Government of Central Kalimantan

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Master Plan for the Rehabilitation and Revitalisation of the Ex-Mega Rice Project Area in Central Kalimantan

HYDROLOGY OF THE EMRP AREA: WATER MANAGEMENT IMPLICATIONS FOR PEATLANDS

Technical Report No. 2

OCTOBER 2008

Euroconsult Mott MacDonald and Deltares | Delft Hydraulics
in association with
DHV, Wageningen UR, Witteveen+Bos, PT MLD and PT INDEC

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Hydrology of the EMRP Area: Water Management Implications for Peatlands

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1 Summary

This report describes the results of the hydrological analysis of the EMRP project area as carried out by Cluster 3 of the EMRP Master Plan project. Furthermore, the implications of the hydrological findings for water management in peatlands in the area are presented.

A database has been assembled containing meteorological, hydrologic, topographic and pedologic information, based on previously available data brought together for the first time, as well as data collected during the project. This database represents the state of the art with respect to knowledge on the EMRP area. Achievements are amongst others a greatly improved digital elevation model and a first peat depth map for the EMRP area. However, due to limitations in availability and accuracy of data, the results still have a significant inaccuracy, especially for Block E. Further data collection work remains to be done, especially in improving the accuracy of the elevation, peat depth and rainfall information.

The information in the database has been used for the hydrological analysis of the EMRP area and its catchment. The analysis has been carried out by integration of information from different sources, comparison and cross-validation and by implementation and calibration of the following of simulation models:

- for the runoff from the upper catchment the Sacramento model in Sobek – Rainfall Runoff;
- for the water level dynamics in the rivers and main canals within the EMRP area Sobek – Channel Flow;
- for the groundwater dynamics of the peatlands ModFlow linked to Sobek – Channel Flow.

These model implementations have allowed assessment of consistency of the data and interpolation and extrapolation of available data over space and time to get more insight in the hydrology of the EMRP area. Conclusions of the analysis and implications for water management are summarized below.

There is a pronounced gradient in rainfall away from the coast, the Southern part of the EMRP area receiving rainfall at or below 1900 mm/y, the Middle and Northern parts around 2200 mm/y and above 2500 mm/y, and the River basins to the North of the EMRP area around and above 3000 mm/y.

There is a pronounced and long dry season with little rainfall in all of the area, but especially pronounced in the South. In most years, a net water deficit exists for 3 to 5 months (June to September); in 1 in 10 years it exists for 6 months (May to October). On the basis of rainfall patterns, conditions for peatland conservation and rehabilitation must be considered more favourable in the Northern than in the Southern part of the EMRP area.

Over the last century, and especially in recent decades, there appears to have been a trend towards dry seasons becoming even longer and drier, with rainfall dropping especially over Feb-May. It is unsure whether this is a result of local change (possibly due to forest loss) or of global climate change.

Tidal fluctuations, as determined by marine tidal water level fluctuations and water flows from upstream river basins, extend well inland into the EMRP area, especially in the dry season. However tidal fluctuations that allow tidal irrigation do not extent nearly as far and are mostly confined to Block D.

Hydrological model results and field observations show that large-scale and prolonged river flooding presently occurs mostly along the Barito River, affecting parts of Block A and D. Flooding is most frequent and deepest in the Jenamas and Dadahup areas, which may be considered unsuitable for most agricultural uses.

It is found that in most peatlands in the EMRP area, drainability and flooding will become major problem after a few decades of continued subsidence (caused by drainage and fires), as is demonstrated by combining subsidence model results with hydrological models.

Groundwater modelling with ModFlow for study areas in Block A and the north of Block C show that peat hydraulic conductivity is relatively low (around 1m/d). This can be explained by the relatively high degree of humification of peat in the area (which is hemic to sapric). Groundwater table fluctuations in dry periods are therefore controlled mostly by the local water budget, i.e. rainfall and evapotranspiration, and in most areas are affected by groundwater flow over a zone along canals of 500m width at most, resulting in lower water tables there. The implication for water management is that canal blocking may in the short-term have a limited impact on groundwater depth.

Because the drainage impact in the EMRP area is far more severe close to canals, subsidence and possibly fire frequency has been greater there, resulting in relatively steep surface slopes away from canals. Peat surface elevations 1km away from canals are now generally 0.5 to 1m higher than canal sides. Instead of the original low-gradient peatland landscape that functioned as a single hydrological system over tens of kilometres, a ‘mini-dome’ topography has in fact developed in 12 years that now controls hydrology.

The implication of the limited groundwater impact zone along canals, in combination with the new ‘mini dome’ morphology, is that canal blocking 10 years after drainage can have only limited impact on water levels further away from canals. This, in turn, means that the impact of canal blocking on fire risk and subsidence is also limited to a narrow zone, at least in the short term. In the long term, higher canal water levels should create a higher ‘base level’ where peat subsidence should stop.

These conclusions on the impact of drainage and canal blockings apply to the study areas in Block A and the Northern part of Block C. The impact of drainage is known to extent much further in some other Indonesian peatlands with flatter topography and higher hydraulic conductivity. It may be that the latter situation also applies in Block E and the Southern part of Block C (and in the Sebangau peatlands to the West of the EMRP area), where peatlands are more extensive and peat may be less humified, but we have no data for those areas.

Since canal blockings are effective mostly in the long term it is important that they stay in place for decades, i.e. they must be robust. Therefore the water level difference over blockings should be limited to less than (approximately) 0.5 metres. Furthermore, bypasses may be needed to prevent collapse of structures by erosion during high flow events. It has been estimated that, in order to rehabilitate the hydrology of all deep peatland in the EMRP area, a total of several hundreds blockings will be required.

Where the aim is to prevent further peatland drainage, all canals including logging canals should blocked, and construction of new canals prevented. If selective logging in remaining peatland forests is necessary, the preferred method of log removal is by light rail (without side canals) which does less damage to the peatland hydrology and will allow more rapid regeneration of the forest.

We conclude that there is no easy way to come to rehabilitate peatlands in the EMRP area. Blockings are useful, but the short term effect will mostly be limited to zones close to canals. In the longer term, blockings will help to create a new equilibrium, whereby further peat loss and CO_2 emission is limited. The impacts of hydrological rehabilitation efforts in Pilot projects to date are uncertain; much more monitoring will be needed to understand such impacts. Similar uncertainties apply to agricultural development options in some non-peatland tidal areas. In our view, improved monitoring and project design needs to be linked to a major long-term capacity building effort in the areas of water management and planning, if improvements are to be sustained in the long term.

2 Introduction

2.1 This report

This document presents the full results of the hydrological assessments and modelling work in the EMRP Master Plan project Cluster 3, as well a description of data and methods used. The document supports the actual EMRP Master Plan report, which presents only selected results in less detail. The current report focuses on technical issues; the interpretation and conclusions in terms of planning and management can be found in the Master Plan report.

Results on peatland subsidence studies and scenario analysis are presented in a separate report.

More detailed background analyses and data are presented in project 'mission reports' separate from this report. These are not for general distribution but can be made available on request. These reports are:

- Data collection and database
- Tidal dynamics
- Basics of river hydrology modelling
- Peat hydrology modelling

2.2 The role of hydrology and water management in EMRP Master Planning

Hydrology and water management are closely linked and interdependent. The functioning of the water system, referred to as 'hydrology', sets the boundary conditions for human interventions to the water system, while at the same time being influenced by it. This is especially true in the deltas and in peatlands, two landscapes that are fully formed by hydrology. Water management options in the EMRP area, being a delta covered largely by peatland, are therefore very much controlled and in some respects limited by its hydrology. The failure to recognize these limitations is a main cause of the failure of the EMRP project in the 1990s. Intended irrigation canals turned out to be drainage canals because dome-shaped peatland areas were apparently assumed to be flat. Rice crops failed because of flooding, droughts and water quality problems that could have been foreseen. The unsuitability of deep peat soils for rice cultivation was not recognized. Peatlands burnt after drainage because no infrastructure was in place to keep water levels up. In the longer term, peatlands are being flooded more frequently because of subsidence caused by drainage and fires.

Because of its crucial importance to EMRP functioning, hydrological research and assessments were given a key role in the EMRP Master Plan project approach. The goal has been to create a knowledge base that will support development and conservation planning, so earlier mistakes in the EMRP area are not repeated.

2.3 Cluster 3 schedule and data issues

The EMRP Master Plan project was carried out in less than a year, as the urgency of developing a Master Plan for the area is great. Some tasks would normally be planned as part of a 2 or 3 year project, as data availability is often an issue in this type of project and time is needed to assess available data and collect deficient data.

Data deficiencies have indeed proved to be the main bottleneck in the project:

- Almost all hydrological data available, for the EMRP area as a whole but especially for the peatlands, were very limited in terms of area and period covered. Efforts were made to fill data gaps where possible, but of course could not yield the data coverage ultimately required for thorough analysis, in terms of observation duration and distribution.
- Prior to the project, in June-October 2007, a separate mapping project was carried out as part of the CKPP project (with Wetlands International and Delft Hydraulics) to make sure key spatial data were available to the Master Pan project. This has proven successful, providing much-improved and essential peat depth, elevation and land cover maps to the Master Plan project which were suitable for large-scale ‘macro zoning’. However it was also found that much more work will be needed to produce spatial maps at a level of detail and accuracy that is required for detailed design.

The implication of the remaining data deficiencies is that most of the analysis and modelling results have an intermediate character. They have enormously enhanced the knowledge base on the hydrology of the EMRP Rivers and peatlands, and they are sufficient to support the Master Plan project in its Macro Zoning and Priority Action definition goals. But they need further work based on more and better data if they are to be used in support of detailed design studies.

3 Patterns and trends in rainfall rates in the EMRP area and contributing river basins

3.1 Summary

A large number of rainfall records has been screened; part of these could be corrected and combined to obtain 25-year rainfall records for use in analysis and modelling.

Analysis of rainfall patterns in and around the EMRP area has yielded some results which are likely to have management implications:

- Annual rainfall decreases significantly towards the coast, with rainfall rates in the southern part of the EMRP area around or below 1900 mm/y.
- Rainfall is highly seasonal, with a water deficit period of 3 to 5 months on average.
- Annual rainfall appears to have decreased over the last 100 years, due entirely to a decrease in February-May.
- The decrease in rainfall rates appears to be greatest closer to the coast.

While these findings are not new to experts, it appears that the rainfall regime has not been considered an important factor in planning of activities in the EMRP area to date. Consideration of rainfall patterns and trends is strongly recommended in further planning of agricultural development and of peatland carbon conservation efforts.

3.2 Introduction

Rainfall is the sole source of water and primary driver of water flow, and quantification and understanding of rainfall patterns is needed for quantification and understanding of hydrological systems. In the scope of the EMRP MP project, this is particularly important in the following ways:

- Rainfall in the contributing river basins determines discharges and water levels in the rivers in the EMRP, and therefore flooding regime and drainability (tidal influence is also important, and discussed in separate chapter). These are the main parameters in land suitability for agriculture and other uses.

- Local rainfall in the EMRP area determines groundwater depths in peatland areas; peat characteristics and water management are also important factors but rainfall sets the boundary conditions. It also causes, or contributes to, flooding and waterlogging in (potential) agricultural/silvicultural areas.

No thorough analysis of rainfall patterns in the EMRP area and contributing river basins has been carried out to date; it is therefore a first and important step in the hydrological analyses of the EMRP MP project. The emphasis on rainfall analysis has grown during the Master Plan project, as both the critical importance of patternts and trends and the lack of data and of understanding of them became clearer. While much has been investigated, further analyses are required.

3.3 Creating long-term area rainfall records for analysis and modelling

Through data digitization, screening, correction and exclusion we have produced long-term (25 years) rainfall records of sufficient quality for use in hydrological analyses and modelling of the EMRP area and upstream river basins.

A thorough data collection effort was undertaken, resulting in a comprehensive rainfall database for the project area including upstream river basins. Data were collected from PU (Palankaraya and Jakarta offices) and BMP (Palankaraya and Jakarta offices), both in digital format and on paper (digitized in the project). Many available records start in the early 1980s, others after 2000. Data gaps are common and increase after 1997.

3.3.1 Data screening

Daily rainfall records were inspected visually, looking for telltale signs of faulty data such as sudden changes in cumulative graphs (changes in rain gauge or local conditions), periods without rainfall in one station only (data gap not noted), unrealistically high values for brief periods (writing/typing errors), and unrealistically high or low records for entire records (systematic measurement errors). Also, most records of less than 5 years were discarded. After inspection, it was concluded that over 50% of available records could not be used, and in some of the remaining records partial series were deleted.

The remaining series were first averaged by station where there were more records for a single station (Figure 3.1), then by river basin or other relevant area (EMRP North and South). The resulting area series are still not perfect, as many errors remain in the component series, but they are good enough for use in analyses and modelling.

3.3.2 Correction for apparent systematic errors in daily data

The magnitude of systematic measurement errors is evident even in the spread of long-term averages for Palankaraya alone (which has the best-quality records in the area), which range from 2406 mm/y (PU) to 2874 mm/y (BMG), a difference of 16% (Figure 3.1). By using averages of larger numbers of records, these errors are mitigated as much as possible.

An indication of remaining systematic errors in data series after averaging over multiple stations is the finding that monthly average values in the EMRP area as derived from daily data are usually lower than monthly data as provided by BMG, where both types of data are available for the same or nearby stations. For the EMRP South area this difference is the most extreme, the annual average as based on daily data is 1714 mm/y, whereas it is 1943 mm/y on the basis of monthly data. Because the scope for errors in measuring and processing daily data is greater than in monthly data (certainly if monthly totalizing raingauges are used), and because more monthly records are available, we have corrected the EMRP South and North daily rainfall series to present the long-term average as presented by the monthly series.

3.3.3 Elevation correction

It is a basic rule in hydrology that precipitation increases with elevation, and in general in mountainous areas. This is true also in the river basins upstream of the EMRP area, which has significant areas over 1000m and peaks to over 2000m.

This elevation variation is not well represented in the rainfall records available for the river basins upstream of the EMRP area: as rainfall stations are often placed in population centres, they tend to be rare in mountainous areas and absent at higher elevations. The few rainfall records available for such areas tend to significantly underestimate actual rainfall over the wider area. A correction is therefore needed to obtain river basin rainfall records that do represent these higher areas.

Rainfall records as used in our hydrological models for the Barito, Kapuas and Kahayan river basins have been corrected with factors as presented in Table 1.

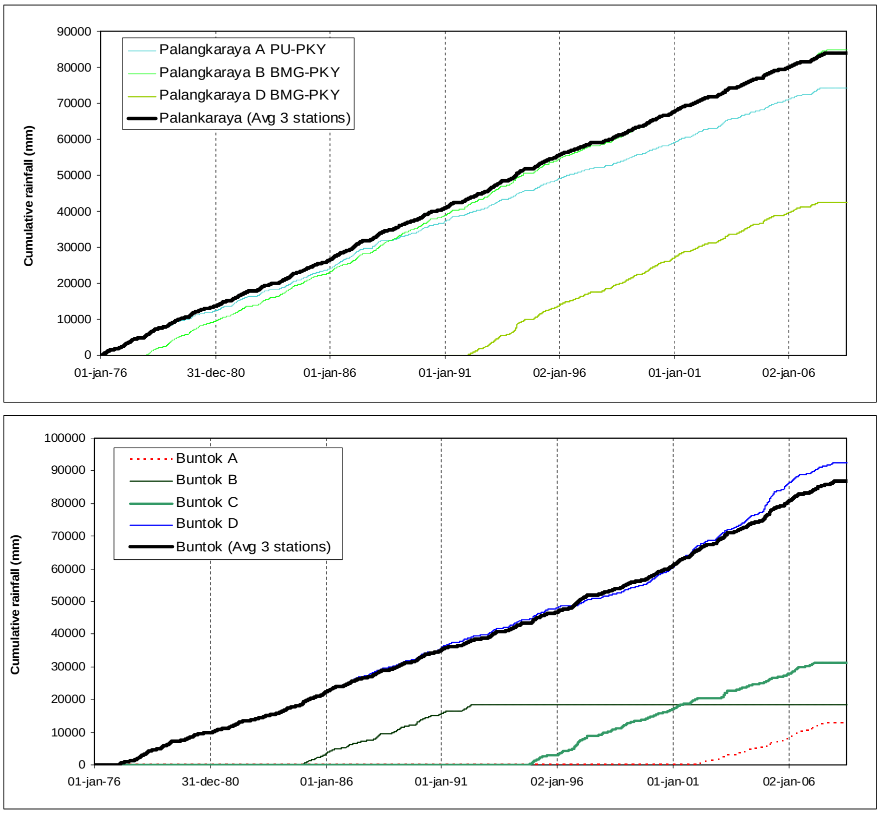


Figure 3.1 Cumulative rainfall records for Palankaraya and Buntok. Cumulative rainfall records are rapid quality checks on rainfall records and illustrate variation in record length and quality, in this case from different sources for one location. Note that there are remaining quality issues in most records, indicated by flat lines (no data) or differences and changes in slope (systematic measurement errors).

Table 1 Long-term average rainfall in regions within the EMRP MP project model area (as derived from daily data, which can be different from monthly records), and correction factors for elevation used to derive area records for river basins upstream of the EMRP area.

	Annual avg. rainfall	River basin characterzation	Elevation correction	Corrected avg. annual rainfall
EMRP MP model area regions	mm/y			mm/y
Southern part of EMRP area	1688	*v. flat, near coast*		
Northern part of EMRP area	2227	*very flat, further from coast*		
Kahayan river basin	3177	*S flat, N mountains*	1,03	3280
Kapuas river basin	3280	*S flat, N mountains*	1,00	3280
Barito river basin total	2834	*mostly mnts; S flat*	1,27	3600
Barito river basin S of M. Teweh	2813	*S flat, N mountains*	1,17	3280
Barito river basin N of M. Teweh	2960	*all mountains*	1,35	4000
The evidence for correction:				
Rainfall in the central mountain ranges of Borneo is known to be around or over 4000 mm/y				
Stations with high rainfall considered typical for Kalteng mountain regions; average 3800 m/y				
Kuala Kurun (Kahayan basin)	3944			
Pujon (Kapuas basin)	3680			

3.4 Regional spatial patterns in rainfall

Annual rainfall decreases significantly towards the coast even over the relatively short distance within the EMRP, from 2700 mm in Palankaraya to 2300 mm or more in the central part of the EMRP area (around Bereng Bengkel - Mantangai) to 1900 mm or less in the southern part (around Kuala Kapuas). Further inland, rainfall rates rapidly increase to around 3000 mm/y, and to around 4000 mm/y in upland areas. With an annual evapotranspiration loss (in forest) of 1350 mm/y, having 2700 or 1900 mm of rainfall a year makes a major difference in the amount of excess rainfall (P-ET; 1350 vs 550 mm/y) annually available to be stored towards the dry season and therefore in the length and severity of moisture deficits in the dry season. While this rainfall gradient has been known for decades, it should be noted that Palankaraya rainfall records (as well as erroneous Banjarmasin records, also apparently indicating rainfall rates in the order of 2700 mm/y) have been used in earlier analyses for the EMRP area and Sebangau NP, which will have resulted in an overestimation of rainfall and therefore of agricultural and rehabilitation prospects. Although a thorough investigation on this has yet to start, we observe that few peatlands exist elsewhere in Indonesia in areas with rainfall below 2200 mm/y rainfall, which suggests that peatlands in drier areas including the southern part of the EMRP area may have developed in wetter conditions and may not be stable at present.

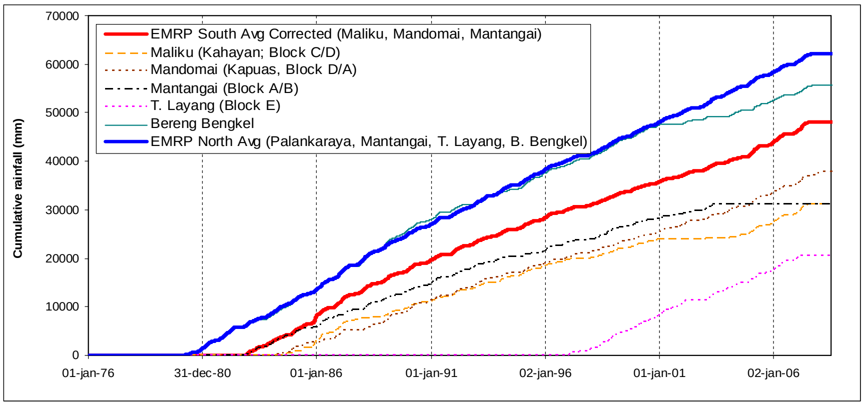


Figure 3.2 Cumulative rainfall graphs for the EMRP area and component station records. Different slopes indicate different rainfall rates.

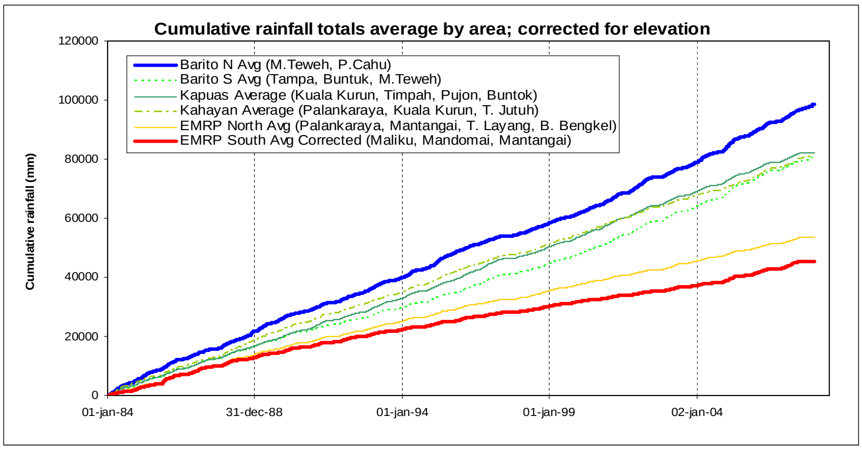


Figure 3.3 Cumulative graphs of EMRP area and contributing river basins.
Note that rainfall rates in the Northern half of the Barito river basin are more than half those of the southern part of the EMRP area.

3.5 Varying differences between locations

While it is common to compare locations on the basis of long-term annual rainfall, there is a danger of oversimplification in this when it comes to risk assessment, in terms of hydrological extremes leading to fires and floods. A similar consideration applies to comparing wet and dry years: a year with an above-average annual rainfall may in fact have a severe dry season. In the EMRP area, there is not only significant variation in rainfall rates in space, but these differences are far from constant. There may be drought in one are but not another. This is demonstrated in Figure 3.5 by the following observations:

- The year 1997 was extremely dry both in the Northern and the Southern part of the EMRP area, with negligible rainfall over a 5-month period (June-October), but rainfall rates before and after this period were significantly higher in the north, which follows the regional trend.
- The year 2006, which is also considered a very dry year in most of Indonesia, had indeed below-average rainfall in the EMRP area for much of the dry season (July-October), and a prolonged dry season with a dry November, but average rainfall, but was very wet in other months in the south while the north had normal rainfall in those months. In fact, the southern part of the EMRP area had above-normal rainfall in this ‘dry’ year, while rainfall in the northern part was well below normal.
- The dry season of the year 2007, which was mostly very wet, was a lot dryer in the south of the EMRP area than in the north.

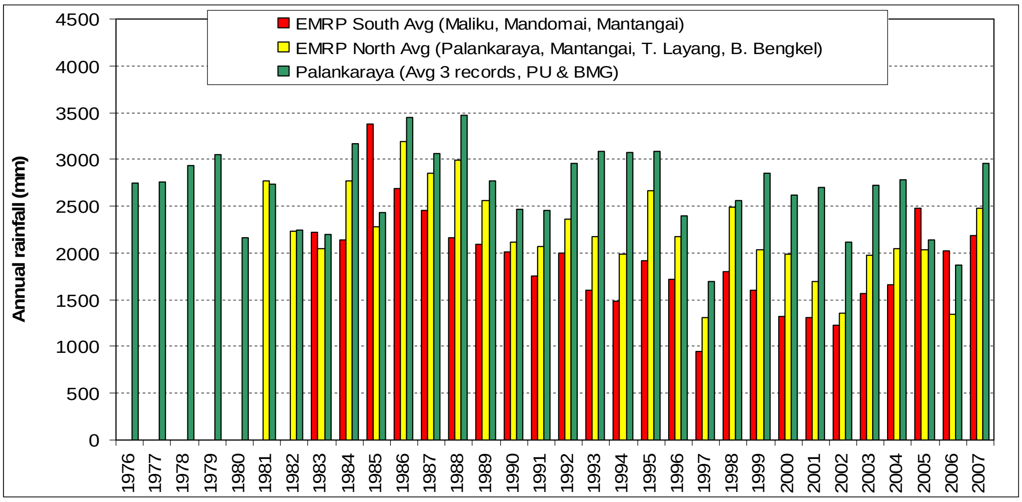
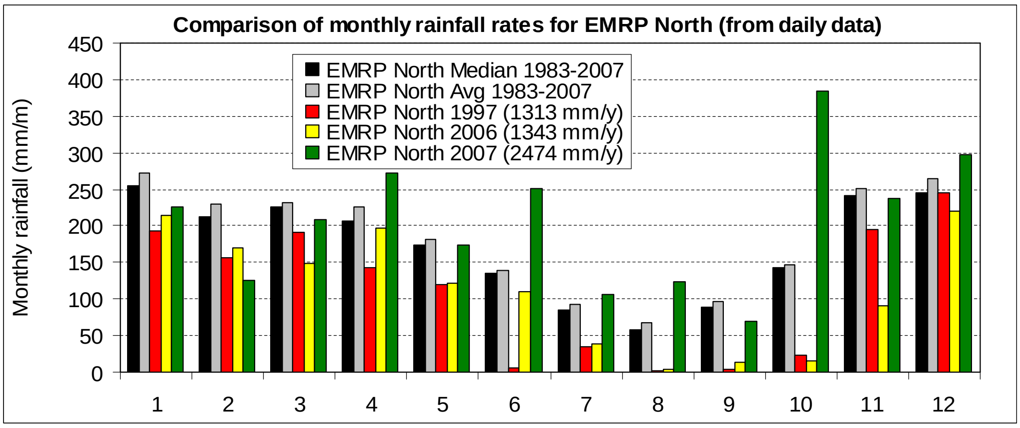


Figure 3.4 Records of annual rainfall in the EMRP area.



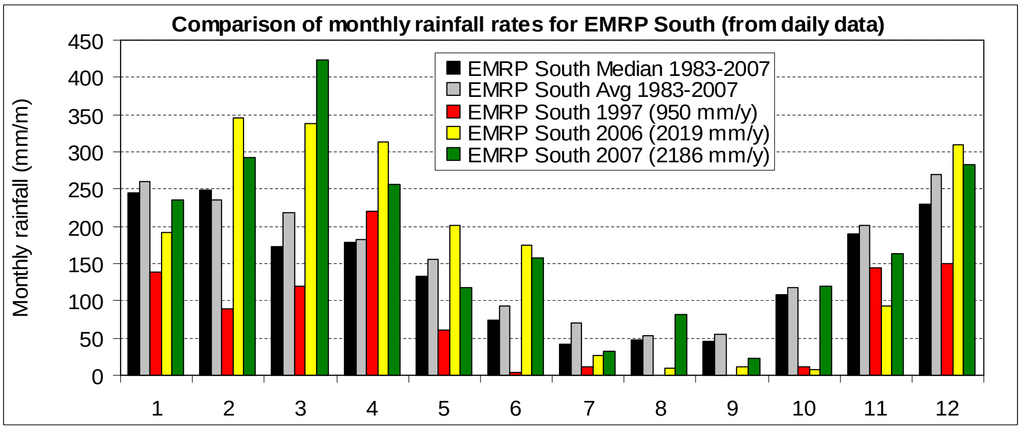


Figure 3.5 Comparison of monthly rainfall rates in EMRP North and South areas, average and median as well as selected years with dry (1997, 2006) and wet (2007) dry seasons.

3.6 Rainfall seasonality and water deficits

Rainfall is highly seasonal throughout the EMRP area. In the southern part of the EMRP area this results in moisture deficits (i.e. evapotranspiration exceeding rainfall) for 5 months (June-October) in most years (50-percentile) and severe deficits for up to 6 months in dry years (10-percentile). In the middle part of the area these deficit periods are 1 or 2 months shorter. Such long and severe deficits cast doubts not only on the viability of drought-sensitive crops (including rice and oil palm), but also of peatland rehabilitation prospects. Certainly, due attention must be given to rainfall availability in plan for the area that aims to achieve long-term sustainability. This seasonality was known of course, but apparently has not been given much attention in earlier studies. Maybe it seemed less of an issue when higher rainfall rates were assumed to be representative for the whole area. The finding is consistent with a publication on climate model results (Li et al, 2007) which concluded that the south of Kalimantan was found to be a 'climate change hotspot' according to 9 out of 11 climate models, with dry seasons becoming dryer and hotter. If historical records are accurate, that change is already underway and one must ask how much drier it will become. To answer this question (as far as possible) we first need to find out A) how statistically significant the pattern is and B) if we are dealing with a local/regional phenomenon (that may possibly be attributed to deforestation) or with a regional/global phenomenon that has nothing to do with local land cover developments.

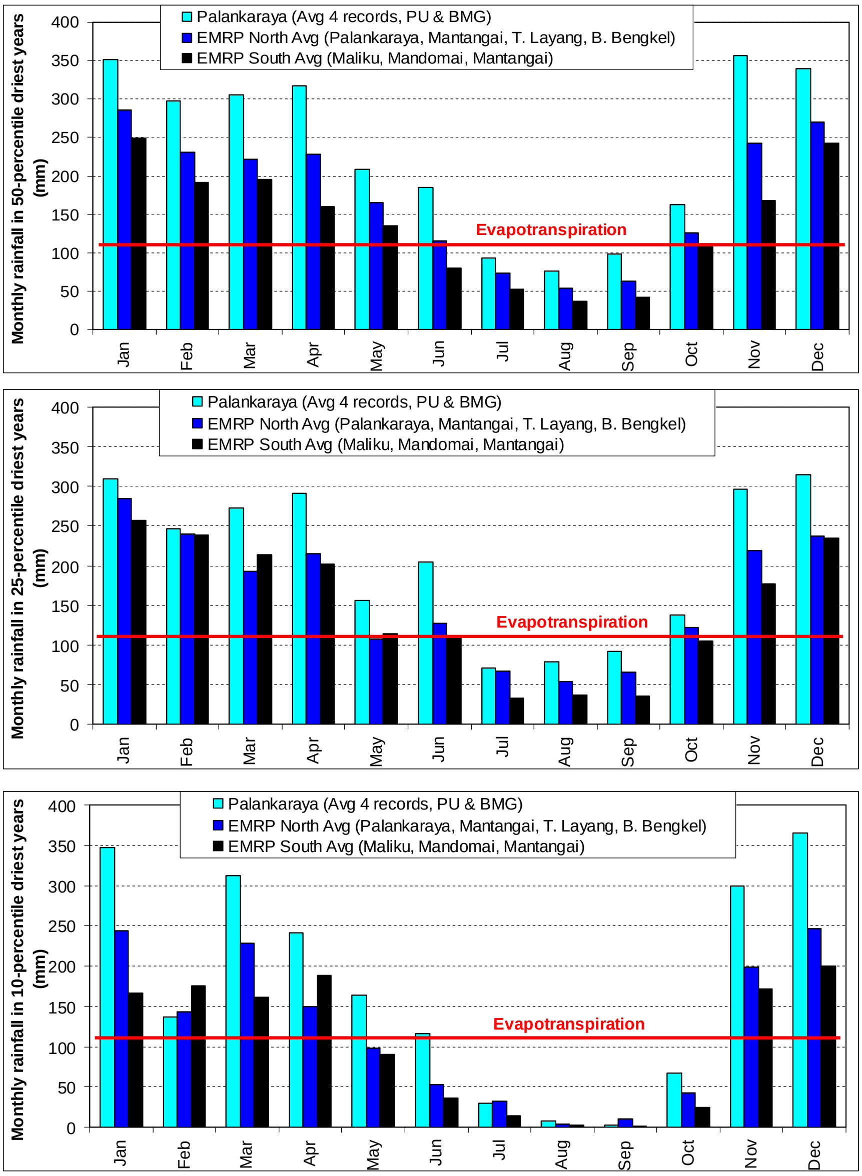


Figure 3.6 Percentile monthly rainfall over driest years on 24-year record (1984-2006).

NB the percentiles were approached by first ranking annual rainfall rates, then calculating monthly averages for percentile groups. Ranking by seasonal rainfall rates might give somewhat different results. Years in percentile groups are:

In lower 10-percentile range (low-to-high rainfall): 1997, 2002

In lower 25-percentile range: 1997, 2002, 2006, 2000, 2001, 1996

In lower 50-percentile range: 1997, 2002, 2006, 2000, 2001, 1996, 1991, 1999, 1983, 1994, 1990, 2004

3.7 Long-term time trends in rainfall

With the current global indications of climate change, and the high vulnerability of peatlands to drought and of the EMRP area as a whole to flooding, the possibility of a change in rainfall regime in the EMRP area should be considered.

3.7.1 Trends and patterns over the last 25 years

Annual rainfall totals over the last 25 years for the EMRP area, as presented in Figure 3.4, suggest a cyclic pattern with an overall decrease. In the EMRP South area, rainfall rates are above 2000 mm/y over during 1983-1989, then below 2000 mm/y until 2004, then above 2000 mm/y again over 2005-2007. The four years with rainfall below 1500 mm/y are all in the second half of the record. Similar patterns, though somewhat less pronounced, are observed in the records for EMRP North and Palankaraya.

Annual rainfall, however, is not the best indicator of dry conditions that affect peatlands in the EMRP area. Actual droughts are best identified using a moving average. In Figure 3.2, 3-month, 6-months and 9-month moving averages (backward-looking) are presented for Palankaraya, EMRP North and EMRP South, and compared with the estimated average evapotranspiration (of peatswamp forest). It is possible to tentatively link ‘drought classes’ to these moving average: when the 3-month moving average falls below evapotranspiration a significant moisture deficit may be assumed, in the case of the 6-month moving average a severe moisture deficit in the case of the 6-month moving average an extreme moisture deficit.

The 3-month moving average is below the evapotranspiration line in most years throughout all records, indicating that significant moisture deficits are common throughout the EMRP area. The 6-month moving average is below the evapotranspiration line rarely in the Palankaraya record, regularly in the EMRP North record (every year in the last 11 years), and almost every year in the EMRP South record. The 6-month moving average is below the evapotranspiration line only once in the Palankaraya record (1997), 3 times in the EMRP North record (1997, 2002 and 2006), and most years in the second half of the EMRP South record (but not 2005-2007, strangely).

It is noted that annual rainfall, as well as month-to month variation, in the years 2004/2005/2006 in the EMRP South area is much higher than in previous years and looks strange, especially as this pattern is not observed in the EMRP North area. However nothing in the data we now have seems to indicate that this is an artefact rather than a natural pattern. This needs to be checked further.

The moving average analysis confirms that there appears to be a trend towards decreased rainfall in the EMRP area over the last 25 years, especially in the dry season and especially in the southern part of the area. However there is a need for further research for quantification of this change.

3.7.2 Trends over the last 100 years

Variations in rainfall over a 25 year period may be caused by climate change, or they could be part of a cyclical pattern. Only analysis of longer records can help tell the difference. There appear to be no reliable and complete rainfall records for the EMRP area for the period between 1941 and 1982, so full analysis of a long-term record is not possible. However, there are data available from before 1941 that cover several decades (the earliest starting 1880) we have used in a rapid assessment of whether significant differences between the two datasets can be found. The data source used here is a publication available from BMG (Berlage 1949/1970, 'Baten Meteorologi Geofisika', Jakarta).

It is found that significant differences exists between rainfall patterns as determined from the 1983-2007 data and the pre-1941 data. While both datasets contain many stations, only few in and around the EMRP area are present in both datasets. Palankaraya, for instance, had no rainfall station before 1941. For at least 3 stations that occurred in both datasets (Kuala Kapuas, Buntok, Ampah; only the first one actually within the EMRP area), two differences are apparent:

- Annual rainfall rates over 1983-2007 were significantly lower than over the pre-1941 period. This difference varied from 200 mm in Kuala Kapuas to 80 mm in Ampah. As these stations are closest to the coast and further away from it, respectively, it may support the earlier observation that that greatest change in rainfall regime may occur closest to the coast.
- All or almost all of this reduction in rainfall appears to occur in the months February, March and April, the months leading into he dry season (in Ampah the reduction also occurs in May, while rainfall in February appears to increase). Monthly reductions very between 50 and 100 mm/month.
- Rainfall changes in all other months are below 30 mm/m and appear randomly distributed through the year and among stations.

The fact that these changes occur only in specific months, and rainfall over the rest of the year appears relatively unchanged, indicates that we are not dealing with an artefact here. If a change in monitoring practice or another systematic change would be the cause, it would occur throughout the year.

There is more data avaiable than could be used in this rapid assessment (is it became available late, is incomplete, is mostly not diggital and needs to be quality controlled); first indications area that similar differences are found for other stations. Research on this will continue.

It should be noted that a significant change in rainfall regime was found within the 1983-2008 record (see above). As average data over 1983-2007 were used in the analysis, the actual change from pre-1941 to 2007 may therefore be even greater than described above. Refining the assessment for recent years will also require further investigation.

