DECISION SUPPORT SYSTEM FOR PEATLAND MANAGEMENT IN THE HUMID TROPICS[1]

Henk P. Ritzema[2], Tom Grobbe[3], Tom Chong[4] and Henk Wösten[5]

ABSTRACT

Large areas of globally important tropical peatland in Southeast Asia are threatened by land clearance, degradation and fire, jeopardising their natural functions as reservoirs of biodiversity, carbon stores and hydrological buffers. Many development projects on tropical peatlands have failed because of lack of understanding of the landscape functions of these ecosystems. Utilisation of these peatland resources for agriculture or other land use requires drainage which, unavoidably, leads to irreversible loss of peat through subsidence, resulting in severe disturbance of the substrate, CO_2-emissions and problems for cultivation.

To assist planners and managers in wise use of these tropical peatlands a decision support system (DSS) has been developed. This DSS, which is based on a GIS application, combines the Groundwater Modelling Computer Programme PMWIN with expert knowledge on subsidence, land use and water management. The DSS can be used to predict the long-term effects of different types of land use, e.g. peat swamp forest, sago or oil palm plantations, on the lifetime and associated CO_2 release of these tropical peatlands. The type of land use dictates the required depth of the groundwater table, which on its turn has a significant effect on the sustainability of the peatland. Therefore, special attention should be paid when deciding which type of land use to pursuit. The Decision Support System (DSS) will help to improve the decision-making process.

The groundwater model PMWIN was selected because it maintains a good balance between the complexity of the model (esp. regarding to its input data requirements) and the availability of input data. The groundwater model was calibrated using data from the Balingian Area, Central Sarawak, Malaysia. The model was used to predict, based on a given land use scenario, the ratio between surface and groundwater runoff, the depth of the groundwater table and recharge and discharge zones of the peat dome. Various land use scenarios, each with its own specific water management requirements, were developed and used to predict the long-term changes in ground level and associated CO_2 release. For each scenario the following outcome was generated: time span after which the water management systems have to be deepened, time span after which gravity drainage is no longer possible, time span for peat disappearance. Final results are presented in the form of maps generated by the GIS application. These maps serve as a communication tool with stakeholders to demonstrate what the hydrological effects are on for instance a certain land use type and drainage system lay-out.

Keywords: Water Management, Tropical Peat, Management, Borneo, Stakeholder Communication

1 INTRODUCTION

The majority of the world’s tropical peatlands (11 million hectares) occur in South-east Asia, mainly in the coastal regions. Many of these coastal regions are identified as major regions for development with agriculture as its driving force. Agricultural development includes oil palm, sago and forest plantations, aquaculture, paddy and miscellaneous crops including pineapple and vegetables. The peatlands in these coastal regions have global ecological significance, being some of the largest remaining areas of lowland rainforest in SE Asia that provide the habitat of many endangered species. In addition, they are large stores of carbon and water and also play an important regional economic role, providing forest products and land for settlement. Owing to a lack of awareness and understanding about sustainable land management practices, however, many peatland development projects fail, resulting in serious environmental degradation and impoverishment of local communities (Diemont et al 2002).

Tropical peatlands consist of waterlogged organic soils that have formed from dead organic materials from plants and trees. According to the common definition of peat, these lands have at least 0.5 m of organic soil materials that consist of more than 35% of organic matter in various stages of decomposition. Peatlands are waterlogged most time of the year and need drainage to make them suitable from agriculture or other land use (Alan Tan and Ritzema 2003). 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 and Ritzema 2001). Another major difference is the subsidence behaviour of peat: it is never-ending and partly caused by oxidation. This oxidation leads to CO_2 emissions, which under Borneo conditions, is estimated to be in the order of 26 tonnes per hectare per year.

