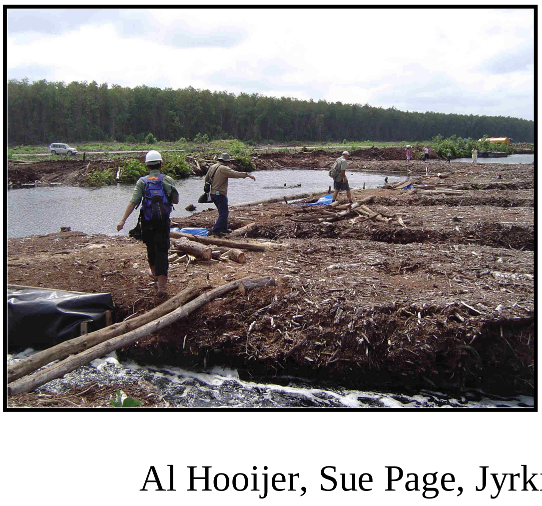
Kampar Peninsula
Science Based Management Support Project

Summary Interim Report, 2007-2008

First tentative findings on hydrology, water management, carbon emissions and landscape ecology



Al Hooijer, Sue Page, Jyrki Jauhiainen

For APRIL

Final version for distribution, September 2009

Preface

APRIL Statement on the Science Based Management Support Project (SBMSP)

Sustainable plantation and natural forest management in peatland presents specific challenges for the resource manager. Responsible management must focus on achieving enhanced, long-term productivity of plantations; minimised impact upon intrinsic and adjacent natural forest conservation areas; reduced CO2 and GHG emissions from the plantation and conservation landscape, as well as optimised livelihood opportunities for communities living in close proximity.

In the past, achieving a balance between plantation productivity and sustainability of the wider peat land landscape has been thwarted by insufficient development of a scientific and practical knowledge database, against which managers may adapt and improve.

Recognising the above, APRIL initiated the Science Based Management Support Project (SBMSP) to provide a solid science foundation for plantation planning, management and monitoring, relevant to own operational areas, and also as a potential contribution to responsible peatland management efforts on the wider, national scale.

Through collaboration between world-recognised scientists and the in-house expertise at APRIL, early results have shown that “lessons learned” from plantation management on dryland mineral soils are not applicable to peatland landscapes. Responsible peatland management translates into an emphasis on optimised management of water table levels by zoning and managing hydrologically distinct, landscape-level watershed units.

In peatlands, natural forest set-asides must be delineated in larger contiguous blocks that represent intact hydrological watershed units. Transport canal systems within plantations must follow along contours of high resolution topography in order to minimise drainage out of upland deep peat areas, reducing subsidence and ensuring long-term water supply from upstream to downstream through the managed area. Through intensive monitoring and control of water, ”hydrology buffer zones” are set aside and managed to isolate and so protect the hydrological integrity of critical upstream water zones from drainage impacts of the production plantation zones.

With an enhanced awareness of the impacts of drainage and the need for managing whole watersheds (in particular in accordance with management of the critical upstream areas) APRIL’s plantation management practices have been revised. We refer to these practices as based on principles of “Eco-Hydrology”. Into the future, and as more data is gained, the planning and implementation of water management in peatlands will be continuously improved through revision to company SOPs, while forming the basis for adaptive management to reduce impact and maintain productivity.

APRIL thanks the scientists of SBMSP for this support and ongoing collaboration.
Through a combination of the best science and practical management expertise, the partners to SBMSP hope to contribute solutions for arresting the ongoing trajectory of degradation of the peatland and forest resource.

On a landscape scale, matching Eco-Hydrology management with the efforts of other stakeholders can potentially provide win-win solutions that balance sustainable economic development, GHG emissions, local livelihoods, and the security of high conservation value forests through active management and investment.

Brief Summary

Peat soil consists of 90% water and 10% vegetation remains. Peatlands therefore are not really ‘land’ but are wetlands, and in some ways need to be managed rather like water bodies to prevent loss of the water that supports the peat surface, i.e. to prevent subsidence. Until now most peatland water management in SE Asia does not recognize this fact and can therefore not result in sustainable peatland development. Widespread overdrainage is resulting in loss of conservation forest, in CO_2 emissions and ultimately in loss of productivity through flooding caused by subsidence. The Kampar Science Based Management Support Project was instigated and funded by APRIL in line with its commitments to develop methods of sustainable peatland and water management that will reduce impacts in and around its plantations on the Kampar Peninsula.

The SBMS Project aims to help mitigate drainage impacts as follows:

A. Bring up plantation water levels, and reduce water table variations including flooding.
B. Improve understanding of drainage impact on carbon emissions and forest health.
C. Minimize drainage impacts in adjoining conservation forest.
D. Provide guidelines for responsible plantation management and planning in the Pelalawan plantations and the wider Kampar Peninsula peatlands.

The SBMS Project team consists of consultants and scientists working with APRIL staff on the basis of scientific understanding of the peatland system, i.e. interactions between hydrology, peat soil and vegetation (natural forest and plantation forest). This understanding is based on field monitoring, surveys, model studies and analyses of satellite images. The three-year project started in April 2007; this report presents first findings over 2007 and 2008. All results to date are highly tentative and are not yet a solid basis for science-based peatland management; they may be modified as data collection and analyses proceed.

Hydrology and water management

Preliminary results show that the impacts of past overdrainage in APRIL peatland plantations prior to SBMSP have been considerable. Subsidence rates have been high and water tables in conservation areas adjoining acacia plantations were lowered over several kilometres, affecting forest health. However the project results also show that significant improvement in plantation water management can be achieved. Such improvement has started in 2006, with a focus on Pilot areas developed for the SBMS Project, promising benefits not only to conservation but also to plantation productivity (through decreased subsidence as well as decreased frequency of flooding and water deficits). Recently developed dam-and-bypass systems have shown to be able to keep water levels largely within the target range in Pilot areas in 2008, and to be able to withstand the high peak flows that occur in drained peatlands after heavy rainfall.

An unexpected finding has been that the hydraulic conductivity of the ‘dome’ peat in Pelalawan plantations is much higher than commonly reported for peatland areas, at around 100 m/d. Combined with the great peat depth on the KP, often over 10 metres, this means that groundwater flow controls hydrology in and around drained areas, which has major implications for water management. It means that undrained buffer zones near conservation areas need to be wider than in less permeable peat (at least 800m, but 1600m may be assumed until analyses are completed), and it is suggested that reducing field drainage density in plantations on ‘dome’ peat will reduce peak flows and make water levels easier to control.

Due to delays and complications in data collection, only 4 to 10 months of hydrological data could presently be analysed; hence findings to date are highly tentative. Moreover, the research years of 2007 and 2008 have been without pronounced dry seasons. In fact, no extreme drought conditions have been encountered yet since Pelalawan peatland plantations were developed around 2000, as have occurred regularly in the past (latest in 1997-1998). Keeping water levels from reaching extremely low levels in plantations and adjoining conservation areas is the test for peatland water management systems. It is therefore important to base peatland plantation development and management practices not only on experiences in recent years, but to consider the impact of expected extreme drought conditions as well. This will require continued monitoring and analysis.

Carbon emissions and subsidence

Gas flux emission monitoring has for the first time in SE Asia yielded reliable values for net carbon dioxide emissions that result from peat decomposition alone, i.e. with emissions from root respiration filtered out. Average net emissions measured to date are mostly between 50 and 100 t/ha/y. This is in the range expected on the basis of literature. Further support for the accuracy of this preliminary finding is provided by tentative analysis of subsidence rates, which suggest net emissions of at least 45 t/ha/y. No relation could yet be found between water depth and emission or subsidence. Possible explanations include the relatively limited water depth range in the project sites and years (averaging between 0.61 and 1.14 in gas emission sites, but mostly in a narrower range), a 'lag effect' through which earlier lower water depths partly control current emissions, and the existence of a 'threshold' water depth below which differences in water depth may have limited effect on peat decomposition.

Over the first 7 years after drainage, total subsidence in plantations in 'dome peat' has been 1.33m; current subsidence may be 0.05m/y excluding harvesting and climatic drought effects.

Forest degradation and a management strategy for the Kampar Peninsula

Over the eastern 334,000 ha of the KP now studied in the SBMS Project, 78% (227,380 ha) of the forest was classified as being in good condition. The large areas of pole forest, on top of the peatland domes that form the Peninsula, remain mostly in good condition. In mixed swamp forest there has been more extensive forest degradation, but with substantial areas remaining in either good condition (64.8% of the forest in this class) or in lightly or moderately degraded condition (30.6%). This makes the KP one of the least degraded remaining peatland forest areas in Sumatra and Kalimantan. It should be noted, however, that most forest around the edges of the KP is already heavily degraded, and continues to be illegally logged and cleared at a pace that is understood to accelerate in recent years.

Long-term conservation of the KP peatland forest and carbon resources will require integrated land and water management over the whole area, based on these principles:

- Only entire peatland landscape units, peat domes and river basins within peatlands, can be protected from degradation caused by drainage. The peatland landscape should therefore be the basis for development and conservation planning.
- Responsibly managed buffer zones with no or limited drainage are required between developed areas and conservation areas.
- Clear guiding principles and definitions (e.g. of forest degradation classes), agreed between stakeholders, are needed for development of a 'KP Zoning Map' that allows sustainable peatland conservation and development. A first set of such principles has been proposed by the SBMS Project, as presented in the Annex to this report.

Contents

To be cited as:
Al Hooijer, Sue Page and Jyrki Jauhiainen. 2009. Kampar Peninsula Science Based Management Support Project, Interim Summary Report 2007-2008; first findings on hydrology, water management, carbon emissions and landscape ecology.

Contact: aljosja.hooijer@deltares.nl

1 Introduction

The first Summary Interim Report for the Kampar SBMS Project, covering activities in 2007, presented the project background and set-up and a few initial results. In 2008, there has been good progress on key project activities. The aim of the current report, over half into the planned project period (April 2007 – April 2010), is to present the first tentative project results to date, as far as possible given the incomplete nature of data collection and analyses.

1.1 The Kampar Science Based Management Support Project

The Kampar Science Based Management Support Project (SBMS Project) was developed with APRIL by a group of consultants and scientists aiming to support improvements in forest conservation and water management in and around pulp wood plantations on peatlands on the Kampar Peninsula (KP), Riau, Sumatra.

In short, the main SBMS Project aims are to:

A. Help bring up plantation water tables to reduce subsidence and carbon emissions in plantations, and reduce water table variations including flooding.
B. Further minimize drainage near adjoining conservation forest to reduce degradation.
C. Monitor and study the effects of these interventions, and draw lessons.
D. Provide guidelines for responsible plantation management and planning in peatlands.

Key activities in the SBMS Project are:

- Monitor and assess relations between water depth (and other land management factors) and peat subsidence, CO_2 emissions and conservation forest conditions.
- Apply these relations in long-term impact projections for different water management strategies, especially subsidence- and CO_2 emission rates over 50 years, for plantations and adjoining conservation areas.
- Help define plantation water management strategies that will minimize impacts, help design and implement improved water management structures and systems, and evaluate in Pilot areas to what extent these targets are met.
- Most of the work in the project focuses on the existing APRIL Pelalawan plantations on the south-western end of the Kampar Peninsula, and adjoining conservation areas. However one activity is to support forest and carbon conservation on the KP as a whole by developing a 'science-based recommended land use zoning map' for the whole area. This will be used in evaluations of how, and to what extent, plantations could be designed and managed to minimize drainage impacts and maximize protection for the KP forest and carbon values.

All final results of the Kampar SBMS Project will be in the public domain; preliminary results will be available for distribution when agreed by the consultants and APRIL. It is hoped that the findings will also help improvement of management systems for other tropical peatlands.

1.2 Kampar SBMS Project Work Packages and consultants

The SBMS Project is organized in 6 Work Packages:

- WP 1.1 Pilot studies of system and structure design.
- WP 1.2 Operational water management system software development.
- WP 1.3 Hydrological studies & database development.
- WP 1.4 Peatland management strategy assessment tool development.
- WP 1.5 Subsidence and carbon emission studies and management support.
- WP 2.1 Development of a recommended land use zoning map for the KP.

The project is lead by Deltares | Delft Hydraulics with major inputs from APRIL staff, University of Leicester and University of Helsinki. Further inputs were provided by ProForest, University of Wageningen, and freelance consultants. The project started April 2007 and is planned to continue for 3 years, until April 2010. Consultants have contributed to the project as indicated in the table below.

	Organization	**Work Package Involvement**						
		1.1	**1.2**	**1.3**	**1.4**	**1.5**	**2.1**	**Mgt**
Dr Al Hooijer	Delft Hydraulics	X	X	X	X	X	X	X
Dr Rinus Vis	Delft Hydraulics						X	X
Mr Geert Prinsen (Eng)	Delft Hydraulics	X	X	X				
Ms Marjolijn Haasnoot (MSc)	Delft Hydraulics				X		X	
Mr Marnix van der Vat (MSc)	Delft Hydraulics	X	X	X	X			
Mr Ronald Vernimmen (MSc)	Delft Hydraulics	X	X	X				
Dr Jyrki Jauhiainen	Un. Helsinki			X		X		
Dr Henk Wösten	Un. Wageningen					X		
Dr Susan Page	Un. Leicester				X	X	X	
Mrs Agata Hoscilo (MSc)	Un. Leicester				X		X	
Dr Ruth Nussbaum	ProForest						X	X
Dr Christopher Stewart	ProForest						X	
Mr Ad van den Eelaart (Eng)	freelance	X		X				
Mr Arnoud Haag (Eng)	freelance	X		X				

1.3 This summary report

This report presents progress at 21 months into the 36-month project. As this is a science-based project we need to follow thorough scientific procedure; presentation of final results will be possible after sufficient data have been collected, analysed and verified. For the hydrological studies, most data collection was delayed until early/mid 2008 and only 4 to 10 months of data were available for the analyses presented in this report, whereas this should be 18 months at least (preferably including a severe dry season) for confident results. All findings reported here are therefore highly tentative and may have to be adjusted, they are not yet a solid basis for science based peatland management.

This summary does not provide a full overview of project activities to date. Some ongoing activities have not yet resulted in results that can be presented with sufficient confidence, and other results do not warrant inclusion in this summary which aims to present key findings.

Key results to date are reported for the following Work Packages:

- Hydrological assessments, and implications for water management (WPs 1.1, 1.2, 1.3).
- First results on peatland plantation carbon emissions and subsidence rates (WP 1.5).
- Quantifying vegetation and degradation patterns on the KP (WPs 2.1, 1.4).