If the apparent change in annual rainfall and seasonal rainfall rates does indeed indicate a fundamental change in the climate of the EMRP area, the question is what caused it and if the climate is likely to change further. There are two possible explanations for a local change in climate: it could be the result of global climate change, or of a local phenomenon linked to land use change. Or it could be a combination of both, of course. Neither option has been studied for Indonesia so far, as we know, and we suggest such research is needed because the implications are significant:

- If EMRP rainfall is diminishing because of global climate change, further and possibly even greater changes may be expected and need to be considered in planning.
- If EMRP rainfall has been reduced because of land cover change, meaning deforestation in this case, it may have stabilized locally; however this would indicate that further deforestation in and around the area, such as is still possible in Sebangau and Block E, would further deteriorate the local climate. While literature reports that impacts of deforestation on rainfall are generally negligible, studies to date have not looked at changes as drastic as found in the EMRP area.

The most fundamental question, of course, is how this apparent change in the rainfall regime, reducing rainfall prior to the dry season and hence water availability during the dry season, has affected and will affect the area in terms of agricultural land use options, water management options, fire risk, peatland forest functioning and peat decomposition rates. The decrease in rainfall rates appears to be greatest closer to the coast, where they already appeared critically low for peatlands and agriculture.
It seems that the consequences may be major and should be well researched and understood before finalizing planning and design for the parts of the EMRP area most vulnerable to drought.

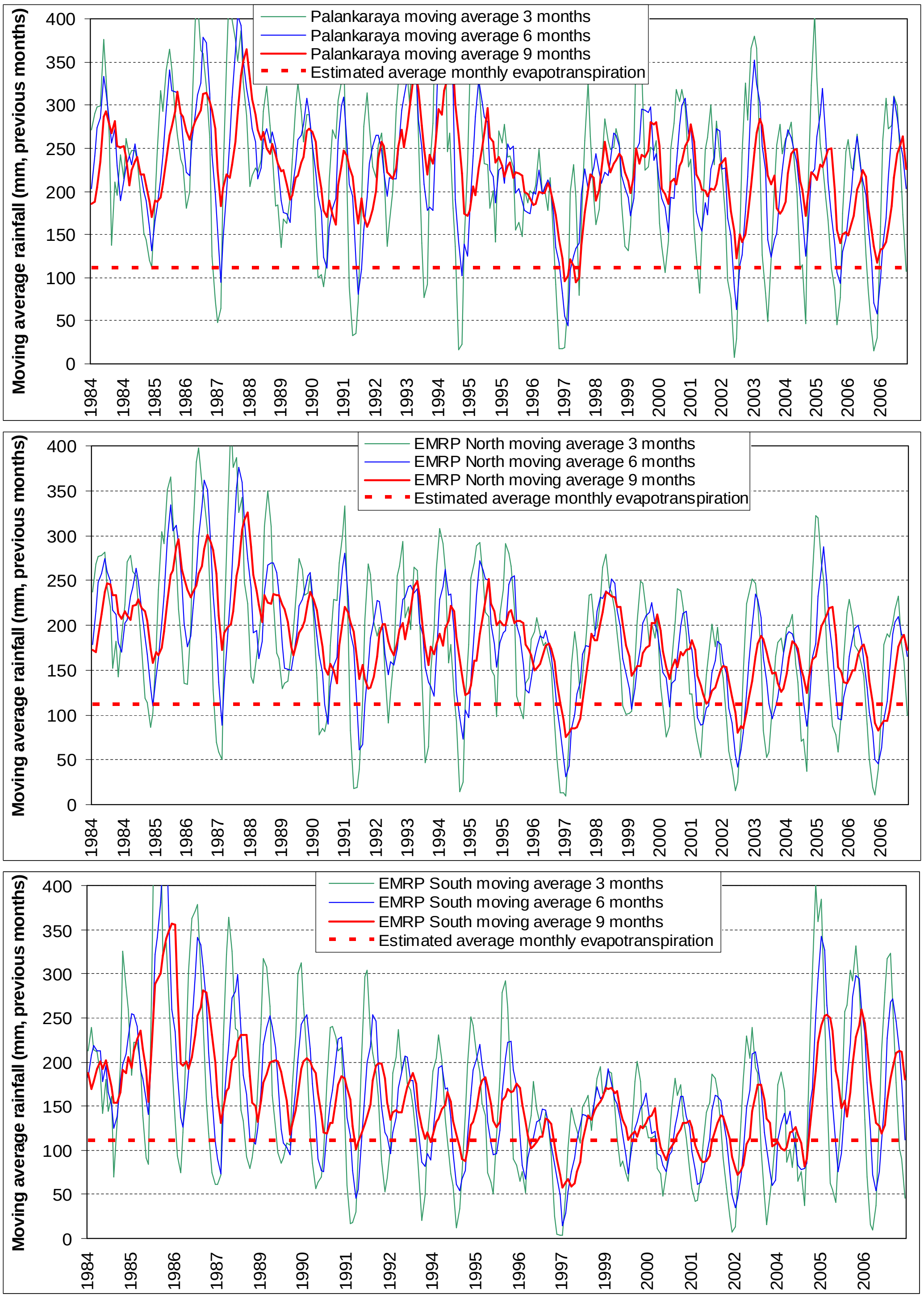


Figure 3.7 Moving average rainfall for the EMRP area, relative to evapotranspiration.

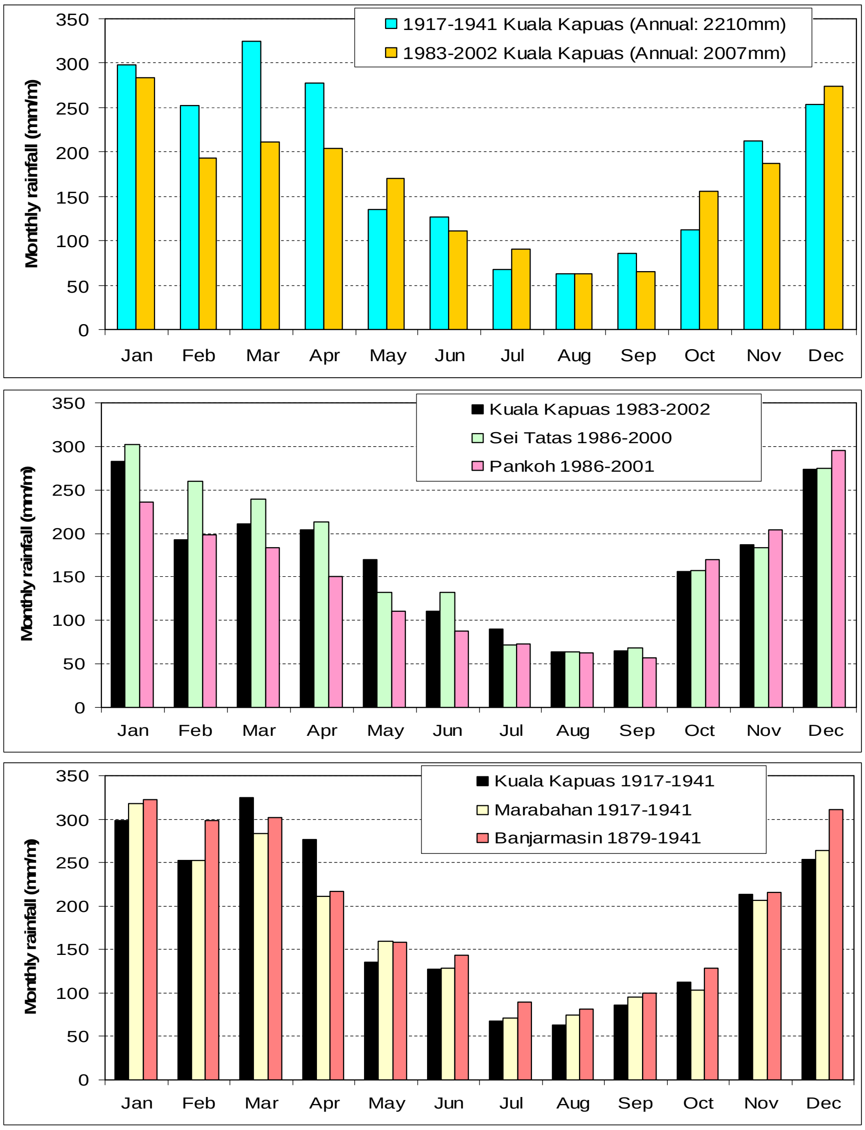


Figure 3.8 Example of apparent long-term change in rainfall regime in Kuala Kapuas, within the EMRP area.

Top: average monthly rainfall rates 1917-1941 and 1983-2002.

Middle and Bottom: monthly rainfall rates at Kuala Kapuas compared to neighbouring stations, for both periods.

Note that variation between three neighbouring stations in both periods is not insignificant, but limited compared with the variation between months.

Note that only monthly rainfall records were used here; for 1983-2007 it was found that these tend to yield higher rates than daily records, which would further increase the difference between the pre-1941 and 1983-2007 rates.

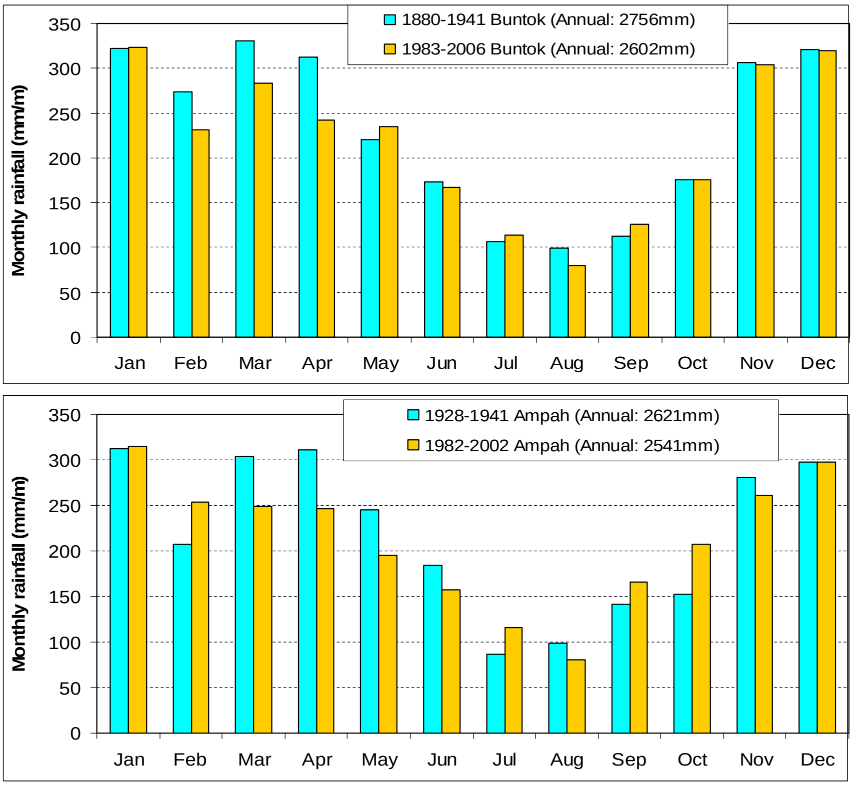


Figure 3.9 Monthly rainfall rates pre-1941 and post 1982 in Buntok and Ampah.

3.8 Implications of rainfall regime for planning and management of the EMRP area

Most of the findings on rainfall regime are not new to experts who worked in the area for a long time, but it appears that the rainfall regime has not been considered a limiting factor in planning of activities to date. However the implications of this finding for current and future land use options and limitations in the area, as well as for prospects of long-term carbon storage in peatlands, could be significant. A re-think of the viability of plans for both agricultural development and for peatland carbon conservation may be needed. The peatland conservation argument could potentially go two ways:

- On the one hand it appears that peatlands in part of the area are facing critical water deficits even under the best land and water management, and that major interventions are required to achieve best management. It should be noted that no peatland in the area is now under ‘best management’, even a protected area like Sebangau NP appears to have many canals for logging, which may have a significant draining effect on the forested peatland (as was recently quantified in the Kampar Peninsula peatland in Riau).

- On the other hand, tough decisions may have to be made on which degraded peatland areas can still be rehabilitated, and what long-term carbon storage can be expected there. The best example is the southern part of Block C, which has very low rainfall, high fire frequency, only little forest left, and drainage schemes for oil palm plantations now actively being constructed on top of the peat dome. It may be that Block B, Block A and especially Block E that have higher rainfall rates, deeper peat (hence more carbon stored per hectare), more forest left and larger areas relatively undrained, have better potential for long term forest and peat conservation on the basis of rainfall availability.

The discussion on viability of peatland conservation in dry areas is necessary to ensure efficient allocation of funds for peatland rehabilitation, but it is also potentially dangerous as it could be seen to support claims that the fires are caused by climate change rather than drainage for development and deliberate lighting of fires for clearing ('climate change' is the easy excuse for many land and water management failures nowadays). It could even discourage investments in peatland carbon conservation, which are now being attracted.

3.9 Further work

3.9.1 Research

To reduce uncertainties in rainfall patterns and trends, more thorough analysis based on further available data must be completed. Although rainfall analysis was not a major item in the EMRP proposal or work plan, it is now seen as a priority for further studies. This will need to include not only records for the Central Kalimantan peatlands but for all coastal peatland areas in Indonesia and possibly Malaysia, to be able to distinguish local/regional trends from regional/global trends, and to see if rainfall characteristics can be linked to peatland characteristics. Trends and patterns in temperature, which may be associated, will also be investigated if records of sufficient quality and length can be identified (usually more difficult than for rainfall records).

3.9.2 TRMM as a data source

Tropical rainstorms tend to be intense but localized, causing significant variation in rainfall rates over short distances. Therefore no rainfall recrd from one or a few rainfall stations can be expected to provide accurate information for large areas. A source of information on spatial variation of precipitation is provided by remote sensing. The Tropical Rainfall Measuring Mission (TRMM; Simpson et al. 1988) satellite provides precipitation estimates based on Passive Microwave sensors on a 28 by 28km grid. Over the past few years the quality of these estimates have improved enormously, and full records are available from 2002 onwards. We have done a rapid assessment of the accuracy and potential use of TRMM data for the EMRP area and its upstream catchments.

In Figure 3.11 TRMM precipitation maps are shown for a sequence of 7 days in November 2004. The localized nature of precipitation in the area is demonstrated, and it is clear that groundstations can not capture the spatial variation even if they were functioning properly.

Figure 3.10 presents the correlation of the monthly total TRMM estimated precipitation and ground measurements for Palangkaraya, by far the most reliable and complete time series in and around the EMRP area. The correlation is evident, but it is also clear that there are large differences. Generally the TRMM provides higher precipitation rates than the ground measurements (nearly 20%) and the correlation appears to be better for the dry season months than for the wet season. It should be noted however that the Palankaraya 'ground station' rainfall record consists of an average of three records, measured within a few kilometres from eachother but nevertheless displaying a ling-term difference of up to 16% (Figure 3.1). The difference between TRMM data and local data is therefore not much larger than the difference between several records within a few kilometres, even though the TRMM data are measured over a large area of 28*28 km.

Figure 3.12 presents the total dry season (July – October) precipitation as observed by TRMM. The years of 2002 and 2006 clearly come out as being very dry, and a clear trend is evident of increasing precipitation with distance from the coast.

While at the start of this project we were not sure whether we could use TRMM data, it is now concluded that TRMM rainfall records for a specific location are probably not much worse than ground station records even in the case of a relatively 'good' record as in Palankaraya (averaged over 3 stations), and probably much better then most ground stations in the EMRP area. Moreover, even if ground stations in the area would provide accurate information, they could not do so for the entire area. It has become clear during the project that ground station records are just too poor and too few for most purposes; for instance this has been a major problem in getting modelled discharge records calibrated properly.

For further work in the EMRP area it is therefore recommended to use ground measurements to use TRMM data for most assessments, the exception being analysis for small areas where local rainfall records are known to be accurate (which will take multiple parallel on-site records for validation). This will not only benefit hydrological assessments for the EMRP area, but also the understanding of discharge coming from the large upstream catchments of the main rivers (see Chapter 5), since the number of rainfall stations there is even more limited while rainfall variation is even greater.

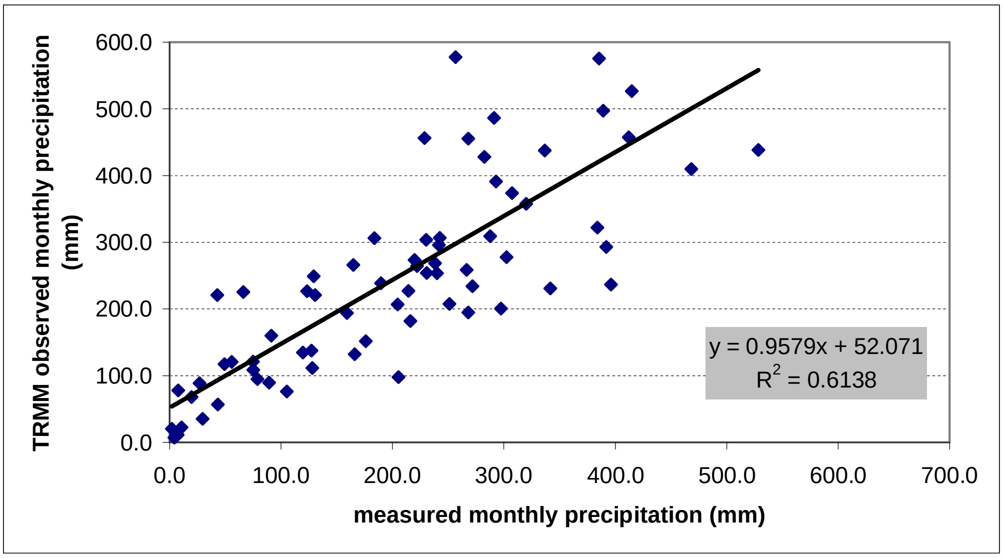


Figure 3.10 Correlation between measured (ground station) and TRMM (satellite) observed monthly precipitation for Palangka Raya for the period February 2002 – December 2007.

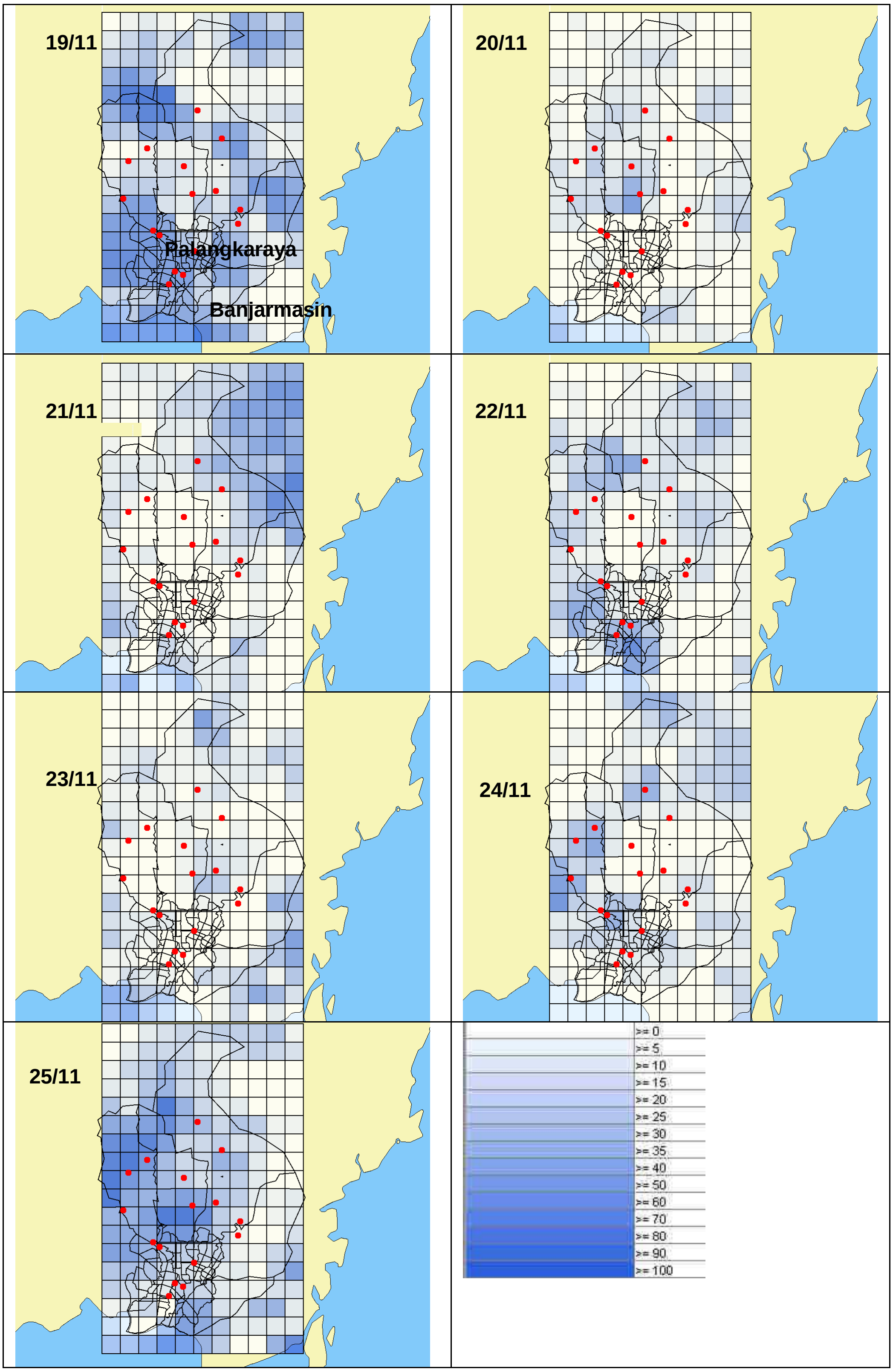


Figure 3.11 Spatial distribution of daily precipitation over the EMRP area and upstream catchments as observed by TRMM for 19 – 25 November 2004. Each cell is 28*28km. Scale is in mm/d. Red dots represent rainfall stations (many of which are not operational at present).

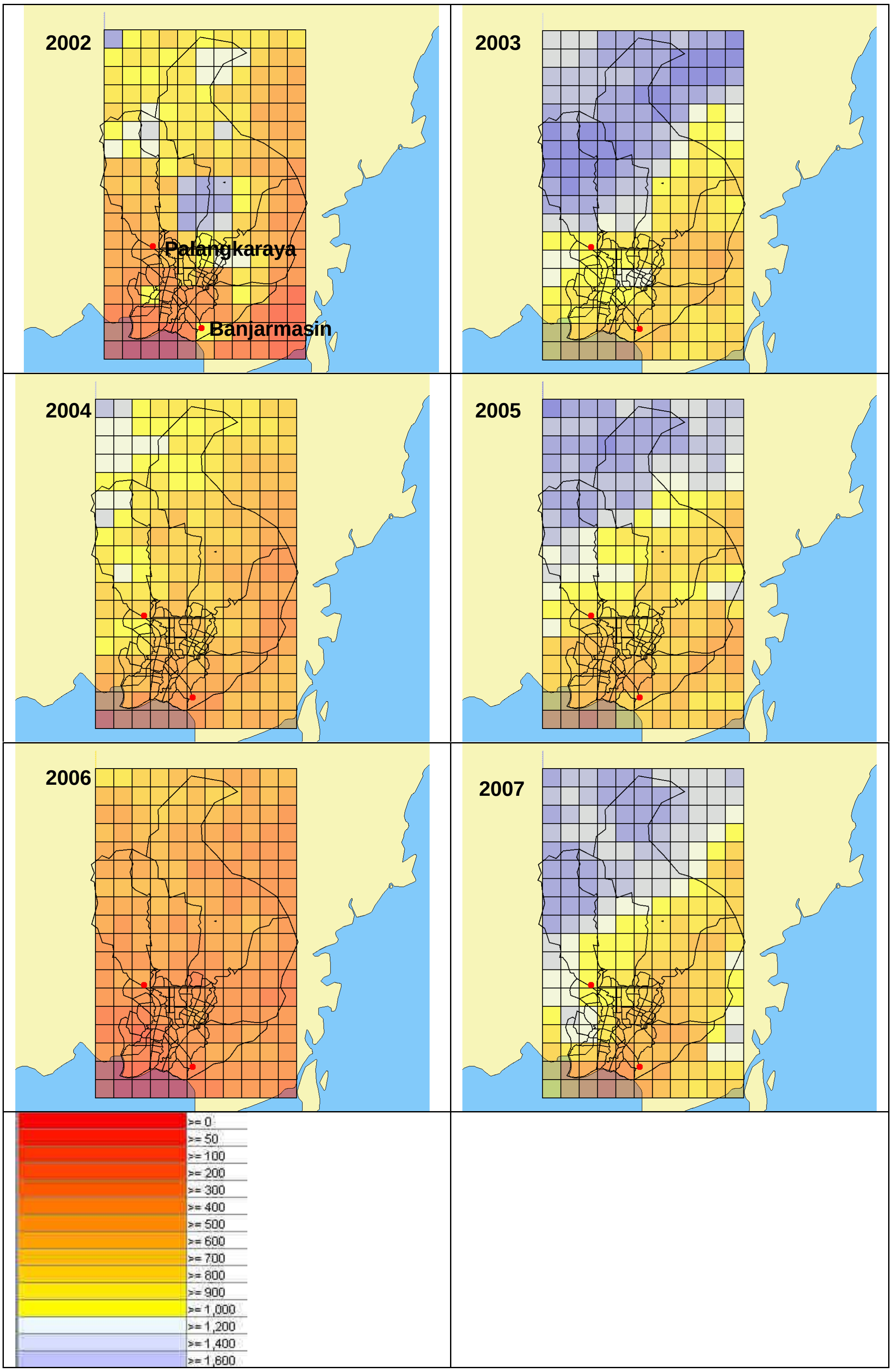


Figure 3.12 Dry season (July – October) total precipitation as observed by TRMM for 2002 until 2007. Scale in mm/6m. Red dots represent palankaraya and Banjarmasin rainfall stations.

4 EMRP area tidal dynamics

This chapter is based on a separate note on the tidal analysis of the Java Sea and Southern Kalimantan (Zijl, 2008). More detailed information can be found in this note. The aim of the tidal analysis was to identify the boundary conditions governing the flow of water and the intrusion of salinity at the downstream boundary of the project area. These boundary conditions have been used in the regional hydrological assessment presented in Chapter 5.

4.1 Data availability

At six locations in the Kalimantan rivers water level measurement data are digitally available. The location of these six stations are presented in Figure 4.1. The water level data consists of hourly data covering parts of the years 1980 and 1981. These data will be used for a harmonic (tidal) analysis. For the analysis of patterns on longer time scales than possible to extract from the above mentioned sources, two other data sets from stations in the Java Sea have been used. For both those stations measured, hourly data over a period of 21 years (with some gaps) was available. These stations are Tanjung Priok (Jakarta) and Surabaya. In Figure 4.2, an overview of the locations of the two stations is given. These data, with station numbers h161 and h160 for Tanjung Priok and Surabaya, respectively, are taken from the University of Hawai'i Sea Level Center (UHSLC) website (http://ilikai.soest.hawaii.edu/uhslc/). The reference level is unknown.

4.2 Harmonic analysis

The tidal analysis is carried out with the T_Tide toolbox: a Matlab based toolbox for the analysis and prediction of tides that is widely used and published. A description of the theoretical basis of the toolbox and some implementation details can be found in [Pawlowicz, 2002].

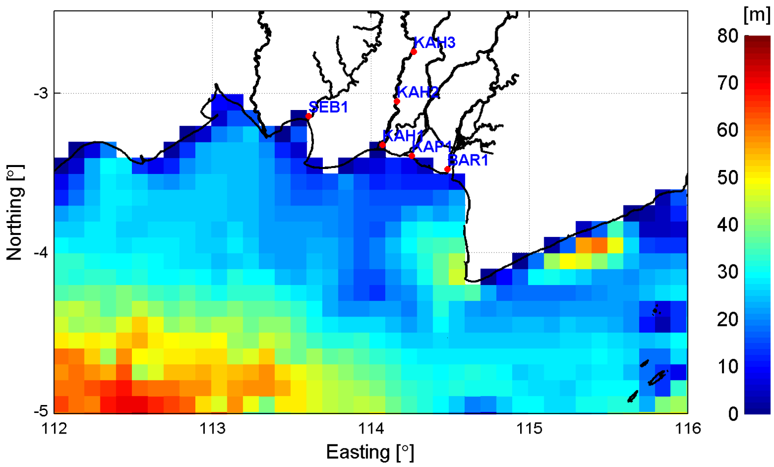


Figure 4.1 Location of water level measurement stations in the Kalimantan rivers with digitized data available.

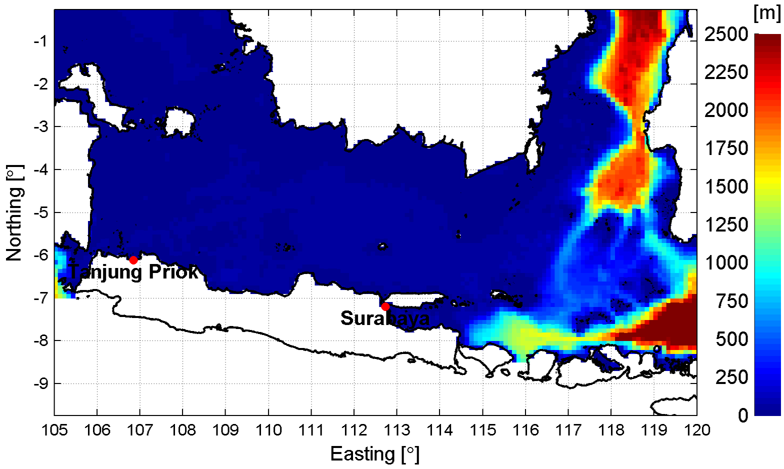


Figure 4.2 Location of (long term) water level measurement stations Tanjung Priok (Jakarta) and Surabaya.

The digitally available water level data in or close to the Kalimantan rivers subject to the present study have been analysed. With the data gathered from a tidal or harmonic analysis it is possible to predict the tidal variation of the water level at any given period in time. The number of tidal constituents that has been used in the harmonic analysis is different for each station and is determined by the maximum length of the time series available in which no major gaps are present. For all stations except KAH1 and SEB1 a coupling relation between K1 and P1 is used, as the length of the time series was insufficient to distinguish between these tidal constituents. The coupling relation was derived from the analysis of station KAH1, as this station with sufficient length to derive the coupling relation was closed to the other stations where a coupling relation was needed.

In Table 4.1 an overview is given of the station for which and harmonic analysis is done. In this table, the length of the time series is also mentioned, together with the number of constituents that was used and the RMS of the residual. The residual is derived by subtracting from the measured values the predicted value based on the analysed constituents as well as the MSLA (Mean Sea Level Anomaly). The residual contains short duration (< 25 hours), and presumably local, events (e.g. a local land-sea breeze), possible inaccuracies in the harmonic analysis and measurement errors. On average, the residual is small compared to the tidal signal. The MSLA is derived (defined) by applying a 25 hour moving average low pass filter on the measured signal.

Table 4.1 Overview station for which a harmonic analysis is done. The number of constituents mentioned includes the coupled constituents.

Station name	Short station name	Length of time series (days)	Number constituents	RMS of residual (m)
Kahayan 1	KAH1	273	30	0.11
Kahayan 2	KAH2	61	16	0.09
Kahayan 3	KAH3	77	16	0.13
Kapuas 1	KAP1	179	13	0.1
Barito 1	BAR1	125	14	0.1
Sebangau 1	SEB1	356	35	0.1

Plots have been made of the results for all months where data was available for the Kalimantan river stations. The plot for station KAH1 is presented in Figure 4.3. These clearly show that in all months presented, the residual is small compared to the tidal signal.

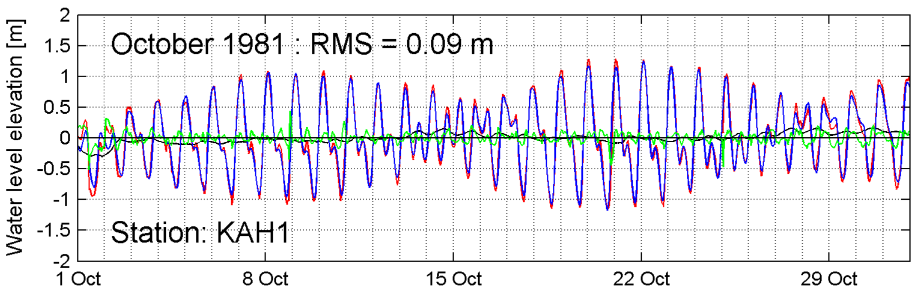


Figure 4.3 Water level elevation at station Kahayan 1 in October 1981. The red line represents the measured water level, the blue line represents the tidal water level component including the MSLA, the black line represents the MSLA only and the green line represents the residual.

4.3 Analysis of spring tides

In Figure 4.3 a spring-neap cycle in the tide can be discerned. During spring tide, the tidal range is significantly larger than during neap tide. A spring-neap cycle is caused by the interaction of two (or more) tidal constituents with different phase speeds. When consecutive spring tides are compared it becomes clear that maximum spring tide levels vary. The maximum spring tide levels have therefore been analysed. The analysis is based on predicted water levels covering a 100-year period (1920 to 2020). For the prediction of the tidal water level, the tidal constituents for Kahayan 1 (KAH1) have been used. From this 100-year predicted water level, the maximum spring tide levels have been taken. These levels are plotted in Figure 4.4.

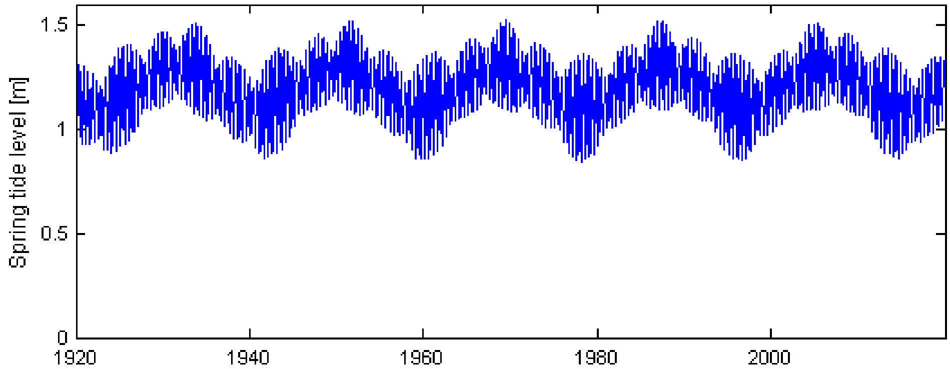


Figure 4.4 Maximum spring tide levels at the mouth of the Kahayan River from 1920 to 2020 based on water level predictions with tidal constituents derived from water level measurements.

The maximum spring tide levels in clearly show a periodicity with a period of between 18 and 19 years. This periodicity is caused by the fact that the moon's orbit around the earth is elliptical. Therefore, the moon is never at the same distance from the earth from one month to the next. The strength of the tides is dependent on the distance between the moon and the earth. Indeed, it takes 18.6 years for this cycle to repeat. From it becomes apparent that between 2005 and 2010 this 18.6 years cycle reaches a peak.

In Figure 4.5, the same maximum spring tide levels as in Figure 4.4 have been plotted, now for a smaller period of 10 years (2000 to 2010). From this figure it becomes apparent that apart from an 18.6 year periodicity, there is also a semi-annual periodicity in the maximum spring tide levels. This can also be explained by theory. In diurnal tides, which are dominant in the Java Sea, the length of a spring neap-cycle is not the usual 14.77 days. The combination of the diurnal tidal constituents K1 and O1 would give a cycle of 13.66 days. The combinations of K1 with other constituents would give different cycles. Therefore, in reality, the length of the spring-neap cycles is mixed. However, the predominant spring-neap cycles in diurnal and semi-diurnal tidal regimes have periods of 13.66 and 14.77 days respectively. In mixed tidal regimes, such as the Java Sea, these diurnal and semidiurnal spring-neap cycles interfere, and theoretically exhibit a virtually semi-annual periodicity (168 days) [Hoitink, 2003].

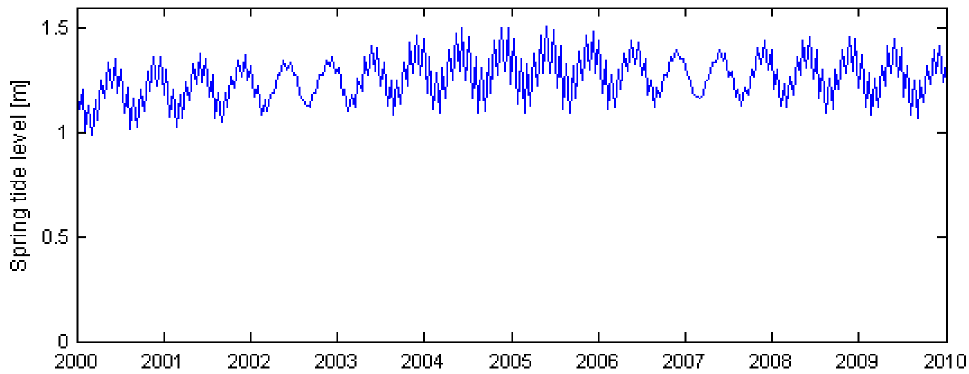


Figure 4.5 Maximum spring tide levels at the mouth of the Kahayan River from 2000 to 2010 based on water level predictions with tidal constituents derived from water level measurements.

