Peat – water inter-relationships in a tropical peatland ecosystem in South-east Asia

J.H.M. Wösten[1], E. Clymans[1], S.E. Page[2], J.O. Rieley[3], S.H. Limin[4]

[1] Alterra, Wageningen University and Research Centre, P.O. Box 47, 6700 AA Wageningen, The Netherlands
Phone: +31 317 486478, e-mail: henk.wosten@wur.nl

[2] Department of Geography, University of Leicester, Leicester LE1 7RH, United Kingdom
Phone: +44 116 252 3318, e-mail: sep5@le.ac.uk

[3] School of Geography, University of Nottingham, Nottingham NG7 2RD, United Kingdom
Phone: +44 1949 20920, e-mail: rieleyconsultants@btinternet.com

[4] University of Palangka Raya, Palangka Raya 73112, Central Kalimantan, Indonesia
Phone: +62 536 36880, e-mail: suwido@palangkaraya.wasantara.net.id

Summary
Implications of groundwater level fluctuations were studied using a hydropedological modelling approach for adjacent relatively intact and degraded peatland in Central Kalimantan, Indonesia. Ideally, to prevent subsidence and fire, groundwater levels should be maintained between 40 cm below and 100 cm above the peat surface. Calculated groundwater levels for different years and for different months within a single year showed that these levels can drop lower than the critical threshold of 40 cm below the peat surface whilst flooding of more than 100 cm above the surface was also observed. The relatively intact peatland showed resilience towards disturbance of its hydrological integrity whereas the degraded peatland was susceptible to fire.

Key index words: hydropedological modelling; peat subsidence; fire susceptibility; peat humification; peatland restoration

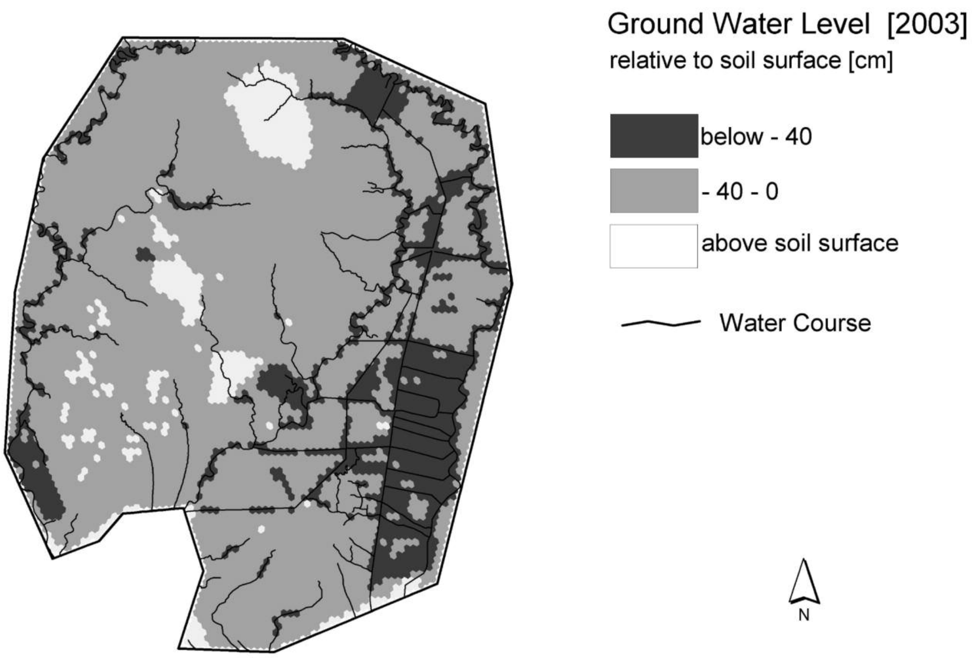
Introduction
The study area is the catchment of Sungai (= river) Sabangau in Central Kalimantan, Indonesia. Sg. Sabangau is a blackwater river that originates in, and drains, the last remaining, large continuous area (13,000 km^2) of dense peat swamp forest in Borneo. The area between the Sg. Sabangau and the Sg. Kahayan is 'Block C' of the former Mega Rice Project area. Since the study location consists of both the relatively intact Sabangau catchment and the degraded Block C of the former Mega Rice Project, it is possible to compare two contrasting peatland landscapes in terms of their fire susceptibility. Annual precipitation for the period 1994 – 2004, used in the hydropedological modelling fluctuates considerably (Takahashi *et al.*, 2004). Over this eleven year period, 1997 was the driest year with 1848 mm rainfall, 2003 was a 'normal' year with 2570 mm rainfall and 1999 was the wettest year with 3788 mm rainfall. In unsaturated tropical peatlands, almost all of the rainfall infiltrates owing to the high hydraulic conductivity of the surface peat layer (Takahashi and Yonetani, 1997). When the groundwater level in tropical peat drops below 40 cm from the surface, which under hydrostatic equilibrium is equivalent to a pressure head of -4 kPa, the moisture content of the barely humified top layer decreases from about 0.90 cm^3 cm^{-3} at saturation to about 0.50 cm^3 cm^{-3} at a pressure head of -4 kPa (Rieley and Page, 2005), thus making it susceptible to fire (Takahashi *et al.*, 2003; Usup *et al.*, 2004).