2 First tentative results on hydrological assessments, and implications for water management

2.1 Introduction and objectives

The assumption at project outset was that improved water management should help APRIL achieve the following:

- Minimize degradation in conservation areas adjoining plantations and roads caused by low water tables.
- Reduce CO_2 emission from peat decomposition, that is caused by low water tables.
- Avoid short-term production loss in plantation areas through avoiding inundations and minimizing water table fluctuations.
- Reduce or delay long-term production loss in plantation areas due to subsidence and loss of drainability, caused by low water tables in the peat.

These aims all require improved control of water levels in plantations within a target range, which is to be achieved by building dams to bring water levels up, and bypass systems to efficiently discharge peak rainfall and prevent flooding. However these measures can only be effective if their impact can be well predicted. Improved understanding of the hydrological functioning of the peatland is therefore the basis for improved management.

The hydrology and water management studies in the SBMS Project consist of 3 main activities:

- Development of Pilot areas that allow us to control, monitor and understand peatland system response (WP 1.1).
- Development and application of hydrological models representing the peatland system (WP 1.2).
- Data collection, and scientific analyses, to feed the models (WP 1.3).

While the three WPs comprise different activities, the outcomes are evaluated and applied in combination so they will be discussed together in this section.

Table 1 APRIL water depth targets as defined late 2006 at the start of the SBMS Project and somewhat adapted in 2008.

Operational Water Management Goal	**Water table depth to surface[1]**		
	Min	**Max**	**Mean**
[1] 90% compliance (90% of observations from frequent sampling of 100% compartments)			
2006 situation (before SBMS Project start) Water steps 1 m max, water gates adjusted quarterly, canal levels fluctuate +/- 0.3 m			
(a) without mid-field drain (70% of Pelalawan)	0.5 m	1.8 m	1.2 m
(b) with mid-field drain (30% Pelalawan)	0.6 m	1.5 m	1.0 m
2008 target Water steps 0.2 m, water gates adjusted daily, water levels stabilized as guided by 'tuned' water model, additional structures etc. and operational procedures			
(a) Acacia with mid-field drain (90% of Pelalawan)	0.5 m	0.8 m	0.65 m
(b) Buffer zone Melaleuca compartments	0.2 m	0.6 m	0.4 m

2.2 Methods

2.2.1 Pilot studies of system and structure design (WP 1.1)

Whereas the other SBMS Project work packages aim to find out what conditions should be met to manage the Kampar Peninsula peatlands responsibly, this work package focuses on creating the conditions where the hydrological characteristics of the KP peat, and their response to water management conditions, can be evaluated. This is done through development of Pilot Areas where water flows and storage changes can be controlled (with dams and bypasses) and monitored.

Two Pilot areas have been finalized by mid-2008: one in the Phase 2 plantations and one in the Phase 3 plantations (Figure 1). Two other Pilots were created in the Madukoro area in 2007 but have been discontinued because of accessibility problems. In analyses to date, only data from the Phase 2 Pilot have been used, which is the largest Pilot area which covers a range of different typical conditions along the slope of a peat dome, including a conservation area. The cross section for the Phase 2 Pilot is shown in Figure 2.

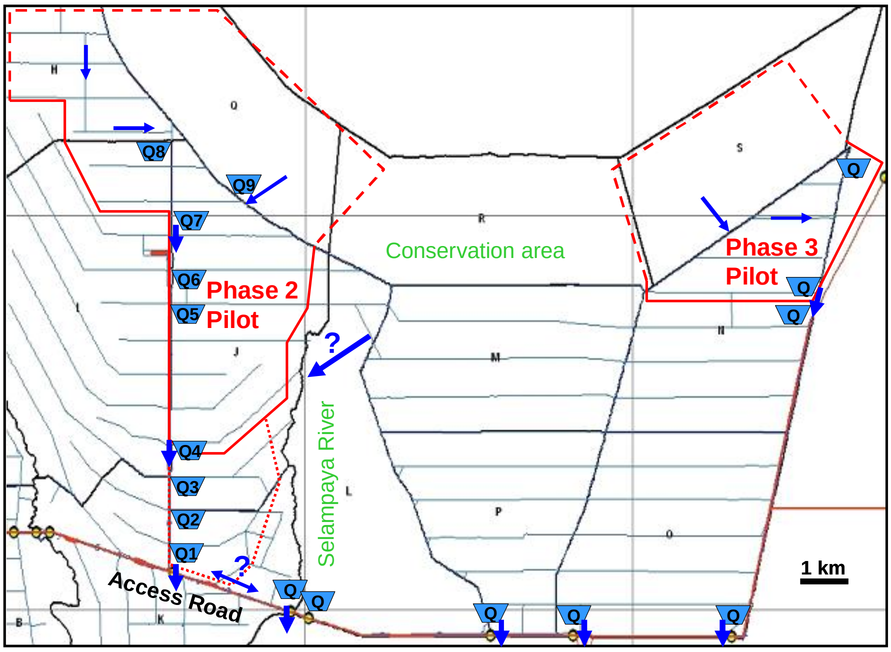


Figure 1 Boundaries of the Phase 2 and Phase 3 Pilot areas, and main discharge monitoring points as used in the analyses. See Figure 16 for the position of these Pilot areas within the Kampar Peninsula peat dome.

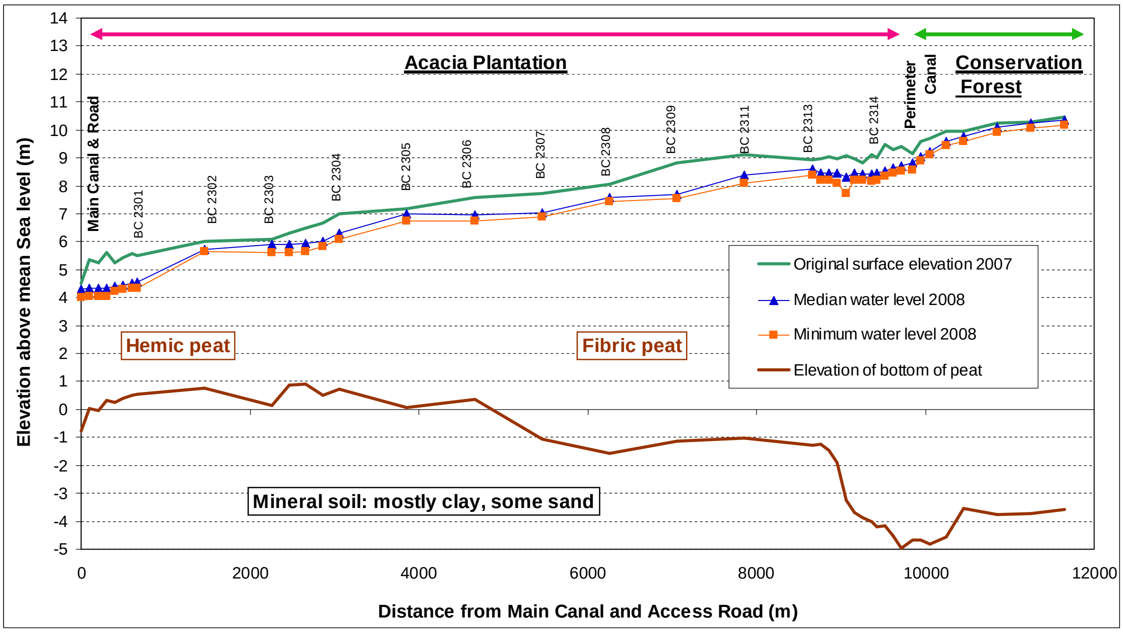


Figure 2 Cross section along the dipwell transect in the Phase 2 Pilot area.

2.2.2 Development and application of hydrological models representing the peatland system (WP 1.2)

Water levels in peatland plantations and adjoining conservation forest areas can only be maintained within the 'responsible management' target range if water management systems succeed in storing enough water for long enough between rainfall events to prevent water levels from dropping too much in dry periods (including droughts of several months), while releasing enough water fast enough to prevent flooding following extreme rainfall events. As these requirements can be conflicting, smart system design is required and possibly event-based system adaptations.

In a system as large and complex as the APRIL plantations on the Kampar Peninsula peatlands, system design optimization (in terms of location and dimensions of structures) requires hydrological models to answer questions that can not be answered with measurements alone, which have limited coverage in space and time. The strength of a hydrological model is that it allows extrapolation, in three ways:

1. Assessment of extreme conditions that are unlikely to be encountered in measurements, e.g. peak discharges and drought periods.
2. Assessment of future conditions, when the landscape and hydrology has changed due to subsidence (and possibly climate change), and there will be water management problems that may be mitigated if anticipated in time.
3. Spatial extrapolation to areas where no monitoring takes place, e.g. for planning of conservation and new plantations on the KP, requiring impact assessment before development.

Hydrological models are produced (in SOBEK[1]) for pilot areas (developed in WP 1.1), representative for typical conditions in and around the peatland plantations. Models simulate

[1] SOBEK is Delft Hydraulics software: http://www.wldelft.nl/soft/intro/index.html

water flows through canals and through the peat itself, in response to rainfall, evapotranspiration and management interventions (canal and structure design and operation).

2.2.3 Hydrological studies, analyses & database development (WP 1.3)

Inside and around the Pilot areas, a hydrological monitoring network has been established that includes dipwells (for groundwater depth and subsidence monitoring), staff gauges (for canal water level monitoring) and rain gauges. Most monitoring is done manually, at monthly intervals (daily for rainfall), but 'diver' recorders have been placed for automatic water level monitoring (at hourly intervals) at selected locations. Along the dipwell transects, peat depth and peat surface elevation are measured, as shown in Figure 2 for the Phase 2 Pilot area. Some hydrological monitoring is linked to the gas emission monitoring as discussed in this report.

Data are collected by APRIL staff, and entered into a database that consists of a series of customized Excel spreadsheets. Analyses are performed by SBMSP consultants in communication with APRIL staff.

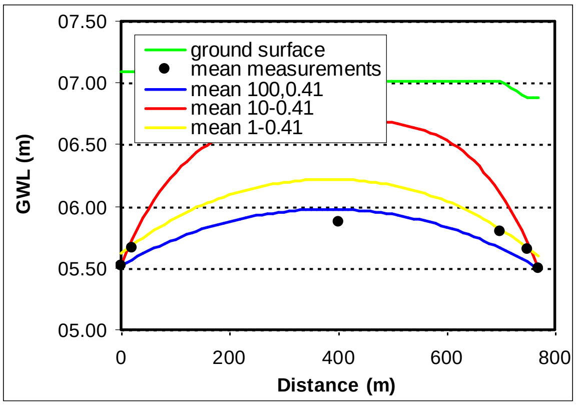
2.3 Discussion of results to date

2.3.1 Findings on the fundamentals of peatland hydrology

Peat hydraulic conductivity

One of the most surprising findings in the SBMSP project, with great relevance to water management requirements, is that the 'dome peat' (the APRIL operations term for deep peat that is highly fibric i.e. relatively unhumified), that underlies much of the plantations and that forms most of the KP as a whole, has much higher hydraulic conductivity (K_{sat}) than expected on the basis of literature. Different model approaches in different areas all indicate average values between 50 m/d and 200 m/d for Pelalawan dome peat (
Figure 3 , Figure 7), whereas values between 10 and 0.5 m/d have earlier been used in calculations for other peatland areas in the region. The fact that such high K_{sat} values have not (or hardly) been reported earlier for other peatlands in the region may be due to the fact that measurements were mostly confined to peat at lower elevations near the edges of peat domes (that are more accessible but have more decomposed peat that may not be typical for the greater part of the peat landscape) and were mostly 'pumping test' experiments that are in fact unsuitable for this type of peat and are likely to have yielded inaccurate results. It appears that insufficient consideration has been given, in research and in peatland development, to variations in peat characteristics within and between peat domes.

As the Pelalawan dome peat not only has high hydraulic conductivity but is also very deep (5 to 15 metres in the Phase 2 Pilot), this means that groundwater flow is a dominant component of the hydrological system once the peat is drained. What kept the water locked inside the natural Kampar peatland was the very low water table gradient, and this gradient is greatly increased when drains are constructed. The consequences of drainage in this situation are that A) rainfall on plantation compartments enters canals rapidly, minimizing local flooding but increasing downstream peak flows, and B) the impact of drainage extends over large distances into conservation areas, certainly in the 'central dome' areas. It is likely that lower hydraulic conductivity values occur in the more humified and shallower peat (called 'basin peat' in APRIL operations) near the edge of the Kampar Peninsula and streams within it, and that groundwater flow is less dominant there, but this needs to be tested. Currently no measurements are taking place in basin peat, as the SBMS Project has so far focused on the most vulnerable dome peat areas.



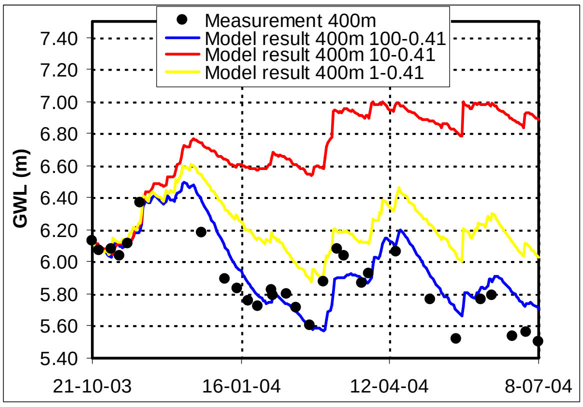


Figure 3 Simulation in hydrological model (Modflow) of water table fluctuations along a cross section in K Estate (Phase 2), over 2003-2004 (data provided by John Bathgate). Left a cross section view comparing modelled with observed water tables, right a time series of the same. This dataset is suitable for determination of the hydraulic conductivity, because field drainage had little impact on water depths in this situation (as is now the case on the Pilot areas, with higher water levels). In this example, modelled water table fluctuations are shown with hydraulic conductivities of 1, 10 and 100 m/d. The lower the hydraulic conductivity, the higher the water table. Comparison with measured water depths, at this and other 'dome peat' sites in Pelalawan, show that hydraulic conductivity is between 50 m/d and 200m/d. A storage coefficient of 0.35 was used in models, as derived from analyses of water table response to rainfall in the area.

