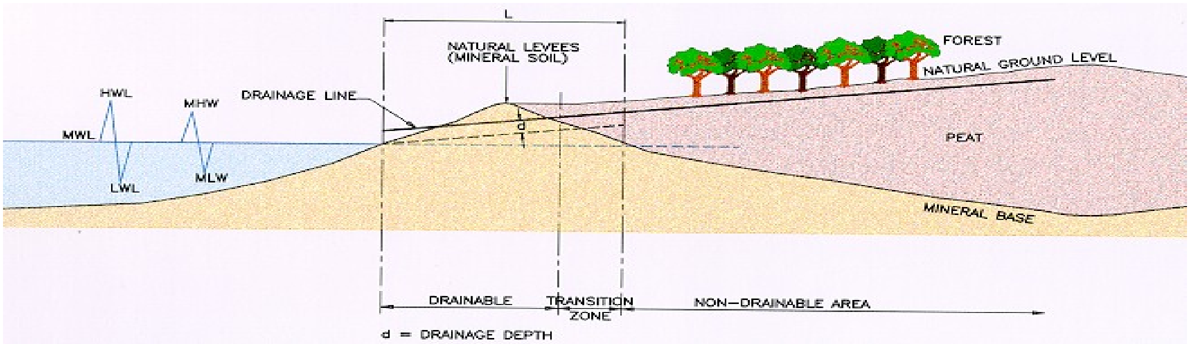

Figure 3 The water level in the adjacent river or stream determines the drainability of a peat swamp

In Indonesia, four types of tidal lands are commonly distinguished in coastal areas (Figure 4). The classification, which is mainly based on the potential for irrigation, is based on the water levels in the main rivers:

- Class A: Areas between mean low tide and mean neap tide. These areas appear close to the sea. The potential for irrigation and drainage is good because there is sufficient tidal fluctuation to allow a daily flooding and drainage. Gravity drainage is possible when the water level in an area is higher than the (outside) water level in the river. In lower-lying areas, drainage may be possible only during low tides. Control structures and embankments are needed to prevent flooding during high tide. Inside the area, storage capacity is required to store excess water until it can be discharged during low tide.

- Class B: Areas between mean neap tide and mean spring tide. Irrigation is only possible during springtide. Absence of daily flooding requires water conservation measures. Daily drainage is always possible.
- Class C: Area above spring tide. No tidal flooding, permanent drainage. In these areas drainage of excess rainfall is always possible due to absence of high water levels in the canals.
- Class D: Area outside the influence of daily tide. No tidal flooding, limited drainage during periods of high river flows. The water table drops during the dry season when evaporation exceeds rainfall.

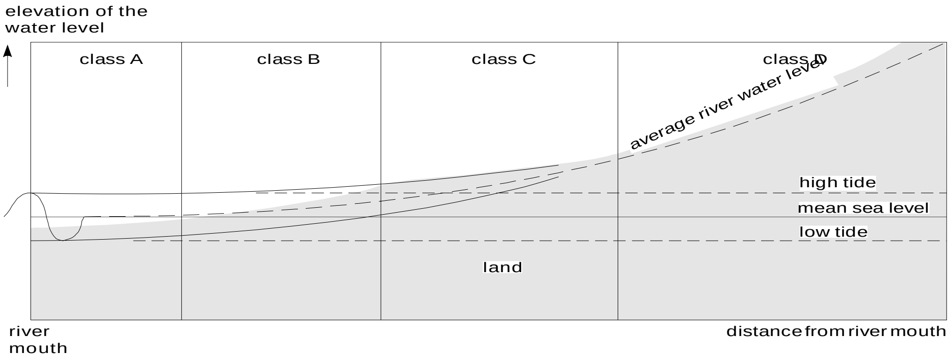

Figure 4 Tidal land classification in Indonesia (AARD and LAWOO, 1992)

Most of the peat swamps in Indonesia are class D and gravity drainage is possible because of their dome-shaped morphology. Drainage, however, results in subsidence and gravity drainage can only continue till the elevation of the land drops below the drainage base. Uncontrolled drainage – and the subsequent excessive subsidence – could put an end to this quickly: depending on its original thickness of the peat layer it may take 50 to 750 years before the overlaying peat soil has subsided so much that gravity drainage is no longer possible (Wösten *et al.*, 2003). After the elevation of the land has dropped below the drainage base, the drainability becomes problematic: gravity drainage and further subsidence will cease. The land will become waterlogged and unsuitable for agriculture. The only option is pumped drainage, which at present is not economically feasible, but it might be in future. Then, on a limited scale, it might be economical for crops with a very high rate of return (e.g. horticultural crops). The alternative is to give the land back to nature.