Materials and methods
The soil elevation map prepared by the Indonesian National Coordinating Agency for Surveys and Mapping (BAKOSURTANAL, 1997) was used to generate a DEM. The physically-based SIMGRO (SIMulation of GROundwater flow and surface water levels) model was used to simulate water flow in the saturated zone, unsaturated zone, river channels and over the peat surface (Dik, 2004). The hydraulic conductivity and also the moisture retention relationship of the peat is strongly influenced by the degree of humification of the peat. Based on hydraulic conductivity measurements using the pumping test method as reported by Ong and Yogeswaran (1992) and by Takahashi and Yonetani (1997) the peat profile in this study is schematized in a two layer system consisting of a fibric to hemic peat top layer (0-100 cm) with an average saturated hydraulic conductivity of 30 m d^{-1} and a deeper, sapric peat layer with an average saturated hydraulic conductivity of 0.5 m d^{-1}. The two layer system applied in this study is consistent with the 'acrotelm' or surface layer and 'catotelm' or deeper layer concept as used to stratify boreal and temperate peatlands (Ingram, 1978). Differences in peat thickness and hydraulic conductivity result in hydraulic transmissivities (cumulative thickness multiplied with conductivity) ranging from 30 to 40 m^2 d^{-1}.

Results

Groundwater levels calculated for July in the non El Niño year 2003 (map at top of Fig. 1) reveal that 23% of the study area was below the critical threshold of 40 cm and thus at high fire risk. In July 1999, however, the area at risk was only 2% (map at bottom of Fig. 1).

In contrast, 40% of the area was prone to fire in July 1997 (El Niño year) showing that there is considerable variation in fire risk from year to year depending upon annual rainfall, length of the dry season and consequent depth of the groundwater level below the peat surface. Comparison of the relatively intact peat swamp forest in the Sabangau catchment with the degraded peatland in Block C shows that in the 3 years, 1997, 1999 and 2003, groundwater levels were lower in the latter and therefore the associated fire risks were higher. This highlights the negative effect of the drainage canals on peatland hydrology in Block C that are leading to enhanced peat oxidation, subsidence and loss of stored carbon (Page *et al.*, 2002). The calculated groundwater levels for the 15th day of every month (Fig. 2) show that from January to May they seldom dropped below 40 cm.



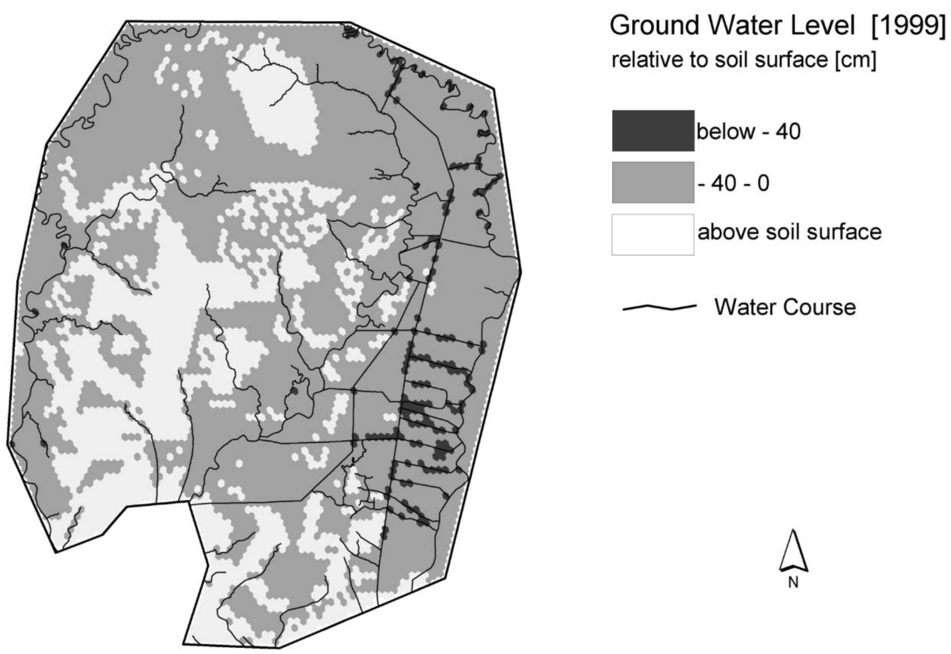


Figure 1. Calculated groundwater levels in the study area for the month of July in the normal year 2003 with 2570 mm rainfall (top) and in the wet year 1999 with 3788 mm rainfall (bottom).