Drought frequency in Pelalawan

Drought conditions as occurred in 2006 on the KP occur at least once in every 4 years on average over the last 45 years (Figure 4). The conditions in the extremely dry and fire-prone year of 1997 occur at least once every 10 years on average. The fact that such conditions have not occurred since 1997 means that Pelalawan plantation water management (and also fire management) has so far not really been tested for conditions that should be expected in the future. The years of 2007 and 2008, during which SBMSP monitoring took place, have been wetter than average, especially in the dry season where 4-month total rainfall did not drop below 200mm as in most years (Figure 5). It is concluded that improvements in the water management system are best based on projections for dry years, as can be provided by the tools now developed in SBMSP, not on experiences over the last few years.

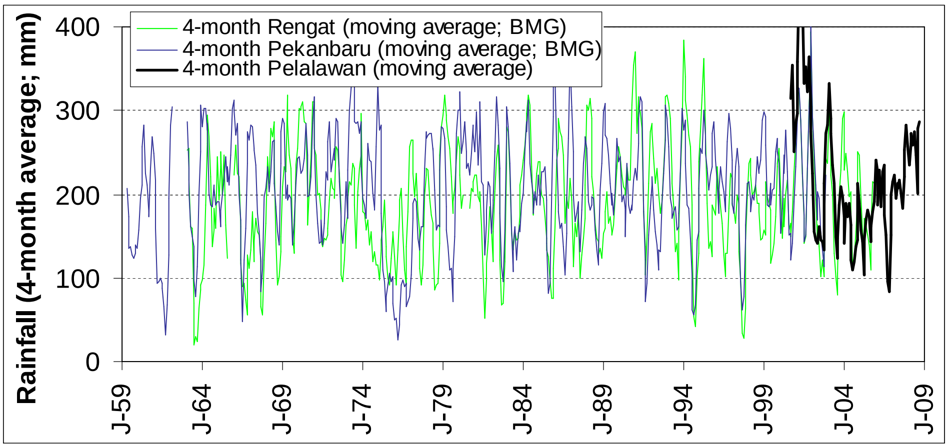


Figure 4 4-month moving average rainfall for Pelalawan and other rainfall stations in Riau. The rainfall threshold below which there is a potential water deficit in Pelalawan (i.e. evapotranspiration exceeds rainfall) is about 100 mm/month at the lowest. Also note that dry years have been remarkably rare since 2000, contrary to the long-term climate trend as observed elsewhere.

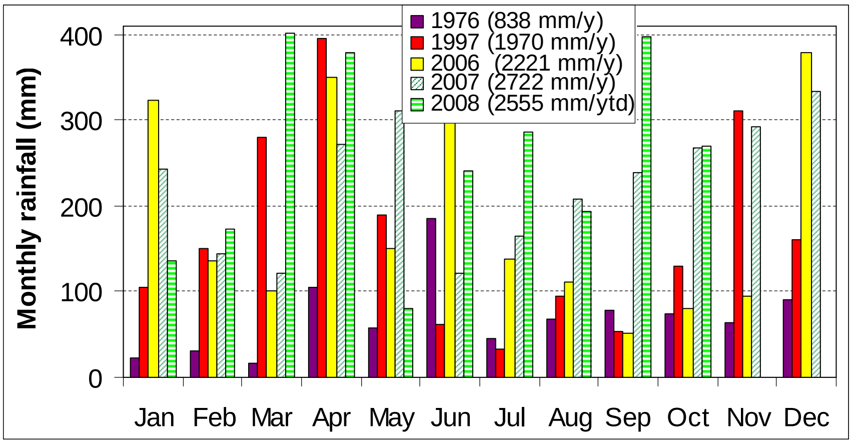


Figure 5 Monthly rainfall in some very dry years compared to recent years, over which SBMSP monitoring took place. Note that rainfall hardly drops below the water deficit threshold of 100 mm/m in any month in 2007 and 2008. In other words: rainfall was almost always higher than evapotranspiration, and water tables and peat soil moisture content were continuously relatively high.

2.3.2 Findings relating to the effects of peatland drainage

Peak flows in and from Pelalawan plantations

It was found that peak annual rainfall events at Pelalawan are quite average for Indonesia at 100 mm/d, not much more than the rainfall event of 80 mm that occurred in the Phase 2 Pilot on March 8 2008, causing some dam breaks and flooding. The one-in-five-year event, that is often used for design of rural drainage systems, is probably around 125 mm/d. Most rainfall during extreme events occurs within a few hours, which means that peak discharges without careful water management will be ‘flashy’ and potentially damaging.

It was found that, in the present water management condition in the Phase 2 Pilot, the March 8 event resulted in a discharge of over 22 m^3/s from the Phase 2 Pilot area and a unit peak discharge of 0.3 $m^3/s/km^2$. A one-in-five-year event will probably yield around 0.5 $m^3/s/km^2$. This estimate can be used tentatively to better calculate discharge capacity requirements for bypasses, which will reduce the risk of bypass/dam destruction, but further monitoring and analysis is needed to reduce uncertainty.

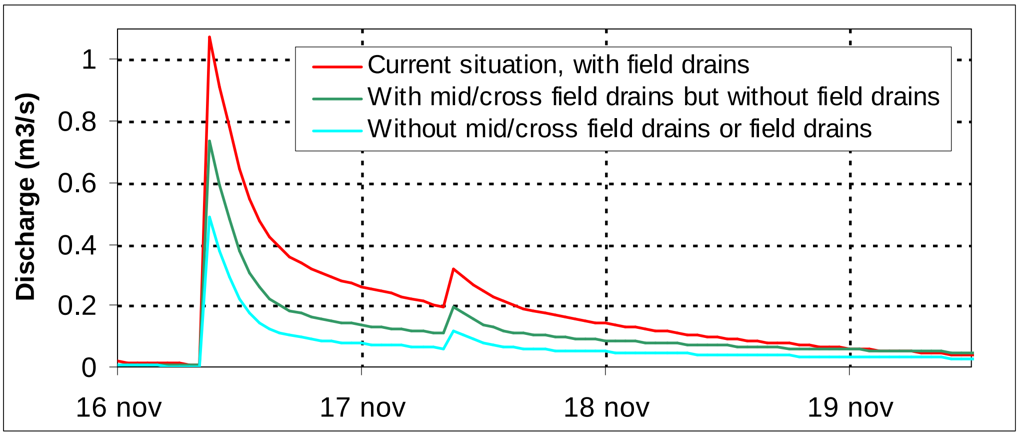


Figure 6 Modelled discharge following a 100 mm rain event with a typical return time of 1 year (followed by a smaller event), from 2 compartments as shown in Figure 7. According to model results, not having any field drainage would reduce peak discharge by more than 50%. Removing field drains but not mid/cross field drains could reduce peak discharge by 30%.

Water depth control in the Pilot areas

Improved water level control in plantations, keeping groundwater depths within 0.5 and 0.8 m for 90% of the time so as to reduce subsidence and CO_2 emissions while preventing floods and production loss, is a key water management target in APRIL plantations that is supported by the SBMSP project. Project results to date show that this can probably be achieved, but they also show that this requires much further work and considerable investment in control infrastructure. In the very wet year of 2008, water depths in part of the Phase 2 Pilot have even been somewhat above target, even though water depths in other parts (and in the Phase 3 Pilot) were still below target. Improved water level control requires use of accurate data on surface elevation and expected discharges. A key management requirement is to have, and use, more accurate and detailed elevation information than is now available for Pelalawan.

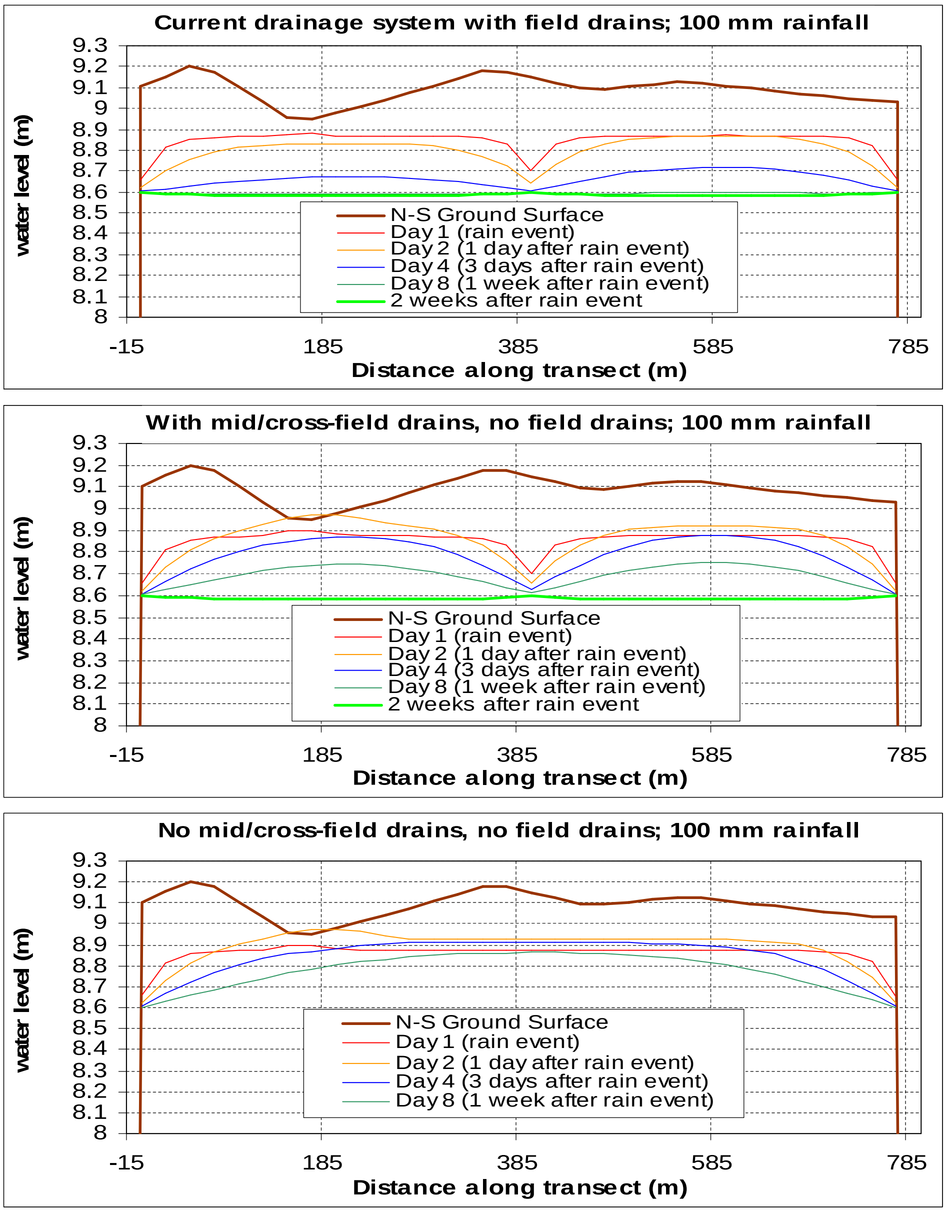


Figure 7 Modelled effectiveness of field drainage in discharging a 1-year rainfall event (100 mm of rainfall). It was assumed that the water table was at the upper range of the management target zone, i.e. 0.5m below the peat surface, at the start of the event. The following is observed:

- *In the current situation, with field drains and mid/cross field drains, water is never at the surface and groundwater levels drop to the original depth well within a week.*
- *In a situation with only mid-cross field drains, but no field drains, water is also removed from fields within days, though slower than with field drains.*
- *Even in a situation without any field drainage, prolonged inundation by rainfall of plantations in 'dome' peat (with high hydraulic conductivity) should be very rare. However, standing water after extreme rainfall would discharge to canals only slowly, so groundwater levels could be above target a larger part of the time than is the case with field drainage.*
- *Note that a K_{sat} value of 50m/d was applied in these calculations, which is at the lower end of values found for Pelalawan dome peat. Using a possible value of 100 m/d or even 200m/d or would remove water from plantation compartments even faster.*

Progress on dam-bypass systems able to deal with peak discharges

Water levels in plantations can only be controlled within the target range if water is not allowed to flow out freely (which would cause permanent 'drought' conditions, as was the case before 2006), but controlled in bypass systems along dams that are placed at water steps of 0.4m or less along steeper slopes and in areas of elevated ('dome') peat. A reliable bypass system must A) be designed on adequate information on the peak discharges expected at each dam location, and B) capable of withstanding higher-than-expected discharges without being damaged.

Such bypass systems, following different test-designs, have already been placed in significant numbers in Pelalawan plantations including the SBMSP Pilot areas. These trial dam-bypass systems do indeed serve to bring water levels up. A major improvement during the SBMSP to the overall stability of the dam system was to always construct dam crests above the surrounding landscape so as to prevent destructive water flows over dams at all times. However the higher and more stable dams have also meant that even the most extreme flows are now channelled entirely through the bypass systems, which are very vulnerable to scouring during such flows. This vulnerability is apparent especially along the lower slopes of the peat dome, where canals have largest contributing areas and highest peak flows. It was found that bypasses that are narrow and/or lined with geotextile/geomembrane are most vulnerable and require most frequent maintenance. The latest trial bypass designs are therefore not lined and are very wide (ensuring sufficient discharge capacity) and shallow (ensuring optimum water level control and low flow velocities i.e. limited destructive capacity). These latest designs appear to perform well.

The impact of field drainage on water depths and peak flows

It was found that the current field drainage system may be improved in plantations on 'dome peat' that has high hydraulic conductivity. While mid-field drains at 400m intervals may still be useful under such conditions, according to model results the smaller and more numerous field drains hardly serve to bring groundwater levels down (Figure 7) while causing peak flows from plantations to be up to 30% higher (Figure 6). Lower drainage density in such plantations could A) reduce construction costs of drainage, B) prolong the lifespan of dam-bypass systems and C) reduce the risk of flooding in downstream plantations on shallower 'basin peat'. In those 'basin peat' plantations, more densely spaced field drainage systems may still be required because outflow of rainwater and flood water through groundwater will be less rapid.

With these findings and additional hydraulic conductivity tests, combined with data on peat characteristics (bulk densities) and topography in Pelalawan, it may be possible to construct a 'zoning map' for field drainage requirements in plantations that would help minimize construction and maintenance costs for both field drainage and the discharge system of dams and bypasses, while minimizing flooding and allowing groundwater depths to be kept within the 'target range'. Note that these concepts will have to be tested in practice first.