Beside 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 (Ritzema et al 2001). To avoid flooding and waterlogging problems during the monsoon season, frequent deepening of the system is required (Fig. 1). This never-ending process threatens the sustainable use of peat areas (Rieley et al 2002). Controlled drainage can reduce subsidence but never arrest it (Ritzema and Wösten 2002a). The rate of subsidence depends on the design depth of the watertable, which in its turn is prescribed by the type of agricultural use: e.g. oil palm requires a water table in the range of 0.60 to 0.80 m compare to sago which only needs a water table in the range of 0.20 to 0.40 m. Thus the type of agricultural development has a direct effect on the sustainability of the peat.

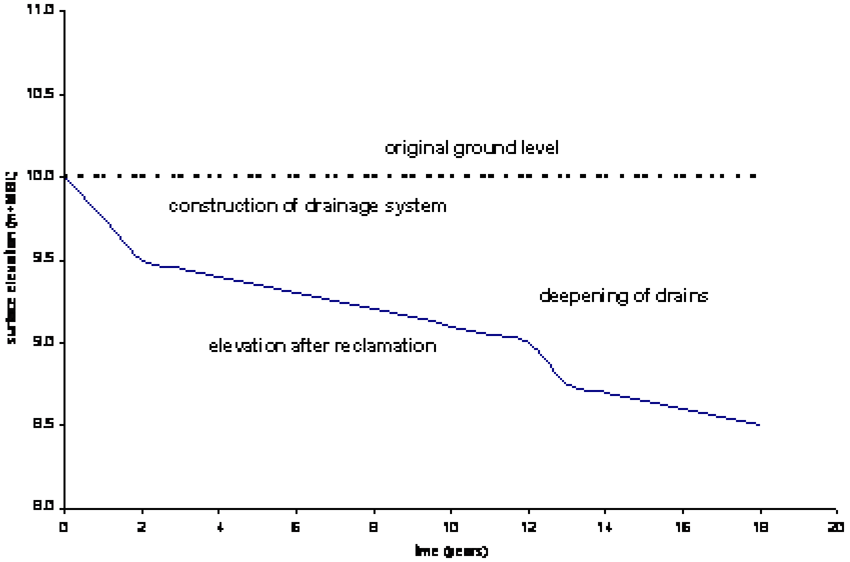

Figure 1 The everlasting subsidence of peat results in a continuously lowering of the land surface (after Eggelsmann 1982).

To assist planners and managers in wise use of these tropical peatlands a decision support system (DSS) has been developed. This DSS, which is based on a GIS application, combines the Groundwater Modelling Computer Programme PMWIN with expert knowledge on subsidence, land use and water management. The DSS consists of three components:

- A groundwater model to simulate the impact of reclamation on groundwater levels;
- A model to calculate the corresponding soil subsidence, and
- A GIS component to visualise the results.

As (ground) water is the driven force in peat formation and destruction, the groundwater model is the core of the DSS. The DSS can be used to predict the long-term effects of different types of land use, e.g. peat swamp forest, sago or oil palm plantations, on the lifetime and associated CO_2 release of these tropical peatlands. As the DSS is based on a GIS application other expert knowledge, for example on water quality, social interactions and economics can be relatively easy incorporated in the future. This paper discusses the development of the three DSS components and its calibration in the Balingian area, a tropical peat dome of about 10,000 ha in the Central Region of Sarawak, Malaysia (latitude 3^0 00' N, longitude 112^0 36' E).

2 GROUNDWATER MODELLING

2.1 PMWIN Package

To simulate the flow of groundwater the PWWIN 5.0-79 simulation package was selected (Grobbe 2003). PMWIN is based on Modflow: a public-domain, three-dimensional, finite-difference, saturated groundwater flow model (www.modflow.com). Modflow was selected because it offers good pre- and post-processing options, requires not too much input data, is well documented and can easily be extended with additional modules.