In Figure 4.6, a histogram with the frequency of maximum spring-tide levels is given, based on a prediction of 5000 consecutive spring-neap cycles at station KAH1. This histogram shows that maximum spring tide levels vary between 0.8 m and 1.55 m, with maximum spring tide levels of around 1.2 m having the highest frequency of occurrence. The average maximum spring tide level is 1.2 m and is indicated with a red line in Figure 4.6.

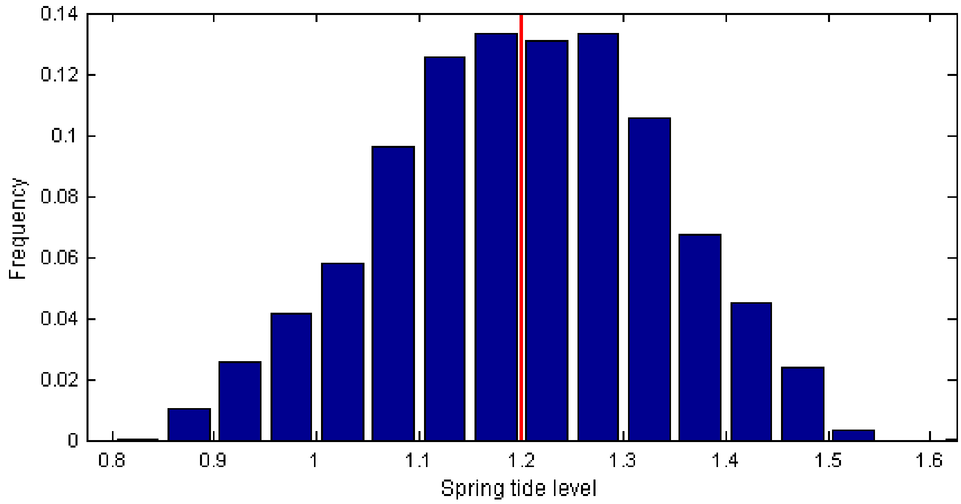


Figure 4.6 Frequency of maximum spring-tide levels at the mouth of the Kahayan River based on a prediction of 5000 consecutive spring-neap cycles.

4.4 Analysis of MSLA

Besides the tide, variations on a longer (e.g. seasonal) time scale also play a role in the water level variation in the Java Sea south of Kalimantan. The water level measurements available for the Kalimantan rivers however, are too short to be able to analyse these longer scale variations for recurring patterns. To analyse these time series covering multiple years are necessary. A large part of these long scale variations in water level variations are expected to be connected to seasonal variations in large scale meteorological (monsoonal) patterns. Therefore it might be expected that these variations are apparent at any location in the Java Sea. To check this hypothesis, the MSLA in both the measurement stations of Tanjung Priok (Jakarta Bay) and Surabaya, both in different parts of the Java Sea, has been analysed. For both stations, water level measurements covering a period of 21 years (with some gaps) were available. Monthly averaged MSLA's have been determined. The averages (over 21 years) of these are plotted in Figure 4.7, together with the standard deviation.

The results shown in Figure 4.7 compare well with results from [Wyrtki, 1961], as also in these results the annual MSLA variation at Tanjung Priok is about 15 - 20 cm, with high values around May and June and low values around December to March. Furthermore, what is important is that the seasonal pattern in MSLA is reasonably similar for both stations in the Java Sea. As the variation in Tanjung Priok is expected to be more representative of the situation off southern Kalimantan (Surabaya is somewhat shielded from the rest of the Java Sea by the island of Madura), this average variation is used for further predictions of the water level signal south of Kalimantan.

The results of the tidal analysis presented above have been used as boundary conditions for the regional hydrological assessment presented in the next chapter.

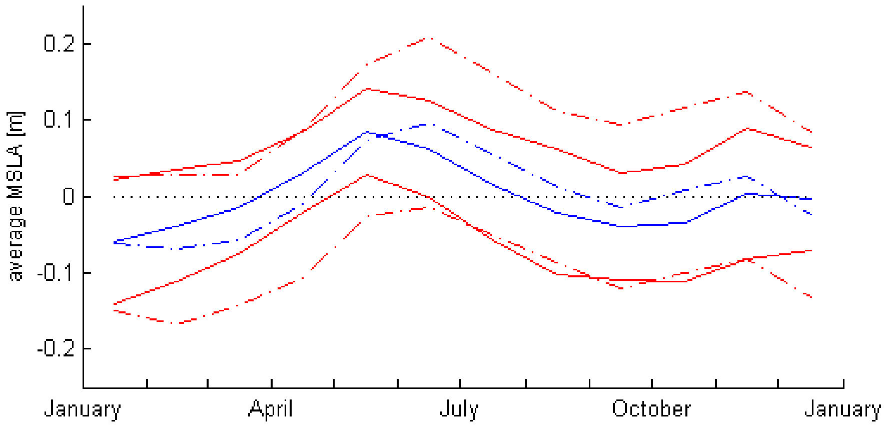


Figure 4.7 Annual variation of monthly averaged MSLA based on 21 year measurements at Tanjung Priok (Jakarta; blue dashed line) and Surabaya (blue solid line). The red lines represent the average MSLA plus and minus the standard deviation at each month.

5 Regional hydrological assessment and model for river water levels and flooding extent

This chapter describes the results of the hydrological assessment of river and canal systems and an analysis of flooding in the EMRP area. The assessment is based on data available from different sources and an application of SOBEK, a mathematical model for the description of hydrology and hydraulics.

5.1 Available data

5.1.1 DEM

Information on elevations forms an essential part of the input for the hydrological and hydraulic models. This information has been taken from the Digital Elevation Model as prepared during the project. It is used as input for unpaved nodes, cross sections of the canals and crest level of the dams.

5.1.2 Meteorology

Six time series for precipitation have been constructed based on the available data producing a continuous data series from November 1983 till February 2008 with a daily frequency.

It is important to note that these time series are based on a limited number of rainfall stations. This is especially important for the huge upstream catchments of the Kahayan, Kapuas and Barito. It is impossible to describe the variation in precipitation over these areas with the limited data available.

Evapotranspiration has been estimated as a function of expected groundwater depth for the whole period based on actually measured evapotranspiration for the years 2002 – 2005 (see Chapter 5). Different daily time series have been constructed for the northern and southern part of the EMRP area. Because of the lack of data for the upstream catchments, the time series for the northern part of the EMRP area has been applied for these catchments as well.

5.1.3 River cross sections

Data on river cross sections are available from the following sources:

- Reports of DPMA of the 80s (DPMA, 1980a, 1980b, 1981, 1985a and 1985b) containing cross sections for all the rivers;
- Information obtain from PU in Palangkaraya regarding the cross section of the Kahayan River in Palangkaraya for different years; and
- A survey carried out in the framework of the EMRP MP project resulting in 19 cross sections for different rivers.

Figure 11.5 presents on a map the location of the cross section information used in the model. Downstream cross section measurements are mostly referenced to MSL while the reference level of most upstream cross sections is unclear. Furthermore, the DPMA reports use a MSL determined from a relatively short time period, which can deviate from the real MSL by 20 to 30 centimetres.

Cross sections from different sources where measurements have been made at approximately the same location have been compared. Generally cross sections at the same location are comparable, providing confidence in the reliability of both data sets. The older data seem to suggest somewhat deeper and less wide cross sections, especially in the Kahayan at kilometres 45 and 50. This might be explained by an increase in sedimentation in the river caused by increased upstream erosion due to deforestation. Further exploration of this hypothesis is recommended, but falls outside the scope of this project.

For most large rivers the cross section information is abundant. Only for the Kapuas River upstream of the junction with the Kapuas Murung the number of cross sections is limited. Furthermore, there is limited information for the smaller rivers Mentangai and Mengkatip.

5.1.4 Canal cross sections

The actual width, depth and elevation of the canals have been measured at more than 800 locations during the surveys of the CKPP PSDM project (Silvius et al., 2007) and the current EMRP MP project. The location of these measurements is presented in Figure 5.1.

The design depth for the Parent Primary Canal and the Main primary Canals was 6 metres. The currently measured depths vary between a few decimetres and 5 metres, with an average of approximately 2 metres. Assuming the canals have been constructed according to design, the difference can be explained by a combination of subsidence and collapse of canal banks, clogging with logs and sedimentation in the canal.

For measured canals, representative cross sections have been selected from the available data. For other canals data from similar canals with measurements have been used.

5.1.5 Tidal boundary

The results of the tidal analysis presented in Chapter 6 and Zijl (2008) have been used to describe the water level fluctuations at the tidal boundary of rivers and canals with an hourly frequency.

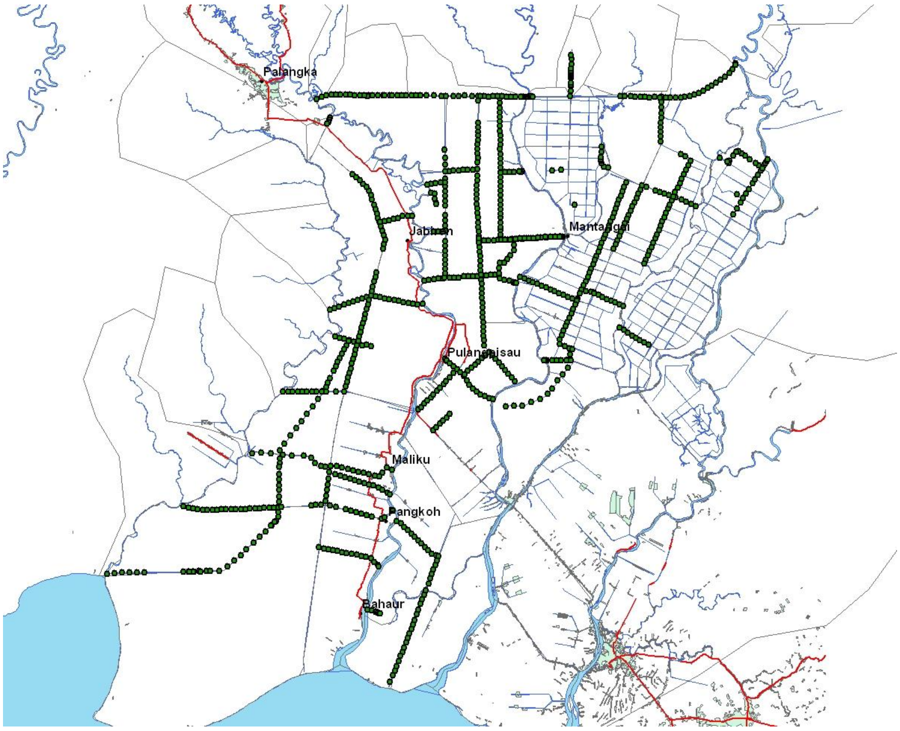


Figure 5.1 Location of canal width and depth measurements of the CKPP PSDM project.

5.1.6 Structures

Structures in the area have been constructed during several periods to regulate the flow of water. No formal overview of structures their dimensions, status and operation is currently available. Since no information on operation of structures exists, it is assumed that no operation of structures occurs. Most large structures dating from the construction of the PLG scheme have been demolished. Several of these structures have been visited. All of these were lacking gates and other metal works, while some had been completely demolished. The influence of these structures is limited and therefore they have been disregarded in the construction of the model.

In the north western part of Block A and the connected southern part of Block E the CCFPI, CKPP and BOS MAWAS projects have constructed dams to increase the water level and limit the drainage of the peat lands. Some of these dams have collapsed, but most of them are still operational. These have been included in the model as weirs with a fixed crest level and crest width, which have been deducted from the available design information and the DEM. The location of these dams is presented in Figure 5.2.

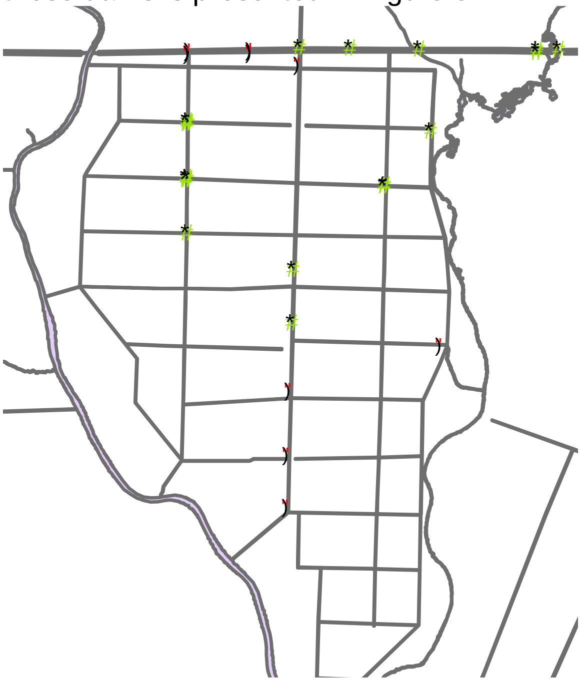


Figure 5.2 Location of the dams (green triangles) and obstructions with small navigation canals (red squares) in the north western part of Block A as included in the model.

Most secondary canals in the north western part of Block A have not been connected to the primary SPI canal. Furthermore, dams for moving around excavators have not been removed and canals have locally filled with sediment and logs. Shallow canals have been dug through these obstructions for navigation with small boats. These small canals have been incorporated in the model as weirs with a crest width of 2.0 metres and a crest level of 1.0 metres below surface level. The location of these obstructions with small canals has been indicated on Figure 5.2.

5.1.7 Calibration data

Most important data for calibration are the water level measurements. Data are available for the period 1981 / 1982 along the main rivers and since September 2007 for a number of locations along the rivers and in the canals. Frequency of the older measurements is hourly, while recent measurements with divers have an hourly frequency and staff gauges are read three times a day.

For the water level monitoring location at Palangkaraya PU has carried out a number of discharge measurements. These have been used to obtain a rating curve and to calculate daily discharges from the water level measurements. During low flow, the water level is determined too much by the tide to establish a reliable rating curve.

A primary source of data on flooding has been the work carried out by SarVision (2008) based on PALSAR radar data. Eight images are available for the period December 2006 – December 2007. For each image the extent of flooding has been determined. Figure 5.3 presents for each spot on the map the number of images on which this spot has been classified as flooded. Dark blue areas in the map were most frequently flooded. This map does not distinguish between flooding from rivers and the sea, wet rice cultivation and local ponding of water as a result of limited drainage.

Village surveys by the provincial government in 1993 and 2005 have resulted in an overview of villages where flooding was mentioned as a problem, which is presented in the form of a map in Figure 5.4.

Furthermore, discussions with officials of PU from Palangkaraya and Banjarmasin have resulted in identification of the following hotspots for flooding:

- Mangrove covered areas near the coast in the south of Block C and D;
- Tidal irrigation and shallow flooding in the south of Block D;
- Sawahs in the north of Block D;
- Southern part of the Dadahup area, depth less than 1 metre;
- Middle branches of the Mengkatip with a depth up to 3 metres;
- Jenamas and northern Barito with a depth up to 2 metres;
- Southern part of the north western part of Block A close to Mentangai village up to 1 metre; and
- Shallow water logging in the rest of the north western part of Block A.

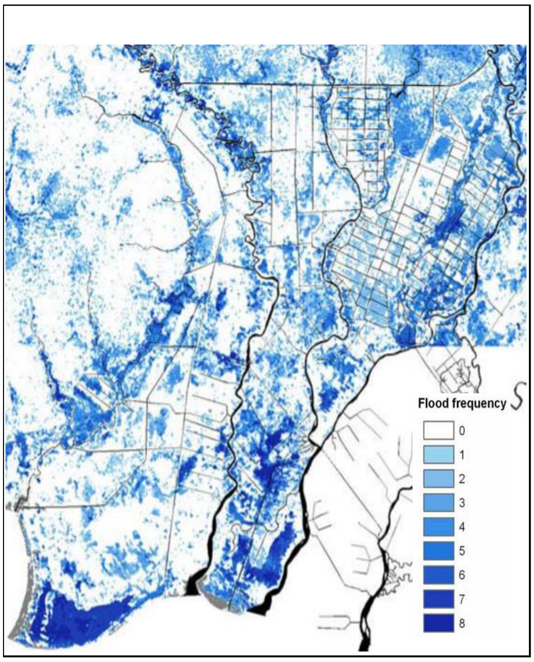


Figure 5.3 Flood frequency map for 2007 based on remote sensing (SarVision, 2008). Frequency classes represent the number of times an area has been inundated over a 1-year observation period (December 2006 – December 2007).

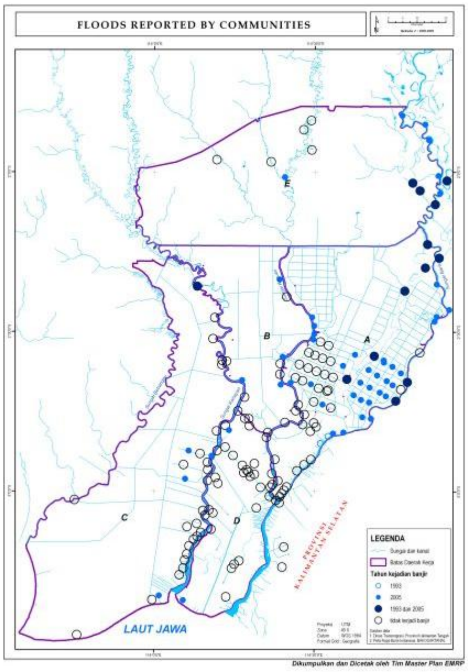


Figure 5.4 Map of villages which reported damage from flooding.

The information from these three different sources provide the same general picture. The remote sensing data indicate as additional flood prone areas the proximity of the Sebangau River and the upper part of the Kahayan River, south of Palangkaraya.

In studies during the 80s some measurements have been made of intrusion of saline water from the sea up the rivers. The boundary of intrusion of saline water is here taken as the place where the sea water is diluted to a vertically averaged salinity of 1 0/00. For Sebangau River the intrusion varies between a few kilometres in the wet season up to 45 kilometres in the dry season (DPMA, 1980a and 1981, Nedeco – Euroconsult, 1981). For the Kahayan River an intrusion of 20 kilometres is measured at one moment during the wet season (DPMA, 1980b). While one measurement for the Barito in the wet season shows an intrusion of 15 kilometres (DPMA, 1985a).

Anecdotal evidence collected during this study regarding the presence of fish species and salinity problems experienced by farmers suggest a salt intrusion along the Kahayan and Kapuas Rivers of approximately 70 kilometres.

5.2 Calibration and results of EMRP hydrological models

5.2.1 Model setup

The SOBEK modelling suite consists of a number of modules for different aspects of hydrology, hydraulics, water quality and morphology. To simulate the hydrology and hydraulics of the EMRP area in light of the objectives mentioned in chapter 1 the following modules were selected for application:

- RR (Rainfall – Runoff): to describe the transformation of rainfall into discharges into the rivers and canals;
- 1D Flow: to describe the flow and water level in the river and canal system;
- Overland flow: to describe flooding;
- Water quality: to calculate the origin of water at different locations in the area.

The area modelled includes the whole of the EMRP area located between the Sebangau River in the west, the sea in the south, the SPU canal in the north and the Kapuas, Kapuas Murung and Barito Rivers in the east. The downstream part of the Barito River has been included as well to be able to describe the division of the flow at the bifurcation of the Barito and the Kapuas Murung. Furthermore, the complete upstream catchment the rivers Kahayan, Barito and Kapuas had to be included since no reliable measurements of their discharge at the northern boundary of the EMRP area are available.

Figure 5.5 presents the schematisation for the whole of the EMRP area and zoomed in on the north western part of Block A.

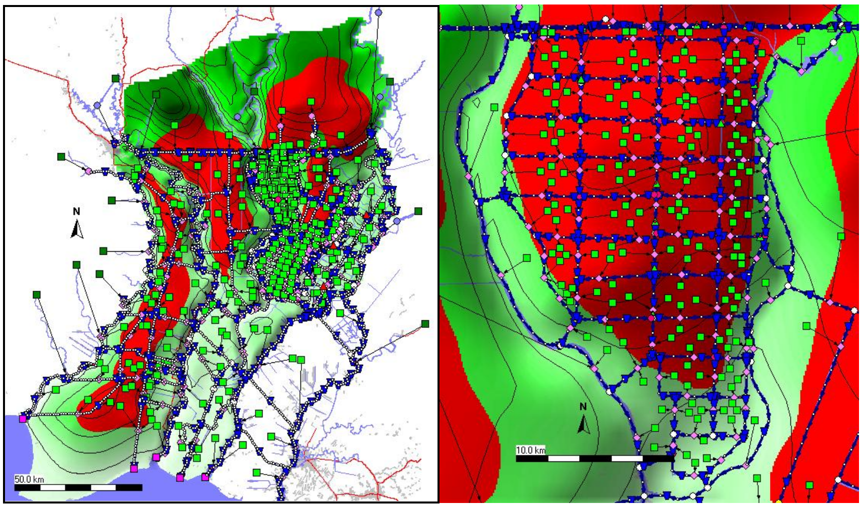


Figure 5.5 Schematisation for the SOBEK modules 1D Flow and RR for the whole EMRP area (left) and for the north western part of Block A.

All simulations have been carried out with a calculation and output time step of one hour.

5.2.2 Calibration of discharge upstream catchments

The first step in getting to a calibrated model is the calibration of upstream inflows. Use is made of the Sacramento model of the upstream Palangkaraya catchment in Kahayan River, since at Palangkaraya a long rainfall and water level record is available. Using the rating curve, the water level record is converted to a daily discharge (runoff) data series. For a complete description of the Sacramento model as implemented in Sobek-RR and its input parameters, the reader is referred to the Sobek help file, which is available from http://www.sobek.nl.

Model parameters for Palangkaraya were obtained by running the model and adjusting some coefficients describing especially the delay in runoff slightly to obtain a better fit. No formal calibration including optimisation of parameter settings was executed, since the reliability of both input precipitation data and output discharge data does not justify this.

Based on the derived Sacramento parameters for Palangkaraya, all the other upstream catchments are modelled using the same parameter values (but different rainfall time series). For the large Kahayan, Kapuas and Barito catchments an additional delay (Muskingum) was used to predict the inflow at the EMRP boundary.

The calibration of Sacramento model for Kahayan catchment upstream of Palangkaraya was carried out for the period 1983-2007. The whole catchment was modelled using one catchment with homogeneous characteristics. The rainfall time series was derived as the average of the reliable stations in the catchment for that period; the average was taken of one to four stations, depending on data availability.

The result of the calibration for some selected time periods is shown in Figure 5.6 and Figure 5.7.

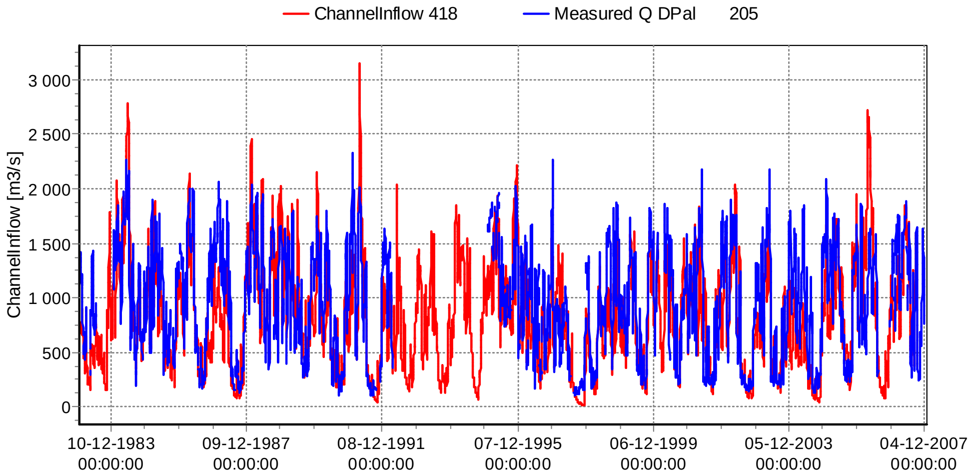


Figure 5.6 Comparison of Kahayan Sacramento results with observed flows at Palangkaraya, 1983-2007.

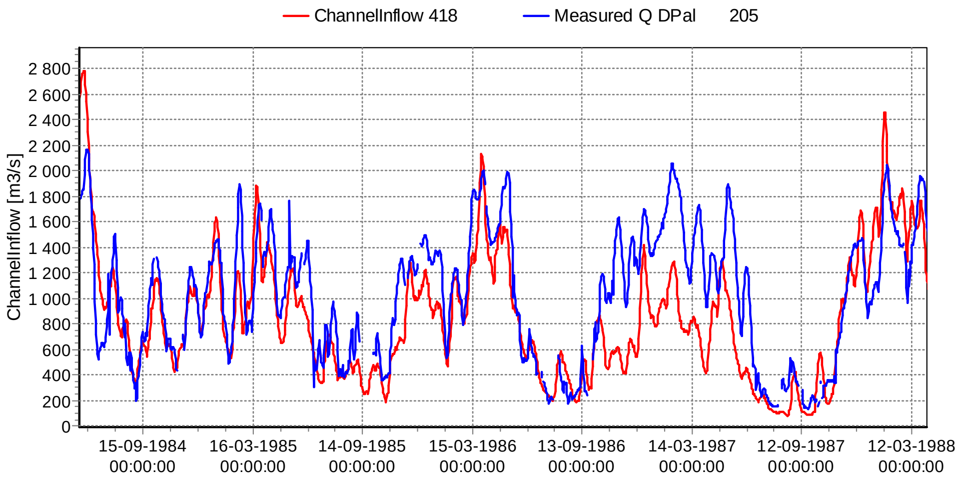


Figure 5.7 Kahayan Sacramento results with observed flows at Palangkaraya, 1984-1988.

From the figures above it is concluded that the calibration is quite satisfactory. The dynamics in runoff pattern are reproduced quite well. The whole catchment of approximately 12,000 square kilometres is simulated using only one real average rainfall station. Inevitably, storm events are sometimes missed (underestimated) or overestimated. Also the pattern in the dry seasons of 1997, 2002 and 2006 is good. The observed flow, calculated using the rating curve from observed water levels, is not very good for very low flows because of tidal influence reaching up to Palangkaraya station. Overall, the calibration does not allow accurate description of individual events, but the range and pattern of discharges is described reliable enough to be used as boundary conditions for the further hydrological analysis.

5.2.3 Calibration of water levels

The SOBEK model has first been run for the calibration period of March 1, 2007, till February 28, 2008. The bed roughness of the rivers and canals was determined from calibration on water levels. The values for the Chezy coefficient vary between 50 and 60 $m^{-0.5}/s$. No further effort was done to optimise the calibration, because of the large uncertainties in the upstream discharges and the canal bed levels.

The figures in this paragraph present a comparison of measured and simulated water levels for four locations. The following conclusions can be drawn:

- Water levels and discharges are dominated by the boundary conditions posed by downstream tide and upstream discharges. The discharge generated from runoff within the EMRP area itself has limited impact on water levels and discharges in the main rivers, due its relatively small area of little over 10,000 square kilometers, compared to a total catchment area of approximately 87,000 square kilometers.
- Description by the model of water levels in the rivers and canals dominated by tide is excellent, with a slight deviation in timing and maximum and minimum levels;
- Description by the model of upstream river water levels is in the right order of magnitude, with the correct mix of overriding influence from upstream discharge and tidal fluctuation. However, there is an important difference in magnitude of individual discharge events between measurements and model. The upstream discharges for a total catchment area of approximately 53,000 square kilometers have been derived from four precipitation time series based on incomplete records of ten stations (Chapter 3). This results in overestimation and underestimation of specific rainfall events, because the ten stations cannot represent the spatial variation in precipitation;
- Description by the model of water levels in canals further away from the coast and rivers is more problematic due to the lack of detailed information on elevations of canals and canal cross sections.
- The input data for the model depend to a large degree on the DEM. As described in Chapter 2 the accuracy of the DEM is estimated to be in the range of 0.5 – 1.0 metres. The accuracy of the model results will never be better than the input data. Therefore, the accuracy of the model results is generally expected to be in the same range. Significant additional

inaccuracy can be expected for the results of the canals where no data on cross sections are available.

- The model results do not describe accurately the water levels of individual events. However, the range and pattern of water levels is described accurately for the rivers. In the canals the accuracy is limited by the uncertainty in canal bed levels. Overall, this provides enough basis for the further hydrological analysis in the framework of the EMRP Masterplan. However, the hydrological and topographical database should be improved to support further implementation of the Masterplan.

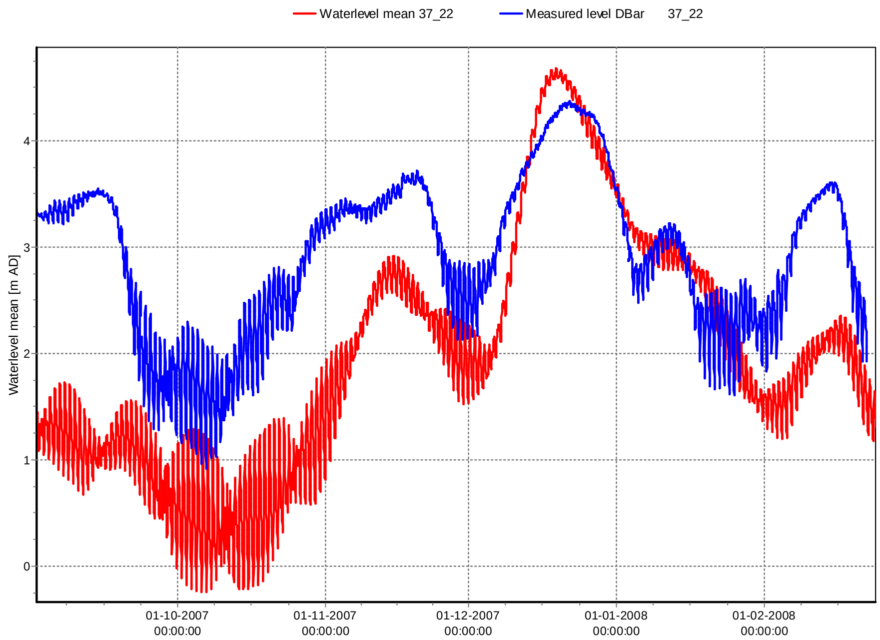


Figure 5.8 Comparison of water level measured (blue) and modelled (red) at the Barito River 172 km from the mouth.

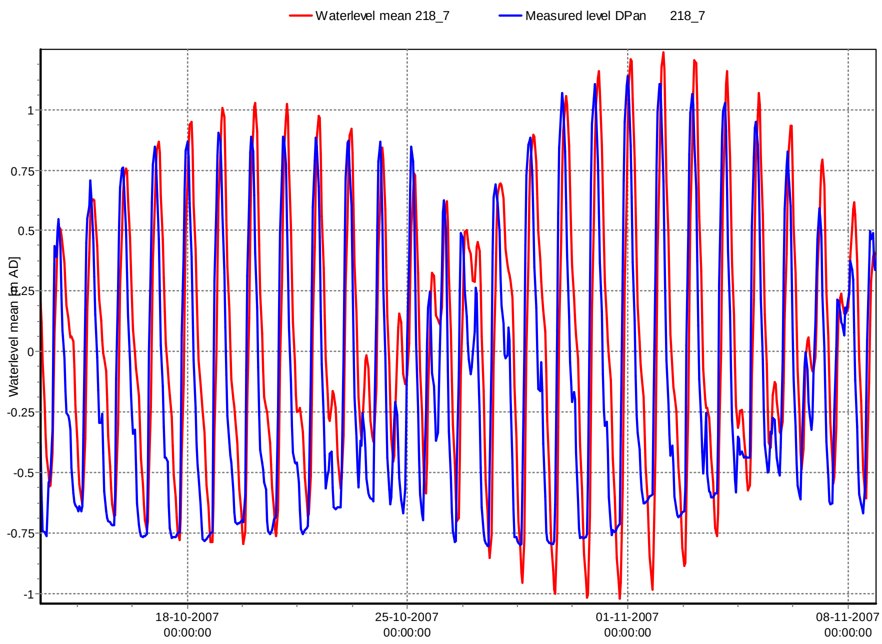


Figure 5.9 Comparison of water level measured (blue) and modelled (red) at the Pangkoh canal in the south east of Block C.

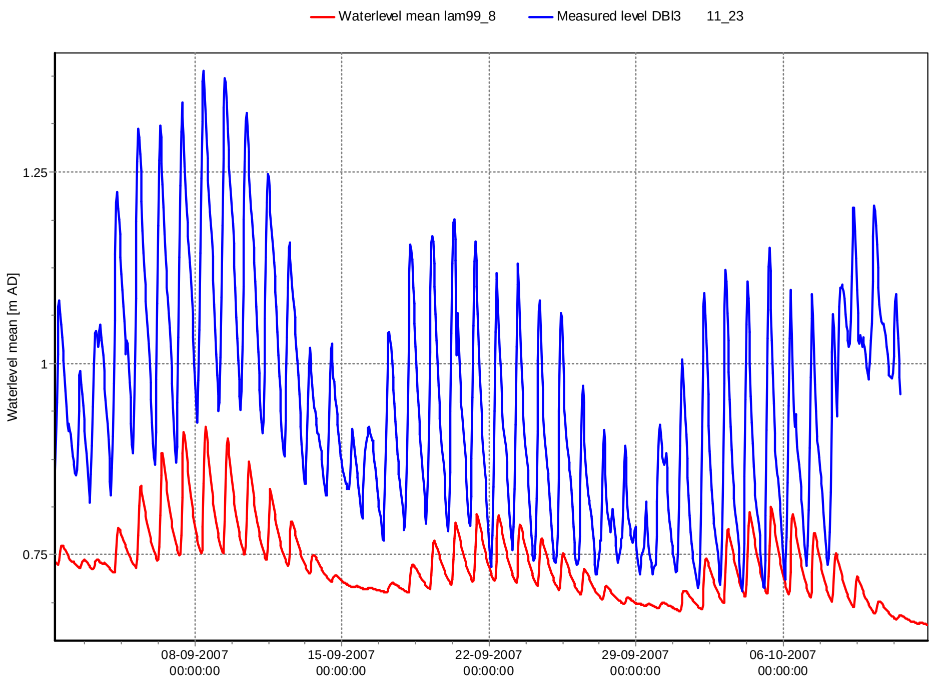


Figure 5.10 Comparison of water level measured (blue) and modelled (red) at the monitoring station Block III C in a canal in the Lamunti area.

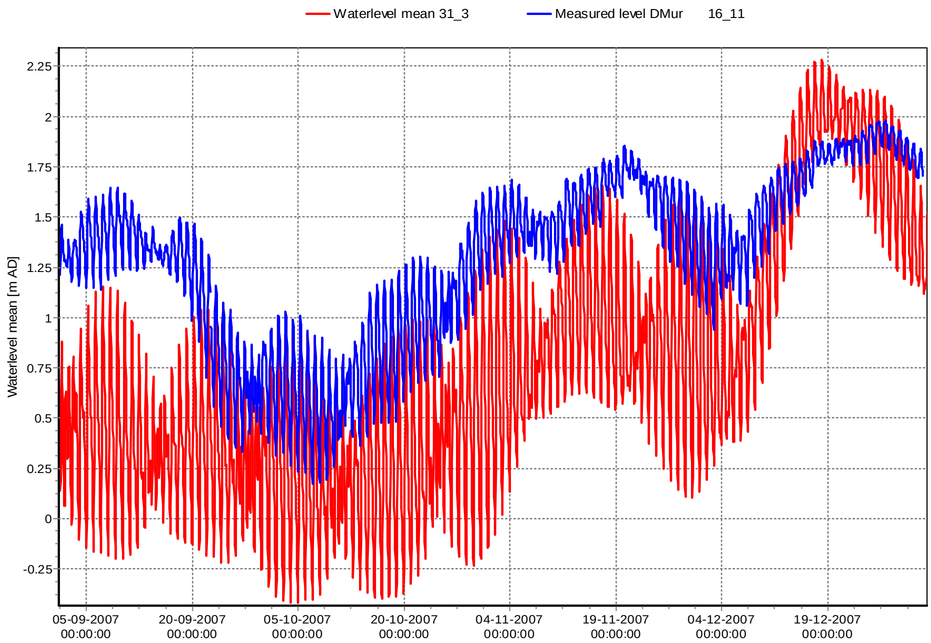


Figure 5.11 Comparison of water level measured (blue) and modelled (red) in a canal in the Dadahup area.

Model results make it possible to analyse the extent of the tidal influence in the project area. Figure 5.12 presents a classification of the tidal influence based on the maximum difference in water level over 25 hours for a spring-neap cycle in May 2007, representing the wet season, and October 2007, representing the dry season. The accuracy of this analysis is mostly limited by the accuracy of the bed levels in the model, which is especially important for the canals. The results show that the tidal influence in the main rivers extents far into the EMRP area, even up to its northern boundary in the dry season. In the canals the influence of tide is limited, because of their higher elevation.