The impact of plantation drainage on conservation area water depth

A hypothetical perimeter canal water table at 2m below the peat surface, as is commonly found in peatland plantations in Indonesia, would lower dry season groundwater depth in the conservation area adjacent to a plantation by more than 0.5m over the first kilometre (which is understood to cause forest dieback), and the zone of significant hydrological impact will extend 2 to 3 kilometres (Figure 8).

However, tentative findings suggest that, even in highly permeable peat higher up the peat dome, a well-managed plantation buffer zone of more than 800m wide, without perimeter canal or any field drainage, could mitigate much of the impact of plantation drainage on the conservation forest, if plantation water levels outside the buffer zone are kept within the target range of 0.5-0.8 metres. To recommend a more specific width for the buffer zone, data for a dry period are needed that were not yet collected in the project.

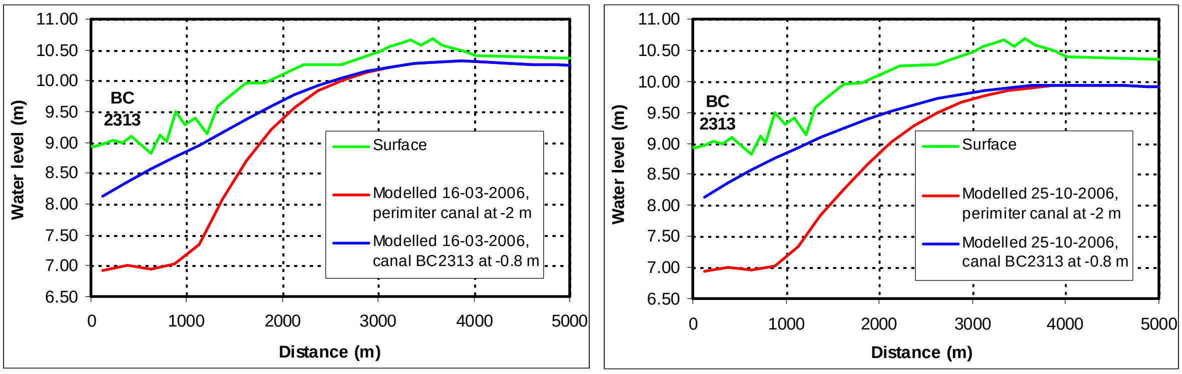


Figure 8 Modelled water depths for the dry year of 2006 (left: wet conditions; right: dry conditions), in the conservation area and in the buffer zone, for the hypothetical cases that A) the water level in the perimeter canal would be at 2m depth, or B) that the perimeter canal and drains in the buffer zone are fully closed and water depth water table in canal BC 2313 are kept at 0.8m depth.

2.4 Conclusions and recommendations for further work

The SBMS Project hydrological studies to date have yielded some important findings that can benefit conservation of forest and carbon around plantations, as well as improve efficiency of plantation water management. Key findings are:

- Hydraulic conductivity of the deeper 'dome peat' is very high, with major consequences for water management and conservation options.
- Nevertheless, an undrained plantation buffer zone of at least 800m may greatly reduce impact of plantations on water depth in conservation forest, even in the highly permeable 'fibric' peat found higher up the peat dome. In 'dome peat' areas, a buffer zone width in the order of 1600m is advised until further data and analyses results are available.
- Reducing field drainage density in areas with high hydraulic conductivity will allow sufficient water level control while bringing down peak flows and water management cost.

These findings are tentative, as measurements to date have not included dry periods or conditions in shallower peat where impact zones may be more limited. It is therefore necessary to extend the hydrological monitoring through 2009 to capture those conditions.

Two main recommendations for further work are:

1. Assess hydrological conditions and drainage impacts on the Kampar Peninsula as a whole. With the current findings and data, and with continued monitoring in 2009, the SBMSP project can develop a hydrological model for the KP as a whole, which

would allow assessment of the impact on water depths (and carbon emissions and ecology) of current canals in the area as well as different management strategies.

2. Develop a water management zoning map for existing peatland plantations. With additional measurements of hydraulic conductivity in ‘basin peat’ areas, and a survey of bulk density throughout the plantations, it may be possible to construct a map with hydraulic conductivity zones. In combination with data on peat depth and elevation, this can be used to define a zoning map that identifies optimum drainage systems in different conditions.

3 First tentative results on quantifying peatland plantation carbon emissions and subsidence

3.1 Introduction and objectives

Depending on vegetation characteristics and conditions in the physical environment, peatland ecosystems can form carbon sinks or carbon sources. Permanent peatland drainage inevitably leads to net carbon emissions and peat subsidence, but rates vary within and between peatlands in ways that are not yet well understood. Such understanding is necessary to be able to take measures (in plantation location selection, design and management) that reduce the carbon emissions from plantation operations in peatlands, as well as reduce increased flooding that results from subsidence.

Key questions to be answered by this research activity in the SBMS Project are:

1. What is the range of net carbon dioxide emissions from peat now occurring in acacia plantations?
2. Can variation within this range be attributed to water depth or to other variables including peat characteristics?
3. Can emissions from plantations in peatland be reduced by improvements in management in the currently existing plantations or in planning of new plantations, and how?

Good progress has been made especially in answering the first question; it is now clear that peatlands drained for plantations do indeed emit carbon dioxide in quantities that would be expected based on less thorough studies elsewhere. With the present data, that do not include very low or very high water table conditions, it is not yet clear to what extent this emission is affected by specific factors including water depth, as explained below.

3.2 CO_2 emission monitoring: methods and results

3.2.1 Approach to quantifying net carbon dioxide emissions from peatland plantations, excluding root respiration

There are two major sources of carbon dioxide emissions from the peat surface: root respiration and breakdown of organic matter. The first process occurs under all conditions, in every landscape covered by living vegetation. The rate of the second process depends on the decomposability of the available peat material and on the suitability for decomposers (mostly bacteria and fungi) for the physical and chemical conditions in the peat matrix. The rate of the second process is increased when peat is not saturated with water and it occurs at high rates especially in drained peatlands. It is the breakdown of organic matter that leads to the 'net' carbon dioxide emission from the system. Distinguishing between the two processes is difficult as it requires exclusion of vegetation roots, in fact there are few if any studies to date that have truly achieved this. The SBMSP project has now done this for the Pelalawan plantations, with sufficient confidence to present some tentative results.

The peat surface carbon dioxide emission detection method applied is based on infra-red gas analysis. This 'closed chamber' techniques' can be applied for instantaneous measurement of carbon dioxide concentrations from peat surface with instantaneous readouts. Peat carbon dioxide gas fluxes are monitored at six locations with the Pelalawan acacia plantations, starting by April 2007 at some of the sites. The selected sites differ by (i) peat characteristics, (ii) water depth, and (iii) land status during rotational acacia production. The site selection aimed to allow comparisons in each characteristic for at least two sites. Three sites have closed acacia canopy, and three are open i.e. recently cleared after the first acacia rotation. More precisely, the sites can be defined by the acacia cycle stages, e.g. ‘open’ 0-6 month old acacia stand, and towards closed canopy developing ‘immature’ 7-30 month and ‘mature’ >30 month old acacia stands. Further information on the gas flux monitoring site characteristics is presented in Table 2.

Monitoring transects were established at each site. Each transect in is 600 m long and has four sub sites. Each sub site was established between two living acacia trees, where 7 gas flux monitoring spots were established at even distances from the trees (Figure 9). There are 168 monitoring spots in total. This arrangement of gas flux monitoring spots within the sub-sites allows quantification of CO_2 emissions including root respiration (near trees) as well as without (or with limited) tree respiration (far from trees). To further minimize root respiration, roots were killed off to 0.5m in the peat around selected monitoring spots, using a saw. Site disturbance was minimized during the first 2 years of monitoring.

It should be noted that individual gas flux measurements are in g/m^2/s. As these measurements vary greatly in time, and only cover a relatively short time period, determining an average or ‘typical’ emission in t/ha/y will not always yield the correct answer.

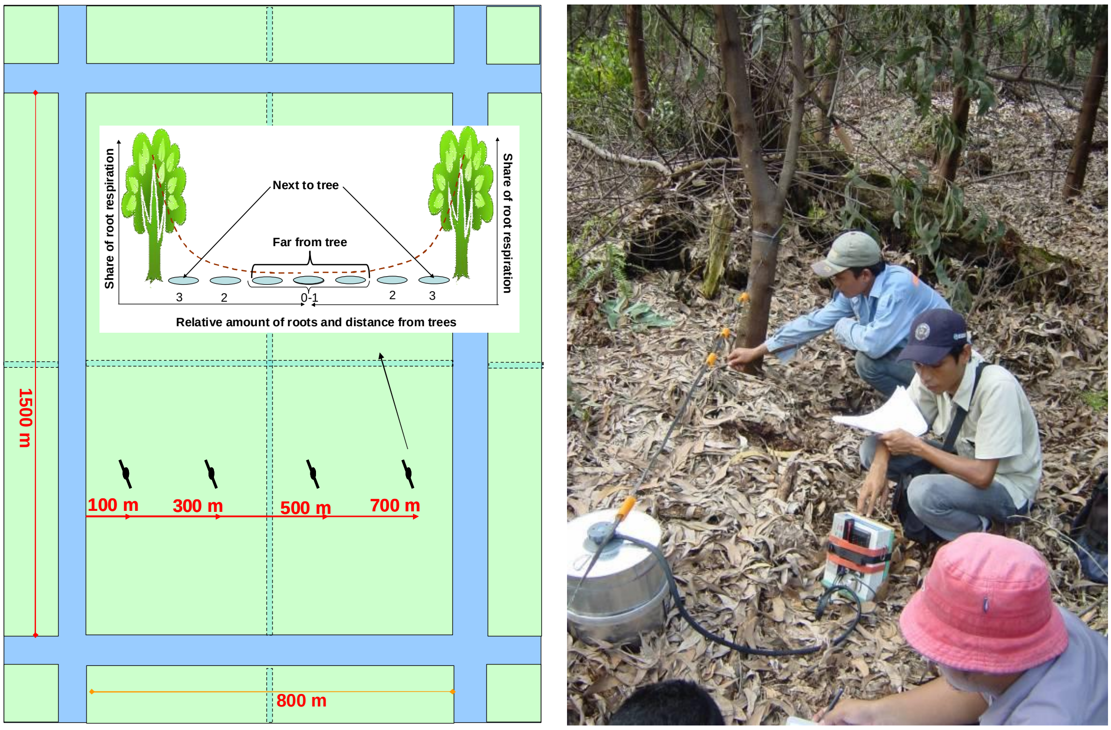


Figure 9 Schematic set-up of peat surface carbon gas emission measurement transect and sub-sites at compartment (on left), and CO_2-flux monitoring event by EGM-4 infra red gas analyzer in progress (on right).

Table 2 Characteristics of the peat surface gas flux monitoring sites.

Working name Official name Location	Elevation (m)	Peat bulk density at 30-50 cm (g cm^{-3})	Peat ash content at 30-50 cm (%)	Site location within the peatland landscape	Range of average spot water depths per site (m)	Rotation cycle and tree stand age ***)
AlamL PEN R022 / 023 E102º17'31.8", N 0º31'43.4"	10.5	0.09 / 0.15	1.10 / 4.11	lower slope	0.88 – 0.65	1st rotation, 26 – 29 months old (immature acacia)
Line0 PEN B120 / 129 E102º4'1.3", N0º28'40.5"	6	0.091	1.71	basin	1.14 – 0.74	1st rotation, 24 – 40 months old (immature to mature acacia)
Selka PES H015 / 016 E102º10'15.9", N 0º29'19.7"	7.5	0.09	1.54	lower slope	1.09 – 0.66	1st rotation, 40 – 56 months old (mature acacia)
Selka2 PES H015 / 016 E102º10'10.65", N 0º29'22.74"	7.5	*)	*)	lower slope	0.98 – 0.65	2nd rotation, 0 – 6 months old (open site)
K0 PEN K001 / 010 E102°7'26.96", N0°31'32.89"	8.5	**) 0.07	**) 0.46	mid slope	0.87 – 0.61	2nd rotation, 5 – 7 months old (open site)
B18 PEN D035 / 038 E102º2'32.2", N 0º32'32.2"	10	0.11	1.16	upper slope	0.95 – 0.73	2nd rotation, 0 – 10 months old (open site to immature acacia)

*) Data not yet available
**) Data from nearby compartment J024 (E102º8'10.2", N0º32'0.5")
***) Acacia cycle stages; 'open' 0-6 month, 'immature' 7-30 month, 'mature' >30 month

3.2.2 Approach to identifying drivers of peat decomposition

Peat, i.e. partially decayed vegetation material, is decomposed through biogeochemical processes, including the activities of bacteria and fungi as well as the effects of direct chemical reactions. We can presently only guess at the precise nature and relative importance of the processes involved in tropical peat decomposition, as the limited research that has been done into the decomposition dynamics has focussed on temperate and boreal peatlands. It is clear, however, that most efficient decomposition processes involved will require the availability of oxygen, water and an energy source. High temperature will also enhance breakdown. It follows that organic matter decomposition is enhanced by:

- lower water levels (increased oxygen supply to greater depths i.e. exposure of more organic matter to aerobic conditions)
- peat surface disturbance (easier transport of oxygen into peat)
- fertilization (increased nutrient availability)
- vegetation removal (increased residual organic matter availability and higher peat surface temperature)
- frequent rainfall (sufficient soil moisture content throughout unsaturated zone).

The original characteristics of the peat, especially its density and nutrient content, also have an effect on decomposition rates.

The SBMS Project gas flux monitoring experiment has been set up to allow determination of the relative importance of variables controlling peat decomposition, as well as possible given the limitations in time and the nature of study sites, which are not stable but in a constant state of change. The 168 monitoring spots cover different conditions, including a range of water depths during the observation period, full or no plantation forest cover, and different types of peat (Table 2).

Of the different variables controlling peat aerobic decomposition, water depth is generally thought to be the most important one, because A) no high rate of decomposition has been reported for areas with high water levels and B) observations of peat subsidence and emissions with different water depths do suggest a distinct relation (at least in the water depth range between 0 and 0.8m). However such observations to date have been mostly in a limited range of environments and conditions, measurements of both net emission and water depth have often had limited accuracy and frequency, and other controlling variables were usually not measured. So while there is no doubt that a lowered water table causes enhanced peat decomposition, it is largely unknown what truly is the relative importance of variables controlling peat decomposition and carbon dioxide emissions, certainly at water depths around or below 0.8m.