Geometry of the peat domes

The peat domes in the study area are purely rainfed with a lens-shaped domed surface. Because of the coastal and alluvial geomorphology, they are often elongated and irregular rather than having the 'ideal' round shape that is characteristic of peat domes (Figure 2). Surface slopes vary between 1 and 2m/km at the edges near adjacent rivers to less than 0.5 m/km at the centre of the domes. The depth of the peat varies from less than 1 meter near the coast to more than 20 m inland with a surface level of some 4 m above the adjacent river levels near the coast to some 9 m above these levels in the swamps that are more inland. The subsoil is either sulphidic in nature, or consists of a mixture of marine and riverine deposits, especially along river courses. Because of the dome-shaped surface (ground) water flow takes places in different directions.

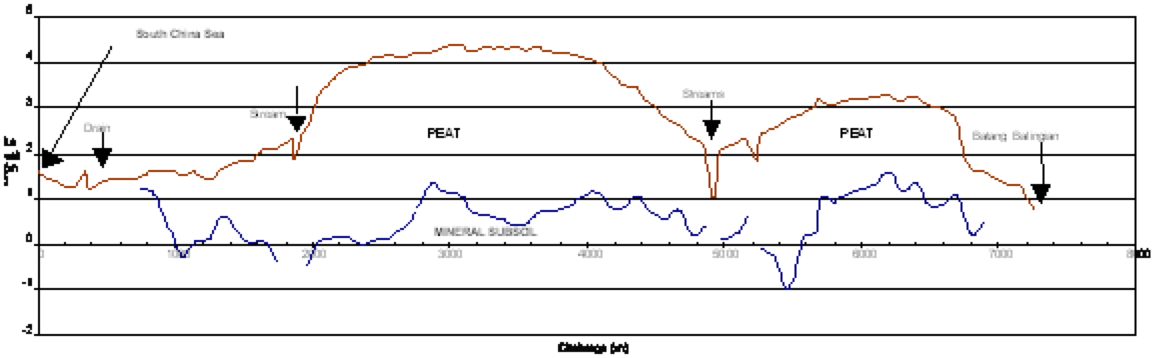

Figure 2 Cross-section of a peat dome in the Balingian area (PS Konsultant 1998)

In the model, the peat domes were schematized as a one-layered, unconfined aquifer with the mineral subsoil at mean sea level as the bottom boundary. The mineral subsoil was considered to be impervious. The top boundary was the soil elevation of the peat layer, which in the waterlogged peat soils, is also the elevation of the groundwater level.

2.2 Hydraulic conductivity

Hydraulic conductivity of the peat domes is very high, but varies considerably with the type of peat and the degree of humification (Wösten & Ritzema 2001). For the model simulation the horizontal hydraulic conductivity in the peat layer was assumed at 30 m/d, based on long-duration pumping test data (Ong and Yogeswaren 1991).

2.3 Recharge and discharge

The peat domes are purely rainfed with a total annual rainfall of about 3700 mm. Although the rainfall is not evenly distributed over the year, the average rainfall in the dry season (March –November), about 200-300 mm/month, still exceeds the rate of evaporation, about 120-130 mm/month (Ritzema and Wösten 2002b). For the model, the peat dome was divided in a recharge and discharge zone with the 2.5 m contour-line as the boundary (Figure 3). This 2.5 m contour was identified as boundary because it marks a change in peat soil types and slope of the soil surface (Grobbe 2003). The amount of recharge was deduced from the water balance study in the nearby Kut catchment (SWRC 1997):

Rainfall (100%) = Evapo-transpiration (45%) + Surface Runoff (37%) + Interflow (12%) + Groundwater Recharge (6%)

For the Balingian area, with a total rainfall of about 3700 mm/year, this results in a recharge of 222 mm/year.

2.4 Model calibration

The model was calibrated using the recharge as input and the elevation of the groundwater table as output. Using the above mentioned values of the hydraulic conductivity and recharge the simulated groundwater levels were far too high. A sensitivity analysis conducted for the horizontal hydraulic conductivity showed that the hydraulic conductivity had to be increased to unrealistic high values (> 180 m/d) to obtain acceptable groundwater levels, thus the value of the hydraulic conductivity was left unchanged. Subsequently, a value of the recharge was determined using the inverse modeling package PEST, which is part of the PMWIN programme. This resulted in a recharge of about 40 mm/year (or only 1.1% of the total rainfall), considerably lower than the recharge of the SWRC water balance study, but in agreement with hydraulic studies in European peat domes (van der Schaaf 1999). The subsequent model simulations were run with a value of 30 m/d for the hydraulic conductivity and 40 mm/year recharge.