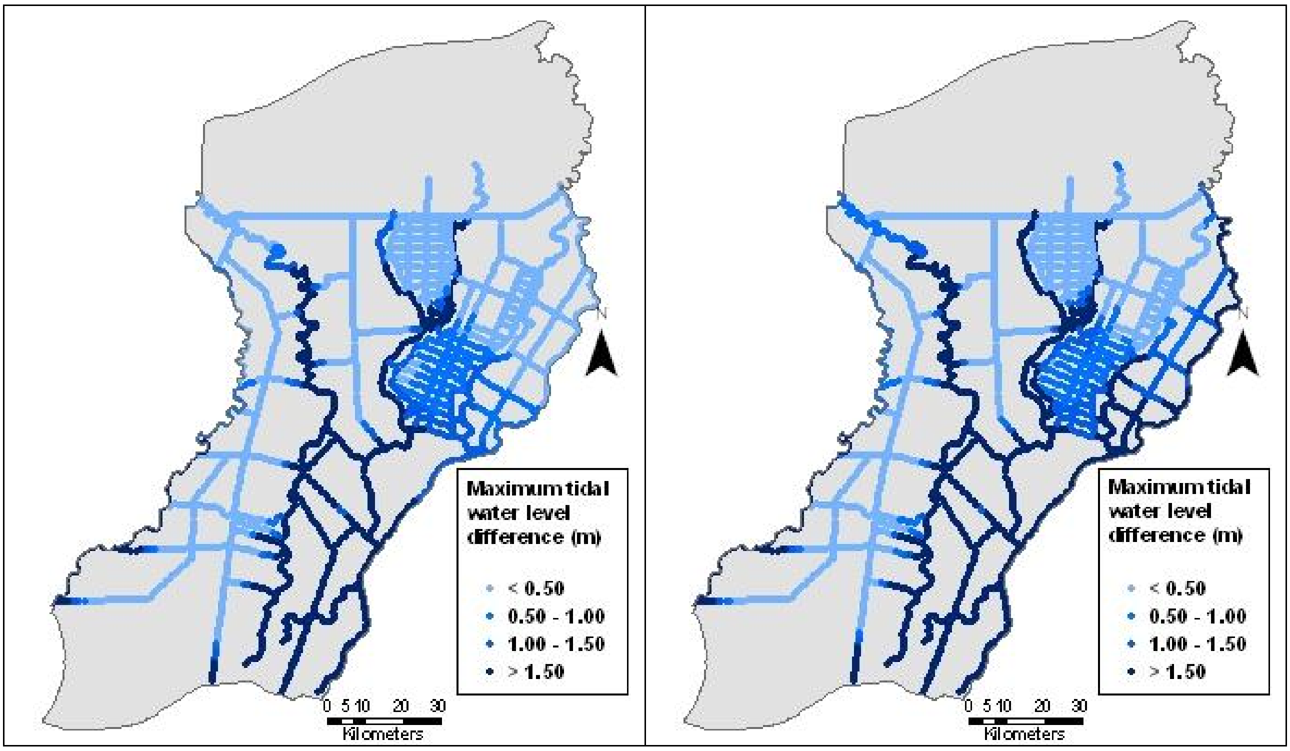
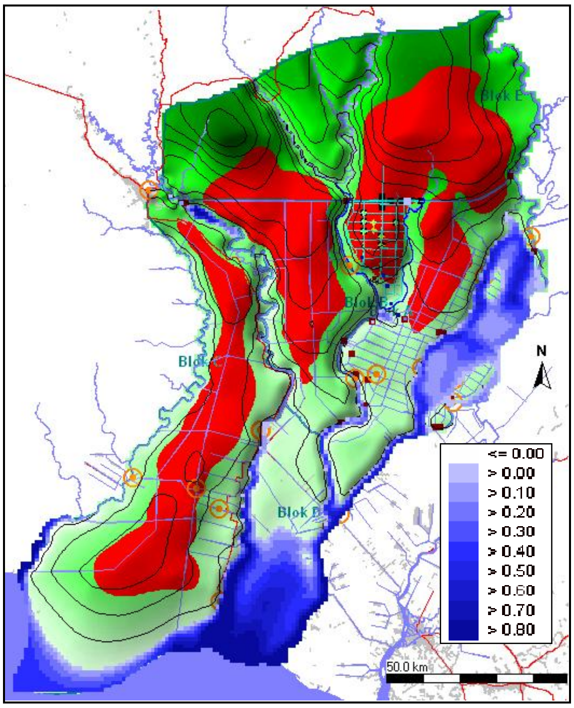


Figure 5.12 Tidal influence on water levels (presented as maximum difference between consecutive high and low tide levels during one spring-neap cycle) for May (left) and October 2007 (right)

5.2.4 Flooding

The overland flow module has been used in combination with the 1D Flow and RR modules to calculate the flooding for the calibration period on a 1 by 1 km grid. In this set-up water levels in rivers and canals are calculated 1D and linked with a 2D model describing the overland flow. Water from 1D branches flow into to 2D model whenever the water level in the branch exceeds the local elevation. Figure 5.13 presents the results.



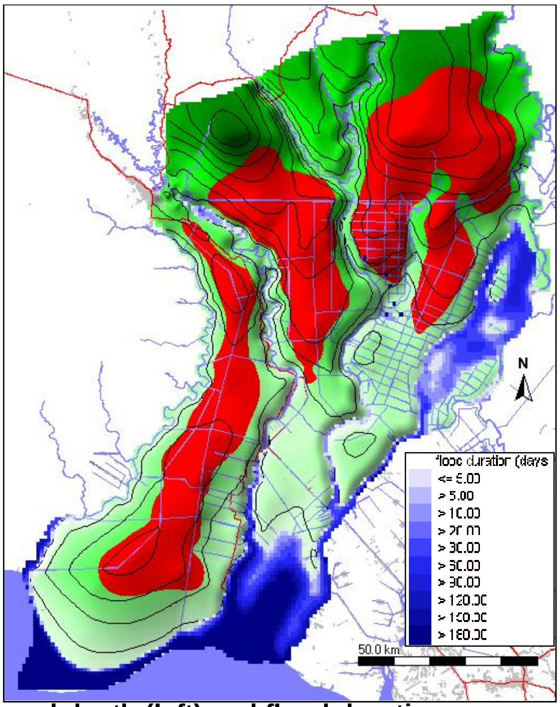


Figure 5.13 Maximum flood extent and depth (left) and flood duration (right) for the calibration period.

The main areas of inundation correspond with the information on flooding presented in Chapter 7.1.7. Inundation along the Sebangau and Kahayan is underestimated by the model, while the extent of flooding in the coastal part of Blok D is overestimated. Both are most likely caused by the description of the topography in the DEM, which does not include local features such as natural levees, man made dikes and back swamps. Furthermore, areas with water at the surface due to ponding spread over the whole area in the flood frequency map, are not shown on the simulated flood map. The description of the overall flood pattern by the model provides reliable information, but for a more detailed assessment of local flooding conditions the model results cannot be used without further verification and more detailed topographical input. The main advantage of the model is that we can use it to extend observations of flooding and to estimate future flooding under different scenarios.

5.2.5 Sea water intrusion

The water quality module of SOBEK is used to calculate the transport of water from different origins through the system based on the flows calculated with the RR and 1D Flow module. As an example Figure 5.14 shows the variation over time of the fraction composition of the water in a canal in the eastern part of the Lamunti area. From this figure it can be concluded that the most of the water at this location is from local origin, except for significant contributions of the Kapuas and especially the Barito Rivers during the wet season peak discharges of the rivers.

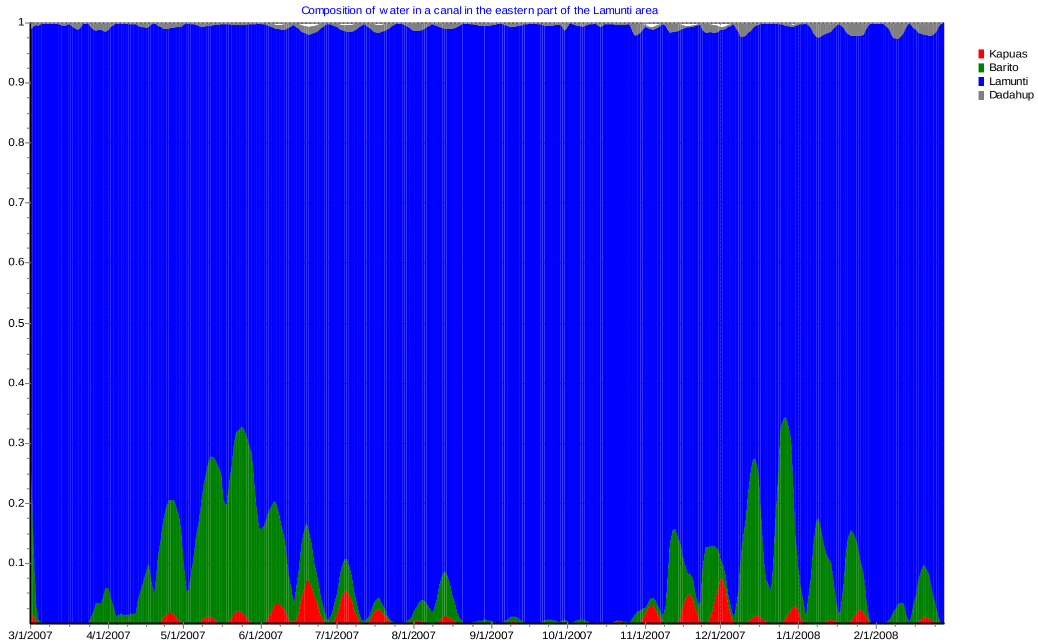


Figure 5.14 Simulated origin of water in a canal in the eastern part of the Lamunti area.

Sea water is one of the fractions modelled. This enables estimation of sea water intrusion. However, it should be noted that the 1D Flow module does not take into account the fact that sea water has a higher density than fresh water and therefore does not mix easily with fresh water in deeper parts of the rivers. Estimates of sea water intrusion and salinity based on 1D flow calculations will therefore generally overestimate the salinity for the upper layer of the water and underestimate it for the lower layer of the water.

The water of the sea near the mouths of the rivers has a salinity ranging between 20 and 25 ‰ due to mixing with fresh water (DPMA, 1980a). This means that a salinity of 1 ‰ coincides approximately with a sea water fraction of 0.05. Figure 5.15 shows maps of annual maximum simulated sea water intrusion for 2005 (a normal to wet year) and 1997 (a very dry year). Figure 5.16 presents simulated sea water fraction as longitudinal profiles along the Kahayan River. Similar profiles have been made for the other rivers. Maximum simulated salt intrusion is in a normal year in the order of 60 – 100 kilometres, but less for the Barito. In a very dry year the model suggests that sea water can intrude much further, especially along the Sebangau and Kahayan Rivers.

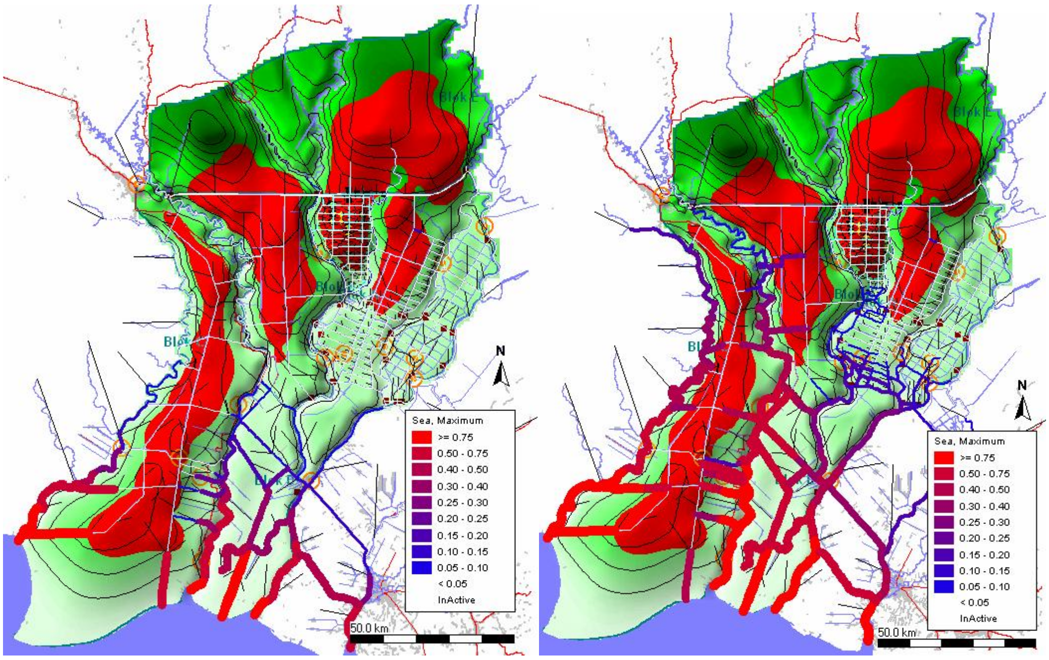


Figure 5.15 Simulated annual maximum sea water intrusion for 2005 (left) en 1997 (right).

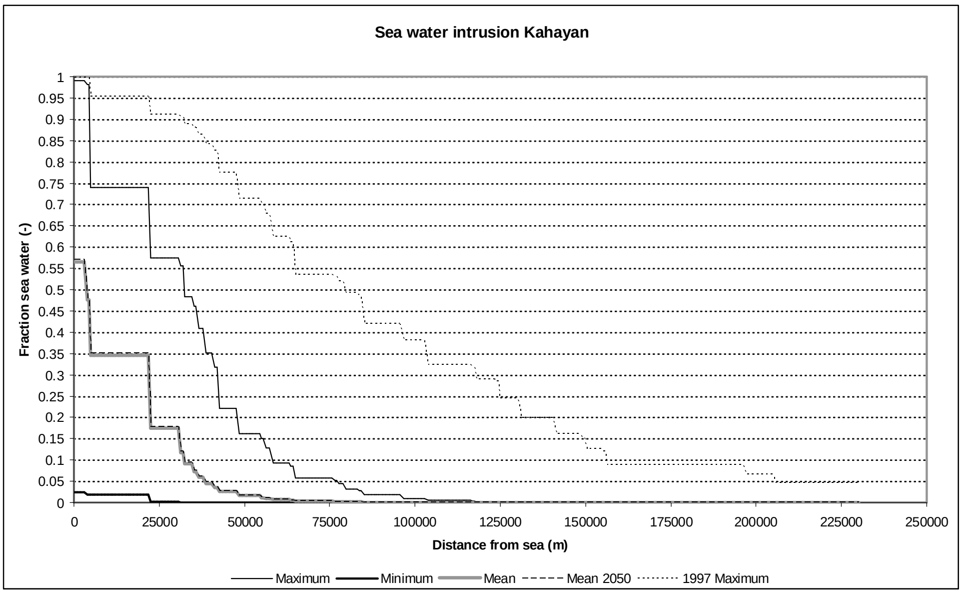


Figure 5.16 Longitudinal profile of simulated sea water fraction along the Kahayan River for 2005 (maximum, minimum and mean), mean for 2005 with 20 centimetres sea level rise (mean 2050) and maximum for 1997 (1997 maximum).

5.3 Flood zonation

5.3.1 Analysis of water levels

For the six precipitation time series used by the model a time series has been constructed starting November 1, 1983 and ending February 28, 2008 (Chapter 3). The hydrological and hydraulic SOBEK model described in the previous chapters has been used to calculate water levels for the EMRP area for this whole period based on the RR and 1D Flow modules using these precipitation time series. As explained in Chapter 7.2.2, these model results can differ substantially from actual water levels due the limited amount of precipitation data available for the upstream catchment. However, the model results can be used as an indication for potentially occurring water levels and their probability. The areas prone to flooding by the rivers are mostly influenced by the water level on the Barito River (see Chapter 7.1.7). The highest simulated water levels along the Barito River occur in 2005 (Figure 5.17). This event can be taken as an approximation of a flood event with a probability of 4% (1:25 years).

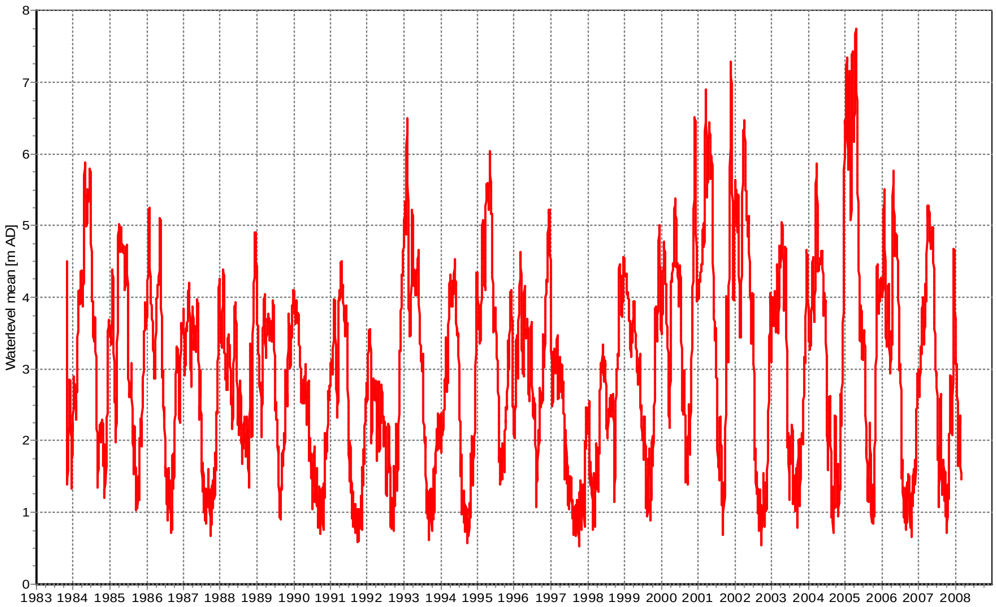


Figure 5.17 Simulated water level for the period 1983 – 2008 for a location on the Barito River 172 kilometres from the mouth.

5.3.2 Flood zonation

Figure 5.18 shows the maximum flood depth as simulated for the year 2005, including the highest water levels simulated for the Barito River for the period 1983 - 2008.

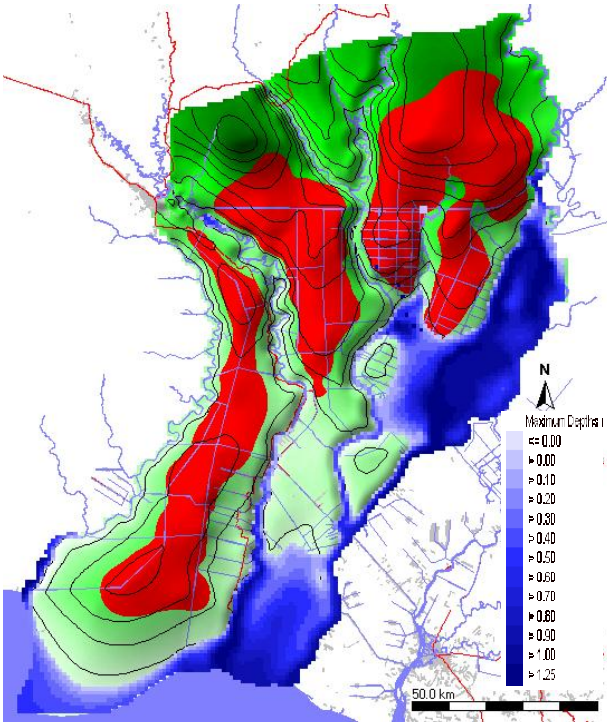


Figure 5.18 Simulated maximum flood depth (m) in 2005.

Figure 5.19 provides an assessment of the average annual flood duration based on inundation modelling for the period 1998 – 2007. The valley of the Mengkatip River, the Jenamas area and the mangrove areas in the south of Block C and Block D can be clearly identified as the areas with the longest flood duration. The flood duration and depth in the rest of Block D is overestimated in simulations, due to the limited representation of micro-topography in the DEM, such as natural levees along the coast and rivers and embankments around development zones.

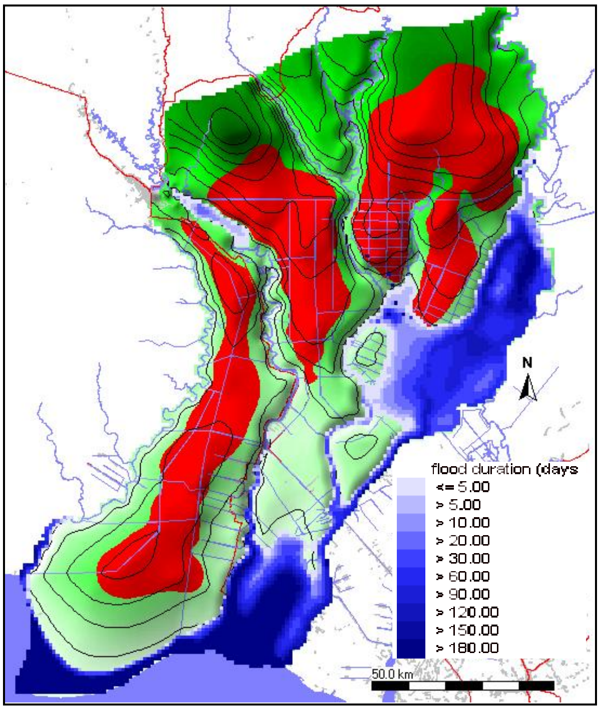


Figure 5.19 Simulated average annual flood duration for the period 1998 – 2007.

5.4 Results of scenario calculations

5.4.1 Climate scenarios

Sea level rise in this century is expected to amount to between 4 and 6 mm/year. This would result in approximately 10 centimetres rise in 2025 and 20 centimetres in 2050. Figure 5.16 showed limited impact on the mean annual salt intrusion.

The assessment of the impact of sea level rise on maximum water levels has been made by comparison of simulated maximum water levels for the year 2005 with and without 20 centimetre sea level rise at the tidal boundary conditions. The result is presented in Figure 5.20 and shows that the impact is limited to the lower 70 kilometres of the river and has no influence on flooding in the areas Lamunti, Dadahup and Jenamas. However, flooding in the coastal areas of Block C and Block D will be influenced.

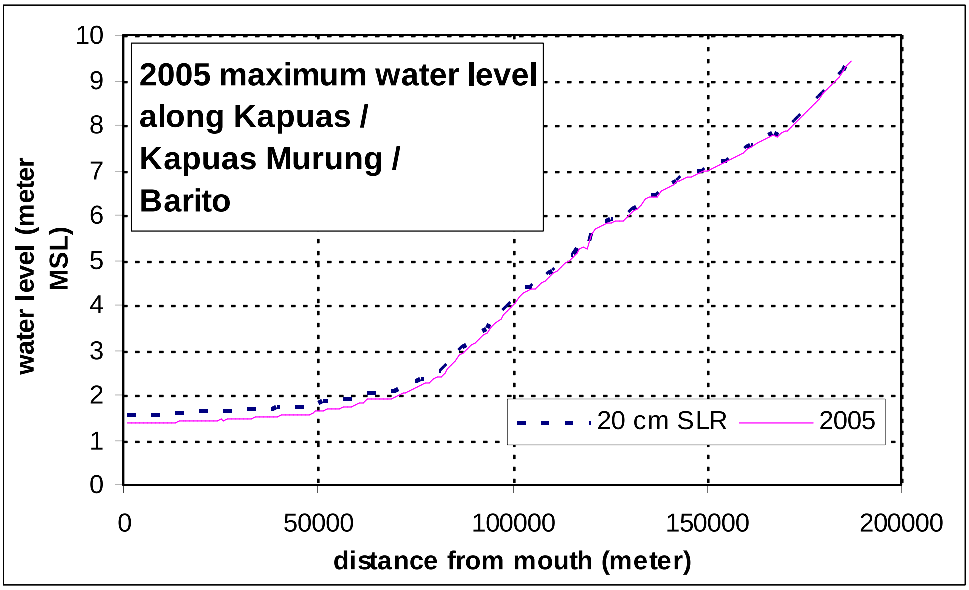


Figure 5.20 Impact of 20 centimetres sea level rise on simulated maximum water level along the Kapuas/Kapuas Murung/Barito for the year 2005.

5.4.2 Subsidence scenarios

The Peat Strategy Analysis Tool (see separate report) has been developed to assess the impact of drainage level on subsidence and greenhouse gas emission and resulting flooding and drainability. The SOBEK model described above is used to describe the boundary conditions for PSAT in the form of water levels on the rivers. The following series of water level information have been calculated with the SOBEK model:

- The maximum water level in the period November 1983 – February 2008;
- The maximum water level with a probability of 0.2 (a so-called 1 in 5 year flood);
- The average water level in the dry season (between December 1 and May 31) in the period November 1983 – February 2008; and
- The average water level in the very dry period between October 15 and November 1, 1997.

PSAT assesses the topography resulting from subsidence in 2025 and 2050 under different land use and drainage scenarios. It calculates flooding based on the water level in the rivers. This will be an estimation of the maximum flood extent, since upstream flooding outside the riverbed will reduce downstream water levels on the river and therefore flood extent. To incorporate this ‘system’ effect, flood simulations have also been made with the SOBEK model. Figure 5.21 presents the maximum flood depth and flood duration for the year

2005 as simulated on a 5 by 5 kilometre grid. Figure 5.22 presents the results for the same meteorological input but based on a digital elevation model modified by PSAT to incorporate the subsidence to 2025 caused by the “reference” land use and drainage scenario and incorporating the effect of fires. A description of the scenarios, PSAT and its results can be found in a separate report. The conclusion from simulation of floods with SOBEK is that PSAT identifies the correct locations of potential flooding, but overestimates the extent and maximum depth. However, PSAT flood results can very well be used to compare the impact of different land use and drainage scenarios on flooding.

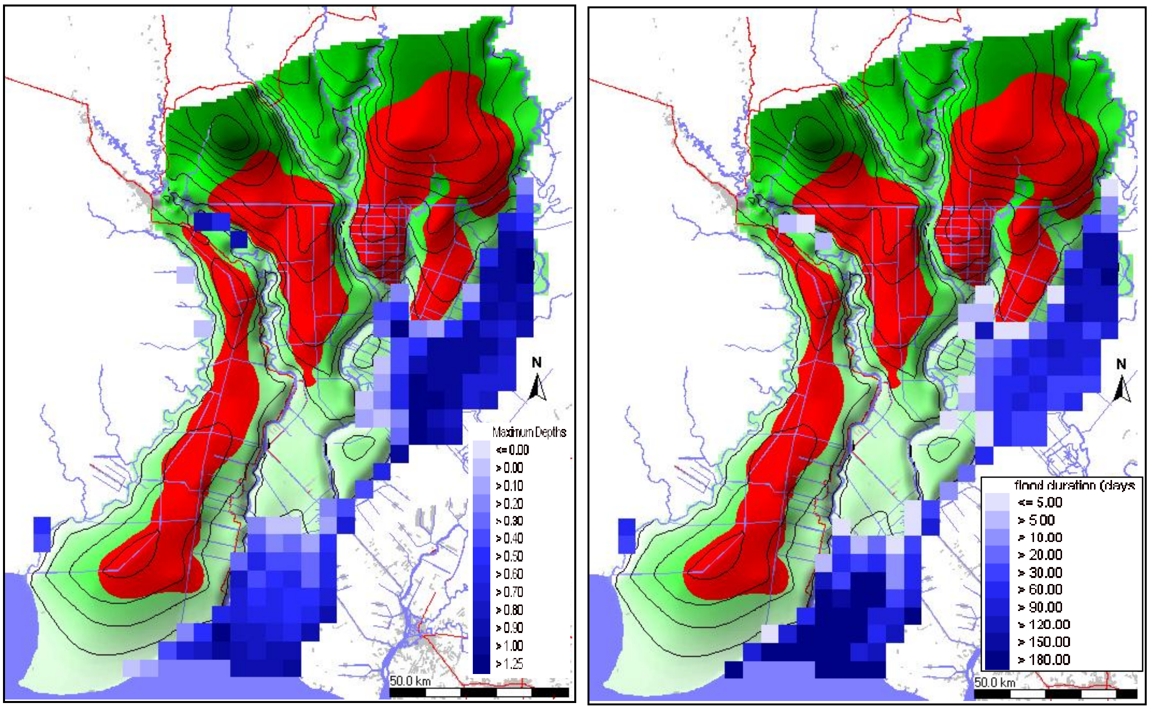


Figure 5.21 Simulated maximum flood depth (left) and flood duration (right) for the year 2005 on a 5 by 5 km grid.

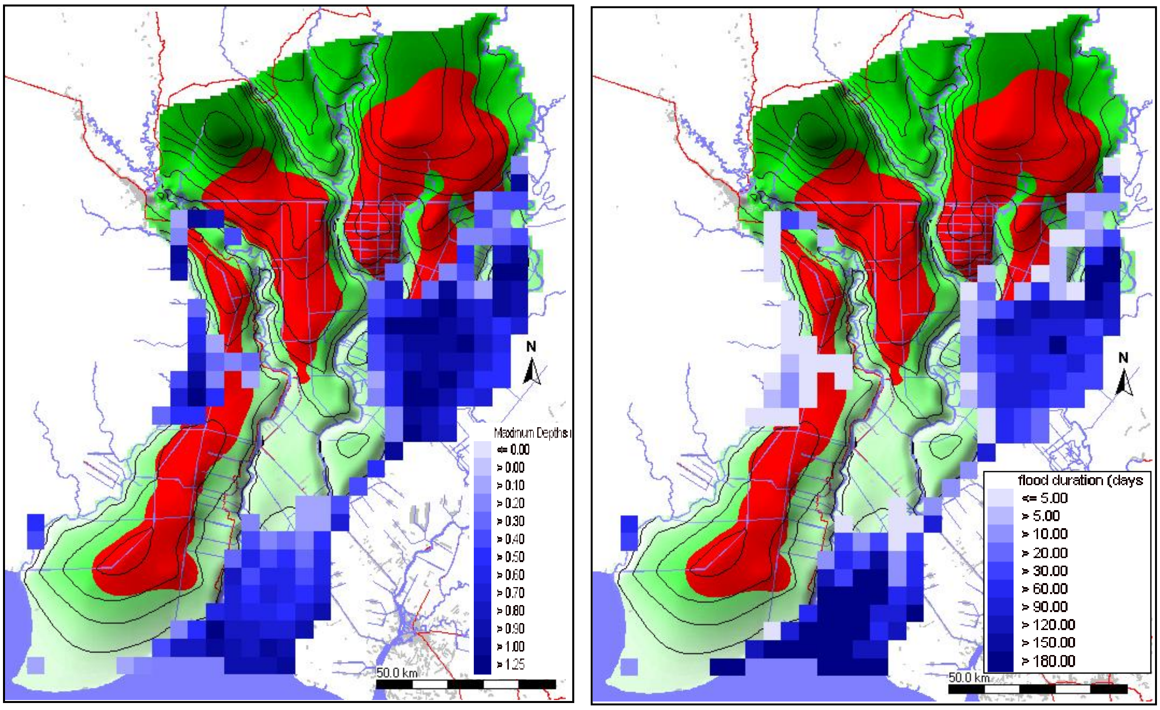


Figure 5.22 Simulated maximum flood depth (left) and flood duration (right) for the meteorology of the year 2005 combined with the topography resulting in 2025 from the reference scenario including fires.

6 Hydrological assessment and modelling for peatlands

6.1 Introduction

The aim of the peatland hydrology and water management assessments in the EMRP project is to A) quantify the functioning of the peatland hydrological system to be able to B) recommend methods and locations for water management as part of rehabilitation efforts for peatlands in the area that should reduce the impacts of unwise development of drainage canals in the area in the 1990s. The main impacts are: fires, forest loss, CO_2 emissions and subsidence resulting in loss of economic functions.

Rapid ssessment of peatland hydrology was undertaken for two study areas where sufficient data were available. Full assessment will take more data. While there are remaining unknowns, some important questions, such as drivers and degree of groundwater table fluctuations and the role of groundwater flow therein, could be answered confidently for much of the study areas.

Three fundamental questions need to be answered in this analysis:

1. Comparison of the existing (drained) and original (natural, reconstructed in models) situation, to understand how the peatland hydrological system has been affected. What was the impact of canal implementation in 1997 on the hydrology of the EMRP area? How did it affect water flow paths, water depths, fire risk, carbon balance and morphology? In other words: what damage has the drainage done?
2. Assessment of positive impacts that water management interventions can have. In other words: to what extent can the drainage damage be undone?
3. Assessment of optimum locations, types and dimensions of water management interventions. In other words: how can the drainage damage be undone most efficiently?

The assessment was undertaken in the following steps:

- The first and fundamental step is to collect, quality control and analyse data. This has also been the main bottleneck in this activity, some crucial data was obtained only by early June. Although there are still major data gaps, we now have a comprehensive database that allows in-depth analysis.

- Process parameters were quantified directly from the data where possible, including actual evapotranspiration of peatland forest and degraded areas, peat storage coefficient, and peat hydraulic conductivity, the impact of drainage on peatland subsidence and morphology.
- Hydrological models were applied to answer specific process and intervention questions where necessary; this included simple water balance models, groundwater–surface water models for selected sites (Modflow-SOBEK) and a surface water model for the entire peatland area.

6.2 Data

6.2.1 Data used

For two case study areas, the north of Block C (CIMTROP research area) and the northwest part of Block A (CKPP Pilot area), sufficient data could be collected to allow analysis of peatland hydrology conditions in the EMRP area. The following data were used:

- WI-IP (CKPP) water depth and rainfall data for Block A Northwest
- Elevation and peat depth data for Block A NW collected in Master plan project in collaboration with WI-IP.
- CIMTROP water depth, rainfall, elevation and peat depth data for Block C North.
- Hokkaido University evapotranspiration for Block C North
- PU-BMG rainfall data for EMRP area

See Section 11.1.1 for a further description of these data. Note that none of these data became available before March 2008.

In addition to the hydrometeorological data described above, the following data was used for this analysis:

- The Digital Elevation Model produced in Cluster 3 (Section 11.2.3).
- The peat depth model produced in Cluster 3 (see Section 11.2.4).
- The modelled river water level information produced in Cluster 3 (see Chapter 5).

6.2.2 Spatial rainfall variation and water table fluctuations

It is often necessary to rely on literature data for process parameters like actual evapotranspiration, peat storage coefficient, and peat hydraulic conductivity; this of course limits the value of analysis results. In the current study, datasets of sufficient quality and coverage (in space and time) were obtained to allow accurate analysis for 2 sites. Site specific data are far preferred to literature data because of spatial variability in these parameters, so having them in this project allows more accurate overall analyses than is often the case.

For hydrological assessments in the EMRP area, we have compiled 25-year 'area rainfall' records for the Northern and Southern part of the area by averaging a number of records for individual stations (see Section 11.1.1). This has the advantage of creating consistent long-term records that would otherwise not be available. However these 'area rainfall' records can only be as accurate as the rainfall records it is based on, which are mostly poor for the EMRP area, bot in data coverage (percentage of time that data were collected), and accuracy. Also, it is necessary to check such records against independent records in the area, to see if they sufficiently represent local conditions. Issues of rainfall variation and data quality have been discussed earlier in this report.

6.2.3 Analyses of recorded groundwater levels

Groundwater depths recorded along 4 groundwater transects in Block C, as shown in Figure 6.1 (map) and Figure 6.2 / Figure 6.4 (cross sections), results in the following immediate observations:

- Water tables are deepest and water table gradients highest near the canal, but this zone appears less than 300m in extent which is the zone over which groundwater flow is most significant.
- Further away from the canal, water tables are not very deep for most of the year, with an average within 0.5m. However minimum water levels in 2006 are still around 1m deep.
- Water depths to the Southwest of the canal are consistently greater than to the Northeast, which may be explained the the NE side is 'upslope' and has a catchment which feeds the area when water tables are high.

Effect of drainage on water flow: groundwater and surface water

Figure 6.3 shows that water tables in the Block C study area are considerably lower near canals, but that there is not a great difference between water depths at 300 or 1300 metres from the canal. Similar water depth fluctuation patterns, with low water levels near canals and fairly uniform depths more than a few hundred metres away from canals, are recorded in Block A (Figure 6.16). The patterns observed in the Block A study area have been simulated with a groundwater model applying a low hydraulic conductivity; water fluctuations more than 300m away from the canal in Block C can be simulated using a water balance model assuming zero groundwater flow. It can therefore be tentatively concluded from these observations and models that, at least in the North of Block C and in Block A, groundwater flows appear limited apart from relatively narrow zones close to canals. If we take into account that canals are widely spaced (at 2.7km in part of Block A, but >10km in most of the area) and that spatial variations in rainfall, evapotranspiration, peat storage coefficient, surface runoff and ponding will all cause variation in water depths, it appears that water depths in much of the EMRP area are not greatly affected by groundwater flow, once water tables are well below the peat surface.

It should be noted that this apparently limited groundwater flow towards canals does not mean that the canals do not greatly impact water depths. Lateral flow in these peatlands mainly occurs in a relatively thin surface layer which may either be considered a 'catotelm' type topsoil or a surface runoff layer with high roughness. As long as the water table is within that zone, it is affected by canal drainage over great distances. In drained areas, therefore, the typical dry season water table drawdown period starts weeks earlier than in undrained areas, and water depths will therefore be significantly lower throughout that period.

This observation, which has major implication for water management and rehabilitation potential in these peatlands, is confirmed by two independent modelling approaches (Sections 6.3 and 6.4). The finding of limited groundwater flow once water table are deeper is explained by the fact that the degree of humification in these areas (and presumably in most of the EMRP area) is fairly to very high, resulting in low to very low hydrologic conductivity of the peat.