A difficulty with determining the importance of water depth in controlling peat decomposition is that water depths do not only vary between measurement sites and sub-sites, but also in time. Indeed, variations in time often exceed the differences between sub-sites. Water depths encountered during the study range from peat surface flooding to 2.0 m water depth, although sub-site averages vary only by 0.5 metre, between 0.61 and 1.14 metre. An important question therefore is what characteristic of water table fluctuation it is that most influences microbiological processes: is it the average, the median, or a parameter describing lowest water depths? Pending further analyses, the results presented here related to median (most common) water depths in time, as indicated in Figure 10.

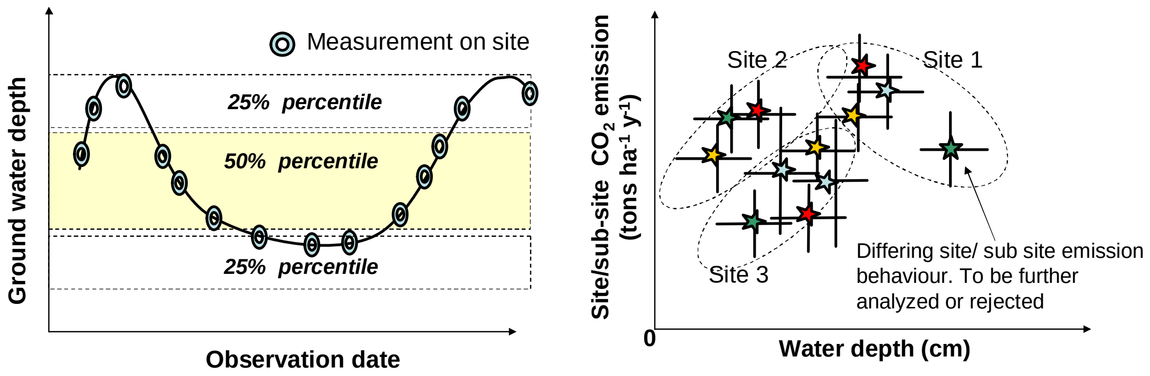


Figure 10 Schematic outline of data selection for analysis describing typical hydrological conditions during the observation period (left), and plot of emissions in the typical hydrological conditions on sites (right).

3.2.3 Discussion of results

Peat surface CO_2 emissions measured at the SBMSP sites are within the emission range published for other drained tropical peatlands with comparable water depths (Figure 11). Peat surface gross CO_2 emissions ('next to trees' including root respiration) are towards the higher end of flux rates found in other studies, while the net peat surface CO_2 (far from trees condition and in unplanted sites) are nearer the mean.

Most carbon dioxide emissions from the peat soil in Pelalawan plantations are derived from peat decomposition, as is evident from comparing emissions measured in open areas and far from trees with measurements close to trees, which includes root respiration emissions (Figure 12). Emissions in open areas are between 50 and 100 t/ha/y, those in plantations but far from trees are mostly between 75 and 110 t/ha/y, and those close to trees are between 100 and 150 t/ha/y, with some much higher measurements to over 200 t/ha/y. It may be very tentatively concluded from these data that peat decomposition emissions in the Pelalawan plantations are in the range of 50 to 100 t/ha/y, and root respiration emissions in acacia plantations around 50 t/ha/y with a few higher numbers.

If all measurements are included, including unplanted areas as well as those near and far from trees in planted areas, a relation between water depth and emission is apparent (Figure 11). Total emissions are lower when the water table is nearer the peat surface. However if only net emissions are considered, excluding (most) root respiration as measured further away from trees and in open areas (Figure 12), no such relation is apparent from the current data. This is a rather unexpected result, which may tentatively be explained by the relatively short measurement period as well as the factors discussed in Text box 1.

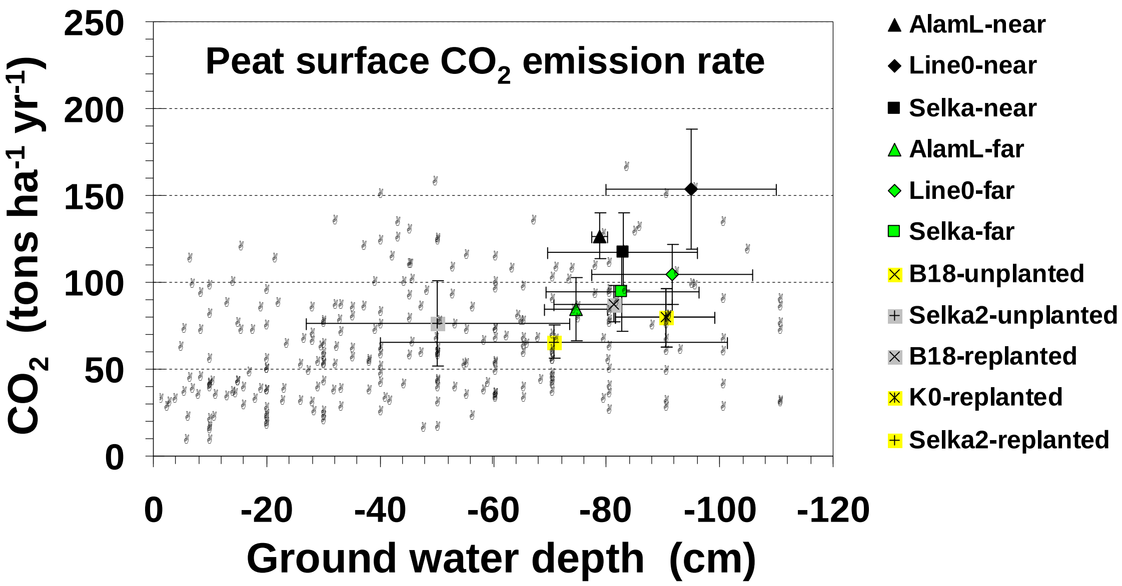
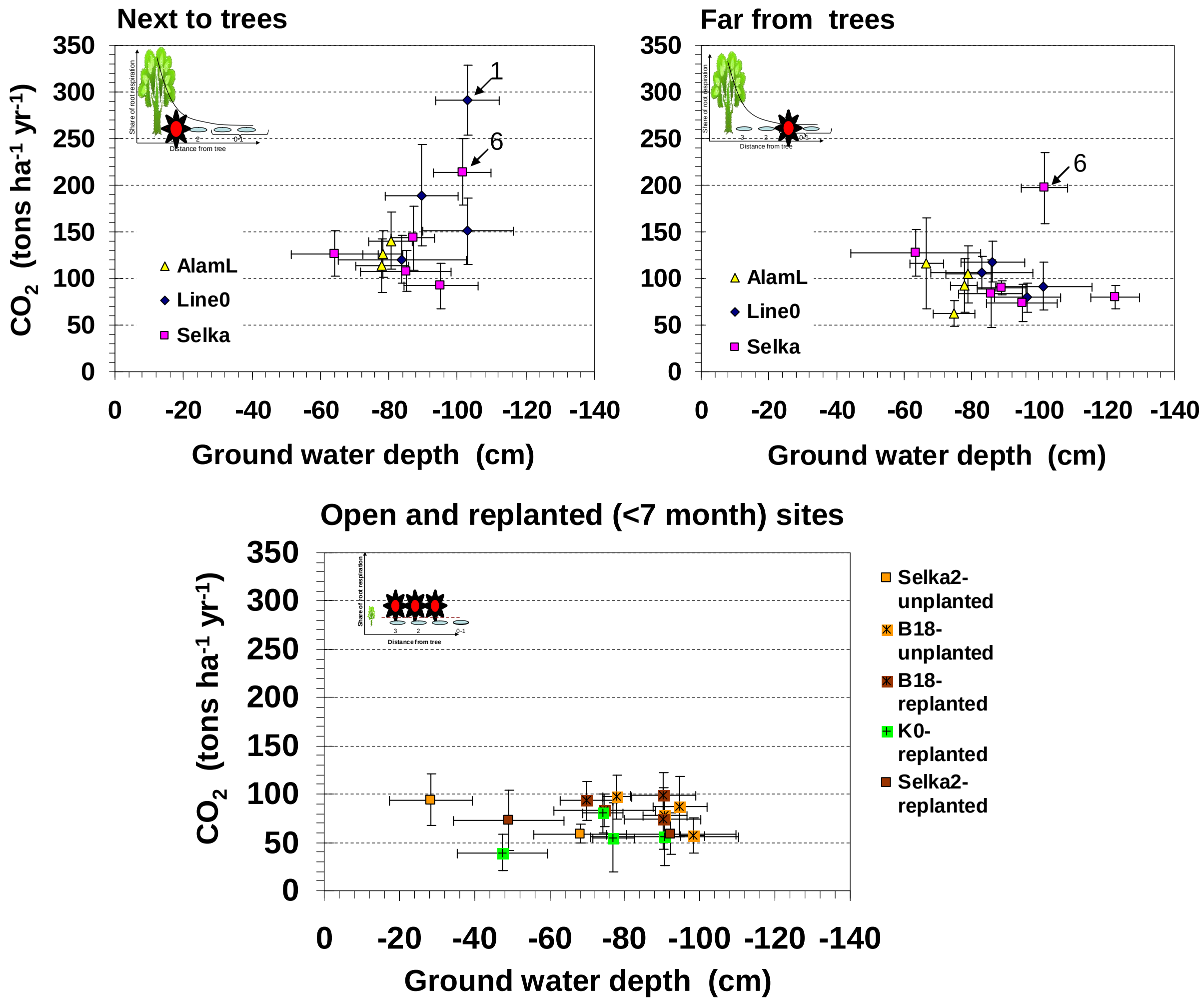


Figure 11 Mean peat surface CO_2 emission (tons ha-1 yr-1) as established from SBMS Project data (symbols with error bars), compared with emission values in various land uses tropical peat as derived from literature and unpublished data (dots). Note that literature based CO_2 emission estimates do not separate emissions from decomposition and root respiration. Vertical error bars denote standard deviation in the CO_2 emission in typical ground water depths and horizontal error bars denote standard deviation of the typical ground water depth.

Results tentatively suggest that higher peat density (and presumably fertility) is likely to result in higher gross and net CO_2 emissions; this was already documented in reclaimed boreal and temperate peatlands, but it needs to be studied in more detail in tropical peat. The highest cumulative annual net CO_2 emission from the peat surface, excluding most of the tree root respiration (i.e. including 'far from trees' measurements only) in maturing acacia stands was 104.9±17.3 tons CO_2 ha-1 yr-1 in nutrient rich basin peat ('Line0' site) and somewhat lower emissions were detected on the peat dome located sites 94.6±23.1 tons ('Selka' site) and 84.7±18.1 tons ('AlamL' site), (Figure 11). In open areas located higher on the peat dome, cumulative CO_2 emissions were between 57.7±16.9 and 87.5±10.6 tons ha-1 yr-1

('K0' and 'B18' sites), (Figure 11). In maturing acacia stands, 'far from trees' peat surface net CO_2 emissions were about 63-68% from the gross emissions 'next to trees' in two sites ('Line0' and 'AlamL'), but in one site ('Selka') the difference was only 20%.



Maturing acacia: ***AlamL = PEN R022/023*** ***Line0 = PEN B120/129*** ***Selka = PES H015/016***

Open sites: ***K0 = PEN K001/010*** ***B18 = PEN D035/038*** ***Selka2 = PES H015/016***

Figure 12 Mean CO_2 emission (tons ha^{-1} yr^{-1}) at typical water depth (cm) conditions in sub-sites at the monitoring sites. Vertical error bars denote standard deviation in the CO_2 flux in typical water depth condition and horizontal error bars denote standard deviation in typical water depth. Typical water depths are defined as 50% percentile of the water depths in CO_2 flux measurements. The sub-sites in LineO and Selka, which have rather different emissions from the other sub-sites, are pointed out.

3.3 Subsidence and soils monitoring results to date

The most direct and probably most accurate measurement of net carbon emission from peatland is by measuring the lowering of the peat surface ('subsidence') and the accompanying change in bulk density of the peat. The combined data allow determination of the amount of solid peat matter lost (to the atmosphere, with water discharge and with tree removal), corrected for the peat shrinkage and compaction processes that also contribute to subsidence. The difficulty with monitoring subsidence however is that it is a very slow process and that it is not easy to define the 'ground level' that is monitored; it therefore takes a number of years before subsidence rates can be quantified accurately. As most studies need to be completed in a few years, subsidence monitoring is rarely properly applied.

Subsidence has been monitored in Pelalawan plantations at a number of sites since 2002, by measuring the height of the top of dipwells (anchored in the mineral substrate) relative to the peat surface, as they seem 'pushed out' when the surface subsides. A much larger number of additional dipwells has been installed in 2007 and 2008 to extend this approach within the SBMS Project, including all gas emission plots, but this record is currently too short to yield accurate numbers. Until these numbers are available, subsidence numbers can only very tentatively be interpreted in terms of carbon emissions.

The tentative subsidence analyses presented here is based on findings at two sites: J Estate and K Estate in the Phase 2 plantations (Figure 13). Total average peat surface subsidence at these sites since monitoring started is 1.33m (Table 3), or 0.17m/year on average. Note that subsidence in the first 15 months after drainage in July 2002, before monitoring started in October 2003, was estimated at 0.59m from field observations at the time. This initial rapid subsidence is largely explained by consolidation that is caused by the entire peat body (including the saturated zone) being compacted somewhat after the top soil is dewatered and exerts downward pressure on the peat below. This consolidation is thought to occur mostly in the first year after drainage, and is estimated at up to 0.5m in the study area.

After the initial rapid subsidence that is mostly caused by consolidation, subsidence slows down to 0.15m/year on average in the subsequent years (October 2003 to May 2008), including a harvesting period during which water levels were temporarily lowered and the peat surface further disturbed. From May 2008 to August 2009, subsidence appears to have slowed down to 0.05m/year. While a reduction in subsidence rate in time is indeed expected, the rate of decline in subsidence rate suggested by these last numbers should be interpreted with caution because this follows a harvesting period during which the surface is likely to have been mechanically compacted (as is seen in the J Estate measurements, Figure 13), which may somewhat reduce subsequent subsidence rates. Also, the dry season of 2008 was very wet, which may have reduced subsidence. Subsidence should be monitored over long periods, covering representative conditions including dry seasons, to yield accurate results.