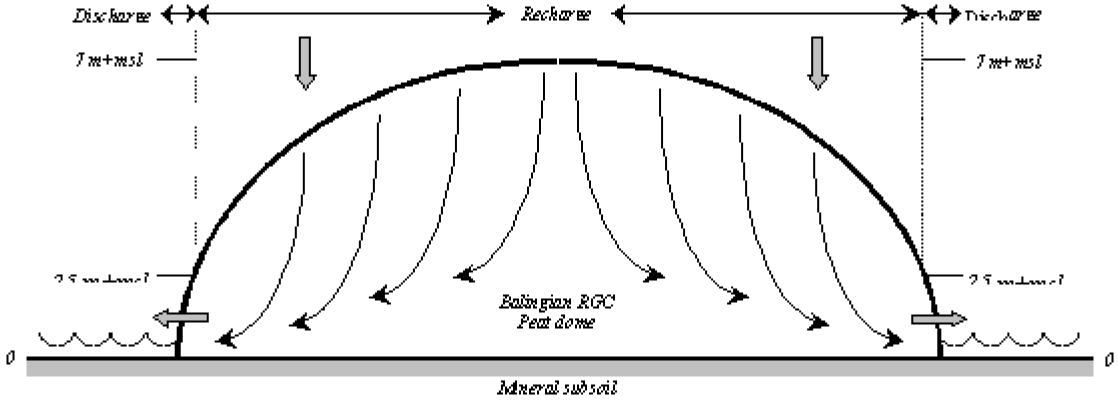

Figure 3 Model schematization of the recharge and discharge zones (not to scale).

3 SUBSIDENCE MODELLING

The outcome of the groundwater modeling was used to calculate the subsequent subsidence using the following relation:

Subsidence (m/year) = 0.1 x groundwater depth (m – ground level)

This relation is based on data of peat subsidence in Western Johore, Peninsular Malaysia, (Wösten et al 1997) and corrected for the conditions in Sarawak (Wösten and Ritzema 2001). To overcome local disturbances in the actual elevation of the ground level, the initial ground (water) level has been smoothened and made equal to the initial groundwater level. The resulting simulated levels are in good agreement with the measured data (Figure 4).