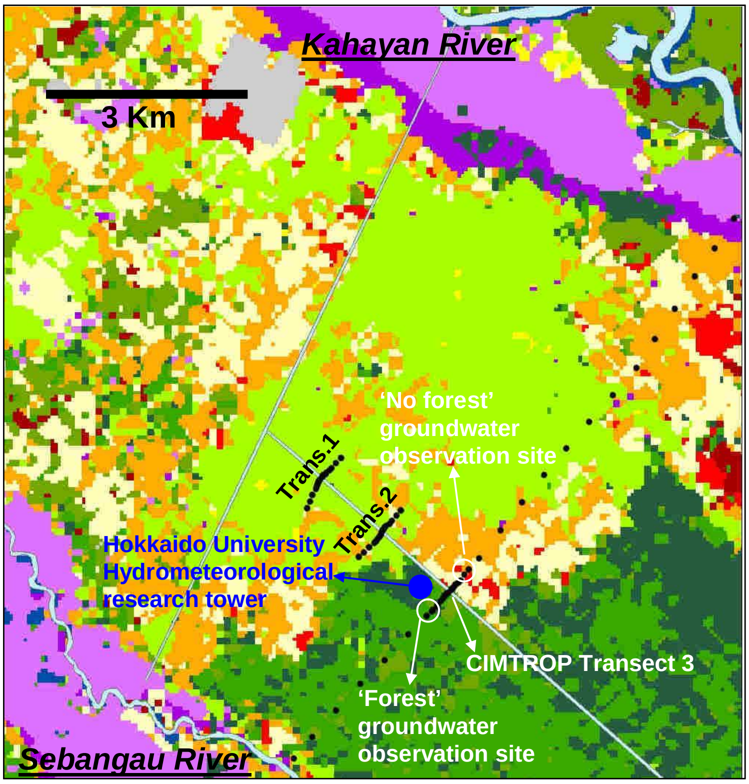


Figure 6.1 Map of locations at the CIMTROP research site in Block C.

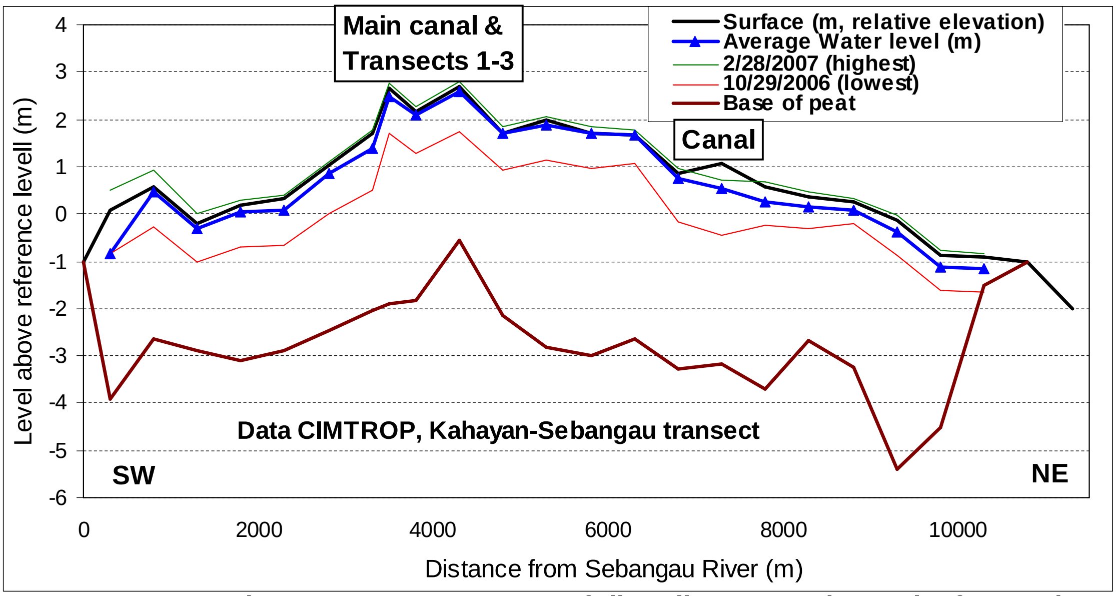


Figure 6.2 Long transect of dipwells at 500m intervals, from Sebangau River in the SW to Kahayan River in the NE.

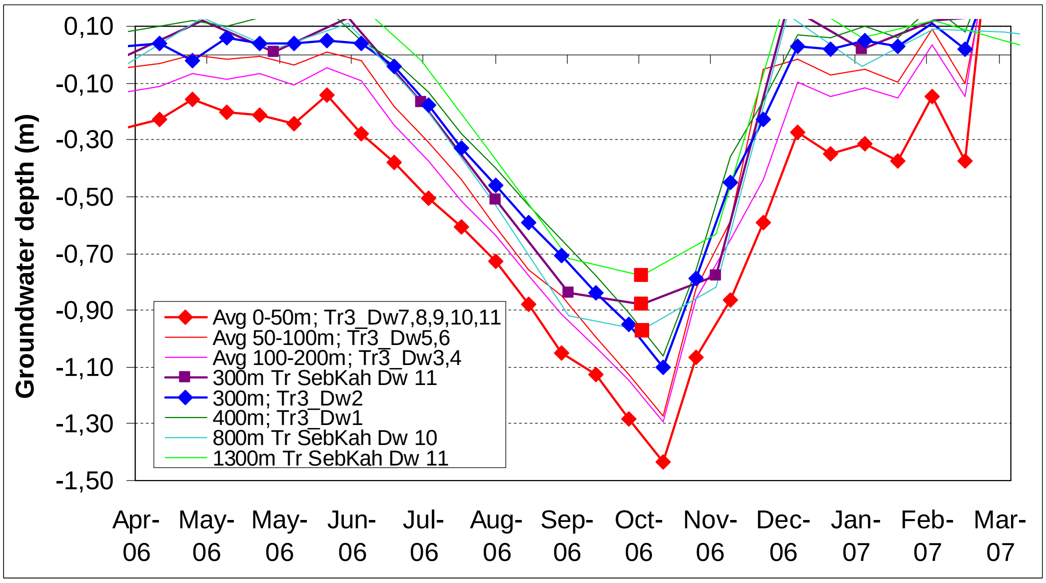


Figure 6.3 Water level fluctuations at different distances from a canal in Block C, along 2 overlapping transects: Transect 3 and the Sebangau-Kahayan transect.

The following can be observed:

- Along Transect 3, there is a clear water depth gradient away from the canal. Depts over 0-50m are some 0.15m greater than over 50-100m, and some 0.45m greater than 300m away from the canal. From 300 to 400m however, there is hardly a difference in water depth.
- Along the Sebangau-Kahayan transect, nu consistent gradient can be detected between water depths at 300, 800 and 1300 metres from the canal.
- Water depth fluctuations within each transect are highly uniform, especially in terms of the slope of the water table drop leading into the 2006 dry season. This suggests that both evapotranspiration rate and storage coefficient are uniform as well.

- Water depth fluctuations as measured along the two different transects (possibly by different teams) are similar most of the time but rather different on 29 October 2006. The readings along the Sebangau-Kahayan transect on that day is much higher that along the Transect 3 transect; this may be a measurement error since rainfall data strongly .

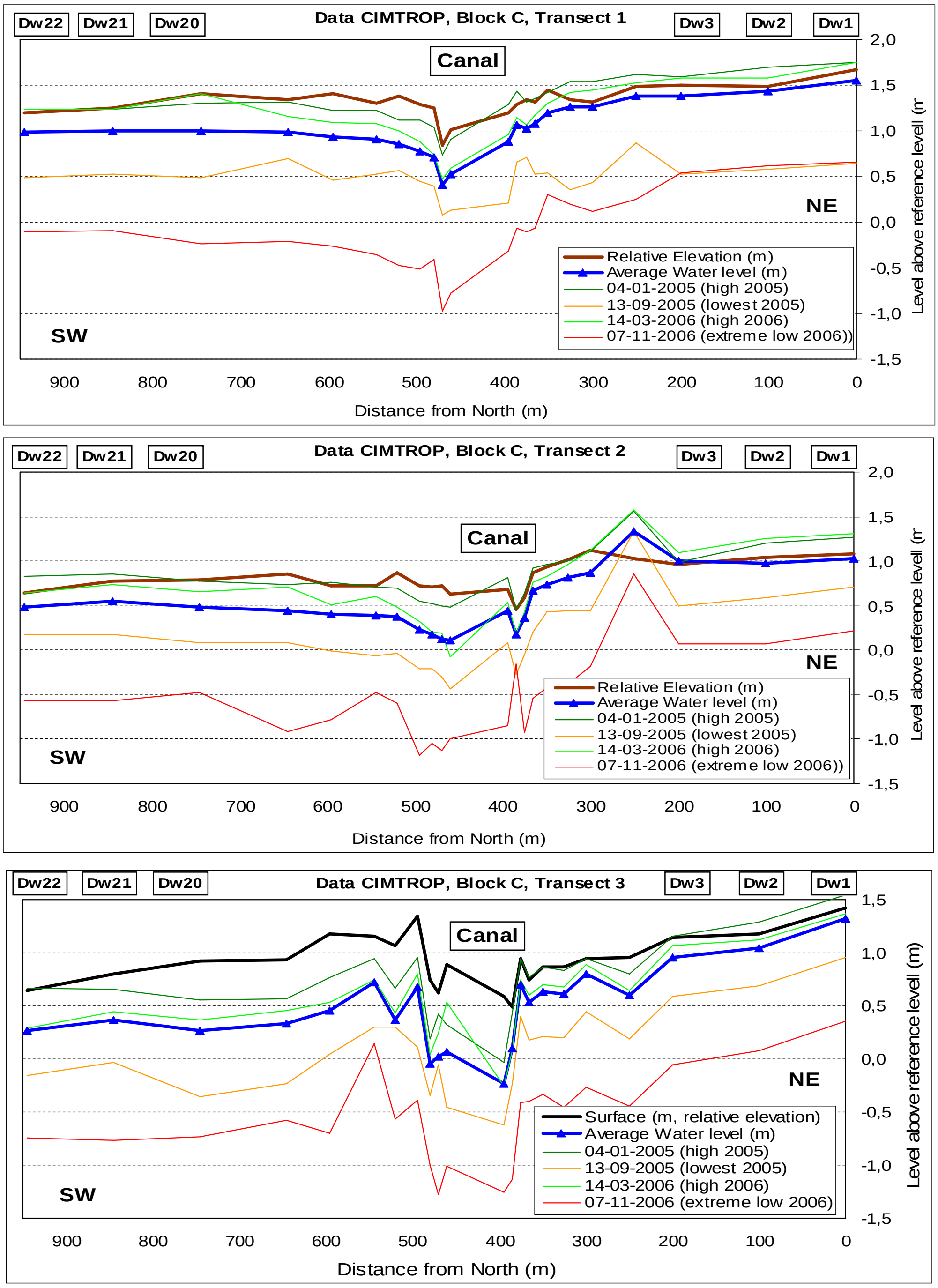


Figure 6.4 Short groundwater transects across the main canal in the CIMTROP research area.

Top: Transect 3, short transect with small intervals, parallel to Sebangau-Kahayan transect, crossing the main canal.

Bottom: Transect 1, 3km NW of Transect 3, with same dipwell set-up.

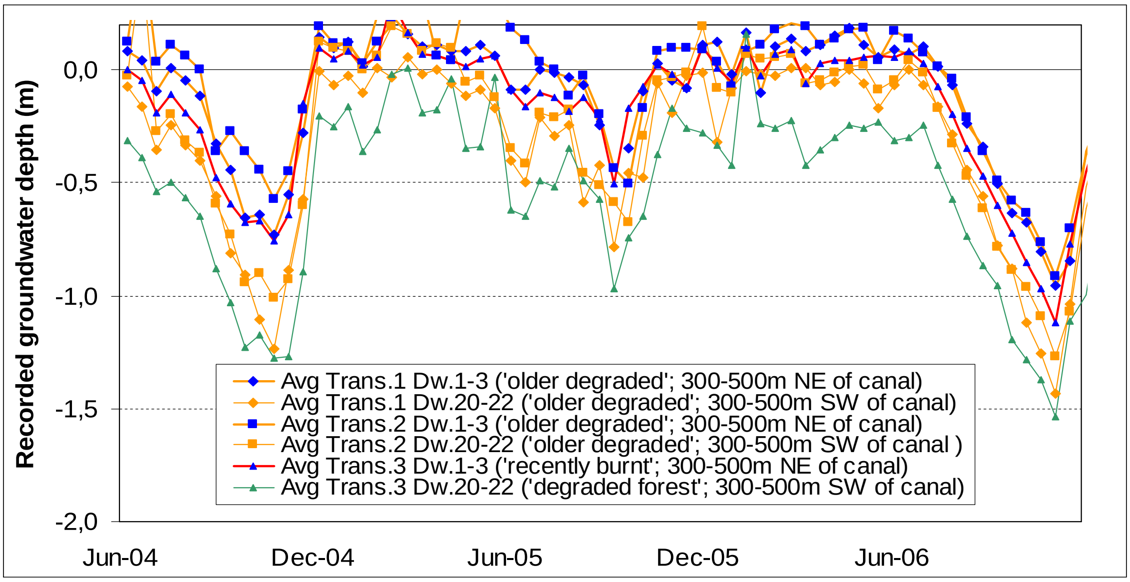


Figure 6.5 Comparison of observed groundwater depth records in the CIMTROP area, Transects 1-3. For each of the transects, water table fluctuations to the Northeast and to the Southwest of the canal, and for different land cover types, are shown separately. Groups or dipwell recordings have been averaged that are least impacted by canal drainage.

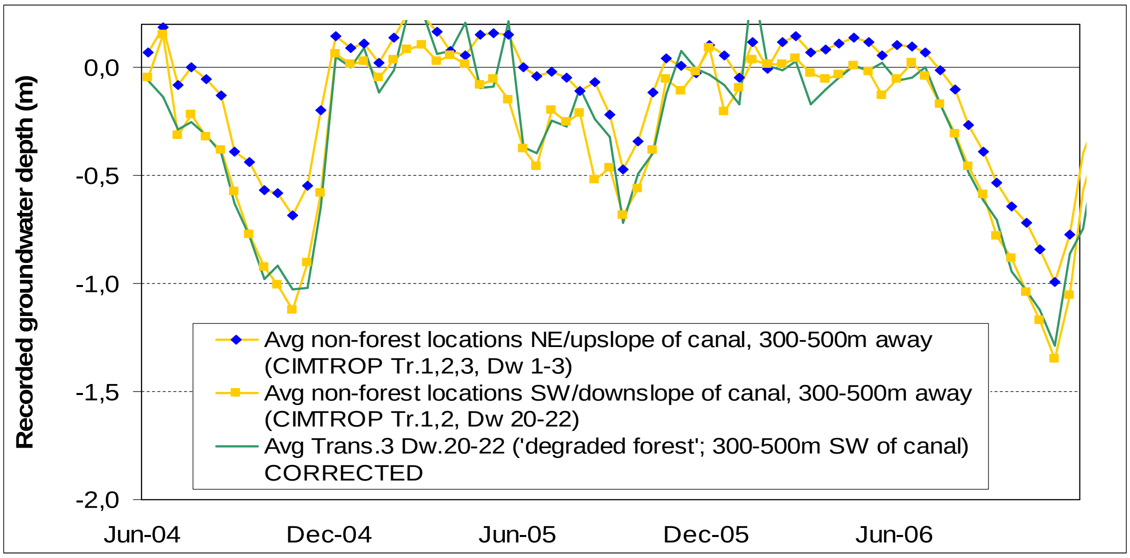


Figure 6.6 Average of water depth records for locations upslope and downslope of the main canal in the North of Block C, illustrating the impact of drainage on water depths in EMRP peatlands, mainly through interception of surface runoff. Also shown is corrected water depth in forest depth; 0,25m is added to the water level because dipwells are apparently not placed in the lowest parts of the forest floor that represent the 'true' ground level.

Effect of vegetation cover on groundwater depth

Peatland vegetation affects the water deoth in two ways:

- Directly, it determines evapotranspiration, which is significantly higher in forest than in the ferns and shrubs found in degraded peatland. The effect of this is that water tables under forest will be lower than in degraded vegetation if all other conditions (rainfall and peat storage coefficient) would be equal.
- A second indirect effect is that land cover and land history have an impact on peat storage coefficient near the surface. To begin with, the hummock-hollow layer that occurs in forest is largely lost when the forest is removed by logging or fire. This layer has very high storage coefficient, as it consists of undecomposed plant remains (hummocks and litter layer) and air (hollows). Secondly, the remaining peat will decompose faster without a protectice canopy cover, as it dries and heats up faster when exposure to sunlight and wind increases. Thirdly, heating by fires may be assumed to break down and compact the remaining peat. In all, the effect of forest removal may be a significantly lower storage coefficient, hence greater water depths if all other conditions (rainfall and peat storage coefficient) would be equal.
- A further consideration is that peatland forest removal in the EMRP area may have had an impact on rainfall itself. However this is uncertain at present, and will not be considered further in this analysis.

The net effect of forest removal from peatland may hence be higher water tables if the decrease in evapotranspiration is dominant, or lower water tables if the decrease in peat storage coefficient is dominant. Much depends the removal method, on the character of the new vegatation, and on soil characteristics.

From Figure 6.5, no relation between vegetation cover and groundwater depth can be determined:

- o The one record in ‘recently burnt’ land has the same water depth pattern as the 2 records for ‘older degraded’ land on the same side of the canal.
- o The one series recorded in forest (Transect 3 dipwells 20-22) has the lowest water depth of all 6 records, however this is the case not only in dry periods but also in wet periods. In fact water depths of 0.3 m are usually recorded in when the water table must be at or above the soil surface. This strongly suggests that not the water depth is different here, but rather the position of the dipwells relative to the ‘true’ soil surface: (see following section). The fact that the slope of the water table drawdown curve in forest is the same as in degraded land (Figure 6.6) also suggests that the net water balance, i.e. evapotranspiration in dry periods, can not be too different.

Somewhat surprisingly, these observations lead to the consideration that evapotranspiration from forest in peatland may not be much higher than evapotranspiration from degraded areas covered with ferns and shubs. As trees are known to transpire more than ferns and shrubs, it may be that this difference is largely compensated by the fact that evaporation from the soil surface will be higher in low vegetation as long as the soil surface is moist. This would imply, however, that in periods when the soil surface is dry, evapotransiration from degraded areas would decrease faster than in forests. This difference would be even greater during severe droughts when during severe droughts when tree roots can still reach the water table while the roots of ferns can not.

Effect of location upslope or downslope of canal on water depth
All groundwater depth records investigated above represent locations relatively close to the canal, at 300 to 500 metres distance. It is concluded, that the only clearly distinguishing characteristic for these records is their position relative to the main canal: all 3 records upslope (to the Northeast) of it have significantly higher water tables than those that are downslope (to the Southwest). This again indicates that drainage impact is dominant especially when the water table is at or above the peat surface as discussed earlier in this section: upslope water tables are above the peat surface most of the time, while those downslope of the canal are usually just below the peat surface.

If we want to consider which of the records are most representative for degraded EMRP peatlands in general, we suggest that records of locations upslope from the canal, which are less affected by drainage, would be most suitable. An average for records of dipwells 20-22 of Transects 1, 2 and 3 will be used to fit the water-budget groundwater model in the following section.

Defining the position of the groundwater table
One complicating factor when interpreting groundwater records for peatlands is that of the position of the 'true' ground surface can be difficult to define. Natural forested areas have a typical 'hummock hollow' topography, with hummocks being rarely if ever inundated and hollows being ponded frequently. The position of a dip well within this microtopography can make a difference of up to 0.5m in water depth; differences around 0.25m are common. This can be illustrated when comparing the Hokkaido University water depth record with three records collected by CIMTROP at the same site (Figure 6.7). The Hokkaido record is consistently lower than the CIMTROP ones, by some 0.3m. The fact that the Hokkaido dipwell is placed on a hummock is also demonstrated by the fact that the water table never reaches the 'surface' level, which can only be explained by lateral groundwater outflow to the adjoining hollows.

As the bottom of hollows represents the true ‘ground level’ in peatlands in hydrological terms, i.e. the level below which lateral water flow can be considered groundwater flow, it is recommended to place dipwells in hollows. In practice, however, dipwells often appear to be placed on hummocks. Where this is the case, groundwater records do not represent ‘true’ groundwater depth and a correction may need to be made.

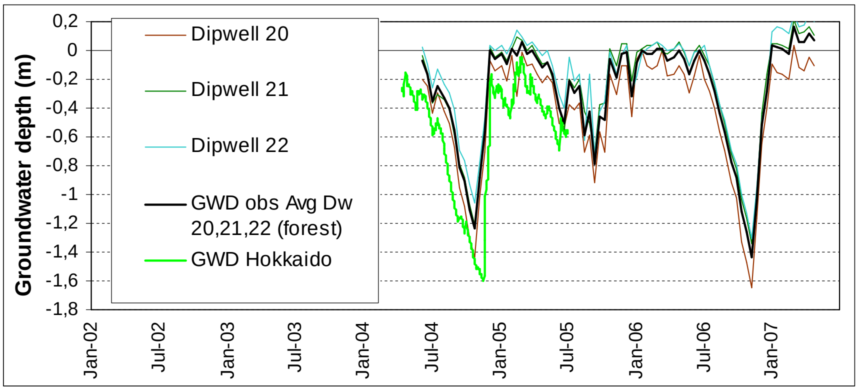


Figure 6.7 Water depth records for the CIMTROP ‘Forest area’ along Transect 3.

6.3 A simple water-budget groundwater depth model for EMRP peatland

6.3.1 Determining actual forest evapotranspiration

The actual evapotranspiration for ‘degraded forest with closed canopy’ provided by Hokkaido university yield an average annual ET of 1350 mm/y (possibly up to 1485 mm/y if further corrections is made, to be discussed further). This is well within the range of SE Asia lowland forest ET rates reported in literature (roughly 1200 to 1800 mm/y; e.g. Bruijnzeel 1990), indicating that peatswamp forest evapotranspiration is not significantly different from ET from other lowland forest types despite having much wetter soils and generally lower canopy. This in itself is important information.

Inspection of ET rates shows that they have significant day-to-day variation from 1 to 6.1 mm/d, corresponding with variation in cloud cover, wind speed etc. A 30-day moving average, however, is in fact remarkably constant around an average value of 3.7 mm/d. During dry periods, however, ET drops significantly and consistently, to below 2.5 mm/d (Figure 6.8) during the extreme drought conditions in the 2002 El Nino year. This is presumably because water depth drops below a threshold value, and water availability to the shallow root systems becomes a limiting factor.

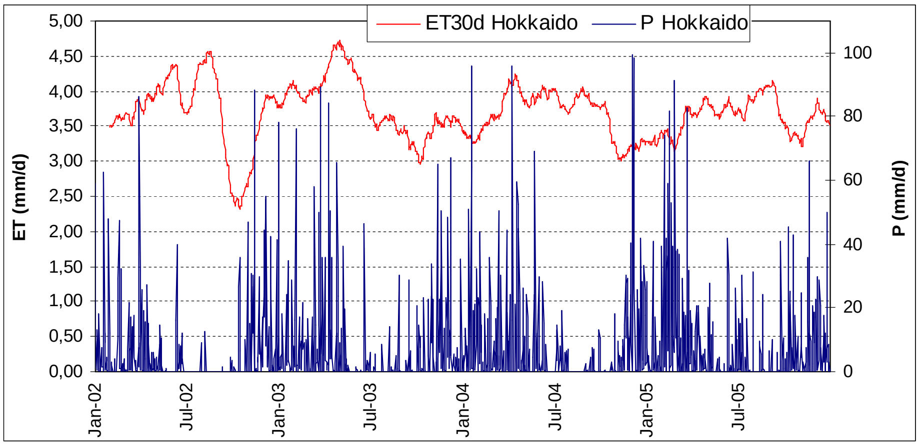


Figure 6.8 Actual evapotranspiration (30d moving average) and rainfall in degraded forest in the North of Block C; Provided by Hokkaido University.

Simulating actual forest evapotranspiration in the dry season

Because ET is the main (or only, see below) driver of water table drawdown in the dry season, and because predicting dry-season water depths is a main aim of peatland hydrology modelling in this project, it is important to determine the feedback mechanism from water depths to ET. This has been done in the following steps:

1. An approximate water depth record for forest is simulated using the simple spreadsheet model presented later on in this section with as input daily rainfall (obtained from Hokkaido University), an average ET of 3,7 mm/d and a storage coefficient of 0.29 (see below). The assumption is that no lateral groundwater flow takes place, see below in this section.
2. Periods of groundwater depth below a threshold value of 1m (which corresponds with the sharpest declines in ET) are identified. It is found that ET in such periods is 2.9 mm/d on average, whereas it is 3.8 mm/d in the remaining period.
3. The relation between approximate water depths below 1m and ET is established as: $ET = 1{,}977 * GWD_{previous\ day} + 5{,}75$ (with ground water depth defined negative below the surface level, see further
4. Figure 6.9).

Figure 6.10 presents a comparison between the original measured evapotranspiration data and the evapotranspiration time series generated based on the relation with measured ground water depths.

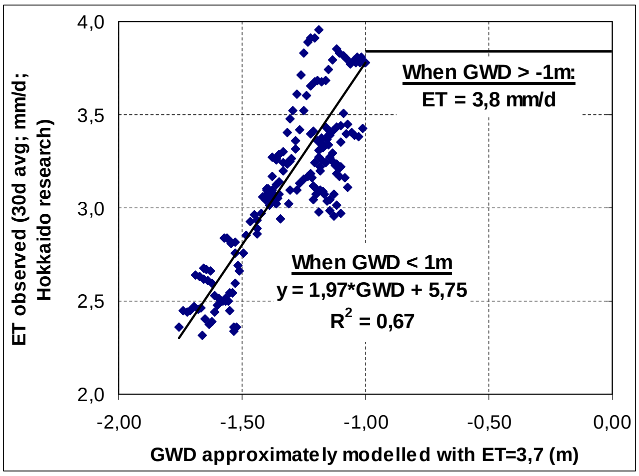


Figure 6.9 Relation between actual evapotranspiration and groundwater depth, for forest. Note that a first approximation of simulated groundwater depth was used here, with ET kept constant at an average value of 3.7 mm/d.

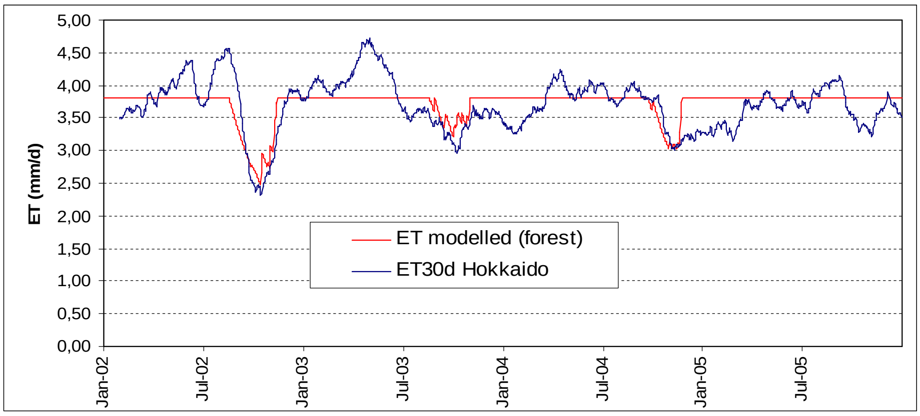


Figure 6.10 Observed evapotranspiration and simulated evapotranspiration, the latter derived using the relation with water depth.

6.3.2 Simulating water depths in deforested peatland

A spreadsheet model has been prepared to calculate the groundwater depth from the water balance, on a daily basis. The net flux of water to the groundwater table is calculated for each daily time step as the difference between the precipitation and the actual evapotranspiration. The change in water storage resulting from the net flux (upwards or downwards) is divided by the storage coefficient to determine the change in groundwater depth. If the groundwater level exceeds the surface level, all water on the surface is assumed to run off within a day.

The model was calibrated against the average of water depths monitored in 3 groups of dipwells to the NE ends of CIMTROP Transects 1, 2 and 3 in Block C (Figure 6.6). These wells are selected because they are furthest away (300-500m) and upslope of the main canal and therefore most representative of other peatlands in the EMRP area in terms of canal drainage impact (considering that canal spacing in the EMRP area is 2.5-10km). Water levels above the peat surface were excluded from the analysis, as the objective is to be able to simulate groundwater depths not surface water levels.

The calibration had two variables:

- Crop factor. This relates evapotranspiration in the degraded peatland to that in forested peatland. Most of the EMRP is deforested and will have lower evapotranspiration than forest according to common hydrological wisdom. However, the comparison of water depth records for different landcover types discussed earlier (Figure 6.6) suggests that the difference is not as great as might be assumed. A ‘crop factor’ of 0.8 was considered reasonable as an initial value for degraded peatland.
- Storage coefficient. This determines the way in which a change in water storage translates in a change in water level, the assumption being that the unsaturated zone remains at field capacity (which is realistic as long as there are periodic rain events rewetting the top soil). The initial value was 0.29, which was found for Sarawak peatlands (Hooijer et al 1997; Hooijer 2005) and fits well within the range of storage coefficients reported for other SE Asian peatlands.

It should be noted that changes in these two parameters have a very similar effect on water table fluctuations; there is a difference only in time steps during which rainfall occurs. This makes it difficult to independently optimize the two parameters. However this proved not to be a problem as the calibration required only minor modification of the staring values deemed ‘most likely’ in advance.

The best fit (r^2=0,72) for observed and modelled water table depths was achieved using a storage coefficient of 0.31 (only slightly changed from the initial value of 0.29) and sticking to the initial ET crop factor value of 0.8 (Figure 6.11).

Considering the data limitations and uncertainties involved, the fact that the best fit was achieved using (almost) the initial values considered most likely is seen as very encouraging for the model appraoch and parameters used, which will be developed further when more information becomes available (for EMRP and other areas).

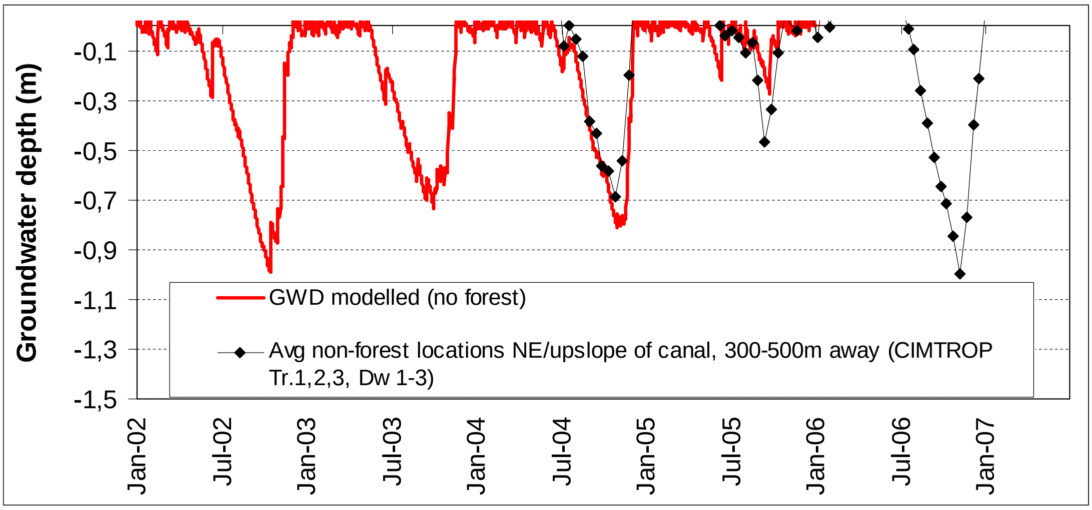


Figure 6.11 Observed and modelled groundwater depths at a deforested site in the North of Block C. Observed values are averaged from Transect 1, 2 and 3 Dipwells 20-22, which are all well away (300-500m) and upslope from the main canal and considered most representative for degraded peatlands in the EMRP area.

Assumption: lateral groundwater flow is negligible

A fundamental assumption in the above analysis has been that the local water balance is controlled entirely by rainfall, evapotranspiration and surface runoff when the water table is above the surface. No lateral groundwater flow is assumed to take place at the groundwater recording locations. This assumption is discussed elsewhere in this report, and based on observed water table fluctuations in Block A and Block C (see previous section), modflow model results (see following section) and the finding that most peat in the study areas is moderately to highly humified and therefore will have low hydraulic conductivity. The lack of groundwater flow is clearly confirmed for this part of Block C by the very good water balance model fit.

6.4 Modelling peat water flows and depths with Modflow

6.4.1 Model setup

In the north western part of Block A groundwater level has been measured along 2 transects crossing secondary blocks (Figure 6.12). Transect A is in a forested area, while Transect B is located in a more degraded forest area. The Modflow model application has been focused on calibration for these two transects.

Five different schematisations have been prepared for the Modflow model:

1. The whole north western part of Block A as bounded by the SPU canal in the North, the Kapuas River in the west and the Mentangai River in the east and south;
2. The secondary block containing Transect A;
3. The secondary block containing transect B;
4. Transect A;
5. Transect B.

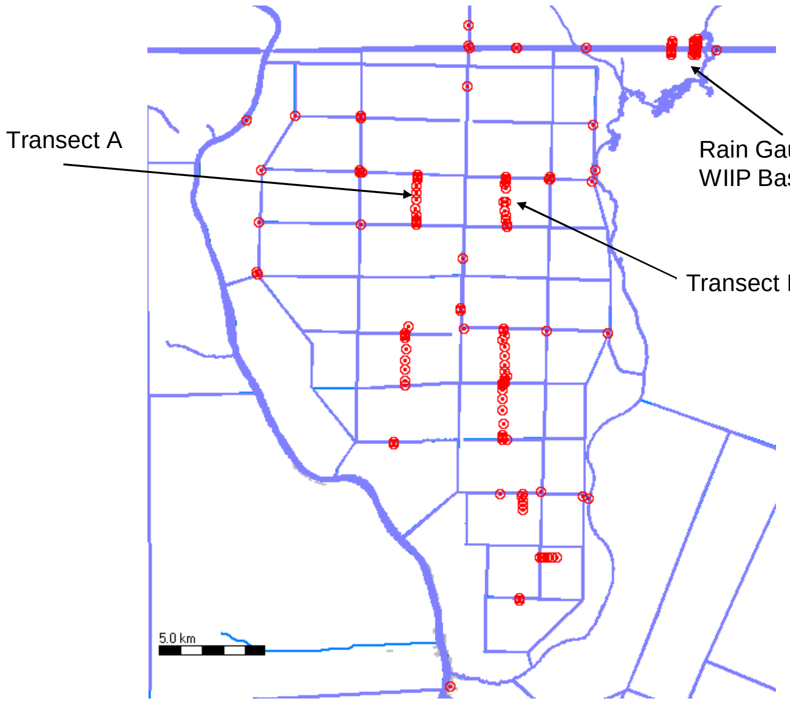


Figure 6.12 Location of Transects A and B in the northwestern part of Block A.

Details and results from the different schematisations are shown in the Technical Report Modelling of Peat Land Hydrology (Prinsen et al., 2008). In this paragraph only the most important results are presented, mainly based on calculations for the Transects.

The schematisations are based on the 100 by 100 metre DEM (see Section 11.2.3) and the peat depths from the peat map presented in Section 11.2.4). The EMRP North time series (see Section 11.1.1) has been used to describe the precipitation. Evapotranspiration and storage coefficient have used as presented in the previous paragraph.

Important assumptions are that there is no difference between horizontal and vertical conductivity, no anisotropy, no interaction with deeper mineral soil layers, and there are no groundwater extractions.

The models of both transect A and transect B strip each only consists of 2 columns and 26 rows, with river cells on the north and south edge of the strip (Figure 6.13). The assumption in these models is that the groundwater flow to the canals east and west can be neglected, since these canals are at a much larger distance from the strip than the northern and southern canal. This assumption has been checked using the models for the whole secondary blocks and proves to be valid. For calibration purposes, the DEM at the transect strip is adjusted to the observed surface levels at the dip wells. These levels are extrapolated to the 100 m grid.

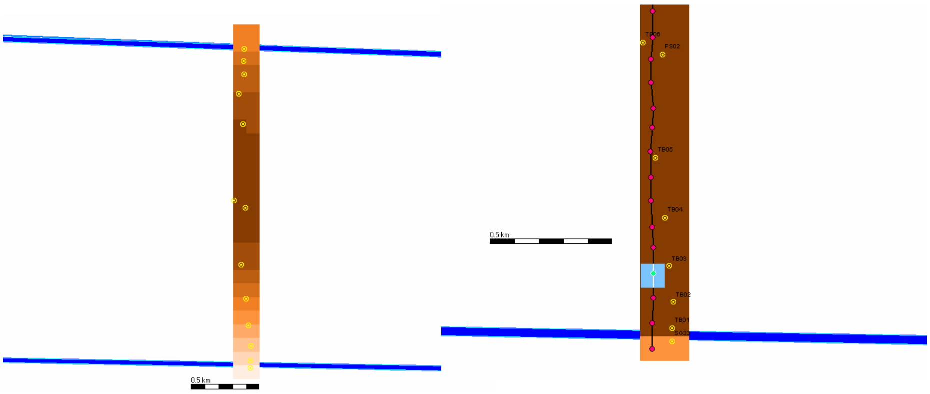


Figure 6.13 Schematisations of Transect A (left) and B (right) with cell 23 highlighted.