Apart from consolidation (in the first year) and peat decomposition, part of the subsidence will have been caused by shrinkage and mechanical compaction of peat in the unsaturated zone. Bulk density figures suggest that this may explain up to 0.3m of subsidence to date (Figure 14). This leaves at least 0.53m (1.33-0.5-0.3), or 0.075m/y, of subsidence that must be explained by peat decomposition resulting in carbon emissions. This number can be used for a first rough emission calculation as a check against the flux measurement emission data.

If we tentatively assume an average bulk density in the unsaturated peat zone of 0.1 g/cm^3 (values found to date are mostly between 0.07 and 0.15 g/cm^3, Figure 14) and a carbon content of 60% (a commonly used value for Indonesian peat), this would yield a carbon dioxide emission of 45 tCO_2/ha/y. The main uncertainties in this number are:

- If compaction in the unsaturated zone explains less than 0.3m of subsidence, subsidence caused by decomposition would be more than 0.075m/y and emission would be higher than 45 tCO_2/ha/y. Continued subsidence monitoring and a larger number of bulk density profiles, at the subsidence monitoring locations, will be needed to verify this.
- It is likely that carbon content of the Pelalawan peat, which is less decomposed (more fibric) than most peat in Indonesia, is higher than 60% (numbers up to 90% have been reported in literature). This would also suggest that emission could be higher than 45 tCO_2/ha/y.

The subsidence rates at the J Estate and K Estate sites are almost identical, despite the sites having different water depths (Table 3) and water management regimes (J Estate is inside the SBMSP Phase 2 Pilot, K Estate just outside of it). This may suggest that water depths at both sites are still below a threshold level below which subsidence is at a maximum, despite improvements in water management. However it may also suggest that peat decomposition (i.e. subsidence) still responds to previous lower water depths when peat was partly broken down and became 'labile' (Text box 1).

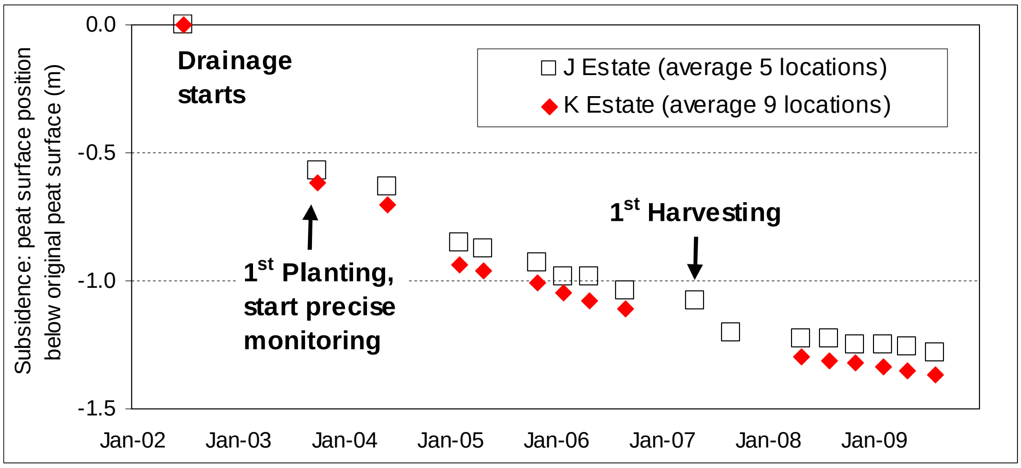


Figure 13 Subsidence in J Estate (Phase 2, inside SBMSP Pilot) and K Estate (Phase 2, just outside SBMSP Pilot, in same landscape but different water management regime). Peat depth is 7.5-9 m.

Table 3 Summary statistics on subsidence and groundwater depth in J Estate and K Estate.

	Peat Surface Subsidence (m)**				Water depth (m)***	
	J	K	Avg	Avg/yr	J	K
Average 8.5 years to date (2001-Aug09)	1.28	1.37	1.33	0.166		
Jul02-Oct03 (1st 15 months after planting)	0.57	0.62	0.59	0.48		
Oct03-May08 (including R1 harvesting)	0.658	0.680	0.669	0.149	-1.00	-1.37
May08-Aug09 (after R1 harvesting)	0.054	0.072	0.063	0.051	-0.75	-1.27

**est., pers. comm APRIL*
***Average 5 locations (J) and 9 locations (K)*
****Average 6 locations (J) and 9 locations (K); note there are considerable fluctuations*

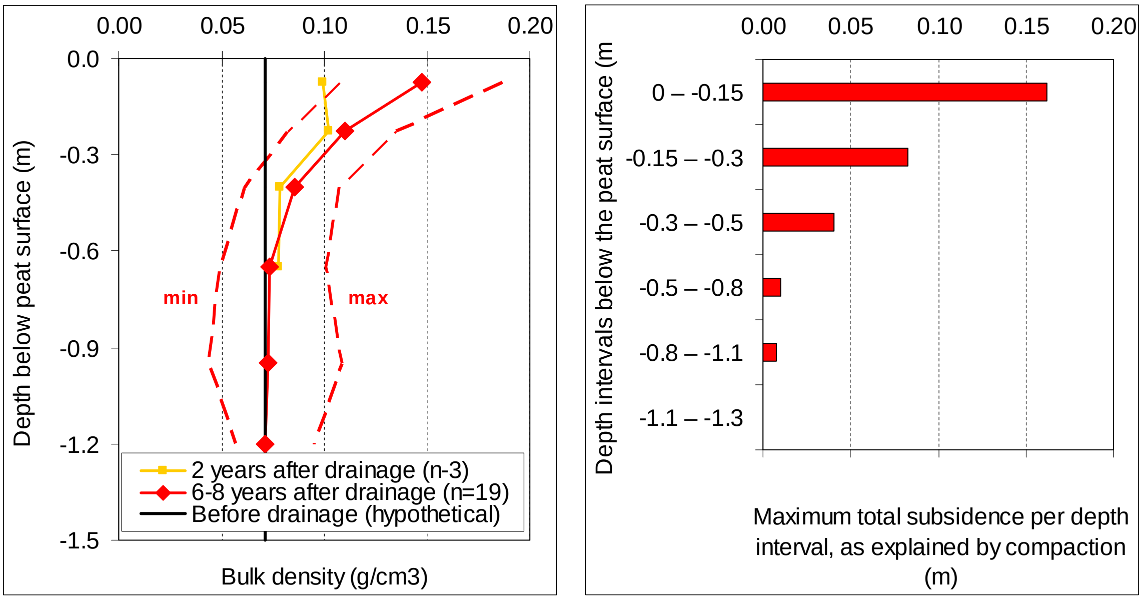


Figure 14 Preliminary analysis of Bulk Density data in Pelalawan plantations (left), and how much of total subsidence they may explain assuming an original BD of 0.07 g/cm (right). Bulk density samples were taken from the side of 22 soil pits that were dug to just below the water table in peat that is mostly fibric. Three replicate samples were taken at each standard depth; average values for each depth are presented here.

3.4 Key results to date

Results so far allow the following tentative conclusions:

- Using the 'closed chamber' method, we have been able to measure CO_2 emissions from peat decomposition in peatland acacia plantations through experimental plot set-ups, allowing elimination of all or most CO_2 emissions caused by root respiration.
- CO_2 emissions from peat decomposition, as measured with the closed chamber method, are in the range expected on the basis of findings elsewhere: 50–100 t/ha/y over 2007-2008.
- This number is supported by tentative results of the subsidence monitoring, which suggest CO_2 emissions of at least 45 t/ha/y over 2002-2009.
- A figure of 50 t/ha/y is tentatively accepted as a conservative estimate for CO_2 emissions in Pelalawan plantations in 2007 and 2008.
- These numbers are valid for fibric peat with low bulk density. There are some indications that more mature peat with higher bulk density ('basin' peat) yields higher emissions when drained. However this finding is still highly uncertain.
- Unexpectedly, the data now available do not yet allow determination of a relation between water depth or subsidence and CO_2 emission. There may be several reasons for this, see Text box 1.
- Total subsidence over the first 7 years after drainage has been 1.33m at two locations in 'dome peat', or 0.17m/y. This includes an estimated 0.5m of consolidation in the saturated zone in the first year after drainage, and up to 0.3m of subsidence through shrinkage and compaction in the unsaturated zone.
- Subsidence in 2008-2009 appears to be 0.05m/y. However this excludes subsidence during harvesting (when the peat is mechanically compacted) and during more extreme dry seasons (which did not occur in the study period), so this number may underestimate the underlying long-term subsidence rate.

3.5 Recommendations for further work

The main obstacle in translating our much increased knowledge of Pelalawan CO_2 emissions into practical plantation water management recommendations is the lack of a clear relation with water depth in the data so far. The possible reasons for this are discussed in Text box 1. The following checks and tests are proposed, at selected peat gas emission monitoring sites:

- Continued monitoring in a dry season with lower water tables and soil moisture.
- Further analyses and interpretation of subsidence data, for which additional analyses of bulk density and carbon content will be necessary.
- Peat profile chemical characterization and nutrient concentrations in (1) peat, (2) residual old wood, and (3) residual harvest litter; for characterization of organic matter decomposability.
- Correlation of peat water table depth and peat moisture profiles; for interlinking water table, moisture conditions and decomposition CO_2 loss.
- Correlation of peat profile moisture with redox conditions, pH, and peat temperatures; for interlinking oxygen availability and soil chemical processes.
- Sampling on peat profile of greenhouse gas (CO_2, CH_4 and N_2O) concentrations, for detection of main depth for formation and possible transformations of these gases in peat in differing environmental conditions.

Text box 1 Factors complicating the establishment of a clear relation between water depth and CO_2 emission in peatland plantations.

Figure 11 and Figure 12 present carbon dioxide emissions against water depth. Unexpectedly, no significant relation between the two can be found with the current SBMSP data. The three most obvious explanations for this are:

1. There may be a strong reduction in the increase in decomposition-derived emissions when the water table falls below a certain threshold level. If all or most water depths encountered in the current study are below this threshold, emissions would not vary much between sites. Such a threshold could be explained if we assume that peat decomposition leading to carbon emission occurs largely in a limited zone above the water table where peat moisture content is optimal for microbial activity: if the water table falls below the depth of this zone, decomposition may not increase much further. Indications of the existence of such a threshold in peat soils have been found earlier, both in boreal and tropical peat. In the case of the SBMSP study, it is not unlikely that the threshold depth is above or around the depth range of 0.7-1 metres that applies to most measurements.

2. A key factor in determining biochemical transformations in peatlands is the degree of aeration. It may be that oxygen availability for aerobic decomposing microbes becomes a limiting factor as the water depth below the peat surface increases. CO_2 production itself may also limit aerobic decomposition with falling water levels, as upward flow of CO_2 saturates the peat profile and reduces downward flow of oxygen through air filled pore space. This could put a ‘ceiling’ on emissions, similar to the ‘threshold depth’ discussed above.

3. It should be noted that water levels have been significantly below current levels in the early years after plantation development, before they were brought up in recent years. When water tables were lower, a reservoir of fresh labile carbon in partly decomposed peat is likely to have formed in the peat profile that is now easily decomposed even with limited oxygen availability now that water levels have been brought up. If this is the case, CO_2 would be produced at high rates until this reservoir is depleted, and it may take years after bringing up water levels before emissions will be significantly reduced.

A combination of all three explanations may apply in this case. It may also be that the combined effects of controlling variables other than water depth are strong enough to obscure the effect of water depth alone, especially since the range in average water depths is rather limited to begin with (between 0.61 and 1.14 m;). Whatever is the case, this can not yet be established with the present data.

4 First tentative results on quantifying degradation and landscape-ecological relations on the Kampar Peninsula

4.1 Introduction and objectives

Several activities in the SBMS Project contribute to better understanding of how the wider KP may be managed in a sustainable way, allowing conservation areas to coexist with plantation areas in the long term. Work Package 1.4 aims to apply knowledge on peatland functioning derived from the Work Packages focussing on the Pelalawan Plantations (and in other projects) to the Kampar Peninsula as a whole, with a focus on understanding the impacts of drainage on water depths and forest and carbon conservation. This knowledge is integrated in a spatial planning tool. Work Package 2.1 investigates patterns in natural forest types and forest degradation, in relation to logging and drainage patterns. It aims to apply these findings in the spatial tool to produce a 'recommended land use zoning map' in support of planning conservation and sustainable development on the KP. As the two work packages are closely interlinked, they will be presented together here.

4.2 Methods

Quantification of landscape condition and the level of degradation was carried out using combined information derived from remote sensing (SPOT, Landsat), aerial photography (SCAP), site visits (on the ground plus helicopter over-flights) and previous surveys, supported by knowledge of tropical peatland ecology and hydrology. Data processing has involved analysis of remote sensing images, land cover classification, verification (employing ground data, aerial photography and local knowledge), calculation of spatial statistics using a GIS, and data interpretation and assessment.

4.3 Results to date

4.3.1 Natural conditions on the KP

Map of original vegetation

A tentative map of natural forest types on the Kampar Peninsula is shown in Figure 15. This is based on analysis of a 1990 satellite image in order to understand the condition of the vegetation before large-scale land development and illegal logging activities had become established. This analysis has shown that natural vegetation patterns on the KP are very complex and heterogeneous. At one end of the ecological continuum (series) of vegetation types are the tall riverine and mixed swamp forest types, which grade into successively lower growing forest types on the higher parts of the peatland domes. The transition between forest types is linked to changes in peat depth and slope gradients, which influence depth of groundwater, period of waterlogging, and water/nutrient supply rates. Methods for a more detailed analysis of current forest patterns and status were developed and further analysis of forest condition was undertaken (see below).

Digital Elevation Model

A Digital Elevation Model (DEM) for the year 2000 was developed as part of this work package, as no accurate model of the Kampar Peninsula existed and elevation and gradients are key parameters in strategy assessment and modelling. Several data sources were used: field surveys by APRIL over the coastal zone of 10-20 kilometres around the KP, a DEM derived from SRTM data (by SarVision), the pattern of natural streams, and other sources for the NW part of the area. The result is still not accurate within a metre, certainly now that the peatland landscape has been altered by subsidence in drained areas, but it does credibly represent the landscape and gradients of the KP (Figure 16).

Catchment map for the KP

The Elevation Model developed in WP 1.4 has allowed development of a first tentative catchment map for the Kampar Peninsula (Figure 17). Moreover, tentative forest status assessment has allowed identification of two largely intact catchments that cover much of the inner part of the Kampar Peninsula and would, with the addition of forested buffer zones for protection of ecological and hydrological values, need to be part of the 'core conservation area' in their entirety.