An Improved Water Management Strategy for Tropical Peat Swamps

The strategy for the new water management approach is based on the principle that peat is a precious resource that should be handled with care to prolong its life. This can only be achieved if there is a shift from the concept of unrestricted removal of excess water to controlled drainage. This integrated water management principle combines drainage, irrigation and water conservation. Drainage is needed during the monsoon season to control the watertable and to remove excess surface and subsurface water from the land. Irrigation, which in this case is called sub-irrigation or inverse drainage, is needed to supply water through capillary flow during dry spells. And water conservation is needed to control the water table at a higher level throughout the year to avoid excessive subsidence and to reduce the risk of fire. Thus a water management system in peatland has three functions, i.e.:

- Removal of excess (surface and subsurface) water during the monsoon season
- Control of the (ground)watertable, and
- Conservation of the water during dry periods.

These functions are somewhat conflicting: on the one hand removal of excess water requires unrestricted outflow conditions and on the other hand the control of the water table and water conservation can only be achieved by restricting the outflow. The water management requirements also vary within a year. Water table control is required the whole year around, with removal of excess water only during periods with excess rainfall, whilst water conservation is essential during prolonged dry periods. Borneo has two seasons: in the dry season, rainfall is lower or equal to evaporation and water conservation is required. In the wet or monsoon season, rainfall exceeds evaporation and drainage is needed to remove the excess rainfall. On top of this, there are short periods of extreme rainfall requiring an extra drainage capacity. To fulfil these conflicting needs, controlled drainage is required. Two conditions have to be considered:

- To maintain the watertable at a level that is low enough to enhance the agricultural use and, at the same time, high enough to sustain the peat. This watertable criterion will determine the spacing of the drains. It should be based on the drainage requirement during an average wet season.
- To remove excess rainfall during extreme events. This discharge criterion will determine the capacity of the drains (dimensions) and should be based on an extreme (e.g. one-in-5 year rainstorm) rainfall event.

The design should also take into account the specific soil hydraulic characteristics of peat, i.e. the very high infiltration rate, storage capacity and permeability. Because of these characteristics, excess rainfall is not removed as surface runoff but mainly as interflow and (to a smaller extent) groundwater runoff. The change from surface to interflow and groundwater runoff has a significant effect on the discharge: model simulations for a similar peat area in Western Johore, Peninsular Malaysia, showed a reduction of the peak discharge by more than 100% (Ritzema et al., 1998). For conditions in Borneo, with its humid climate and prolonged periods of rather uniform rainfall, the steady-state approach (e.g. the Hooghoudt Equation, see for example Ritzema, 2007) can be used to calculate drain spacing. The simplicity and the limited requirement of input data of this approach make it very suitable.

Structures are needed to control the drainage. Because peat is so permeable, structures with small head differences are recommended. The dynamic storage capacity in the drainage system is small compared to the recharge by excess rainfall and the corresponding discharge. Therefore it is possible to use the steady-state approach for the design (Beekman, 2006). Structures act as barriers to prevent the flow but water cannot be stored for long periods as it will seep away through the surrounding peat. Computer simulations show that a cascade of closely spaced dams is most effective for water control (Figure 5) (Ritzema *et al.*, 1998).

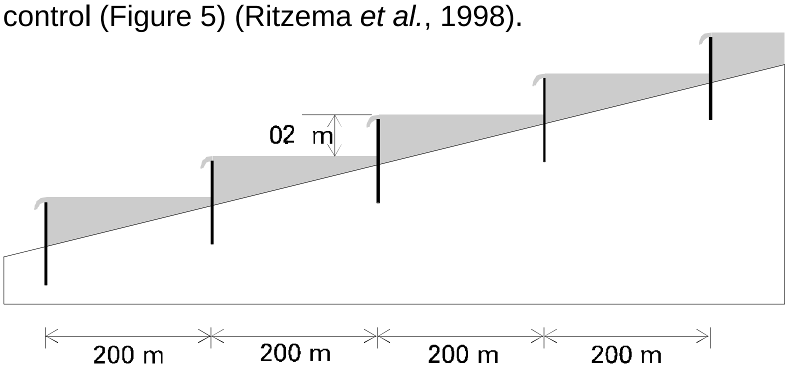

Figure 5 A cascade of closely spaced control structures is needed to maintain high water levels in the drain during the dry season (Ritzema *et al.*, 1998).