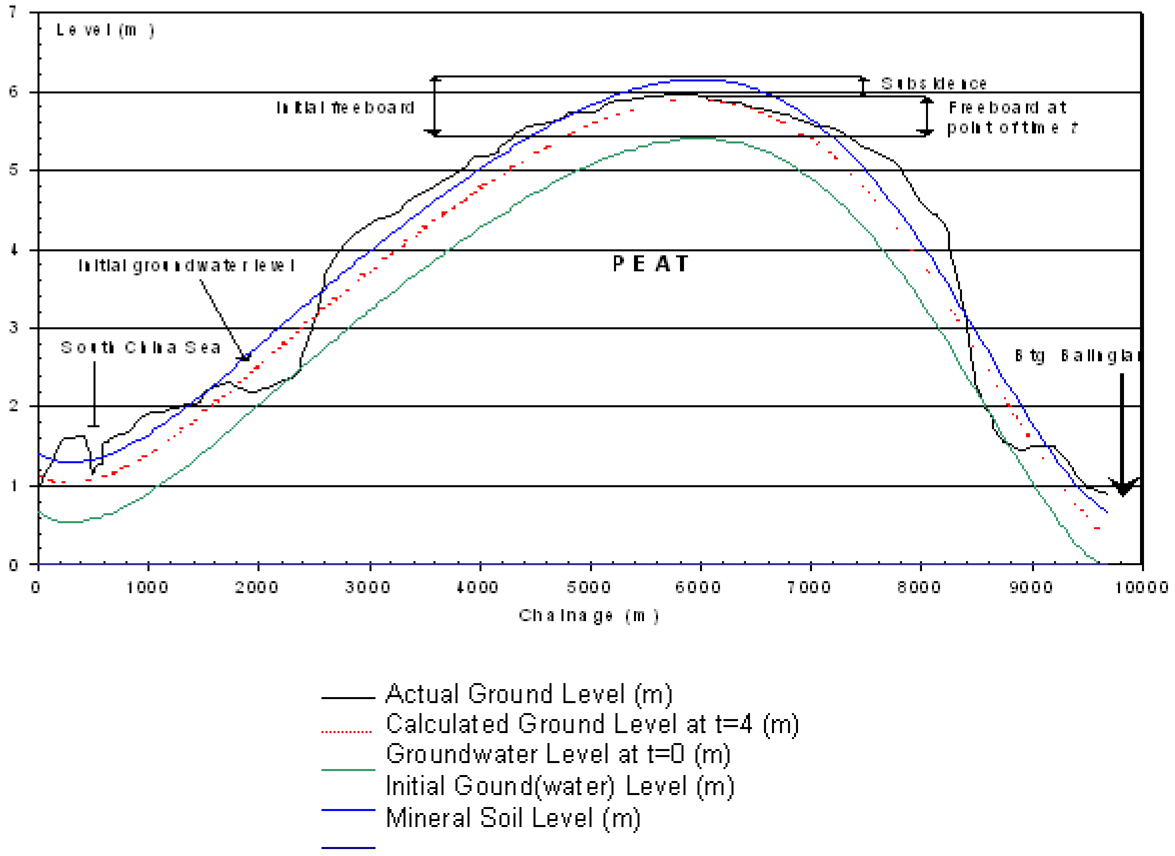

Figure 4 Simulation results of the subsidence modelling: initial ground(water) level and calculated subsidence after t = 4 years,

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The groundwater model was used to simulate the effect of the reclamation of part of the peat dome on the depth of the watertable, subsequent subsidence and the elevation of the ground surface in the surrounding part of the dome. Changes were calculated after 1, 2, 5, 10, 20 and 50 years. The simulations were done for two land use options, i.e. oil palm plantations with a required depth of the water table of 0.8 m below ground surface and sago plantations with a required depth of the water table of 0.4 m. The plantations were situated either on top of the peat dome or along the edges (Figure 5), resulting in the following scenarios:

1. Deep drainage (0.8 m below ground surface) on the top of the peat dome;
2. Shallow drainage (0.4 m below ground surface) on the top of the peat dome;
3. Deep drainage (0.8 m below ground surface) along the edges of the peat dome;
4. Shallow drainage (0.4 m below ground surface) along the edges of the peat dome.
5. Combination of scenario 2 and 3

Despite the subsidence and the resulting lowering of the ground surface, the depth of the drainage base was left unchanged during the simulation runs. Consequently the depth of the groundwater (= difference between the groundwater level and the ground surface) reduced over time ultimately resulting in an equilibrium condition in which the groundwater level was again at the ground surface. Under normal operation conditions, the drains should have been deepened every so many years and an equilibrium conditions should only have been reached when all peat had disappeared (= oxidized).