Groundwater measurements are only available from June 2007 till March 2008. Unfortunately this is a rather short record, including a relatively wet dry season and a wet season. So there are no measurements available for a very dry period like the second half of 2006; this data would have been interesting to check the groundwater drawdown in the dry season. It is therefore strongly advised to continue measuring the surface water levels and groundwater levels along the transects in order to extend the measurement time series.

The simulations are done for 1983 till March 2008 eliminating the effect of the initial conditions for the period where measurements are available. Surface water levels in the canals are prescribed based on measurements.

6.4.2 Calibration of the Modflow model

The most important parameter remaining to be calibrated is the hydraulic conductivity. The model has been run with the hydraulic conductivity ranging from 0.5 to 10 metres per day. Figure 6.14 presents some of the results of these runs for the period for which measurements are available. The dip well presented here is located approximately 250 meters from the canal. This location is selected because here the ground water level is most sensitive to the hydraulic conductivity. Cleary best results are obtained with a hydraulic conductivity in the range of 0.5 to 1.0 metres per day. This is a rather low value for peat and provides further evidence that lateral groundwater flow is of minor importance for the peat lands under consideration. The value of 1.0 metre per day for the hydraulic conductivity is used in the rest of the analysis.

Figure 6.15 presents a comparison of measured and simulated water levels along Transect B for one moment.

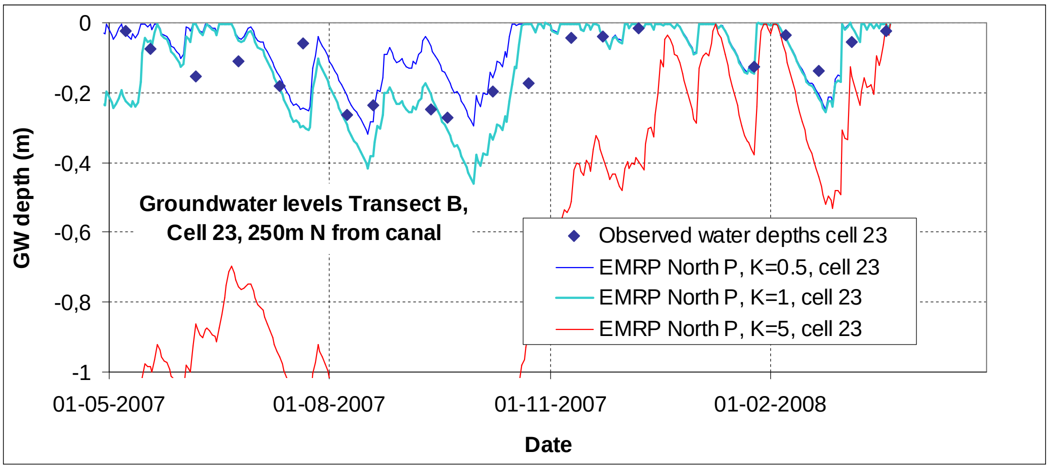


Figure 6.14 Calibration results for cell 23 in Transect B.

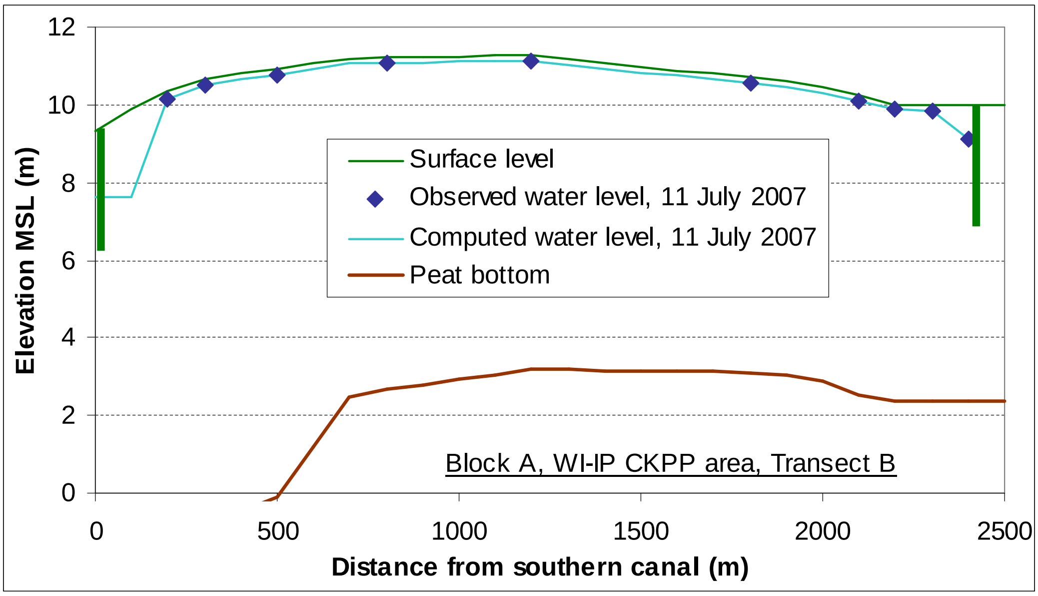


Figure 6.15 Measured and simulated Transect B ground water levels for July 11, 2007.

Transect A is located in a forested area. A two layer approach is chosen here to describe the impact of the hummock-hollow micro-topography and associated ‘interflow’ on the measurements and the surface run-off. Based on the measurements the depth of the top layer is set to 20 centimetres. The flow through the top layer has been described in the model in two different ways:

- As a separate groundwater layer with a high hydraulic conductivity; and

- As a reservoir on top of the soil from which runoff is described by a first order runoff coefficient in Modflow's runoff (SOF) package.

Results for both approaches and different values for the runoff coefficient are presented in Figure 6.17. Best results are obtained describing the flow through the top layer as runoff with a coefficient 0.1 per day. Results are presented in the form of a cross section in Figure 6.18.

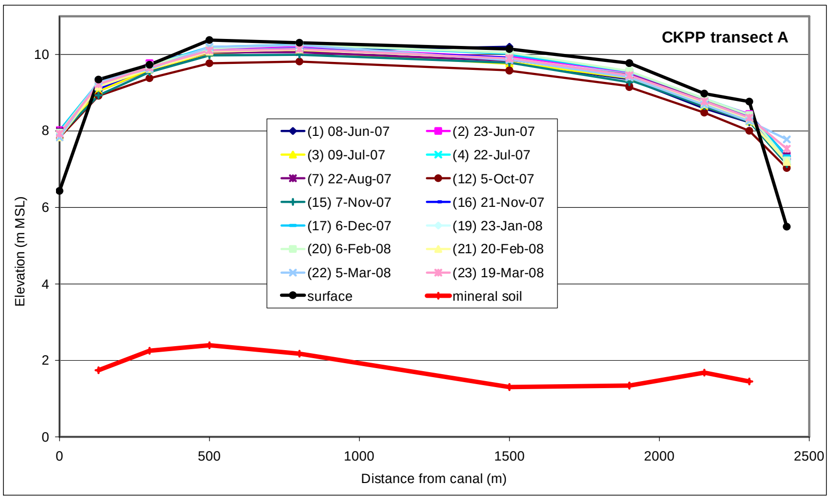


Figure 6.16 Cross section through EMRP Block A peatland (WI-IP CKPP intervention area) between drainage canals, showing elevation, peat depth, and groundwater depth at different times.

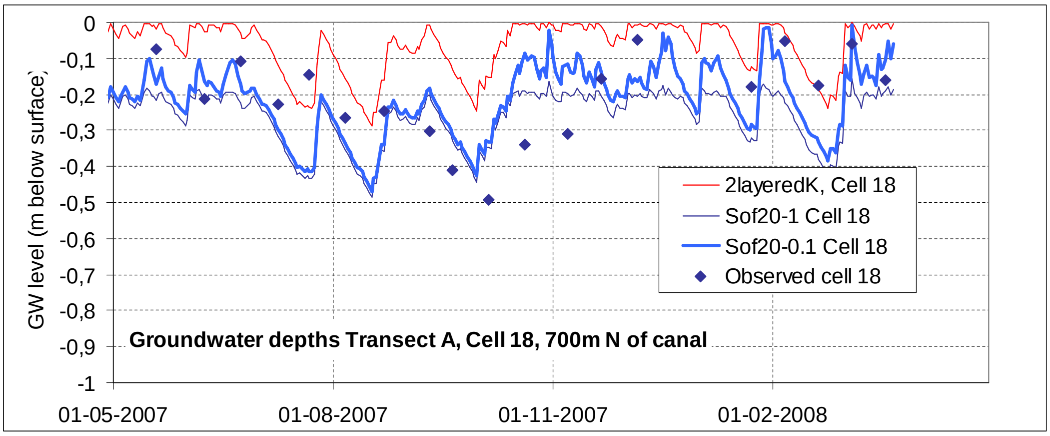


Figure 6.17 Calibration results for Cell 18 along Transect A.

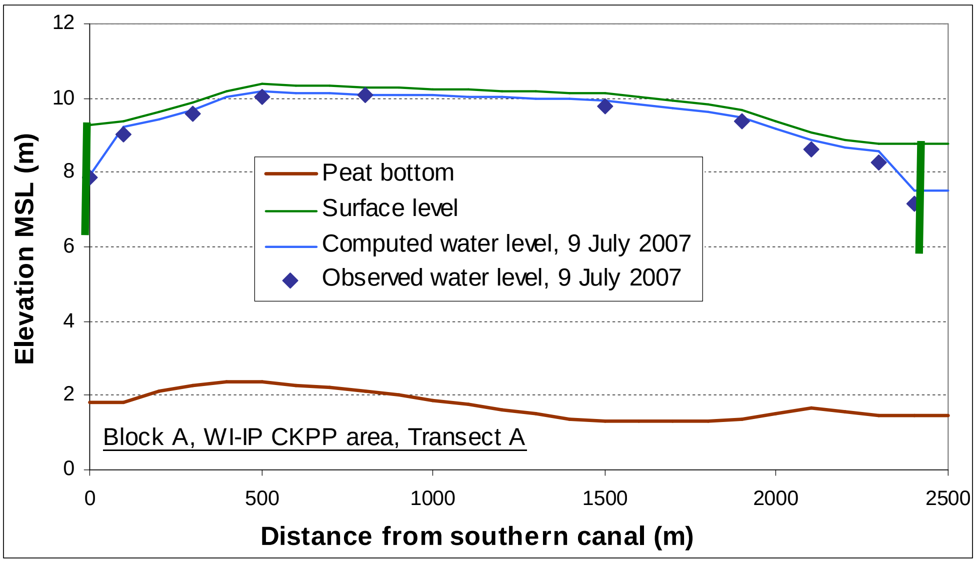


Figure 6.18 Measured and simulated Transect A ground water levels for July 9, 2007. The following parameters were used: hydraulic conductivity = 1 m/d, SOF runoff coefficient = 0.1.

6.4.3 Simulated transect water balance

Table 6.1 presents the water balance for Transect B as calculated by the Modflow model. Evaporation accounts for nearly two thirds of the water loss, while surface overland flow accounts for nearly one third. Groundwater outflow to the rivers and canals accounts for the remaining 6%.

Table 6.1 Water balance for Transect B for the whole simulation period.

	Transect B	
	m3	%
In		
Precipitation	29,060,230	100%
Out		
Evapotranspiration	18,365,231	63%
Net river/canal leakage	1,878,770	6%
Net storage increase	51,300	0%
Surface overland flow	8,764,800	30%
Total out	29,060,101	100%
Balance error	129	0%

6.4.4 Long term simulation of groundwater levels with Modflow

Figure 6.19 presents the results of a simulation of groundwater depth for the period January 1985 till March 2008 for Cell 14 which is located at the centre of Transect B. The dry years of 1991, 1997, 2002 and 2006 can be clearly identified. The deepest simulated groundwater level occurs in 1997 and is approximately 1.60 metres below the surface level. Due to the relatively low hydraulic conductivity and as appears from the measurements, the depth below the surface is rather homogeneous for all locations except for those within a few hundred metres from the canals. Therefore, the frequency distribution of ground water depth for the centre of Transect B can be assumed to be representative for most of the area. Table 6.2 presents the frequency distribution in a tabular form. It appears that the simulated groundwater depth is within 50 centimetres from the surface for three quarters of the simulation period and exceeds a depth of 1 metre below the surface for only 5% of the simulation period.

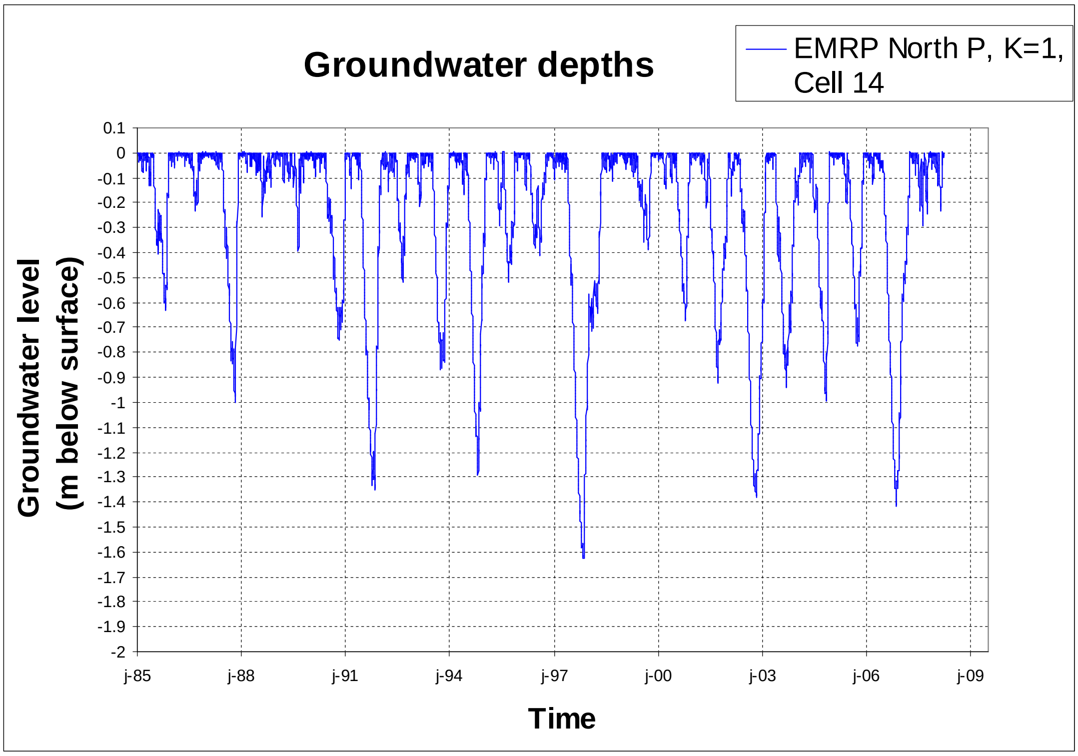


Figure 6.19 Simulated ground water depth at cell 14 in the centre of Transect B.

Table 6.2 Frequency distribution of simulated ground water levels for cell 14 in the centre of Transect B.

Ground water level (m)	frequency	%
above surface	171	2%
0.00 - 0.25	5624	66%
0.25 - 0.50	1072	13%
0.50 - 0.75	755	9%
0.75 - 1.00	435	5%
1.00-1.25	221	3%
1.25 - 1.50	180	2%
> 1.50	31	0%

6.5 Impact of drainage canals on peat land hydrology

This paragraph describes the impact of the construction in the early 1990's of drainage canals in the EMRP area on different aspects the hydrology of the peat lands.

6.5.1 Impact on surface water levels

Surface water flow in natural peatland

Peatlands in their natural state have high water tables, just above or below the peat surface, for most of the time. Especially large peatlands tend to have wide nearly-flat plains on top that can store rainwater above the peat surface for long time periods. In undrained peatlands in Sarawak it was found that slow runoff of surface water from peat domes towards blackwater streams, followed by prolonged storage along these streams that have very low gradients themselves, was the main source of dry-season flows from peatlands (Hooijer et al, 1997; Hooijer 2005). Surface water outflow can take weeks and is so slow that the resulting stream baseflow is sometimes mistaken for groundwater outflow (leading to the concept that peatlands are 'sponges' that soak up rainwater to slowly release it). In wet periods, storage of water on the surface is often such that there is decimetres of standing water for months on end. In very large and flat wetlands permanent lakes may form.

Apart from very low surface gradients, high surface roughness is a crucial factor in the slow movement of surface water through natural peatlands. This surface roughness is caused by the typical hummock-hollow microrelief at the base of a healthy peatland forest. Water flows from hollow to hollow through the litter layer and root material. In fact it can be debated whether this is really very slow surface water flow (with a high roughness) or very fast groundwater flow (through a top-layer of peat with a high hydraulic conductivity). We usually refer to this flow component as 'interflow'.

Impact of drainage on EMRP peatland surface water storage and outflows

Baseflow from intact peatlands as found in the EMRP area, i.e. the discharge in blackwater streams that is maintained for prolonged periods, originates mostly from delayed surface water flow (interflow) through a hummock-hollow and litter layer with high roughness. This flow component can continue for weeks after rainfall because large amounts of water can be stored on the surface of extensive peatlands where the distance to the nearest stream can be over 10 km, because the hummock-hollow layer through which this flow occurs has high roughness, because the top layer has a high storage coefficient (i.e. a certain drop in the water table results in much more discharge that the same drop when the water table is lower, in solid peat with higher humification), and because large-open water areas form along low-gradient streams. This delayed flow component has earlier been named ‘depressional flow’ (Hooijer et al, 1997; Hooijer 2005), and is referred to is ‘interflow’ in this study. Note that this flow component is sometimes attributed to groundwater flow through a top peat layer with very high hydraulic conductivity (likened to the ‘catotelm’ layer typical for temperate sphagnum bogs), and it is of course a but of a mix between surface water flow through hollows and groundwater flow through hummocks and the litter layer.

When intact peatland is drained, the most immediate effect is that the residence time of water at the surface is shortened, and surface water depths in wet periods are lowered, through three sequential processes and feedback mechanisms: 1) the distance to nearest drain is shortened causing faster runoff and hence faster lowering of surface water levels after rainstorms, 2) lower surface water levels will cause decomposition of hummocks and reduce the hummock-hollow topography, 3) surface gradients will increase, further accelerating runoff and lowering water levels. Where forest was removed before or during drainage, as is the case in much of the EMRP area, this process will accelerate. Where fires occur, the hummock-hollow microtopography is lost even faster.

The difference in flood retention between the undrained and drained situation has been assessed for the north western part of Block A using the mathematical model for hydrology and hydraulics, SOBEK. SOBEK provides the opportunity to simulate combined one and two dimensional flow of surface water. The 1D module simulates water flow in rivers and canals, while the 2D module calculates the runoff towards the canals. For this theoretical case it is assumed that the groundwater level at the start of the simulation as at the surface and no infiltration occurs. This assumption will normally be valid for rainfall events leading to floods in the wet season.

For both the actual and the undrained situation the runoff and discharge resulting from a rainfall event of 100 mm in one day has been simulated. For the natural situation the canals were removed from the model and a Chézy roughness coefficient of 5 m 0.5/s was used for the overland flow. The micro topography of the actual degraded situation is assumed to be more flat and therefore a Chézy roughness coefficient of 10 m 0.5/s was used, which means that the roughness is lower.

Figure 6.20 presents a comparison of the total discharge from the north western part of Block A during and after the 100 mm per day storm event. Roughly speaking, drainage has resulted in a 100% increase in peak discharge and a reduction in the duration of the discharge of 50%. Figure 6.21a shows the water depth at the surface 48 hours after the end of the rainfall event for the undrained situation and Figure 6.21b for the drained situation. It is clear that drainage has removed most storage quickly from the surface into the canals and rivers.

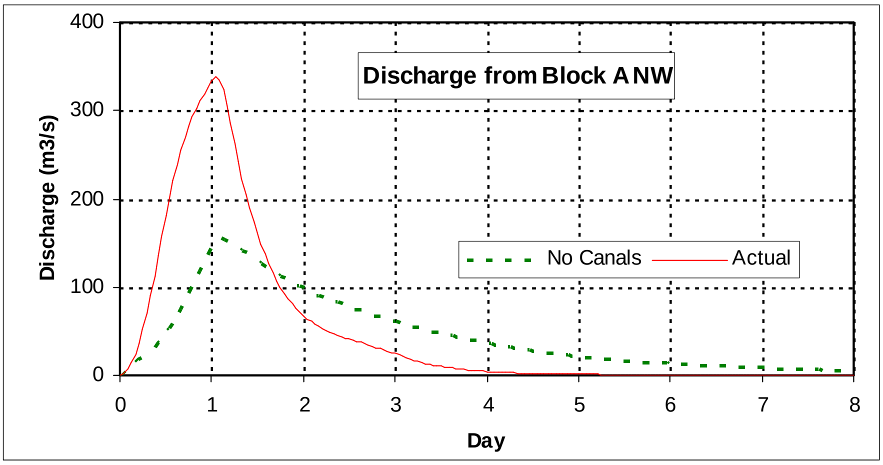
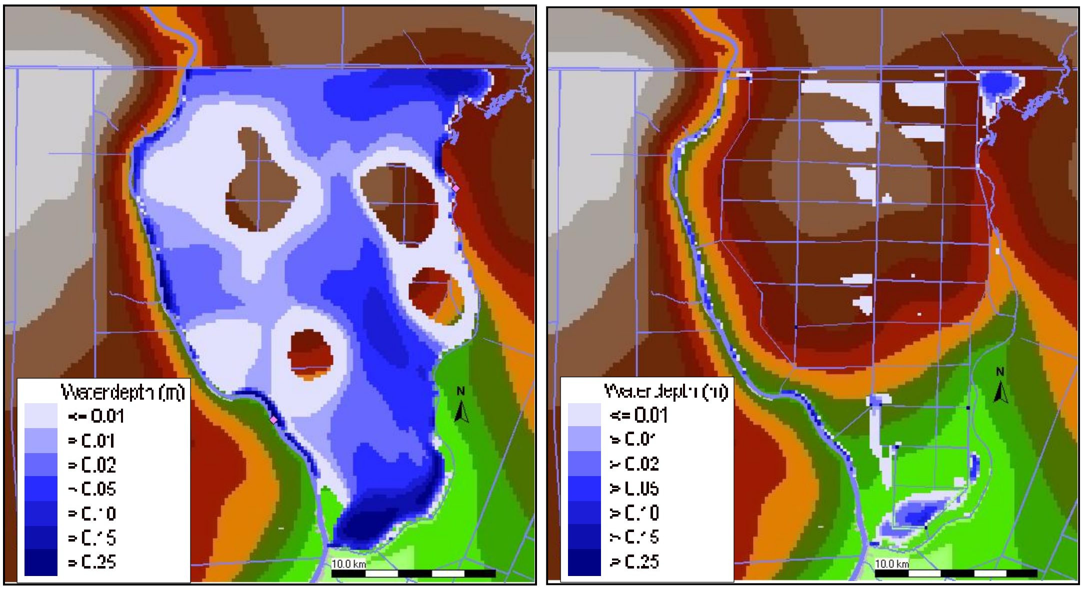


Figure 6.20 Simulated hydrograph of a 100 mm/day storm event for the north western part of Block A comparing the actual situation (in red) with the undrained situation (in green).



(a) (b)

Figure 6.21 Simulated storage of water at the surface 48 hours after the end of the 100 mm/day storm event a) for the undrained situation; and b) for the actual drained situation.

It can be concluded from the results presented above that the drainage of the north western part of Block A by the construction of a system of primary and secondary canals has resulted in a significant increase of the peak flow of storm events (i.e. the ‘flashiness’ of discharge). This reduction in peatland flow regulating capacity reduces the benefit of the peat land for the downstream area in the form of increased flooding and decreased baseflows. However it should be noted that this effect is very localized in this case; the discharges of the greater EMRP rivers are controlled mostly by runoff from the upstream rover basins, not from the peatlands.

6.5.2 Impact on groundwater levels

Groundwater flow in natural peatland

Groundwater flow in natural (undrained) peatlands is a small part of overall outflows because of the low gradients (mostly below 0.5m/km) and limited aquifer depth (usually below 10m); this is the case in all peatlands, but especially where hydraulic conductivity of the peat is low as appears to be the case in the EMRP area. If there is significant groundwater discharge, it is when water tables are high and within the hummock-hollow depth that is sometimes considered the 'acrotelm' (following an analogy for temperate peatlands); however this flow may also be considered surface water flow moving over a very rough surface. Dry-season outflow from natural peatlands is often very limited. This is the case even in peatlands where the peat is fibric and has high hydraulic conductivity: as peatlands have evolved to retain water, they will not release it to streams when it is most needed to keep the peatland wet (Hooijer 1997, 2005).

Historical impact of drainage on EMRP groundwater levels and flows

After drainage, groundwater flows become more significant because water table gradients increase. Where the peat has high transmissivity (conductivity*depth), groundwater flow can become the main mode of rainfall discharge (Hooijer, 2008). In that case the water table rarely reaches the surface level and can be controlled through canal surface water levels. However where peat has low hydraulic conductivity, groundwater flow will mainly occur near the drains. In most of the EMRP area, where hydraulic conductivies are low, groundwater flow is negligible for most of the year. Although water tables may still be lowered to significant distances from canals, this is mostly due to the fact that surface water runs off faster and the drop in groundwater table therefore started earlier as demonstrated in Figure 6.21.

6.5.3 Impact on subsidence and morphology

Where peat transmissivity is high, the impact from drainage can extend kilometres into the peatland and cause high subsidence rates over large distances. This will in time result in a rather smooth new morphology. In the EMRP area however where peat transmissivity is low, the impact from drainage does not extend far into the peatland and high subsidence rates are concentrated in the first few hundreds of metres from canals. This has created a pronounced new morphology as is most clearly visible in the NW part of Block A where a dense drainage network exists and each drainage compartment now is effectively a new mini-peat dome.

6.5.4 Impact on fire risk

Implementation of drainage canals in the EMRP peatlands has greatly reduced their period and depth of surface water inundation, and thereby advanced the moment the annual dry season groundwater drop starts, increased deepest groundwater depths and reduced soil moisture content. Drainage must thus have contributed to an increased susceptibility to fire in the area. The impact of the loss of forest, which kept the topsoil moist by blocking sunlight and wind, may be as great however.

6.6 Impact of rehabilitation dams on peat land hydrology

6.6.1 Blocking schemes

Precise determination of peatland rehabilitation dam locations, dimensions and designs requires knowledge of specific rehabilitation goals, resources and budgets that is beyond the scope of this project. It is useful, however, to provide a first estimate as to how many dams would be required to bring up water levels in specific peatlands.

Dams serve two separate but closely related purposes in peatland rehabilitation, which have somewhat different requirements with regard to dam spacing:

- The first is to bring up surface water levels in canals so at to reduce groundwater depths away from canals. It would be best to bring back wet-season water depths to the peat surface everywhere (as if there were no canals), but this would require a water step (water level difference over dam) of 0.2m or less over dams and therefore many dams. A target groundwater depth range needs to be set to determine the acceptable water step over dams. The water step required to achieve this target depends on peat characteristics (i.e. rate of groundwater flow) and on climate characteristics (especially rainfall rate in the dry season). This will be further studied beyond the current Master Plan project. However it is clear that implementing a water step of 0.5m would be a good start for the purpose of reducing peat subsidence and CO_2 emissions.
- The second reason to reduce the water step over dams is to reduce the pressure on them and hence to prolong their existence. A number of dams, built by different projects in recent years, have been rendered useless within a few years or even months because heads and flows over them have been too large. Design and head requirements for dams are to be determined in Cluster 4, but it seems clear that a water step of less than 1m is the maximum a dam can endure for a number of years.

Combining the two criteria results in a target water step range for peatland rehabilitation dams of 0.5m to 1m. Applying this target range to an elevation model allows rapid assessment of the locations and number of dams needed to raise water levels in specific peat areas. A first tentative assessment of locations (in Blocks A to D, excluding Block E where data is insufficient) is provided in Figure 6.22, and of dam numbers in Table 6.3. It is clear that hundreds of dams will be needed to bring up water levels in much of the EMRP area peatlands. This information does not allow planning and design, for which the drainage scheme design and other parameters need to be accounted for; however it could be the basis for a first rough cost assessment.

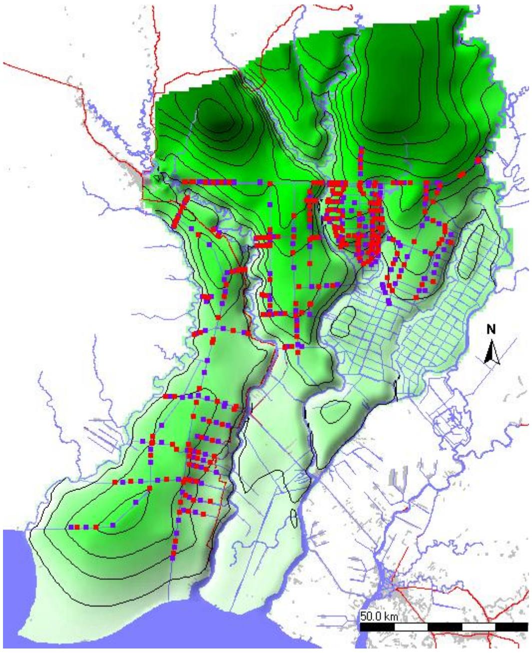


Figure 6.22 Rapid assessment of required locations of rehabilitation dams, based on the tentative peat depth map and elevation model developed in the Master Plan project (locations for an interval of 1.0 meter as red dots and additional locations for an interval of 0.5 meters as blue dots).

Table 6.3 Rapid assessment of required number of rehabilitation dams, based on Figure 6.22.

Peatland area (>1m)	*Number of dams needed for 1m water steps*	*Number of dams needed for 0.5m water steps*
Block A	92	191
Block B	61	116
Block C North	21	43
Block C South	37	72
Total	211	422

Given the typical dome-shape of peatlands, it is not surprising that in most cases relatively few dams would be needed to bring water levels up in the extensive flat top areas, compared to the larger number of dams needed to control water levels in the narrower but steeper slope areas towards rivers. It should be possible to optimize peat dam density and locations applying smaller water steps in flat areas, and larger water steps in steeper areas where there is less peat to be preserved both in area and in depth. However it is not possible to only bring up water levels in the flat top areas with deep peat. It will be necessary to place a number of dams where they will only improve water levels in small areas, simply to reduce the water step for the first dam upstream and to create a robust system.

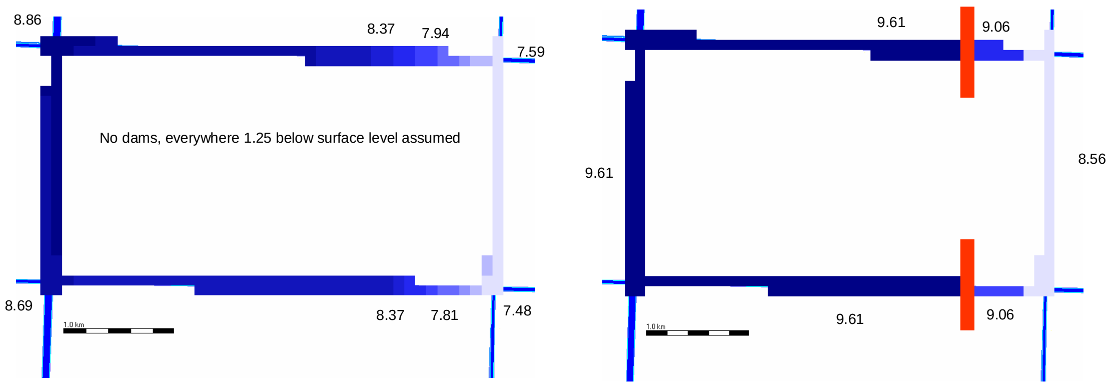
It should be noted that canal blocking in the EMRP area will often have little effect in the short term, because it only brings up water levels in a narrow zone along canals due to the limited groundwater flow through the peat in the area, and the current steep slopes around canals (after 10 years overdrainage). In the long-term however, bringing up and stabilizing water levels in peatlands will prevent further subsidence and degradation. Canal blocking should therefore be seen as a long-term measure, and should only be implemented when the long-term maintenance and protection of dams can be ensured.

6.6.2 Impact on surface water level

Once the natural peatland surface roughness and low-gradient topography has been lost through drainage and fires it can probably only be brought back through the same natural processes that shaped them in the first place: establishment of A) a permanent forest cover and B) a morphology that is in balance with a new stable water depth situation. Both processes will take several decades at best, possibly centuries. Canal blocking can help if is maintained for decades and establishes a new reference level where peat subsidence will stop. In the short term, canal blocking can not help bring water levels back above the peat surface if the morphology has been altered too much.

6.6.3 Impact on groundwater levels

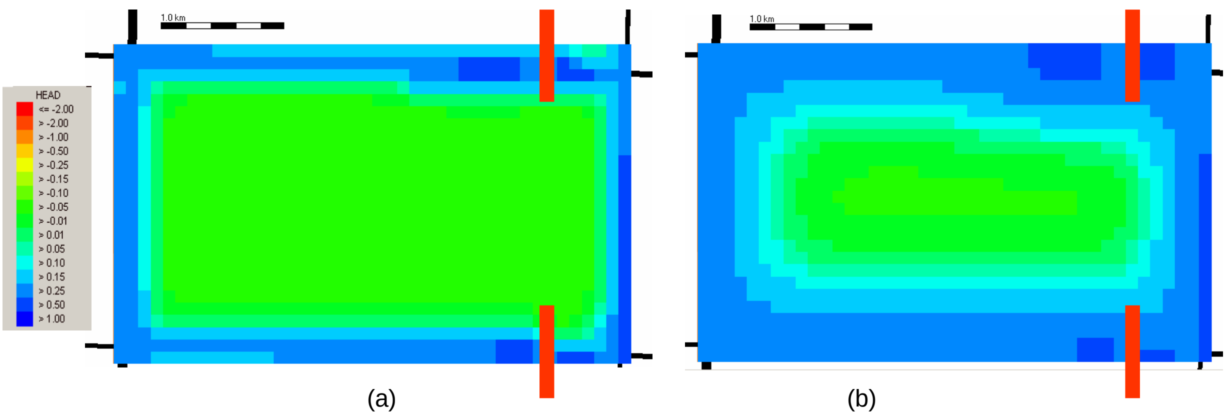
The impact of the construction of rehabilitation dams on groundwater levels has been quantitatively analysed using a Modflow schematisation for a hypothetical typical block surrounded by secondary canals, such as encountered in the north western part of Block A. The groundwater level in this block has been simulated on a 100 by 100 metres grid with hydraulic conductivity of 1.0 and 10.0 metres per day. The DEM for this typical block shows a mini peat dome with a maximum elevation of 11.25 metres in the centre and levels near the canals around 10 metres. Figure 6.23 presents the boundary conditions used for the actual, drained situation (a) and the situation after construction of rehabilitation dams with a water step of 0.5 metres (b). Simulation time, rainfall and evapotranspiration have been used as described for the transects in Section 6.4.



(a) (b)

Figure 6.23 Canal water levels around the typical block: actual situation (a) and after construction of two dams with 0.5 metres water steps (b)

Figure 6.24 presents the increase in groundwater level achieved by the construction of the rehabilitation dams with a water step of 0.5 metres for 8 November 1997, which is the period with the lowest groundwater levels. For the calibrated hydraulic conductivity of 1.0 metre per day (Figure 6.24a) the increase in groundwater level is limited to a zone of 200 to 300 metres from the canals. The increase in the rest of the block is negligible. Figure 6.24b shows that the zone with an increased groundwater level due to dam construction would increase to approximately one kilometre around the canals for peat with a hydraulic conductivity of 10 metre per day.



(a) (b)

Figure 6.24 Increase in simulated ground water levels (metres) after construction of dams with 0.5 metres water steps for a hydraulic conductivity of 1.0 metres per day (a) and 10.0 metre per day (b).

It can be concluded that in most of the EMRP area that is now impacted by drainage, canal blocking will hardly effect groundwater depths on the short term because transmissivities are low and drainage has created a new morphology that does not allow reflooding the peat surface.

6.6.4 Impact on subsidence and morphology

In the new peatland landscape that has been created by subsidence and fires in the 11 years since canals were implemented, canal sides are now 0.5m to 1m lower than the peat surface 1km away from the drain. This means that dams, even if constructed with crest levels at canal side level, will not allow much peatland to be kept wetter than it is now. This, in turn, means that dams can not reduce subsidence in the short term and may not stop the process for decades to come. If wet season water levels are raised to canal side levels now, and not allowed to drop far in the dry season, peat subsidence would still continue until a new balance between morphology and hydrology was found which would probably bring peat surface levels not far above the canal sides.

6.6.5 Impact on fire risk

Canal blocking affects dry season groundwater tables near canals in the EMRP area, but hardly further away from canals. There is likely to be a beneficial effect of canal blockings on fire risk, as fires often start close to canals and might be contained by wet zones around canals. In extremely dry years, however, canal sides will be extremely dry with or without canal blockings and just as susceptible to fire.

6.7 Peatland water depth as a predictor of fire risk

Being able to predict fire risk from groundwater depths and/or rainfall history, parameters that can easily be measured on-site, will allow land managers to reduce fire risk more efficiently. Regulations banning the use of fire for land clearing could be enforced more stringently when fire risk 'thresholds' are exceeded; this is probably the most efficient measure to reduce fire risk in the EMRP area, especially in the short term.