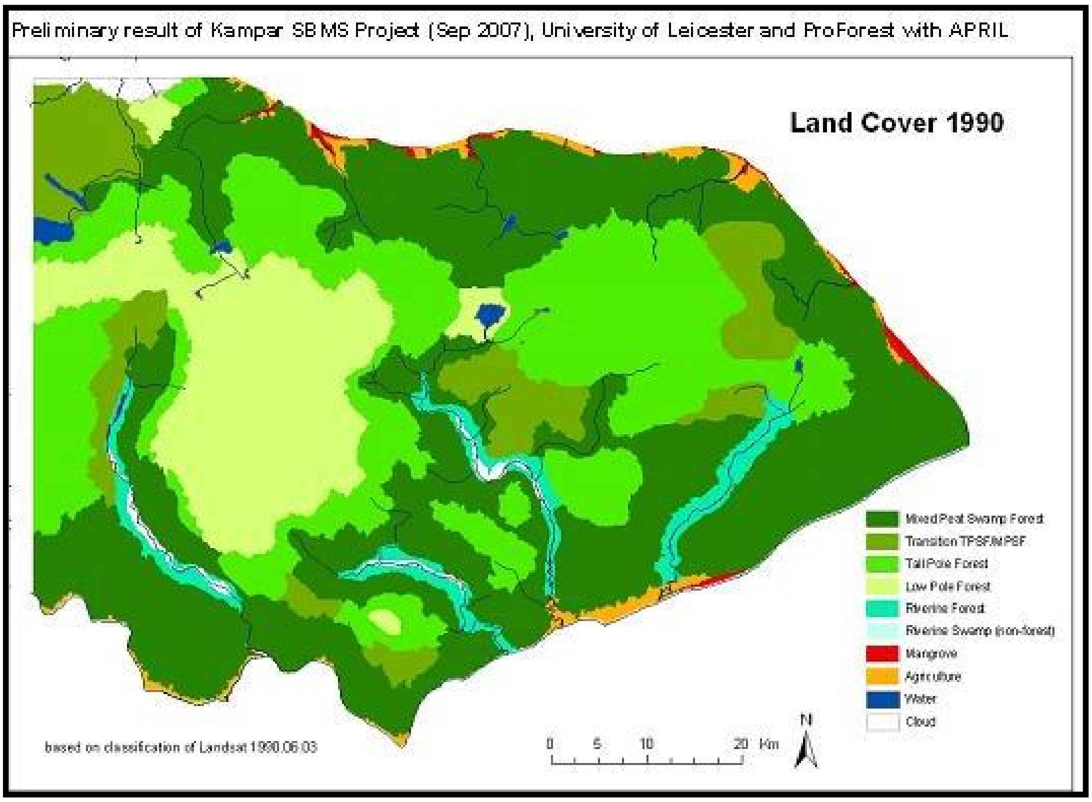


Figure 15 Tentative map of land cover and forest types on the Kampar Peninsula in 1990. Note that much Mixed Peat Swamp Forest has disappeared at present; a land cover map for 2007 is shown in Figure 18.

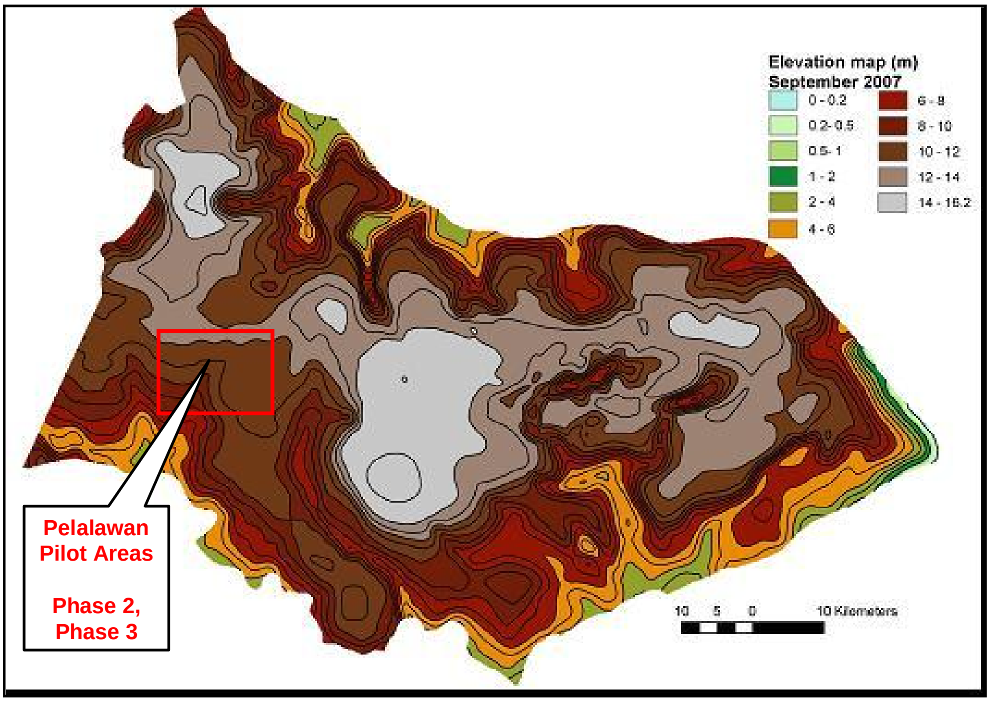


Figure 16 Kampar SBMS Project elevation map for the situation prior to drainage (2000).

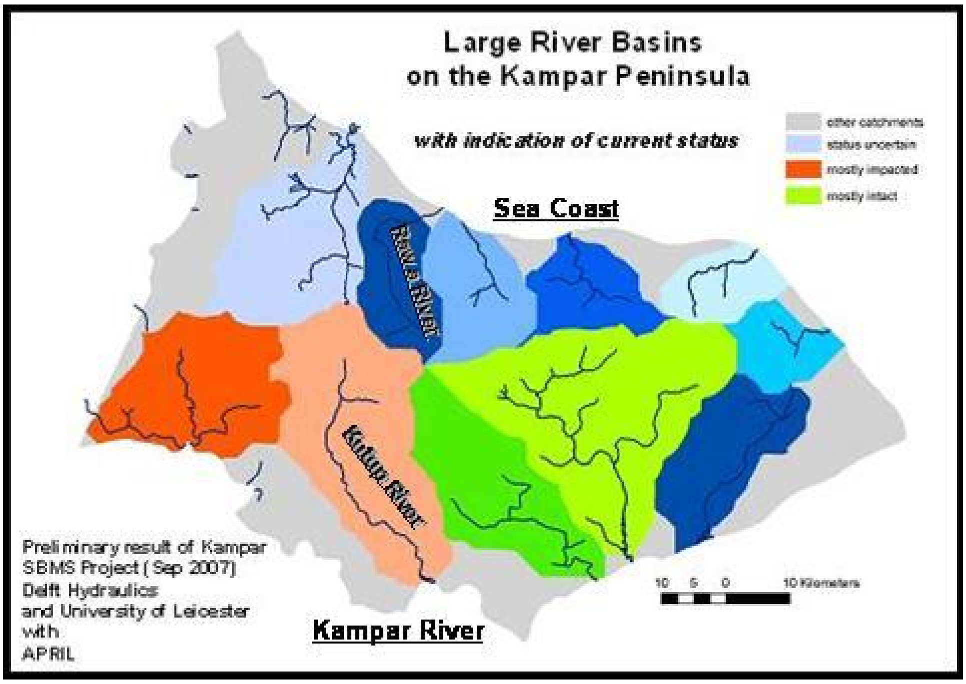


Figure 17 River basin map for the Kampar Peninsula peatlands as derived from the elevation model shown above. This will be an important component of a recommended land use zoning map.

Note that the indication of current river basin status is very tentative, based on limited information, and needs to be refined. However the map makes very clear that any conservation plan would have to include the two relative intact river basins draining to the south (the green river basins), plus significant buffer zones of around them to maintain hydrological integrity. If these river basins are affected by intensive drainage (they are already affected by drainage for logging), it probably becomes physically impossible for much of the Kampar Peninsula peatlands and forests to be conserved in the long term.

4.3.2 Ecohydrological relations: towards modelling conservation impacts of development scenarios

Degradation patterns on the KP

Degradation patterns were identified through detailed analyses of a cloudless SPOT image for 2007, and older Landsat images for 1990 and 2002. The SPOT image used covers most of the KP, but (due to limited image availability) not the western part including the Pelalawan plantations and the Tasik Besar nature reserve as can be seen in Figure 18. This analysis therefore covers only 334,000 ha of the KP and would best be extended to cover the full KP area.

In 2007, the principle land cover of the KP was still forest (Figure 18), with mixed swamp forest occupying 54% of the area included in the analysis and pole forest communities 33%. The total forested area in 2007 was 292,000 ha (86% of the study area), although not all was in an intact condition.

In total, degraded forest classes occupied 19% of the area studied and 22% of the total forest area (64,620 ha). Thus, 78% (227,380 ha) of forest within the area was classified as being in good condition. The principle drivers of forest degradation can be identified as logging activities; in 2007 there was some concession-based timber extraction within the KP but most recent forest degradation could be attributed to illegal logging.

In 2007, forest degradation caused by timber extraction was largely associated with the mixed swamp and riverine forest classes, with much lower levels of degradation associated with the pole forest communities (these areas contain few trees of economic value). Most of the heavily degraded forest and recently opened land (including burn scars) was located around the margins of the study area, although there were smaller areas associated with intensive logging activities in central parts of the Peninsula, particularly in the south central parts. Moderately degraded forest follows a somewhat similar spatial pattern. In contrast, small to medium-sized patches of lightly degraded forest are distributed more evenly throughout the mixed swamp forest zone.

The total length of logging trails and canals increased from 425 km in 1990, to 1,380 km in 2002 and to 2,030 km in 2007 (Figure 19). The incremental increase between 1990 and 2002 translated into an annual rate of 24 m of newly established trail per km^2 of forest. For the period 2002-2007, this rate increased to 34 m km^{-2}, indicating the increasing scale of logging activities over that period.

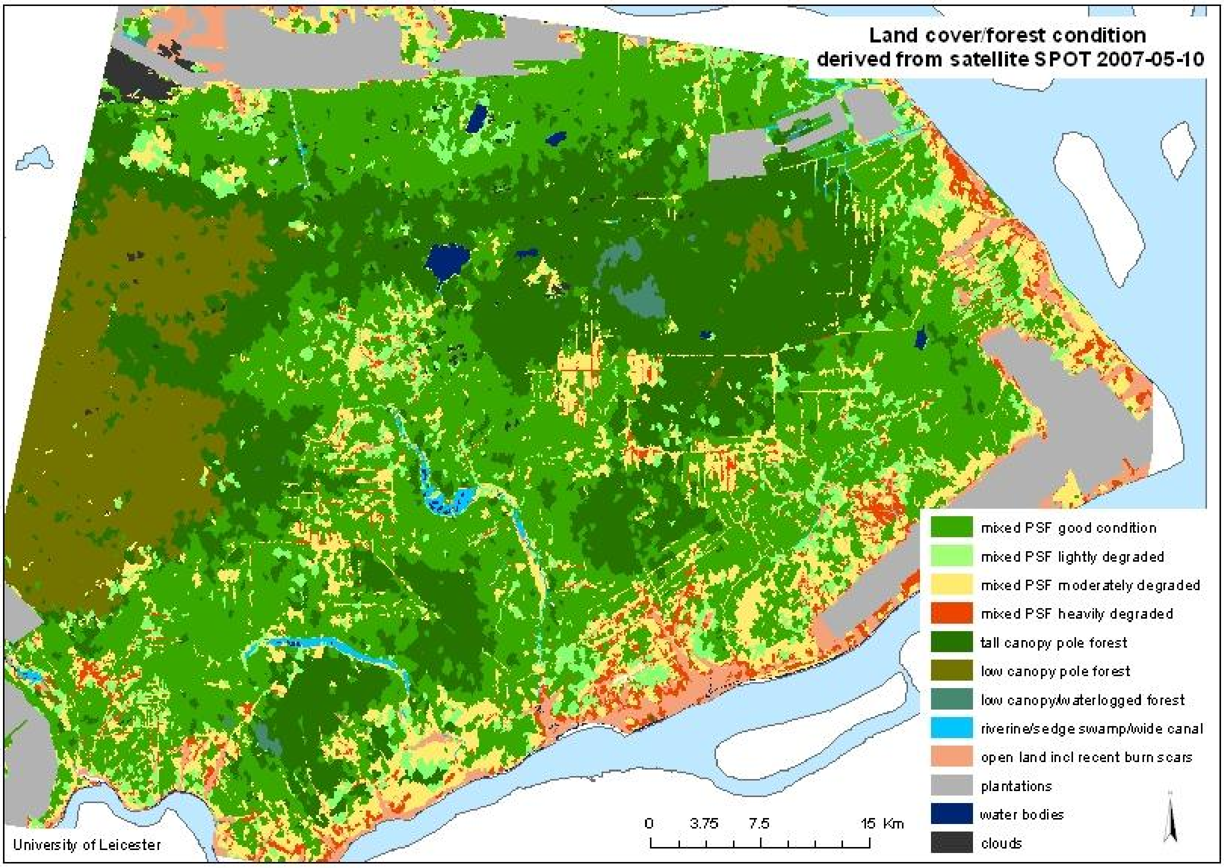


Figure 18 ***Land cover /forest condition map for the Kampar Peninsula 2007.***

<u>First findings on the relation between drainage and forest degradation</u>
Two different approaches are applied to better understand how lowered water tables affect forest health.

The first approach is by analysis of degradation patterns across the KP in relation to distance to canals and water depth. Distance to canals is determined through remote sensing analysis, as are degradation patterns. There are several complications with this approach:

- It is difficult to distinguish canals from logging tracks; this distinction was made as far as possible through detailed (manual) analyses and local knowledge provided by Dr John Bathgate, but a number of linear logging features remain undefined (Figure 19).
- Logging canals have two impacts on forest: they allow access for loggers and they lower water levels. Both processes result in forest degradation (loosely defined as reduction in canopy cover and/or biodiversity), and it is difficult to establish their relative contribution. Over the short-term, drainage increases tree fall, a consequence of peat subsidence and root destabilisation; over the longer-term, drainage leads to changes in tree species composition, favouring species more tolerant of lower water levels and, where tree fall produces canopy gaps, higher light levels. These effects on the forest structure are exacerbated by timber extraction which, even without drainage, will result in similar changes in canopy cover. The effects of canals and

other drainage features (e.g. drainage ditches constructed alongside logging railways) may vary according to location in the peat landscape (gradient, hydraulic conductivity) and the dimensions of the canal. Preliminary findings on the relation between distance to canals and water depth in different forest condition types (Figure 20) indicate that drainage may contribute to forest degradation. It should, however, be noted that A) these are preliminary data that require further field checking, B) they represent a snapshot in time, and C) it is unclear to what extent low water levels contributed to forest degradation or whether both water depth and forest degradation are *independently* affected by distance to canals.