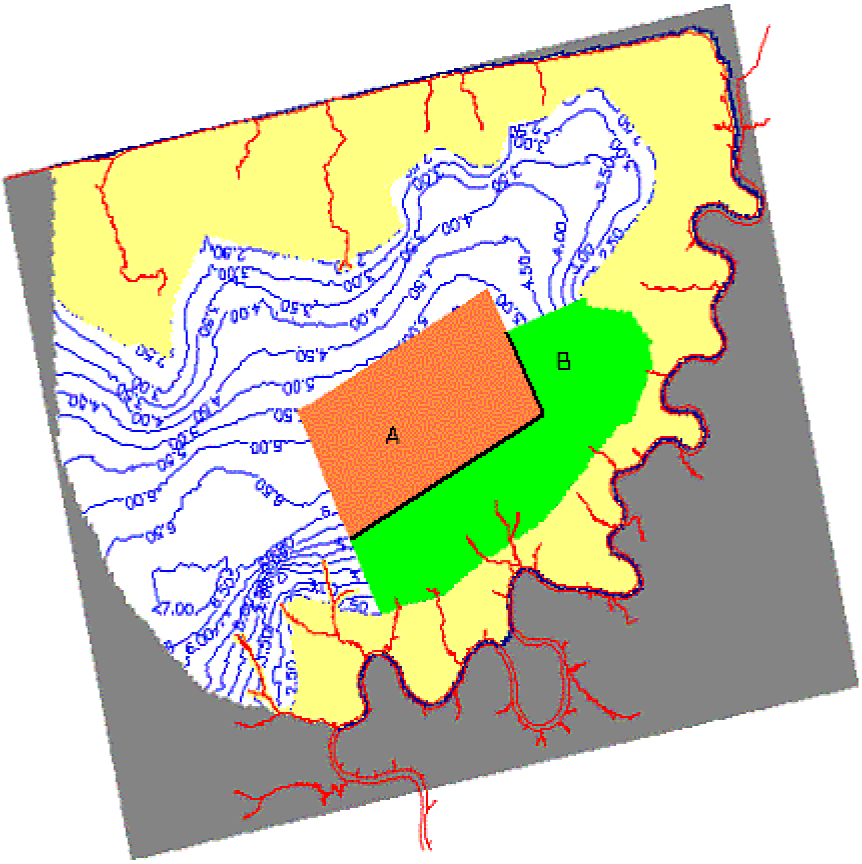

Figure 5 In the scenarios the plantations were either situated on top (A) or along the edge (B) of the peat dome.

4.1 Visualization of the Results of the Simulations

The results of the simulations confirm the hypotheses formulated in the previous studies (e.g. DID 2001), namely that:

- Locating a plantation on top of the peat dome results in a higher overall subsidence over the peat dome than locating a plantation along the edges (Figure 6).
- The deeper the drainage the higher the rate of subsidence.