6.7.1 Background

It takes two things for peatland fires to occur: dry peat soils (fire fuel) and people who set them on fire (fire source). If we assume that the second factor has been constant every year at least for the last 10 years or so, variation in how dry the peat soils are should explain much of the year-to-year variation in fire extent and frequency. The assumption of a constant fire source is not entirely realistic, as there are patterns and trends in where people set fires, but that analysis is beyond the scope of this study.

The dryness of peat soils is determined by its moisture content: in the top soil (which determines ignition rate) and at greater depth (which determines how much peat is available for burning). However soil moisture monitoring data are not collected in peatlands on a regular basis, so water depth is the best proxy. We know the following about the relation between water depth and soil moisture in peatlands in general:

- Moderately to highly humified peat has fine pores and hence a 'capillary rise zone' of up to 0.4m depth, meaning that the top soil would be saturated or nearly saturated when water depth is within 0.4m.
- Evapotranspiration rates in EMRP peatland forest drop steeply when water depth drops below 1m, suggesting that water availability becomes limiting to the shallow rooting system. This in turn suggests that soil moisture content in the top 0.6m (approximately, taking into account capillary rise zone) of peat must be very low.

6.7.2 Fire extent/frequency data

Fire extent data may be a better descriptor of drought-related fire risk than hotspot data, but are harder to obtain. The University of Leicester (Sue Page and Agata Hoscilo) has provided a preliminary data set of fire scar extent for Block C (1991-2005), which has been used to evaluate the relation with water depth. Note that the dataset is not yet complete and does not include the years 1998, 1999, 2000, 2001, 2003 and 2006. From the fire scar data available, the years 1991, 1997, and 2002 clearly stand out as fire-prone years. Although no fire scar data are yet available for 2006, it is known from other sources that extensive fires occurred in that year as well.

6.7.3 Water depth data

Peatland water depths have been modelled accurately in the EMRP Master Plan project. Long-term series of water depths for the Southern and Northern parts of the EMRP area have been produced as shown in Figure 6.25. The following observations are relevant:

- Drought periods occur simultaneously in the Northern and Southern part of the EMRP area, but are significantly longer in the Southern part. Figure 6.26 presents the annual water depths statistics for the southern part of the area.
- There appears to have been a trend towards lower dry-season water depths over the last 25 years.
- Water depths are below 0.4m for prolonged periods in most years including most years with limited fires (Figure 6.27). This water depth is therefore not a suitable 'fire risk' threshold as has been suggested.
- Greatest water depths always occur in November, usually mid-November.

- Water depths in excess of 1m are maintained for long periods only in a few years: 1991, 1997, 2002, and 2006. Water depths in excess of 0.8m also occur for prolonged periods in 1994 and 2003 (Figure 6.27).

6.7.4 Analysis and discussion

The data show that years with a water depth below 1m correspond to years with the most extensive fires: 1991, 1997, 2002 and 2006; with r^2=0,75 a good fit is found between the of days with water depth below 1m and the fire scar extent (Figure 6.27).

A water depth of -0,8m may be a suitable threshold value in an easy-to-use early warning system: when water depth exceeds this, fire prevention measures could be enforced. Water depths can be calculated from the water balance or can be measured directly at a number of fixed reference locations. It is also possible to use a cumulative rainfall index corresponding with this water depth as a fire warning index. An index based on only the number of days without rain, as is often used by fire fighting teams, may be less suitable as this does not account for rainfall intensity: a week of low-intensity rainfall may hardly affect water depth while a single extreme rainstorm can end a drought.

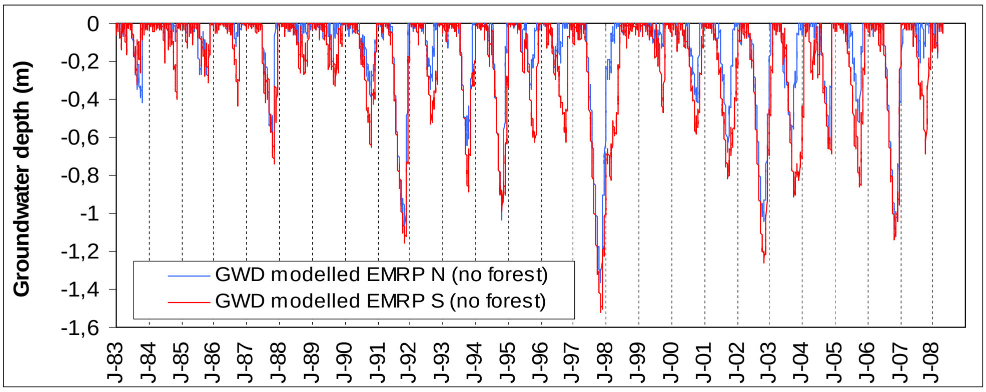


Figure 6.25 25-year series of modelled groundwater depth for the Northern and Southern part of the EMRP area (different rainfall input).

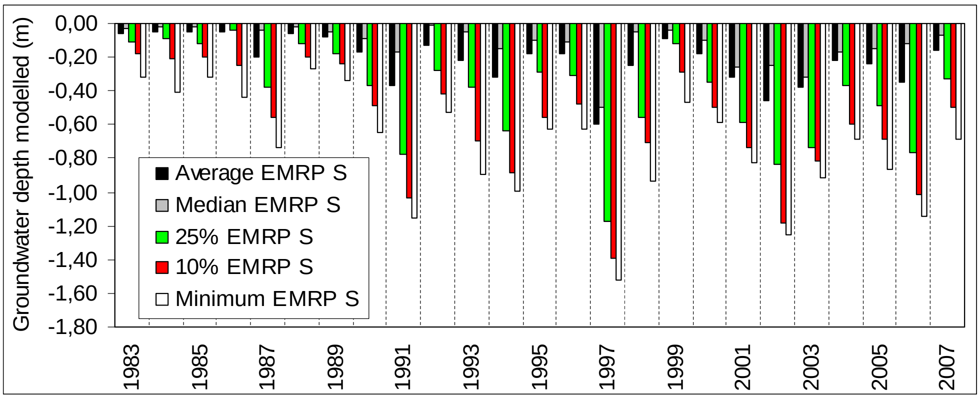


Figure 6.26 Annual water depth statistics for the EMRP South area.

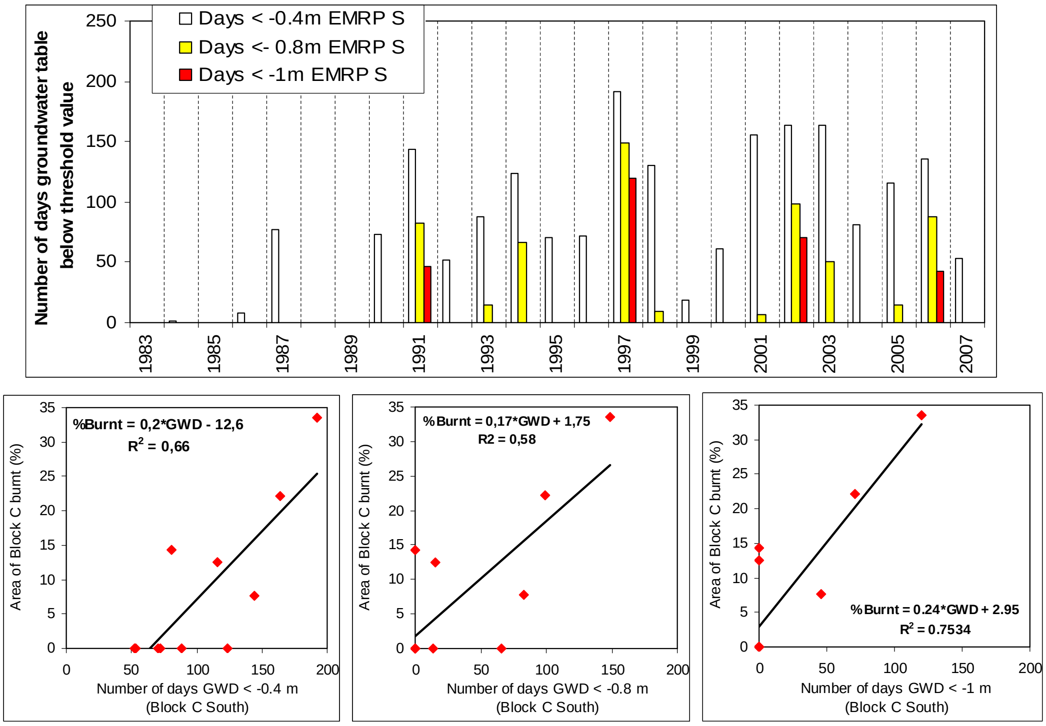


Figure 6.27 Water depth threshold exceedance in relation to annual burn extent in Block C.

7 Hydrological model and database transfer and training

7.1 The need for capacity building

The hydrological model is a platform for analysis, not a stand-alone end-product in its own right. Equally, the EMRP hydrometeorological database is a source of information for analysis. Only by systematically storing, quality-controlling and analyzing data in a digital format can all deficiencies and errors be detected. And only by submitting to the rigorous discipline of a model environment will inconsistencies in analysis assumptions be revealed.

Neither systematic quality control of hydrometeorological data, nor proper modelling, have been practiced in the EMRP area to date (apart from a few projects in the late 1970s and early 1980s, with Puslitbang). In fact much data used in the Master Plan hydrological analyses were not available in digital format, and most data had never before been used for analyses or planning purposes. The consequences of this are clear in many ways. Had proper elevation and hydrological data been available and analysed at the time of the EMRP planning in the mid-1990s, and had analysis results played a role in decision making, the project would not have been implemented in this way, with ‘irrigation’ canals running over peat domes and agricultural production planned in areas that are frequently flooded.

As a motto of the Master Plan project, and indeed of the Inpres, is to “avoid making the mistakes of the past”, an important lesson to learn from past is that data and analysis can be the only sound basis for decision making, certainly when hydrology and water management is concerned. Therefore, starting the capacity building process in these areas has been an important aim in the Master Plan project. As this has been a very brief project (10 months), and capacity building in these complex matters will take years, it is expected that these activities will continue in coming years.

One aim of co-operation and model transfer to Puslitbang is to allow them to develop the ‘COMPREHENSIVE STUDY ON IMPROVED WATER MANAGEMENT IN EX MEGA RICE PROJECT’ which

Puslitbang aims to start up in the coming months and which would use EMRP MP project outputs.

7.2 Capacity building activities

This has been done in three ways:

1. Developing models in a way that they can continue to be used and further developed as analysis platforms for years to come, both in terms of well-structured and transparent set-up and of using a well established state-of-the art platform that is widely used by consultants and Government planners internationally (SOBEK).
2. Involving local consultants in all activities, including a consultant 'on loan' from the CKPP project (Nasrul Ican).
3. Involving Indonesian hydrologists, from Puslitbang, in model development in 'on the job training' (in March and June 2008).
4. Transferring the model and data to Puslitbang, part of PU responsible for this type of work in planning and development projects.
5. Introducing the counterparts to the 'help functions' in SOBEK, which is the digital manual.
6. Organizing a 1-week further model training in Bandung (late July 2008).

8 Summary discussion and conclusions on hydrology aspects relevant to planning, design and management

Several findings in the EMRP Master Plan project hydrological studies have major implications for water and land management options and planning requirements. Some of these are somewhat surprising, other findings confirm existing knowledge that has however insufficiently been considered in past planning and management in the EMRP area.

This section will also discuss the implications of some findings of the subsidence modelling and scenario analysis activities in the project, reported in a separate report. Because hydrology and subsidence are so closely linked in peatland areas, the two can not be seen separately.

8.1 Considerations on rainfall regime in the EMRP area in relation to peatland rehabilitation and agriculture development

Rainfall patterns in space in time. Three important patterns are found that should be taken into account in the planning of peatland rehabilitation and development efforts:

- There is a pronounced gradient in rainfall away from the coast, the Southern part of the EMRP area receiving rainfall at or below 1900 mm/y, the Middle and Northern parts around 2200 mm/y and above 2500 mm/y, and the River basins to the North of the EMRP area around and above 3000 mm/y. Variations within the EMRP area significantly affect peatland water depths and may make the difference between success and failure in rehabilitation. On the basis of rainfall patterns, conditions for peatland conservation and rehabilitation must be considered more favourable in the Northern than in the Southern part of the EMRP area.
- There is a pronounced and long dry season with little rainfall in all of the area, but especially pronounced in the South. In most years, a net water deficit exists for 3 to 5 months (June to

September); in 1 in 10 years it exists for 6 months (May to October). This means that conditions that allow fires to spread over large distances in degraded areas are not the exception but will inevitably occur every few years (possibly most years in the Southern part of Block C), whatever the water management will be. It also means that water availability in the dry season may be limiting to some crops and should be taken into account in tree planting schemes for rehabilitation as well as plans for agricultural development.

- Over the last century, and especially in recent decades, there appears to have been a trend towards dry seasons becoming even longer and drier, with rainfall dropping especially over Feb-May. Rainfall over the other months has remained more or less constant. The implication may be that much peatland may have been too dry for peat accumulation even before drainage started in the 1990s (i.e. most peatlands are now carbon sources even in their natural state), and that peatland vulnerability to drainage has increased due to climate change. It is unsure whether this is a result of local change (possibly due to forest loss) or of global climate change.

8.2 Implications of flooding and drainability for present and future agricultural developments options in the EMRP area

The EMRP area is a River Delta, and the entire landscape and nature of the area is formed by hydrological processes: intermittent flooding and sediment deposition in mineral areas, and permanent waterlogging and accumulation of organic material in the peatlands. It follows that hydrology sets the boundary conditions for what development and conservation approach is appropriate for the area.

- Flooding from rivers as determined by water flows from the upstream River Basins of the Barito, Kapuas, Kahayan and Sebangau Rivers. Hydrological model results and field observations show that large-scale and prolonged river flooding presently occurs mostly along the Barito River, affecting parts of Block A and D. Flooding is most frequent and deepest in the Jenamas and Dadahup areas, which may be considered unsuitable for most agricultural uses.
- Inundation caused by standing rain water transported over only short distances. This type of flooding occurs both in depressional areas in mineral soils and at the footslopes of local peat domes. It is usually shallower and shorter-lived than flooding by rivers, but it is more frequent and affects a larger total area.
- Drainability of existing and possible drainage schemes, as a function of surface gradients and river/tidal water level fluctuations.

It is found that in most peatlands in the EMRP area, drainability will become major problem after a few decades of continued drainage and subsidence, as is demonstrated by combining subsidence model results with hydrological models.

- Tidal fluctuations along rivers, as determined by marine tidal water level fluctuations and water flows from upstream river basins. Tidal fluctuations extent well inland in the EMRP area, especially in the dry season. However tidal fluctuations that allow tidal irrigation do not extent nearly as far and are mostly confined to Block D.

8.3 Key characteristics of peatland hydrology in the EMRP area, with a focus on the impact of drainage

Peatland hydrology in the EMRP area, as studied in the Master Plan project, is mostly the hydrology of drained and degraded peatlands. Over the past decade, drainage by canals has had major and largely irreversible impacts on the EMRP peatlands, over great distances. The hydrological conditions in parts of Block E may be quite different, but we did not have the data to asses this. The following key findings are reported:

- Groundwater table fluctuations in dry periods are controlled mostly by the local water budget, i.e. rainfall and evapotranspiration, and are affected by groundwater flow over a zone of 500m width at most. This is because peat hydraulic conductivity is very low (around 1m/d), at least in the Block A and C study areas, which is explained by the relatively high degree of humification of peat in the area (which is hemic to sapric). This means that the impact zone around canals appears more limited than has been reported for some other peatlands. The implications for water management is that canal blocking will in the short-term have a limited impact on groundwater depth.
- A further impact of drainage is by lowering water tables in a zone along canals through groundwater drainage. Because the drainage impact in the EMRP area is far more severe close to canals, subsidence and possibly fire frequency has been greater there, resulting in relatively steep surface slopes away from canals. Peat surface elevations 1km away from canals are now generally 0.5 to 1m higher than canal sides. Instead of the original low-gradient peatland landscape that functioned as a single hydrological system over tens of kilometres, a ‘mini-dome’ topography has in fact developed in 12 years that now controls hydrology.
- In the two study areas within the EMRP area, both with limited groundwater flow rates due to low hydraulic conductivities,

subsidence is greatest in a zone of less than 500m along canals. However subsidence will extend further at lower rates, probably to well over a kilometre. Note that with the present data it is possible to estimate the subsidence rate near canals, but not far away from canals.

- Evapotranspiration in forested and non-forested peatlands is found to be similar to that in non-peatland areas with similar land cover. ET is reduced significantly when water tables are very low and soil moisture becomes limiting to water availability to vegetation. Being able to quantify ET has allowed simulation of long-term historical water depth records and estimation of current water depths for early warning purposes.
- Baseflow from intact peatlands as found in the EMRP area, i.e. the discharge in blackwater streams that is maintained for prolonged periods, originates mostly from interflow, i.e. from delayed surface water flow through a hummock-hollow layer with high roughness, not from groundwater flow. Peatland drainage in the EMRP area has greatly affected surface water storage and flows, over large distances. The reduced distance to drainage has dried out and thereby removed the hummock-hollow top layer which had an important role in keeping peatlands wet in their natural state. It has thereby increased peak runoff, reduced delayed runoff (baseflow) from peatlands, and prolonged the period that water tables are below the peat surface. This in turn has caused peat decomposition and hence subsidence, and has increased fire risk.
- Both peatland study sites in the EMRP area were relatively narrow peat domes (10 to 20 km across), as they are bordered by rivers, with relatively highly humified peat and relatively steep slopes. It is likely that larger peat domes with lower surface gradients and deeper peat, particularly the peatlands in Block E and B, have less humified peat and therefore higher hydraulic conductivity. This would mean hat the impact of drainage on groundwater depth and therefore subsidence would also extend further.

8.4 Considerations on canal blocking options and requirements in the EMRP area

There is no debating the disastrous effect that drainage has had on the EMRP peatlands. This, however, does not necessarily mean that blocking canals will undo this damage; there are no quick and easy solutions to peatland rehabilitation. Much damage done to the peatland hydrological system is largely irreversible and can only partly be remediated, and this will take decades.

8.4.1 The impact of canal blocking on groundwater level, subsidence and CO_2 emission

The implication of the limited groundwater impact zone along canals, in combination with the new 'mini dome' morphology, is that canal blocking 10 years after drainage can have only limited impact on water levels further away from canals. This, in turn, means that the impact of canal blocking on fire risk and subsidence is also limited to a narrow zone, at least in the short term. In the long term, higher canal water levels should create a higher 'base level' where peat subsidence should stop. Therefore, canal blocking should be seen as a long-term measure that will be useful if infrastructure will be maintained for decades to come.

In the future, subsidence will continue until a new 'hydromorphological' equilibrium between hydrology and peatland shape has been achieved. The timing and shape of this equilibrium depends on many factors including peat hydraulic conductivity, rainfall, evapotranspiration and fire risk, and can not be predicted with current data. However it is clear that it will be achieved sooner with higher water levels. If canal blockings can be maintained at constant levels over decades to come, the peatland landscape will find an equilibrium as determined by the raised canal water levels. Note that the morphology will not return for centuries to the original smooth peatland shape with a natural drainage pattern, but will maintain the new 'mini dome' shape.

These conclusions on the impact of drainage and canal blockings apply to the study areas in Block A and the Northern part of Block C. The impact of drainage is known to extent much further in some other Indonesian peatlands with flatter topography and higher hydraulic conductivity, such as the Kampar Peninsula in Riau. It may be that the latter situation also applies in Block E and the Southern part of Block C (and in the Sebangau peatlands to the West of the EMRP area), where peatlands are more extensive, but we have no data for those areas.

A further implication of the findings is that canal blocking in the EMRP area would have been a lot more efficient if it had been implemented within a few years after drainage, when the morphology would have been less disturbed and it would have been possible to bring up surface water levels over larger areas. A lesson may be drawn from this for other drained and degraded peatland areas where rehabilitation may be considered: time is of the essence in peatland rehabilitation.

8.4.2 'Reconnecting' peat domes through canal blocking

A basic principle in peatland management is that water levels need to be managed at the scale of peat domes. In the case of the EMRP area, where morphology and hydrology have been significantly altered during 12 years of overdrainage and the original domes have effectively been modified to multiple 'sub-domes', the question is now whether these sub-domes can still be reconnected hydrologically.

The largest-scale example is Block E, where two peat domes east and west of the Kapuas River have effectively been split by the E-W SPU canal; the lower parts of these peat domes are now in Block A and Block B. The SPU canal is the widest canal in the EMRP area, in fact that are two parallel canals, some 25m wide and about 100m apart. The canals have drained freely for many years and there have been fires along long stretches; the landscape has been lowered by 1 to 2 metres along their entire length, over a width of hundreds of metres.

It is found that the morphology along the SPU canal has been altered to the extent that the surface water systems of the Block E peat domes can not be reconnected to those of the Block A and Block B peat domes, in a rehabilitation scenario. When all canals including SPU are blocked and water levels along them will more or less follow the ground surface, canal water levels along the SPU canal will be 1 or 2 metres below those in the peat domes on either side, and it will not be possible to generate water flows across the canal.

Not being able to reconnect surface water systems in Block E peatlands to Block A and Block B does not mean that blocking the SPU canal is not useful. Bringing up water levels along this canal, in more places than is now the case, will reduce further subsidence along canals and slow down further destabilization the hydrological system. It could also serve to limit access to the area.

8.4.3 Restoring baseflows from peatlands

Baseflows from peatlands are much reduced after drainage, because the travel distance that runoff has to cover to the nearest open water system is much reduced, and because the hummock-hollow surface layer which has high resistance is removed. Canal blocking does not reduce the travel distance, as canals stay in place, and does not bring back the hummock-hollow layer. It does bring up water levels in canals and a narrow zone around them, but the effect of this on baseflows will be small. Groundwater flows are not a major flow component in the EMRP area (or at least not in the two study areas), so do not contribute much to baseflow, but this component may in fact be reduced when canal water levels are brought up and gradients of groundwater tables towards canals reduced. It is therefore concluded that peatland rehabilitation will not have a great effect on baseflows in streams and in agricultural drainage systems adjoining peatlands (where it is thought they could have a 'flushing' effect, reducing salinity and acidity).

8.4.4 Monitoring and assessing the actual impact of canal blocking

It is worth noting that assessment of effectivity of canal blockings, and of water management impacts on the peatland system in general, is only possible on the basis of process-based quantification of the system functioning. Impact assessments based on year-to-year comparison of water depths, flood extent or fire extent do not allow for variations in rainfall and can therefore not provide insight in the actual effectiveness of measures. For example the dry season of the year 2007, in which dams were piloted by several projects, has been one of the wettest on record with very high water tables everywhere regardless of water management conditions, and therefore does not provide a suitable reference year for evaluating dam efficiency.

8.4.5 Peatland restoration vs rehabilitation

The above considerations on the impacts of drainage on the peatland water system, and the potential effectiveness of canal blocking to bring water levels back up, show that undoing peatland drainage is not simple. In fact the often-used term ‘hydrological restoration’ is not really accurate because it is not possible to fully restore what was there before. At least three aspects of the original hydrological system can not be brought back for many decades, probably centuries:

- The original intricate and ‘diffuse’ surface water drainage pattern, of dry hummocks and wet hollows that lead into small rivulets leading into larger streams, is lost.
- Secondly the hydrological characteristics of the upper peat layer have been lost after being dry and decomposing for over 10 years now. In most areas, especially where fires have taken place, the ‘hummock-hollow’ top layer facilitating interflow has been lost and almost all water flow is now aboveground apart from a zone along canals.
- Furthermore, the original peatland morphology, with very gentle slopes over long distances, has been replaced by steeper slopes over shorter distances towards the nearest drain, resulting in faster runoff and more variation in groundwater depth.

Considering the above fundamental changes, interventions to undo peatland drainage can in the short only aim to bring back the key characteristic of high water levels, and even that not to natural levels. This should in the short term reduce peat decomposition (but not completely), allow peatland tree species to survive and germinate (but not all), and enhance baseflows to adjoining agricultural areas and streams in the dry season. Over decades of maintained improved water management, gradual further restoration will follow as the peatland morphology finds a new balance between hydrology and ecology.

Where the aim is to prevent further peatland drainage, drainage by logging canals should be prevented. If logging in peatlands is necessary, the preferred method of log removal is by light rail (without side canals) which does less damage to the peatland hydrology and will allow more rapid regeneration of the forest.

8.5 Hydrology, water management and fire risk in the EMRP area

Some of the findings on peatland hydrology and water management in the Master Plan project have implications for fire risk assessment and fire prevention planning.
In much of the EMRP area, including the densely drained NW part of Block A, water levels are high for most of the year. This is however often not a sign of 'healthy peatland', but the result of limited groundwater flow rates (because the peat has low hydraulic conductivity) and degraded topography (due to subsidence and fires).

Prolonged inundation with standing rain water takes place especially in burnt areas (where depressions have formed) and along lower-lying canals (where peat has subsided close to canals). This inundation is probably an important factor in preventing vegetation regrowth (this was also reported for Jambi peatland).

In the dry season, water depths in drained and burnt areas are lower everywhere than they would be in natural conditions, because the top 'hummock-hollow' layer of peat and litter has been removed that A) delayed runoff through 'interflow' for weeks because of its high hydraulic roughness, and B) has much higher storage coefficient than the current top layer of decomposed peat. In most of the area, however, water table fluctuations in the dry season are solely the result of the local water budget, i.e. rainfall minus evapotranspiration, which limits water depths to within 0.8 m in most years. Along unblocked canals however, water tables are lowered further by groundwater flow and can be below 1 or even 2 metres frequently and for prolonged periods.

Peatland drainage and associated degradation has enhanced fire risk in the following ways:

- Groundwater depths are lowered in all peatlands affected by drainage, because the top peat layer that regulated hydrology is removed, facilitating fire ignition and spreading.
- Groundwater depths are lowered even further along canals, through groundwater flow, further increasing fire risk.
- Lack of forest cover where areas are indundated in the wet season, as is the case especially in burnt areas and along some canals,

further enhances fires risk in the dry season by allowing the topsoil and herbaceous vegetation to become very dry and flammable.

- Where there are canals in areas with remaining forest suitable for logging (Block B, Block E, Sebangau), canals are the main access routes and zones around canals are most heavily logged, exposing and drying out the peat surface.
- Finally, canals allow easy access to degraded peatlands for people setting fires (intentionally or accidentally). Most peatland fires therefore start along canals.

The tentative conclusion is that while the entire peatland area is at enhanced risk of fires after drainage, the highest risk often occurs along canals. Consequently, overall fire risk in peatlands can in many cases be reduced most effectively by controlling fire risk along canals. The next question is how improved water management in canals can contribute to reduced fire risk. We offer the following considerations:

- Canal blocking can bring up water tables in zones along canals, though in many cases not over large distances from canals.
- However, water tables along canals in very dry periods will still be well below the adjoining peat surface level in the EMRP area, because there is loss of canal water through leakage and very little replenishment by groundwater of canals in dry periods.
- The adapted morphology along canals, with relatively steep gradients towards them, means that canal blocking may in fact result in increased flooding in the wet season of a peatland zone along them, i.e. deteriorated conditions for forest growth, if dam crests are too high.
- As fire risk will remain highest along canals also after blocking them, controlling fire sources then becomes the most important condition for overall fire risk reduction. This means either reducing access for people or reducing the incentive for people to set fires. The second option is controlled by socio-economic factors. The first factor may require an element of enforcement, but the blocking system itself is also important. For peatland rehabilitation, the most efficient canal blocking system might often be one that does not only impede water flow but also people access. This would require multiple blockings over considerable lengths along canals (possibly hundreds of metres), or blockings are easily bypassed (by new canals or by breaking down dams; there are examples of both ways in the Block A CKPP / CCFPI pilot area). Some canals may need to be made impassable over much of their length. A combination of 'hard' wooden dams and 'soft' blockages, the latter created by filling canals with canalside materials (probably requiring excavators) and building 'pallisades' of vertical wooden piles to allow canal fill to accumulate, could be most effective in some cases.

- Fire fighting may be a valuable contribution to reducing fire risk, but only near population centres and then only in the early stage of fires. In reality, most peatland fires start well away from population centres, and only attract attention when they are to big to extinguish. In truly dry years it seems unlikely that sufficient fires can be extinguished to have an impact on the overall fire damage (it appears there are no positive examples of this). The main impact of fire fighting may be through community involvement and awareness raising, which can of course be effective as prevention measures. Suggestions that open water needs to be maintained in canals for fire fighting (for access and water availability) are at best valid near population centres, but certainly not for peatlands in general.
- We suggest that fire prevention needs to be a far higher priority than fire fighting. Apart from canal blocking, fire prevention consists of enforcement of zero-burning policies and of awareness raising. As enforcement is difficult, it may be more effective to enforce efforts only when fire risk is truly high. Periods of high fire risk may be identified in advance by early warning systems based on hydrological knowledge and state-of the art rainfall monitoring and predictions. Note that current systems are mostly based on fire detection, identifying high risk when it is effectively too late for intervention, and are often not efficiently linked to an enforcement system.

8.6 Comparing the EMRP area with other peatland areas

Peatland science has long received relatively little interest from the wider scientific community or from decision makers, as interest in peatlands was limited until recently. The global interest in climate change has changed this, and brought more interest in studies of peatland hydrology and other aspects. New studies are started, and existing studies scrutinized more closely. One finding of our comparison of published characteristics of peatlands in different locations has been that there are as many differences as there are similarities: it is not advised to transfer findings from one area to another without additional studies.

Peatlands differ greatly in depth, in extent and in slopes. They also differ greatly in the characteristics of the peat itself. Depending on historical drainage conditions and associated degree of peat decomposition, both natural and man-made, bulk density of the peat material can vary from below 0.07 g/cm^3 to around 0.3 g/cm^3. As a function of the degree of decomposition and associated pore space, the hydraulic conductivity of peat can vary from less than 1 m/d to over

20 m/d, which has a major impact on the significance of groundwater flow. Also linked are variations in storage coefficient that determine the relation between a change in soil water storage and a change in depth of the water table. All of this greatly affects the relation between current drainage in peatlands and its effect on peatland hydrology, morphology and ecology; in some peatlands the impacted zones are far wider that in others.

The two study sites in the EMRP area both had moderately to highly humified peat. As a result, the effect of drains on current groundwater flows (12 years after drainage) was limited to relatively narrow zones, less that 500 m wide. This means that there is a steep gradient in water depths going away from canals, which in turn causes a steep gradient in subsidence rates. The result of this is that now, 12 years after drainage, the originally low-gradient peatland landscape has been transformed in smaller peat land sub-domes with steeper gradients.

The EMRP peatland seems quite similar in nature to peatlands studies in Sarawak in the 1990s (Hooijer, 1997, 2005), but very different from those now studied in Riau that have far higher hydraulic conductivity and associated impacts of drainage (Hooijer 2008).

8.7 Guidelines for planning and implementing peatland hydrology rehabilitation in the EMRP area

The following guidelines are derived from interpretation of our insights in peatland hydrology and water management in terms of practical advice for the EMRP Master Plan. These are not definitive guidelines, but a contribution to a wider body of ‘wise use rules’ that should be considered when planning for peatland rehabilitation of conservation.

8.7.1 Planning peatland management and rehabilitation

1. When planning for management of peatlands, they should be thought of as highly vulnerable and complex wetlands, not as ‘normal’ land than can be developed or conserved like other land. <u>Peatlands therefore need to be managed at the landscape scale of peat domes and sub-domes.</u> In principle, draining part of a peat dome will impact the entire dome, so conservation/restoration efforts need to apply to entire domes to be effective.

2. Where conservation and drainage (for agriculture, roads or logging) need to coexist within peat domes, water management improvements in the drained areas needs to be adapted to minimize impacts on conservation areas. Even so, a corridor or <u>buffer zone</u> of several kilometres (depending on peat type, depth, and slope) will need to be planned within the conservation/restoration area where

water tables and hence other peatland functions will remain effected by drainage. As a tentative rule of thumb, the minimum width of a viable peatland conservation/restoration area needs to be at least 10 km.

3. Peat type and depth, that determine peatland hydrology, are highly variable in space and largely unknown in many areas. Until these are known, follow the precautionary approach assuming that all peatlands have highest vulnerability until proven otherwise, i.e. hydrological impacts can extend up to 5 km.

4. Peatland hydrology rehabilitation is complex, costly, and will only be fully effective when a new hydro-ecological balance has established which will take decades. Rehabilitation and conservation efforts and investments must therefore be for the long term, for maintenance of rehabilitation infrastructure, enforcement of regulations banning drainage, and blocking of new canals that may still be developed.

5. Because of the need for integrated management of entire large landscape units, as well as the need for long-term maintenance and enforcement, hydrological peatland restoration may only be successful where not only local support and suitable socio-economical conditions but also an efficient framework of monitoring, accountability and enforcement exist or can be created.

6. Peatland hydrology rehabilitation is (at least technically) a lot more difficult than peatland conservation, and will not recreate fully the original system functions or values. Therefore the focus should be on peatland conservation before rehabilitation.

8.7.2 Designing peatland restoration systems

7. Successful restoration of peatland hydrology requires establishing a system that allows a new balance between hydrology, morphology and ecology to gradually develop over coming decades, assuming that some day nature can again take over and dams will no longer be needed. For this situation to emerge, gradual water slopes approaching those naturally occurring in peatlands must be created and maintained. Canal blocking is required where appropriate. This means that a canal blockage design must aim to A) bring gradients back to within 1m/km to 0.5m/km from the top of the peat dome to the river (depending on original morphology and peat type), B) keep canal surface water depth within 0.5m ‘freeboard’ at least in the wet season, C) that water steps over dams should be less that 0.5 m. The last condition will also enhance durability of dams, which suffer much from large water level differences across them. A system that re-creates these conditions over large parts of the PLG will involve hundreds of dams.

8. Peatland rehabilitation water management systems should be designed to keep water levels high in the long term if they are to be

successful. Blocking infrastructure should therefore be able to withstand peak discharges and in some cases allow light boat transport; bypasses may be required in both cases but must be well designed and maintained to prevent them from lowering water levels too much. It should be noted that most canal blocking efforts to date do not meet this requirement and will not last in the long term, so a different approach well be required. Population density and the attitude of local communities should also be considered: dams block not only water but also block access, and wooden dams can provide valuable building materials; they are easily removed if no communities are involved in maintaining and actively protecting them.

9. Where enhancement or maintenance of freshwater baseflows from peatlands to downstream agricultural areas is a goal of peatland rehabilitation/conservation, useful especially where water levels need to be kept high or flushing of saline or acid waters is required; interventions must be designed such that water flows are directed towards the beneficiary areas.

8.7.3 Quantifying and predicting peatland restoration benefits

10. There are two broad approaches to peatland rehabilitation. The first assumes that any rehabilitation intervention will have a positive impact, and will simply implement the measures that seem most effective within the budget. The second approach is to quantify and monitor current and future functions and values over a 'baseline' of what would happen without intervention; this requires thorough data collection and analysis efforts before and after intervention that will require time and budget. The first approach can be valid especially when little time or data is available, but the second approach will be increasingly required if carbon financing is involved. However the functions and values considered and quantified should be broader than carbon storage and include biodiversity, prevention of subsidence and flooding, prevention of haze, and maintenance of dry season fresh water baseflow to downstream areas.

11. When quantifying carbon emission reduction benefits of peatland restoration projects, it should be considered that emissions will probably be significant for decades even if interventions are successful. It is best to be conservative in emission reduction calculations. This should not discourage interventions as emission reductions will eventually be greater than continued emissions.

8.8 Land management options and requirements in the proposed 'adapted management zone'

Adapted management units consist partly of peat, 1 to 3m in depth, and partly of a strip of mineral soil between peatlands and Rivers (and the Coast, in the South of Block C). Adapted management units are delineated to allow conservation or rehabilitation of peatland areas over 3m in depth, but should allow suitable economic land uses in the mineral soil areas and where necessary on the shallow peat.

While the Master Plan recommendation for peatland deeper that 3m can be summarized simply as “conserve natural forest where that is still left, and rehabilitate degraded areas with a focus on carbon conservation and vegetation cover restoration”, recommended actions for the adapted management zones will vary greatly between locations, depending on local conditions. Where there is little need or opportunity for agricultural development, the conservation needs of the adjoining deeper peatland may be the only consideration and adapted management zones may be managed as deeper peatlands. In areas with established populations, however, sustanable development needs to be supported.

8.8.1 Community-level development of Adapted Management Zone peatlands

The primary suitability criterion for adapted land use on peat between 3 and 1m depth is that it must involve minimum drainage, and preferably no drainage at all. A land use that obviously meets this criterion is rehabilitated natural forest, but in part of the Adapted Management Zones there will be a need for productive development. There has been insufficient research and documentation of productive land uses that meet require no or little drainage, and therefore the list of options that the Master Plan can suggest is only short. The known crops that require limited drainage are tree crops. Sago palm and jelutung are in some ways ideal as they are indigenous peatswamp species that produce marketable commodities that can be handled at the community level. Melaleuca plantations for building wood may also be an option. Ongoing research suggests that several fast-growing peatswamp tree species exist that may be used for timber production in an agro-forestry set-up at the community level.