The second approach is to establish permanent plots in conservation forest affected by drainage to different degrees, and to follow tree die-back and regrowth in time and in detail. The advantage of this approach is that it allows separation of different causes of degradation. The disadvantage is that it takes much effort and time. Therefore, no results of this work can be reported yet.

Set-up of analysis tool

The project is developing an analysis tool for the KP peatland area that allows exploration of the land and water management strategies, and quantification of the impacts in terms of peat subsidence, CO_2 emissions and conservation forest degradation. Strategies will take into account the current situation with plantations and roads already in place, and will include options for mitigated water management now piloted in the SBMS Project. Apart from use within the project, the aim is to make the tool and results available to all stakeholders in the future of the KP, hopefully as part of a wider conservation effort and master plan initiative.

The strategy assessment tool is developed in HABITAT[2]. Knowledge rules are derived from literature, SBMS Project results and results of other currently ongoing studies. The knowledge rules include: groundwater depth as a function of distance to canal, annual subsidence as a function of water depth, CO_2 emission as a function of subsidence rate, drainability as a function of hydraulic gradient and distance to drainage base, etc. These rules are then applied to layers of spatial information: drainage system map, elevation model, peat depth map, peat type map, natural forest map, forest condition map, etc. This results in maps of annual subsidence and CO_2 emission rates, habitat suitability maps, as well as maps of peatland morphology, cumulative CO_2 emission and drainability in 10, 25 and 50 years (for different scenarios). These different resulting maps will be the basis for the recommended land use zoning map.

A prototype strategy assessment tool is used for trials; further knowledge rule development is awaiting field data for the dry season.

4.4 Discussion

Despite widespread modification of land cover during the last two decades, the KP still supports extensive, contiguous areas of peat swamp forest in good condition. Especially the large areas occupied by pole forest, particularly on the large peatland domes in the west and the north-east of the peninsula, remain to a large extent in good condition. Logging trails

[2] HABITAT is Delft Hydraulics software.

passing through these forest areas have minimal timber extraction associated with them, thus the forest canopies remain substantially intact.

In the areas occupied by mixed swamp forest, there has been more extensive degradation of forest condition, especially in the peripheral coastal areas of the KP. However there are substantial remaining areas of forest in either good condition (64.8% of the forest in this class) or a lightly or moderately degraded condition (30.6%), especially in the more central parts. Lightly or moderately degraded forest has a high potential for recovery, particularly since degraded forest fragments are usually contiguous with forest in good condition which will facilitate natural regeneration (through seed dispersal etc.). The increasing intensity of logging activities does, however, threaten the continued sustainability of the remaining high quality forest, both through the disturbance caused by timber extraction and the impact of canal construction on peatland hydrology.

In peatlands elsewhere in western Indonesia, fire has been identified as a key driver of forest degradation. Fires on the KP, to date, have been of very limited extent. Activities which facilitate a continued low risk of fire should be given a high priority since fire, and in particular repeated fires, have a strong negative influence on forest regeneration. Fire risk in peatlands increases as a result of disturbance to the forest canopy, which leads to changes in forest microclimate, lowering of the peatland water table by drainage, and human access, which provides a source of ignition. Reducing and preferably removing logging activities within the KP would not only protect the remaining good condition forest and provide an opportunity for forest regeneration in degraded forest, but would also greatly reduce the risk of other forms of anthropogenic damage. Ideally, the long term management of the KP should include measures to rehabilitate the natural hydrology through a programme of canal blocking, which would bring benefits in terms of restoring the hydrological conditions for natural forest regeneration and further reduce the risk and incidence of fire. A peatland rehabilitation and forest restoration programme would also result in co-benefits for biodiversity and carbon storage.

4.5 Recommendations for further work

4.5.1 Recommended land use zoning map

This activity can commence once sufficient understanding has been developed of A) ecohydrological relations and B) likely development scenarios and options for the KP. The aim is to define the optimum (and minimum) requirements for viable forest landscape conservation, in terms both of area and location within the peatland landscape and of mitigation measures required in adjoining plantations. The work package considers requirements and options from a scientific perspective (i.e. not including stakeholder consultations), but aims to provide the basis for responsible planning in practice. Development of a land use zoning map will involve compliance with the HCVF toolkit methodology. As a first step towards this objective, the feasibility of applying HCVF criteria on the basis of current knowledge will be determined. This may require more detailed classification of forest condition, particularly within the mixed peat swamp forest zone where degradation has had the greatest impact, but where biodiversity values were (and likely still are) highest.

A first tentative set of rules for land use zoning has been agreed within the project, as presented in the Annex to this summary report.

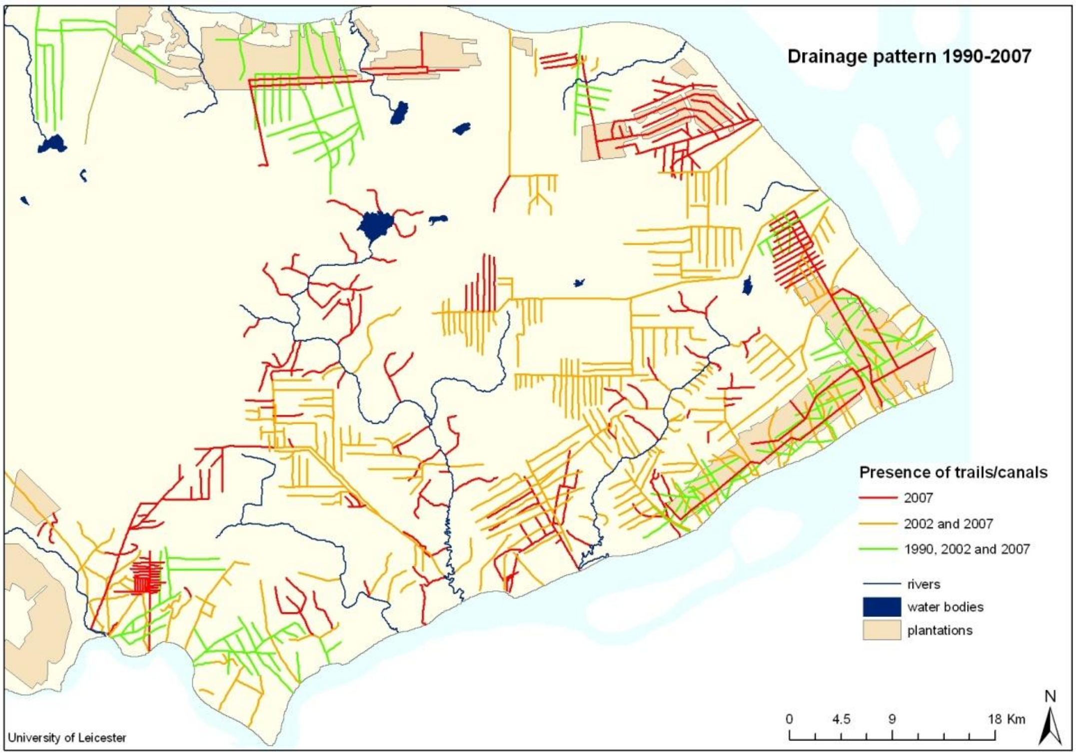


Figure 19 ***Logging trails and canals on the Kampar Peninsula, as detected in 1990, 2002 and 2007 satellite images. Canals and trails can be separated in some cases, but not always, with data currently available.***

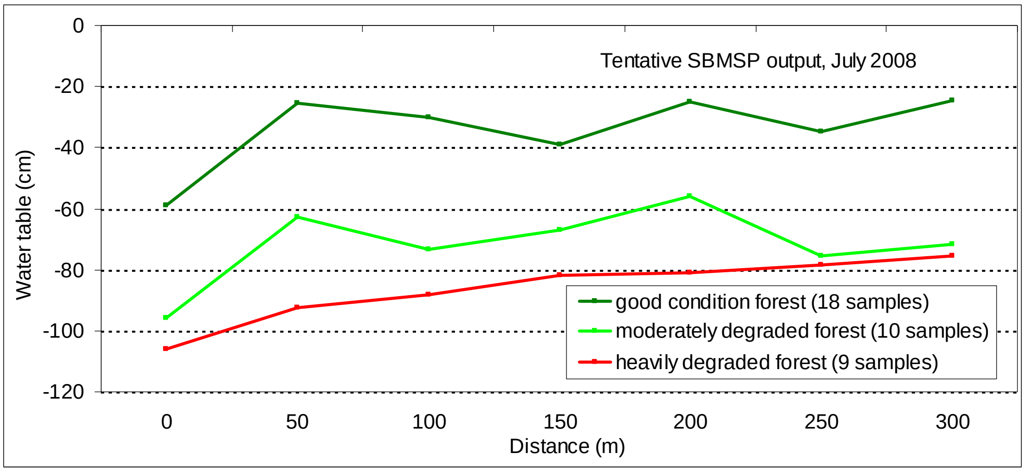


Figure 20 Preliminary findings on the relation between water depth and distance to canals in different forest and drainage conditions on the Kampar Peninsula. Water depth data were collected by APRIL staff during helicopter drops in October 2007. Forest condition was derived from the map shown in Figure 18. Note that the cause-and-effect relation between water depth and forest degradation is not yet clear: forest may be more degraded because water level is lower, or water level may be lower because canals are kept open more actively to allow more active logging. A combination is likely.

5 ANNEX: SBMS Project Statement on tropical peatland conservation and the possibilities for sustainable development (August 2008)

Al Hooijer (Deltares | Delft Hydraulics), Susan Page (Leicester University), Ruth Nussbaum (ProForest)

Peat consists of approximately 90% water and 10% vegetation remains. Peatlands therefore are not really 'land' but are wetlands, and need to be managed as such to prevent loss of the water that supports the peat surface, i.e. to support vegetation and prevent peat subsidence and carbon loss. Until now most peatland water management in SE Asia has not recognized this fact. Widespread overdrainage is resulting in degradation and loss of natural peat swamp forest, in CO_2 emissions and in reduced agricultural productivity.

The independent team members support APRIL in demonstrating its commitment to responsible peatland management by instigating the Kampar SBMS Project. The fundamental thesis of the project is that forest and carbon resources in peatlands can only be managed sustainably if their hydrological integrity is maintained or rehabilitated. This can be achieved only if entire peatland ecological landscape units (i.e. intact peat domes and river basins within peatlands) are managed to minimise degradation caused by on- and off-site drainage. This is essential for the conservation of peat swamp forest, but equally important to prolong the lifespan of peatland resources for economic purposes.

The current situation in Sumatra and Kalimantan is that most peatlands are already partly or fully converted and/or degraded as a result of logging, deforestation, drainage and/or fire. Degraded areas have a low conservation value in their current state and limited or no present agricultural production, but often still store large amounts of carbon and may have development and/or rehabilitation potential. There is an urgent need to manage such land to at least limit fire risk and carbon emissions. Where remaining peat swamp forest and converted peatland coexist in a single peatland landscape unit, a new approach needs to be applied to balance opposing water management requirements by the delineation of buffer zones of adequate size and investment in appropriate water control structures where that is necessary.

The Kampar SBMS Project team proposes the following tentative 'wise use rules' for peatland conservation and development, to be developed further as more is learnt about the functioning of peatland systems:

1. **Remaining High Conservation Value Forest on peatland should be conserved as a priority, together with as much as possible of the surrounding 'ecologically and hydrologically significant landscape'.**
2. **Prevention of further degradation and rehabilitation* back to sustainable peat swamp forest should be the priority for degraded peatlands* where this is still feasible*.**
3. **Responsible development (for agriculture and plantations) should be considered as an option for degraded peatlands where rehabilitation is not feasible in the short to medium term (rehabilitation may still follow in the longer term), in order to maximize economic development as well as minimise loss of the peat carbon store.**
4. **There is an urgent need to define better the terms 'degraded peatland' and 'feasible rehabilitation' to clarify these issues for policy makers, business, NGOs and other stakeholders.**
5. **The aim of peatland management, either for conservation or crop production, should be to maintain water levels as high as possible under the range of management requirements.**

(*See Definitions overleaf…*)

Tentative Definitions of Key Concepts:

Degraded Tropical Peatland

Peat swamp forest that has been severely damaged by the excessive harvesting of wood and/or non-wood forest products, poor management, drainage, fire, or other disturbances or land-uses that damage the peat and vegetation to a degree that inhibits or severely delays the re-establishment of forest after abandonment (modified from ITTO, 2002). Degraded peat swamp forest is unlikely to recover its former forestry resource value without active rehabilitation and may no longer support the livelihoods of local communities. Nevertheless, the peat still contains a large amount of carbon that will continue to be released to the atmosphere as CO_2 (a greenhouse active gas) as a result of oxidation and fire. Under these circumstances alternative ways of maintaining this residual carbon store for as long as possible and the funding to do it have to be found. Properly managed economic land use with high water tables could be considered a 'wise use' approach under these circumstances.

ITTO (2002). ITTO guidelines for the restoration, management and rehabilitation of degraded and secondary tropical forests. ITTO Policy Development Series No 13. ITTO, Yokohama, Japan.

Peatland rehabilitation

Peatland rehabilitation aims to bring back important functions to degraded peatland. These functions can be ecological (rehabilitate natural forest functions), hydrological (rehabilitate low-flows, streams), forestry (rehabilitate a forest cover that can be harvested), or carbon storage (rehabilitate the conditions under which peat carbon remains stored). It is preferred if all these functions are rehabilitated if feasible. Rehabilitation is not necessarily the same as restoration, which aims to recreate original physical and ecological conditions and is even more difficult to achieve.

Feasibility of peatland rehabilitation

The feasibility of rehabilitation intervention should be considered on the basis of the hydrological and ecological state of the peatland at the landscape scale, financial resources and socio-economic conditions.