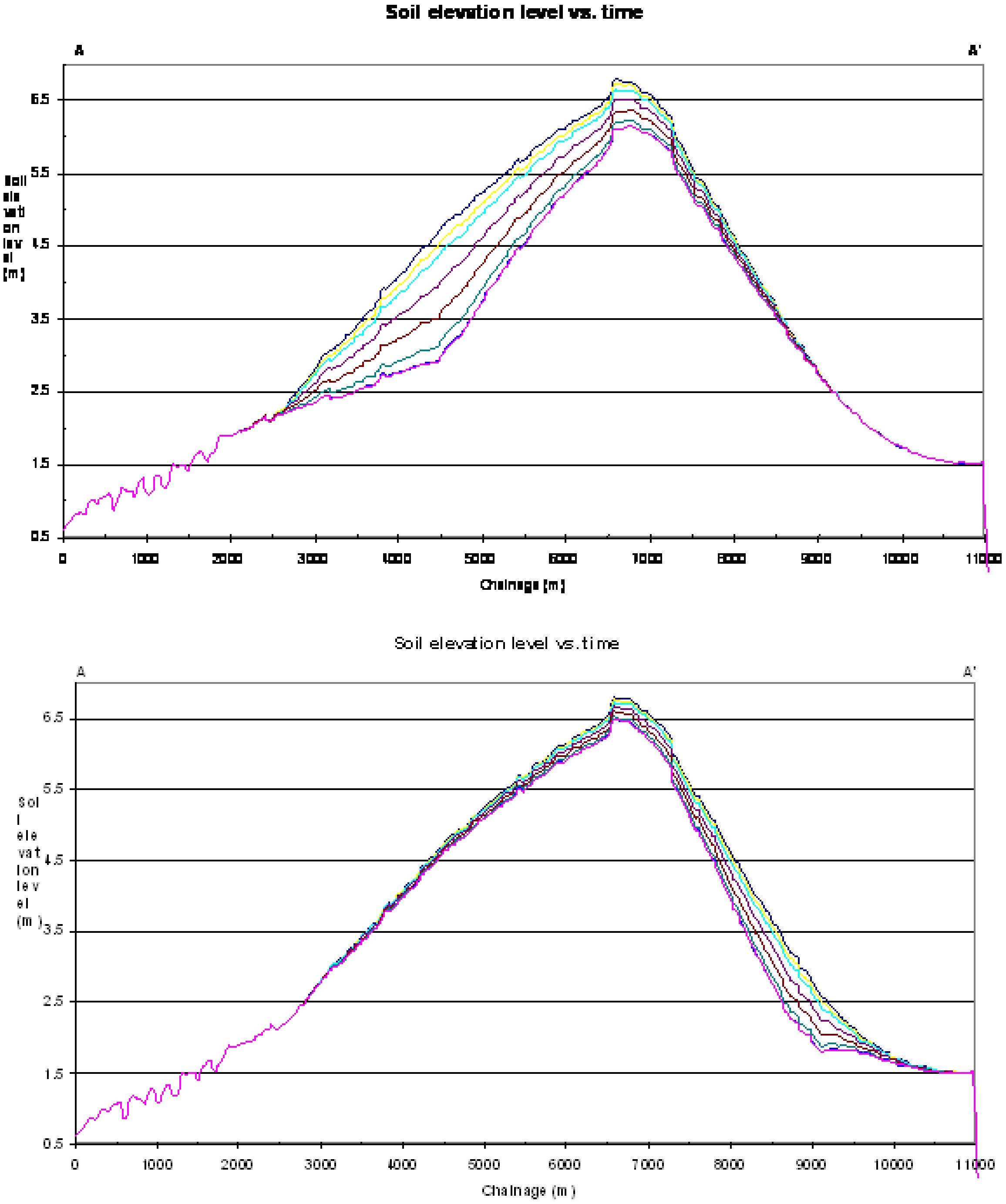

Figure 6 Drawdown of the ground level after 1, 2, 5, 10, 20 and 50 years for a plantation on top (left) and along the edge (right) of the peat dome.

The DSS was also used to visualize the differences the various scenarios have on e.g. the groundwater elevation over the peat dome (Figure 7), soil subsidence and the time it takes for the peat layer above the groundwater to disappear.