The distance between the structures depends on the gradient of the peat dome (Beekman, 2006). In the central part of the dome, the slope is often less than 0.5 m km^{-1}, increasing to more than 2 m km^{-1} near the edges. Consequently, the distance between structures in the central part of the dome can be as far apart as 1 to 2 km, but this must be much less towards the edges. As the structures are intended as water control rather than water impoundment structures, they do not have to be watertight and their construction can be relatively simple. Structures have to be adapted to the specific characteristics of tropical peat, in particular its very high hydraulic conductivity (Wösten and Ritzema, 2001) and low load bearing capacity (Salmah, 1992). In Block C, structures, constructed of locally available peat and timber, are successful in raising upstream water levels. An additional benefit of using peat, which has a low bulk density, is that expensive foundations are not needed.

The above considerations result in a water management system with narrowly spaced drains in combination with an intensive network of control structures. A consequence of this high intensity system is that the percentage of the area occupied by the water management system is high: between 15 and 20% compared to less than 5% in mineral soil areas.

The layout of the water management system should also make use of the dome-shaped topography of the peat lands. Field drains should be located parallel to the contour lines and collector drains perpendicular to these. The best location for water storage, needed to replenish the groundwater during prolonged dry periods, is in the centre of the peat dome (Figure 8).

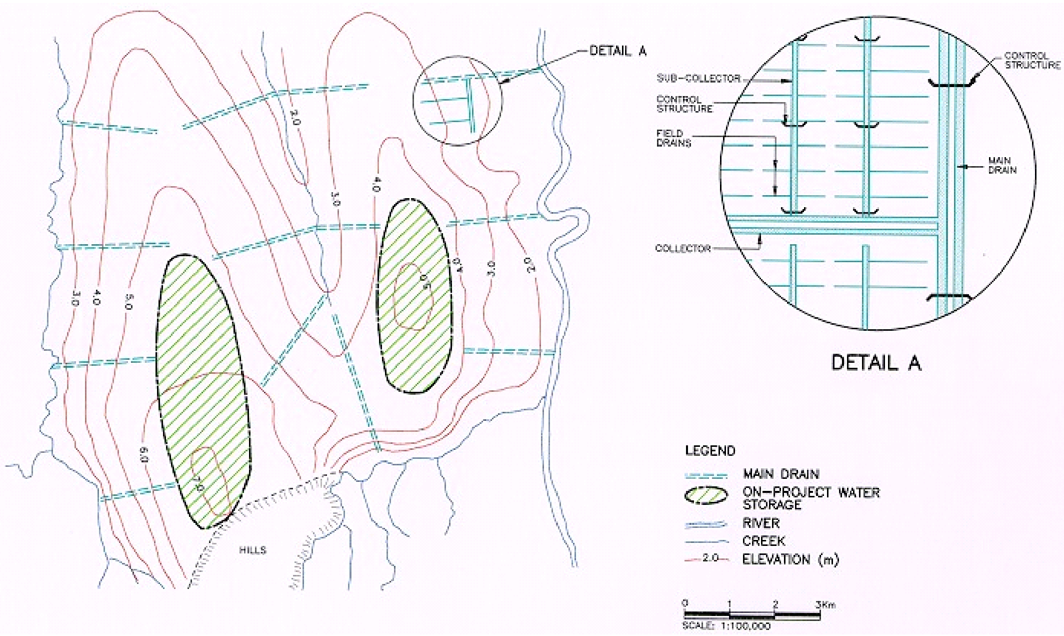

Figure 8 Typical layout of a drainage system in which the centre of the peat-dome can be used to store water

CONCLUSIONS AND RECOMMENDATIONS

To sustain the lowland peat swamps of Borneo, a new approach in water management has been developed. In this approach, the emphasis has shifted from removal of excess rainwater to water control. The challenge is to strive for a balance between water levels allowing optimum crop production and water levels minimising peat subsidence. Furthermore, the system is designed using the unique characteristics of peat: its huge infiltration, water-holding capacity and permeability. This will result in a system with closely-spaced, shallow drains in combination with an intensive system of control structures. Although the concept is clear, applying it effectively will take time. What are the best methods to use? What are the best structures to control the water level and how do you operate those structures? It's a process of optimisation that, e.g. in The Netherlands and other countries in Northern Europe, has been going on for centuries (Ven, 1996 and de Bakker and van den Berg, 1982). Also in Borneo, this process will take years. It will only be successful if the principles and practices of sustainable 'wise use', especially with respect to hydrology and water management are taken into account (Rieley and Page, 2005). And only when all organisations working in lowland peat swamps of Borneo join hands, the implementation of the recommended approach will lead to a success in sustaining one of Borneo's precious resources: its lowland peat swamps.

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