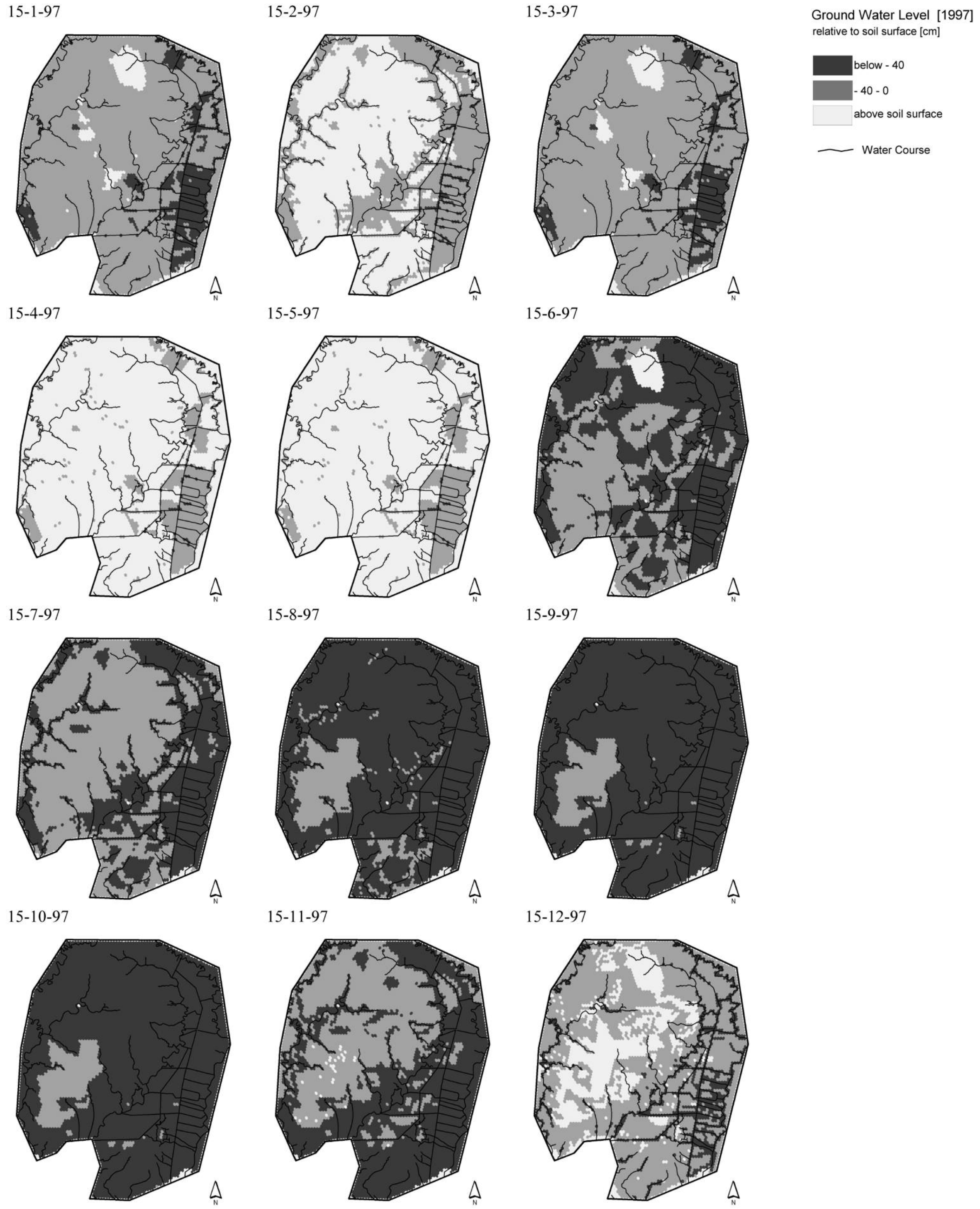


Figure 2. Calculated groundwater levels in the study area for the dry year 1997 at every 15th day of the month.