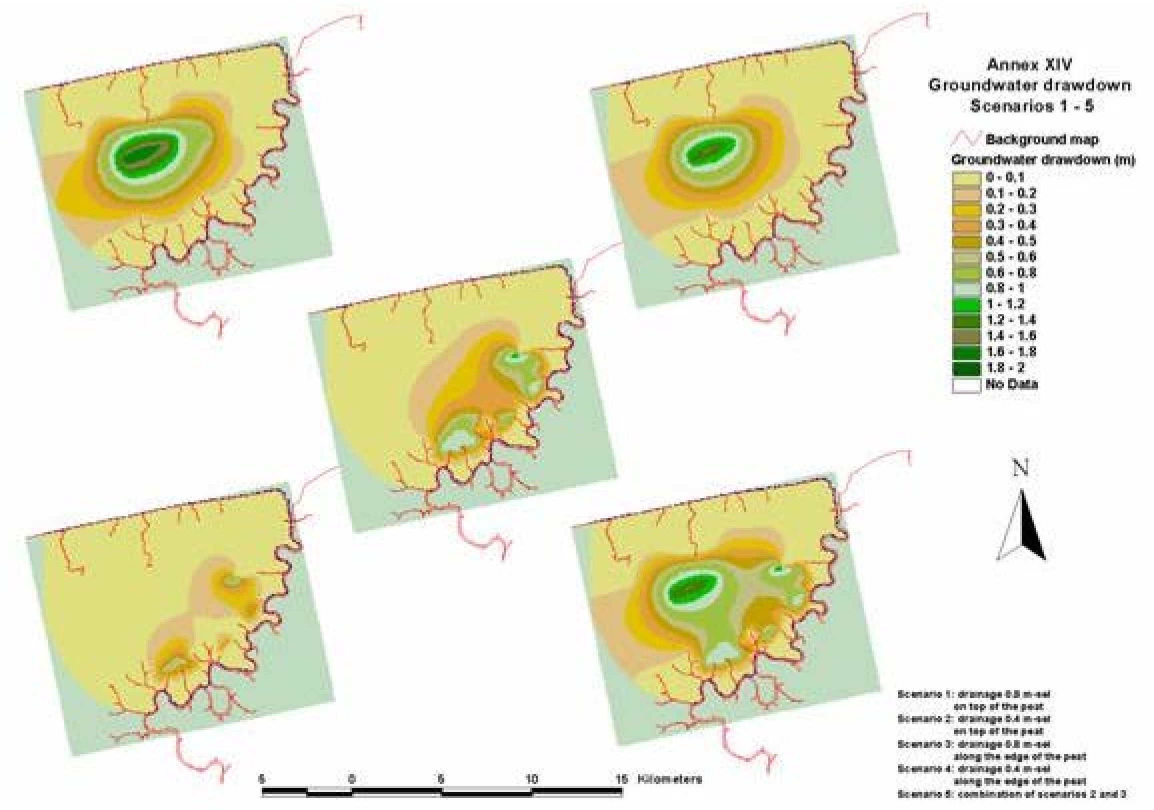

Figure 7 Effect of the installation of a drainage system on the groundwater levels surrounding the plantations (top left - scenario 1; top right – scenario 2; middle – scenario 3; bottom left – scenario 4 and bottom right – scenario 5).

5 CONCLUSIONS

In this study a decision support system (DSS) for peatland management in the humid tropics was developed. This DSS, which is based on a GIS application, combines the Groundwater Modeling Computer Programme PMWIN with expert knowledge on subsidence, land use and water management. The groundwater model (Modflow in the PMWIM 5.0-79 version) was used to simulate the groundwater flow inside a tropical peat dome. The groundwater model was calibrated for the Balingian area, a tropical peat dome of about 10,000 ha in the Central Region of Sarawak, Malaysia. Although actual field data was scarce, the initial results are rather promising: the model was calibrated by simulating groundwater table fluctuations based on actual rainfall data. Inverse modeling was used to access the recharge to the groundwater. Results indicate that the total amount of recharge, i.e. around 40 mm/year or about 1% of the total rainfall, is considerably lower than found in previous studies (around 220 mm/year or 6% of the total rainfall), but more in agreement with results found in European peat domes. Sensitivity analysis of the horizontal hydraulic conductivity shows that the assumed value (30 m/d) is quite realistic.

The groundwater model was combined with expert knowledge on subsidence in a GIS to compare the effect of various land use options. The resulting Decision Support System (DSS) made it possible to visualize the effect caused by certain land uses options, e.g. the effect of reclaiming part of the peat dome for (oil palm or sago) plantation development on the groundwater levels, subsequent subsidence and ultimate elevation of the ground surface. The GIS structure of the DSS allows the incorporation of other model parameters such as water quality, crop yields, etc.) in future versions. Final results are presented in the form of maps generated by the GIS application. These maps can also serve as a communication tool with stakeholders to demonstrate what the hydrological effects are on for instance a certain land use type and drainage system lay-out. This makes the DSS a useful tool for planners and designers to optimize the sustainable use of these valuable peat domes.

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[2] Senior Staff Member, Alterra-ILRI, Wageningen University and Research Centre, P.O. Box 47, 6700 AA Wageningen, The Netherlands, e-mail: henk.ritzema@wur.nl

[3] Staff Member, Water Board VeltenVecht, Coevoerden, The Netherlands

[4] Senior Consultant, PS Konsult, Kuching, Sarawak, Malaysia

[5] Senior Researcher, Alterra, Soil & Land Use, Wageningen, The Netherlands