Flooding occurred in February, April and May but from June onwards groundwater levels dropped progressively and sharply, with the result that water levels were below the 40 cm critical threshold in 91% of the area by October and therefore susceptible to fire. By the same time, 33% of the area had groundwater levels deeper than 100 cm below the surface making these an extreme fire risk. By November and December groundwater levels had started to rise once more resulting in some flooding in December. Groundwater level rise occurs some time after the rain commences owing to water retention within the dry surface peat as the water reservoir recharges (Fig. 2). From Fig. 2 it is also evident that the Sabangau catchment returned to its original hydrological status in December 1997, whereas Block C remained drought affected and thus susceptible to fires for longer. Maps of groundwater levels can thus be used in land utilisation and restoration planning, for example, to indicate where hydrological restoration efforts should be targeted, as well as in fire hazard warning systems.

Conclusion

This study shows that water management is a key element in the wise use of peatlands. In dry years groundwater levels drop below the critical threshold of 40 cm. Deep groundwater levels mean an increased subsidence of the peat by oxidation as well as an increase in fire susceptibility. Both oxidation and fire transform peatlands from carbon sinks under pristine conditions into carbon sources with important local, regional and global consequences under drained conditions. In wet years, flooding depth and flooding duration have adverse consequences for the restoration potential of peatlands. Ideally, groundwater levels should vary between 40 cm below and 100 cm above the land surface. Comparison of the adjacent relatively intact Sabangau catchment and the degraded Block C area reveals that in their natural state, tropical peatlands show sufficient resilience to disturbance provided their hydrological integrity is maintained or restored. Once they are in a degraded state, however, tropical peatlands become an increasingly fragile ecosystem that is likely to disappear.

Acknowledgement

This study was supported by the European Union RESTORPEAT project (INCO-CT-2004-510931).

References

BAKOSURTANAL (1997). National Coordinating Agency for Surveys and Mapping, Jakarta, Indonesia. www.bakosurtanal.go.id

Dik, P.E. (2004). *SIMGRO 4.1.2 User's Guide*, Alterra-Report 913.3 ISSN 1566-7197. Alterra, Green World Research, Wageningen.

Ingram, H.A.P. (1978). Soil layers in mires: function and terminology. *Journal of Soil Science* **29**, 224-227.

Ong, B.Y. and Yogeswaran, M. (1992). Peatland as a resource for water supply in Sarawak. In B.Y. Aminuddin, S.L. Tan, B. Aziz, J. Samy, Z. Salmah, Siti Petimah, S.T. Choo (eds.), *Proceedings of the International Symposium on Tropical Peatland, Kuching, Sarawak, May 1991*, 255-268. Ministry of Agriculture Malaysia.

Page, S.E., Siegert, F., Rieley, J.O., Böhm, H-D.V., Jaya, A. and Limin, S. (2002). The amount of carbon released from peat and forest fires in Indonesia in 1997. *Nature* **420**, 61-65.

Rieley, J.O. and Page, S.E. (2005). *Wise Use of Tropical Peatlands: focus on Southeast Asia.* Alterra, Wageningen University and the EU INCO STRAPEAT and RESTORPEAT Partnerships, Wageningen, The Netherlands, 266pp. www.restorpeat.alterra.wur.nl

Takahashi, H. and Yonetani, Y. (1997). Studies on microclimate and hydrology of peat swamp forest in Central Kalimantan, Indonesia. In J.O. Rieley and S.E. Page (eds.), *Biodiversity and Sustainability of Tropical Peatlands*, 179-187. Samara Publications, Cardigan, United Kingdom.

Takahashi, H., Usup, A., Hayasaka, H. and Limin, S.H. (2003). Estimation of ground water levels in a peat swamp forest as an index of peat/forest fire. *Proceedings of the International Symposium on Land Management and Biodiversity in Southeast Asia, Bali, Indonesia, September 2002,* 311-314. Hokkaido University Japan and Indonesian Institute of Sciences.

Takahashi, H., Usup, A., Hayasaka, H., Kamiya, M., Limin, S.H. (2004). The importance of ground water level and soil moisture of subsurface layer on peat/forest fire in a tropical peat swamp forest. In J. Päivänen (ed.), *Wise Use of Peatlands. Volume 1. Proceedings of the 12th International Peat Congress, Tampere, Finland, June 2004*, p. 760. International Peat Society.

Usup, A., Hashimoto, Y., Takahashi, H. and Hayasaka, H. (2004). Combustion and thermal characteristics of peat fire in tropical peatland in Central Kalimantan, Indonesia. *Tropics* **14**, 1-19.