8.8.2 Industrial-scale development of Adapted Management Zone peatlands

Some areas of severely degraded shallow peat exist in the EMRP area that may need to be managed at a larger scale than is possible at the community level: because they are very large, very fire prone, very far away from communities or very difficult to manage hydrologically. The adapted management zone in the South of Block C has all these characteristics and is the largest, but probably not the only one. For such areas, the solution may be to allow industrial-scale plantations managed by a company that has established experience in responsible operations at this scale. As few peatland plantations in Indonesia are currently managed for minimum drainage, and because minimum drainage does not only mean high water levels but also limited accessibility, a new plantation model will need to be developed. HTI (timber) plantations may be an option, possibly with a pulp-wood species like melaleuca that can deal with frequent waterlogging and acidity, has limited operational requirements, has a rotation cycle of 5 to 10 years, and could possibly be operated on the basis of coppicing. An alternative potential minimum-disturbance crop is sago palm. With these crops, it may even be possible to develop a largely manual method for harvesting the small densely planted logs resulting in minimum disturbance.

8.8.3 Development of Adapted Management Zone mineral soil areas

The primary suitability criterion for adapted land use on the mineral soil areas, and on peat up to 1m in depth, is that it must not conflict with suitable management of the adjoining peatlands over 1m in depth. Considering the limited extent of mineral soil areas along Rivers, this means that large-scale development must be considered unsuitable, which probably rules out transmigration schemes and oil palm plantations in such locations. The large degraded area to the South of Block C may again be the exception. For most mineral soil areas in the Adapted management Zone, community-level development including tree crops and horticulture are likely to be most suitable.

8.9 Proposed rules for planning conservation and sustainable development in degraded peatland landscapes

(On the basis of a statement developed with Susan Page, for the Kampar SBMS Project in Riau).

Most peatlands in the EMRP area are partly or fully degraded as a result of logging, deforestation, drainage and/or fire. Degraded areas have limited conservation value in their current state and no agricultural productivity, but still store large amounts of carbon. There is an urgent need to manage such land to limit fire risk and carbon emissions, whilst also bringing back some other function to the landscape, be it ecological or economic. Choosing for what purpose to rehabilitate peatlands, and how, is the key issue in the EMRP area.

The EMRP Master Plan proposes the following tentative 'wise use rules' for peatland conservation and rehabilitation, to be developed further as more is learnt about the functioning of peatland systems:

A. 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'.

B. Prevention of further degradation, and rehabilitation* back to sustainable peat swamp forest, should be the priority for degraded peatlands* where this is still feasible*.

C. Responsible development (for agriculture and plantations) should be considered for degraded peatlands where rehabilitation to sustainable peat swamp forest is not feasible, in order to maximize economic development as well as minimise loss of the peat carbon store.

D. 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. Where conservation and crop production coexist in a single peatland landscape unit, an adapted management approach needs to be applied to balance opposing water management requirements by the delineation of buffer zones and investment in appropriate water control structures where that is necessary.

Following these 'wise use rules', the typical peatland landscape in the EMRP requires 3 types of interventions. In the Conservation Zone (peatland over 3m in depth plus peatland with conservation forest), there are A) conservation forest where enforcement of protection is urgently needed to stop illegal logging and burning, and B) degraded areas that need to be rehabilitated to natural forest. In the Adapted Management Zone, there are degraded shallow peatland areas that require rehabilitation to either natural forest of productive use.

Tentative Definitions of Key Concepts:

There is an urgent need to define better the terms 'degraded peatland', 'rehabilitation, and 'feasible rehabilitation' to clarify these issues for policy makers, business, NGOs and other stakeholders. Tentative definitions are provided below.

<u>Degraded Tropical Peatland</u>

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.

<u>Peatland rehabilitation</u>

Peatland rehabilitation aims to bring back 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). The carbon storage function must be maintained in all rehabilitation schemes; it is preferred if more 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.

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11 ANNEX Data availability and collection

This chapter is based on a separate note on data collection and data quality issues in the project (Vernimmen, 2008). More detailed information can be found in this note.

11.1 Assessment of existing data

11.1.1 Hydrometeorological data

BMG and PU

Daily precipitation data were obtained from the BMG (meteorological service) and PU (public works) offices in Palangkaraya. Most of these data were available in hardcopy form only and had to be digitized first. Data were also obtained from the BPTPH office in Palangkaraya but records were incomplete (and only for recent years) and were therefore not used in analysis. All data was quality controlled and consequently some stations proved to have produced unreliable data, datasets were too short or had too much missing data. Those stations were therefore not included in further analysis. They are however included in the EMRP hydrological database. The stations which proved reliable (Table 11.1 and Figure 11.3) were used to generate a dataset for the SOBEK model (Chapter 7). The area was divided into 6 zones and precipitation from stations within the respective zones was averaged. Some additional corrections were applied for differences in elevation and differences found in daily and monthly datasets. An overview of stations which were used for each zone is provided in Table 11.2.

Table 11.1 Precipitation monitoring locations and their data coverage (n.a. means not applicable)

				Data coverage (%)			
Location	*Source*	*From*	*Until*	*Jan 76-Dec 80*	*Jan 81-Dec 90*	*Jan 91-Dec 00*	*Jan 00-Apr 08*
Maliku	PU	1-Jul-84	30-Apr-08	n.a.	51	93	65
Mandomai	PU	1-Jan-84	30-Apr-08	n.a.	59	90	100
Mantangai	PU	1-Nov-82	30-Apr-03	n.a.	73	94	32
Tamiang Layang	BMG	1-Feb-96	5-Jul-07	n.a.	n.a.	39	89
Bereng Bengkel	PU	1-Apr-80	10-Sep-07	15	93	88	51
Palangkaraya	PU	1-Jan-76	30-Apr-08	100	94	100	100

Palangkaraya	BMG	1-Jan-78	20-May-08	60	100	100	100
Kuala Kurun	PU	1-Jan-81	30-Apr-08	n.a.	98	100	100
Tumbang Jutuh	PU	1-Jan-83	15-May-08	n.a.	77	99	88
Timpah	PU	1-Nov-83	24-Apr-08	n.a.	67	95	98
Pujon	PU	1-Jan-84	31-Mar-08	n.a.	62	97	82
Buntok	BMG	1-Jan-02	30-Sep-07	n.a.	n.a.	61	81
Buntok	PU	1-Jan-77	31-Mar-08	75	99	93	100
Muara Teweh	BMG	1-Jan-95	31-Dec-04	n.a.	n.a.	60	55
Muara Teweh	PU	1-Feb-79	30-Apr-08	38	98	92	57
Puruk Cahu	BMG	1-Jan-81	31-Oct-99	n.a.	94	80	n.a.
Tampa	BMG	1-Jan-81	31-Aug-99	n.a.	64	77	n.a.

Table 11.2 Precipitation stations used within each of the 6 zones used in the SOBEK model.

EMRP South	*EMRP North*	*Kahayan*
Maliku	Palangkaraya	Palangkaraya
Mandomai	Mantangai	Kuala Kurun
Mantangai	Tamiang Layang	Tumbang Jutuh
	Bereng Bengkel	
Kapuas	*Barito N*	*Barito S*
Kuala Kurun	Muara Teweh	Muara Teweh
Timpah	Puruk Cahu	Tampa
Pujon	Pujon	Pujon
Buntok	Kuala Kurun	Buntok

CIMTROP

CIMTROP provided us with groundwater and rainfall data for the northwest of Block C. Unfortunately the rainfall and groundwater monitoring for transects 1 until 3 has stopped in April 2007 due to lack of funds. One groundwater transect installed between the Kahayan and Sebangau rivers starting in November 2005 with 19 dip wells is still being monitored although no rainfall nor surface water is measured. The location of the groundwater monitoring transects is shown in Figure 11.2. Prof. Takashi, working in the 'CIMTROP area', has a meteorological tower installed in the forest near the groundwater transects. Using eddy-correlation equipment, evapotranspiration is measured and daily values for the period 2002 – 2005 have been kindly provided as well as rainfall and groundwater data for one dipwell (Figure 11.3).

CKPP

The CKPP project has installed a monitoring system in the Block A NW area in which groundwater is monitored at several dipwell transects (Figure 11.2) as well as surface water levels using staff gauges (Figure 11.4). Rainfall is measured at several locations (Figure 11.3). All CKPP hydrological data are available in a database which has been developed in close cooperation with the MP team.

11.1.2 Flood mapping data

Maps of flooded areas have been produced by SarVision for the EMRP Master Plan project (see Chapter 8). This has been done by identifying 'open water' areas in radar satellite images (ALOS-PALSAR). The maps show areas that are flooded by river water, but mostly areas where ponding with rainwater occurs to depths of sometimes only a few cm depth. It is not possible to distinguish the two types of inundation with this technique, but the data have been a useful check on hydrological analyses and modelling.

11.1.3 Elevation data

During the PSDM-CKPP project elevation data for the area from all known and available sources were collected:

1. CKPP elevation survey Blok A
2. PSDM-CKPP elevation survey
3. DGPS survey
4. Laser altimetry
5. Restorpeat
6. SRTM

These sources have been described in Annex 4 (Data Sets) and Annex 5 (Metadata) of the PSDM-CKPP report which is included in the EMRP hydrological database. Some of these data sets were eventually excluded from the DEM generation. The rational for this is explained in the PSDM-CKPP report and will not be repeated here.

11.1.4 Peat depth and type data

During the PSDM-CKPP project existing peat depth sources for the EMRP area were already collected:

1. Restorpeat (EU-funded project, 1999)
2. BOS-MAWAS (2003-2005)
3. CKPP (2005-2007)
4. Puslitanak (1998)

New peat depth surveys during the PSDM-CKPP project were carried out in the second half of 2007 increasing overall data density with 150 additional measurements. 44 of these measurements were analyzed chemically. Apart from peat depth, the type of mineral soil below the peat was also determined (Figure 11.1). Peat type was determined using the Von Post scale of humification and it was determined visually whether the top of the peat had previously burnt.

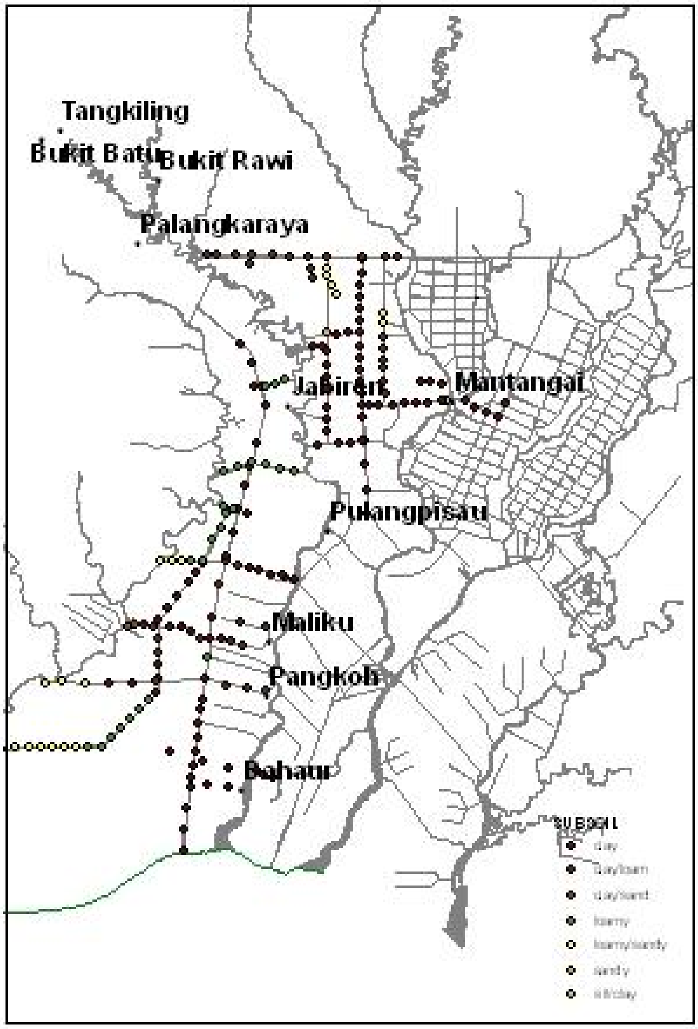

Figure 11.1 Subsoil type observations during the PSDM-CKPP project.

11.1.5 River water levels and cross section data

Water level data

Historical water level data were made available to EMRP by PU Palangkaraya (DPMA Bandung stations) for the stations listed in Table 11.3. More stations were available for Central Kalimantan (Karau river at Ampah; Manuhing river at Tumbang Talaken; and Rungan river at Tumbang Jutuh), but were not used as they were not located in the main rivers. New stations were installed by PU in the EMRP area in 2007 but were not operational yet (Barito river at Buntok, Kapuas river at Timpah, Mengkatip river, Kapuas). The water level data for the stations which are located in the main rivers north of the project area (Kuala Kurun, Pujon, and Muara Teweh) were used to calibrate the Sacramento model and results were used as upstream boundary conditions for the SOBEK model.

Table 11.3 Stations for which water level data were available. Stations 1 to 4 daily interval, station 5, water level measurement at 7:00, 12:00 and 18:00.

No.	*Station*	*StationId*	*Main river*	*Period*[*]
1	Muara Teweh	03-027-00-01	Barito	1977-2008
2	Pujon	03-028-00-02	Kapuas	1996-2008
3	Palangkaraya	03-029-00-01	Kahayan	1980-2008
4	Kuala Kurun	03-029-00-02	Kahayan	1979-2008
5	Mentaren[#]	-	Kahayan	1999-2008

[*] No continuous data set for any of the stations

[#] Tidal area, not in the Kahayan river, but close to the weir at Mentaren village.

Since water levels in a large part of the area are under strong tidal influence, the tidal water level data are an important data source. Since BTA-60, the Rampas program (developed in BTA-60) has been used to predict tidal water levels, if no measurements were available. The Rampas program uses 9 tidal components of which the amplitude and the phase can be specified as input. At the most downstream locations SEB1, KAH1, KAP1 and BAR1 measurements are available for a number of years (see Table 11.4 for locations and sources), albeit with some gaps, and a complete tidal analysis has been done (see Chapter 6).

Table 11.4 Available water level data from BTA-60 studies. x missing data less than one month, + missing data for few months, - less than 15 days of data.

River	*Location*	*Data available*			
		1980[1]	1981[2]	1982[3]	1985[4]
Kahayan	KAH 1		X	+	
	KAH 2	-	X	X	
	KAH 3		X	X	
Barito	BAR 1		X		
	BAR 2		X		
	BAR 3		X		-
	BAR 4				-
Sebangau	SEB 1		X	X	
	SEB 2		X	X	
Kapuas	KAP 1		X		
	KAP 2				
	KAP 3		X		
	KAP 4		X		

[1] Main Wet-season hydraulic Survey Kahayan/Sebangau Rivers South and Central Kalimantan, No PS 714, Aug 1980

[2] Laporan Registrasi AWLR Kalimantan Selatan & Kalimantan Tengah thn 1981, No PS 874, DPMA/P4S/BTA-60, Sep 1982

[3] Laporan Registrasi AWLR Kalimantan Tengah thn 1982, No PS 1109, DPMA/P4S/BTA-60, Oct 1984

[4] Survei Hidrolika dan hidrometri Sungai Barito dan Sungai Kapuas, No PS 1191, P3S, 1985

A problem with part of the data locations is that the reference datum is not known. In that case only the relative water level changes could be used as an indication for model calibration. In Figure 11.4 the locations of the BTA monitoring stations are shown.

Rating curves

For the stations listed in Table 11.3 (except for the tidal area location Mentaren), discharge data were available as well. Until 1994 discharge data were obtained by manually reading rating curves. From 1994 onwards discharge was calculated from water levels using the rating curve which best fitted data measured between 1980 and 1995 using the Delft Hydraulics program Hymos (Table 11.5). After 1995 some more measurements were done and these additional measurements were included in the new rating curves. As a measure of quality control discharges were calculated from the water level using the rating curve equation used by PU. Differences were found in reported and calculated discharges. These differences were caused by corrections due to sedimentation in the pipe of the water level station. As these corrections could not be reproduced it was decided to discard any provided discharge data. Discharges were calculated with the newly derived rating curve equations instead.

Table 11.5 Rating curve equations as they are used by PU from 1994 onwards to calculate discharge (Q, $m^3\ s^{-1}$) from water level (H, m) and the equations which were derived with Q-H measurements after 1995.

Station	*Equation (used by PU)*	*Equation (new)*
Muara Teweh	$159.911\ (H + 0.465)^{1.335}$	$205.2\ (H + 0.570)^{1.175}$
Pujon	$84.348\ (H + 0.376)^{1.228}$	$1.167\ (H + 4.251)^{2.790}$
Palangkaraya	$81.588\ (H + 0.43)^{1.781}$	$36.92\ (H + 1.058)^{1.990}$
Kuala Kurun	$101.372\ (H + 0.020)^{1.346}$	$15.85\ (H + 1.153)^{2.063}$

River cross-section data

Historical data on cross sections were available from BTA-60 reports which were obtained from Puslitbang Air in Bandung. MSL has been calculated as the mean of water level measurements at the mouths of the Kahayan and Sebangau rivers. For the Barito and Kapuas rivers this was derived via a hydro-topographical analysis. The locations of the cross sections can be found in Figure 11.5.

11.2 Field data collection: monitoring and surveys

11.2.1 Case study area hydrometeorological data

A surface and ground water depth monitoring system with rainfall gauges has been placed in and around the priority area in the western part of Block A, complementary to the CKPP monitoring system already in place there. A similar system was placed in the priority area in the southern part of Block C. For the priority area in the northern part of Block C we rely on CIMTROP data. In total 24 groundwater monitoring tubes (dipwells) were installed at 4 locations, 3 transects of 7 dipwells each in peat and 1 transect with 3 dipwells in mineral soil. At the beginning and end of each dipwell transect a staff gauge was installed to measure surface water levels. Locations of the dipwells are shown in Figure 11.2. Locations of rain gauges are shown in Figure 11.3. Data from the rain gauges have not yet been analysed, since monitoring started late and records are too short and need to be extended until at least October 2008 so the dry season is also included. Preferably measurements are continued longer. We received sufficient data from CIMTROP and CKPP for the quick assessments needed in this MP project, but not for more thorough assessments expected to follow in the follow-up project. Additional dipwell transects are installed by SarVision in Block E but data have not been received. As part of the CKPP project WWF and CARE are understood to also monitor groundwater depth and rainfall, but we have not been able to obtain these data.

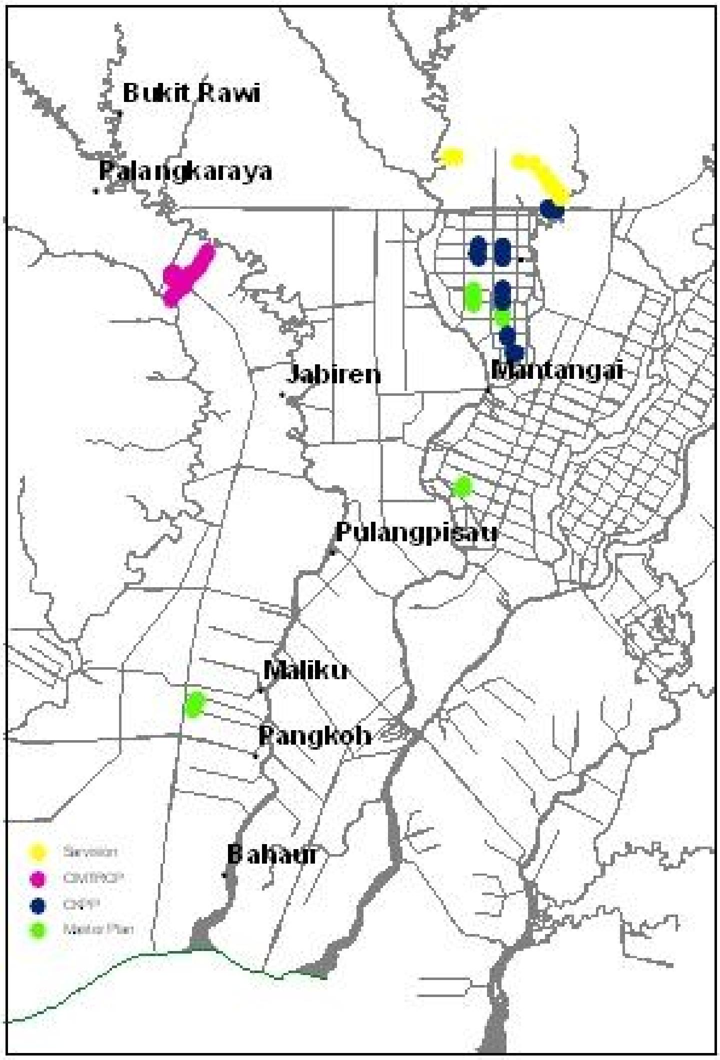

Figure 11.2 Locations of groundwater measurements with dipwells in the EMRP area. SarVision data; CIMTROP since June 2004; CKPP since 2007.

11.2.2 Water level data

A river water level monitoring system of 20 divers (automatic water level recorders, 6 already installed during the PSDM-CKPP project in 2007) and 27 staff gauges has been installed complementary to the existing PU system; resulting data allow us to analyze and model flood and tidal dynamics. A related river cross-section survey (19 cross sections) with echo sounders was completed in December 2007. The locations where the river cross-sections were carried out are shown in Figure 11.5.

Unfortunately two divers were stolen (Palangkaraya and Pangkoh B3), one broke down (Bahaur, due to high salt concentration, the replacement was put in a plastic bag filled with fresh water and performs well), and one did not function from the start (Dusun Bakuta, upstream of Mengkatip). One diver was kept as a reserve. An overview of the locations where the divers and staff gauges are installed is given in Table 11.6 and shown on the map in Figure 11.4. Some of the divers and staff gauges were referenced to mean sea level (MSL), whereas most of them were not.

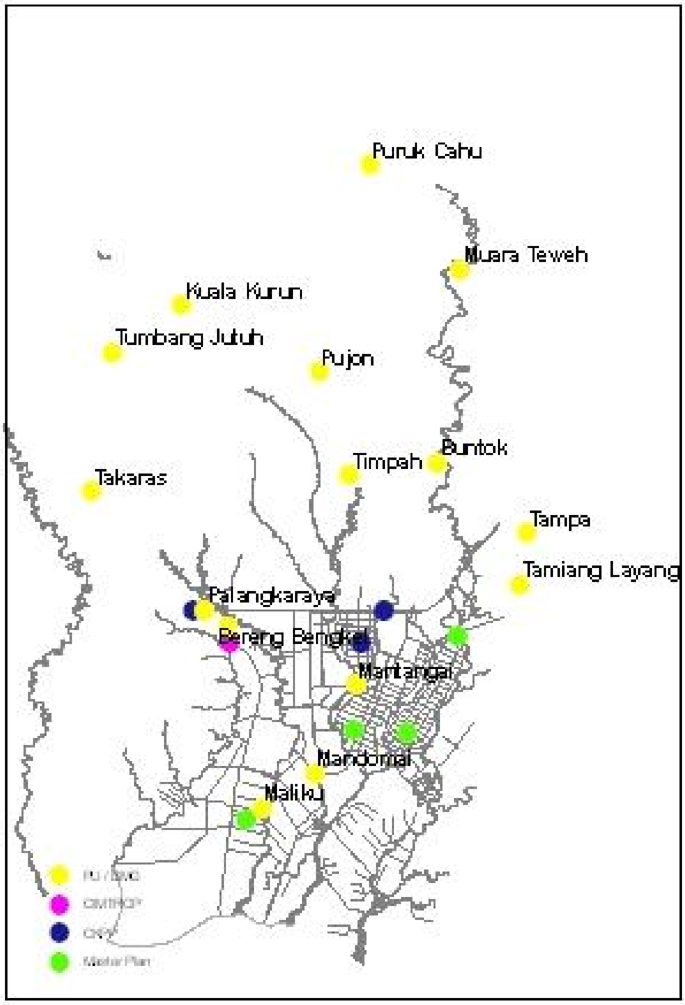

Figure 11.3 Precipitation monitoring locations for all sources available to the project. PU / BMG data since 1977; CIMTROP since 2002; CKPP since 2004.

Table 11.6 Locations of water level measurements in the EMRP area with staff gauges (SG) and divers (D).

SG / D	*Location*	*Start Date*	*Latitude*	*Longitude*
SG67 / D1	Bahaur	30-Jan-08 / 24-Sep-07	-3.237841	114.098908
SG65	Bereng Bengkel	02-Feb-08	-2.250278	114.031194
SG39 / D19	BOS Camp Release	29-Jan-08 / 28-Jan-08	-2.282810	114.559260
SG71 / D21	Buntoi	24-Dec-07 / 09-Aug-07	-2.806951	114.200324
SG69 / D11	Dadahup	30-Jan-08 / 29-Jan-08	-2.650580	114.603111
SG70 / D7	Dadahup A5	30-Jan-08 / 12-Aug-07	-2.681720	114.683822
SG79 / D20	Dusun Bakuta	29-Jan-08 / -	-2.422833	114.760343
SG63	Gohong	01-Feb-08	-2.692833	114.282222
SG73 / D2	Hampatung	01-Feb-08 / 10-Aug-07	-3.017179	114.400510
SG64	Jabiren	01-Feb-08	-2.523802	114.192197
SG38 / D10	Jalur Katimpun	01-Feb-08 / 01-Feb-08	-2.399260	114.473780
SG41	Jalur Kelumpang	28-Jan-08	-2.420650	114.518600
SG42	Jalur Plehud	28-Jan-08	-2.465580	114.526750
SG72 / D14	Jl. Maliku-Pangkoh km. 14	23-Jan-08 / 23-Jan-08	-2.952472	114.039750
SG46 / D18	Katunjung	20-Dec-07 / 28-Jan-08	-2.261533	114.411717
SG77	Lamunti Blok A2-D	31-Jan-08	-2.616889	114.487361
SG76	Lamunti Blok A4	31-Jan-08	-2.575250	114.506528
SG75	Lamunti Blok B5	31-Jan-08	-2.543006	114.543006
SG57 / D6	Lamunti Blok C3	31-Jan-08 / 12-Aug-07	-2.667647	114.490436
SG74	Maliku Lama	24-Jan-08	-2.953944	114.149472
SG58 / D8	Manusup	23-Dec-07 / 28-Jan-08	-2.679138	114.438094
SG59	Mentangai Hilir	18-Jan-08	-2.509540	114.494064
SG60	Muara Dadahup	30-Jan-08	-2.814634	114.593886
SG62 / D13	Pangkoh B3	24-Jan-08 / 10-Aug-07	-3.004444	114.098028
SG61 / D4	Rangga Ilung	30-Jan-08 / 11-Aug-07	-2.320611	114.876306
SG68 / D17	Rantau Bamban	30-Jan-08 / 29-Jan-08	-2.737928	114.681709
SG66 / D15	Sebangau	23-Jan-08 / 23-Jan-08	-2.925616	113.882548

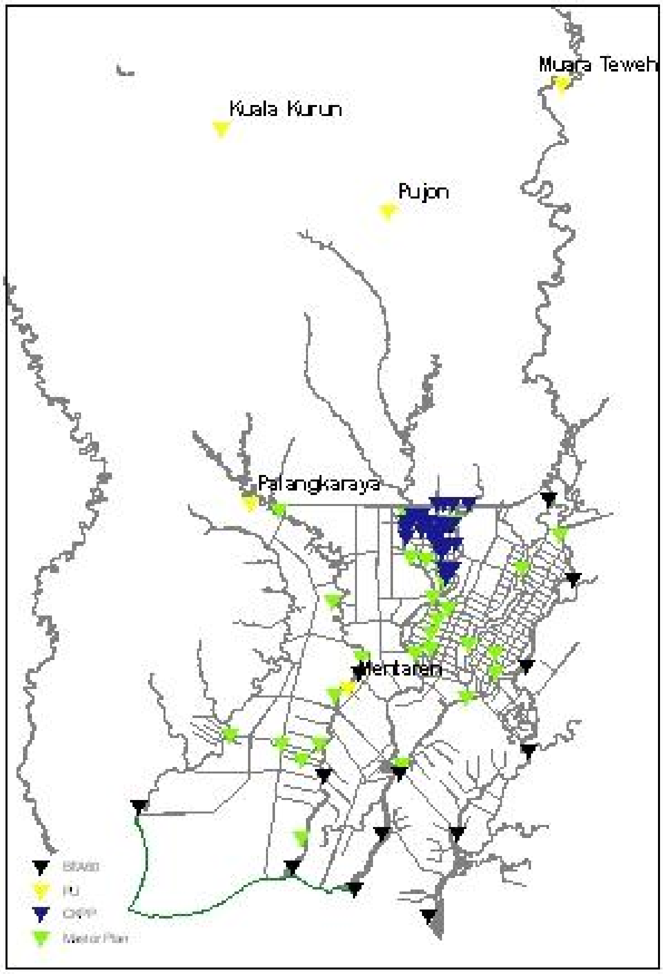

Figure 11.4 Locations of water level measurements in the EMRP area, as used in the Master Plan study. BTA-60 data mainly 1981-1982; PU from 1977; CKPP since December 2004.

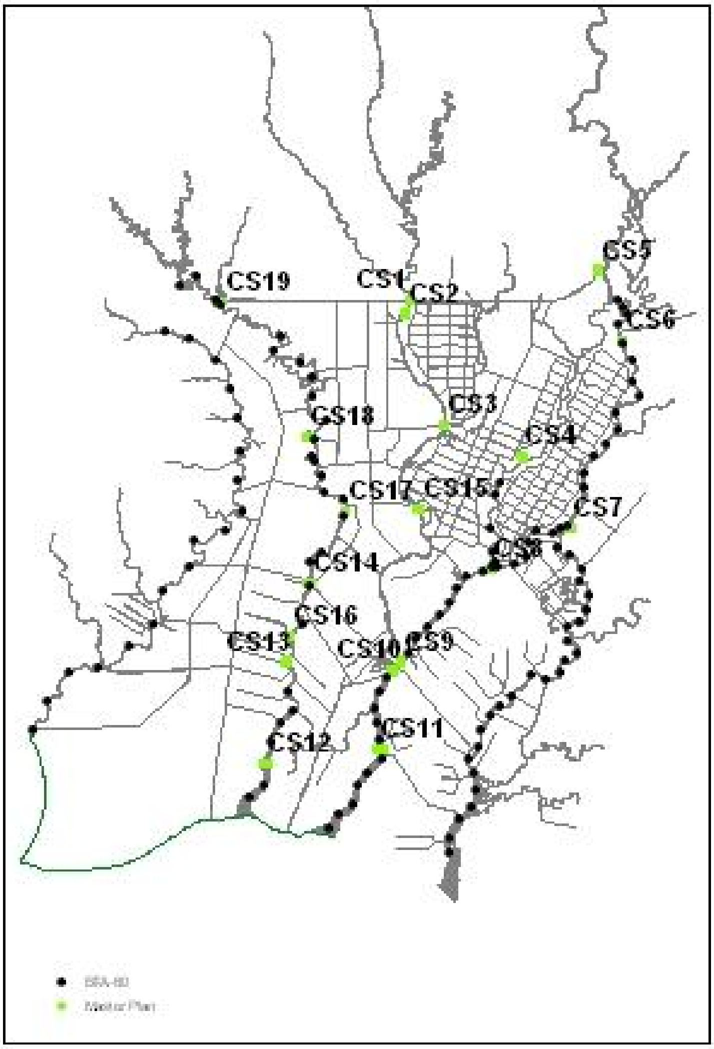

Figure 11.5 Locations of river cross-section measurements.

11.2.3 Elevation

Topographical surveys were carried out during this project in Blocks A and C and locations of these transects are shown in Figure 11.6. The surveys were carried out overland and each individual transect started and ended at a benchmark which were installed by Bakosurtanal during a DGPS survey under the PSDM-CKPP project in September 2007. In total about 220 km was surveyed. Part of the surveys (44 km) was paid for and carried out by CKPP. CIMTROP provided a team which surveyed two transects with a total length of 40 km.

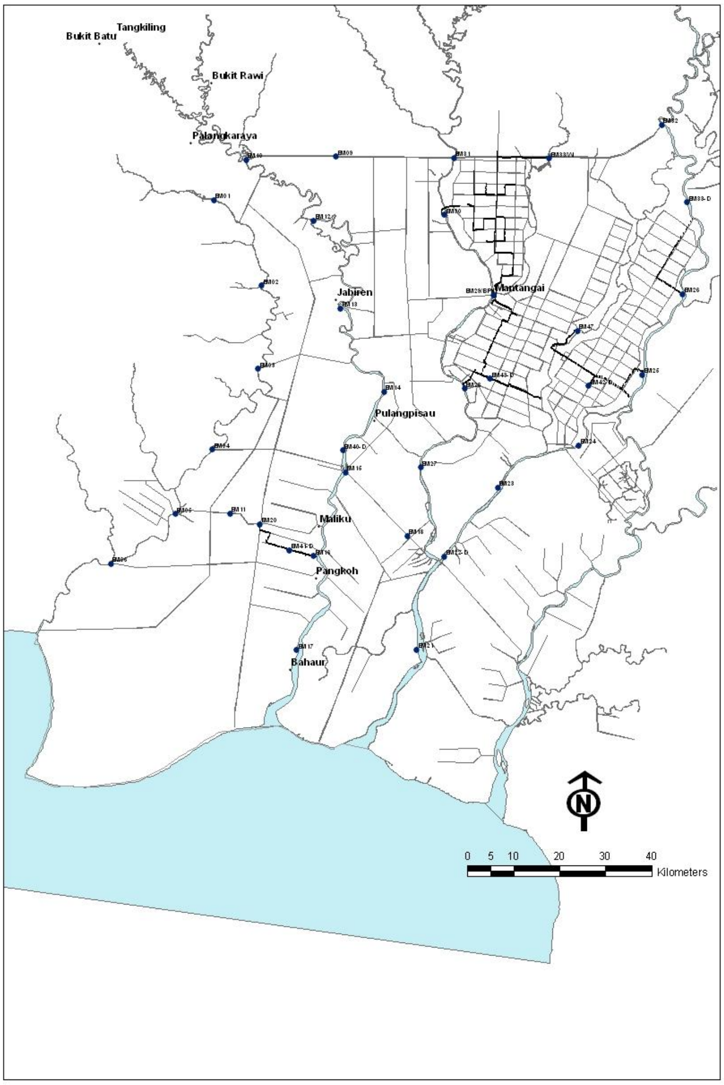

Figure 11.6 Elevation survey points carried out during this project.

Uncertainties

Most of the data contained within the various sources is accurate and consistent within transects, however none of it could be referenced accurately to mean sea level. The DGPS survey done by Bakosurtanal in September 2007 during the PSDM-CKPP project had already raised many questions on the accuracy of the supplied dataset during the DEM development in the PSDM-CKPP project (e.g. the Palangkaraya Airport BM is supposed to be at 25 metres while we find it can not be above 13 metres). During this project the reliability of the dataset was tested by carrying out land-based topographical surveys connecting DGPS benchmarks. It turned out that the elevation of DGPS benchmarks had to be corrected with several meters. For example, a transect in the Lamunti area (Block A) starting at BM43-D (at Block C3) and ending at BM28 (at Manusup) found an elevation difference between the two benchmarks of 0.40 m (8.356 – 7.953 m) whereas based on the DGPS measurements this difference was 3.38 m (8.356 – 4.976 m). Differences such as the one in this example were found for each transect carried out between two benchmarks and created many problems during the development of the DEM.

Coincidentally further errors were encountered after talking to Bpk. Kitso Kutsin from CIMTROP who was involved in an elevation survey carried out in April - May 2008 in the south of Blok C (Pangkoh area). The CIMTROP team made photographs of the BMs they encountered during their survey and found that the BM Id's were different from the data that were supplied by the EMRP team.

The CIMTROP findings initiated a comparison of documents and files supplied by Bakosurtanal. They supplied a report with BM descriptions together with an additional dataset which included all measured points. After comparing the metadata contained within the BM description report with the dataset it was found that a total of 10 BM Id's were at the wrong location (see Table 11.7 and the red dots in Figure 11.7) and consequently also had a different elevation.

Table 11.7 Differences found comparing BM descriptions report with the dataset.

BM Id (old)	*BM Id (new)*	*Elevation MSL (old)*	*Elevation MSL (new)*
11	21	7.379	4.006
12	11	5.400	7.379
13	12	3.248	5.400
14	13	3.069	3.248
15	14	2.774	3.069
16	15	1.856	2.774
17	16	1.292	1.856
18	17	1.512	1.292
20	18	7.056	1.512
21	20	4.006	7.056

Unfortunately, the findings did not provide answers for the differences found in the Blok A area (wrong BM IDs occurred only west of the Kapuas). It is not known if because of the mix-up only the locations of the BM Id's were effected or if also other DGPS measuring locations (where no benchmarks were installed) were effected.

Other considerations

Apart from the unreliability in elevation of the DGPS benchmarks it was observed in the field that some of the benchmarks were already sinking into the underlying peat and would render these benchmarks in the near future useless. Secondly, the benchmarks were installed too close to the river (during the dry season). Consequently, during the cross section measurements in December 2007 surveyors found it difficult to find them as they were flooded.

Digital Elevation Model

Results from the topographical surveys carried out in this project were used to improve the DEM already produced during the PSDM-CKPP project. With the tidal data collected in the EMRP MP project we have been able to better link survey elevations to sea level. Still, elevation data remain a weak link in the EMRP MP hydrological assessments and modelling, though major improvements were made. Standard error over the entire area is estimated to have been reduced from well over 5 metres to below 1 metre. The final DEM together with all used survey points is shown in Figure 11.8.

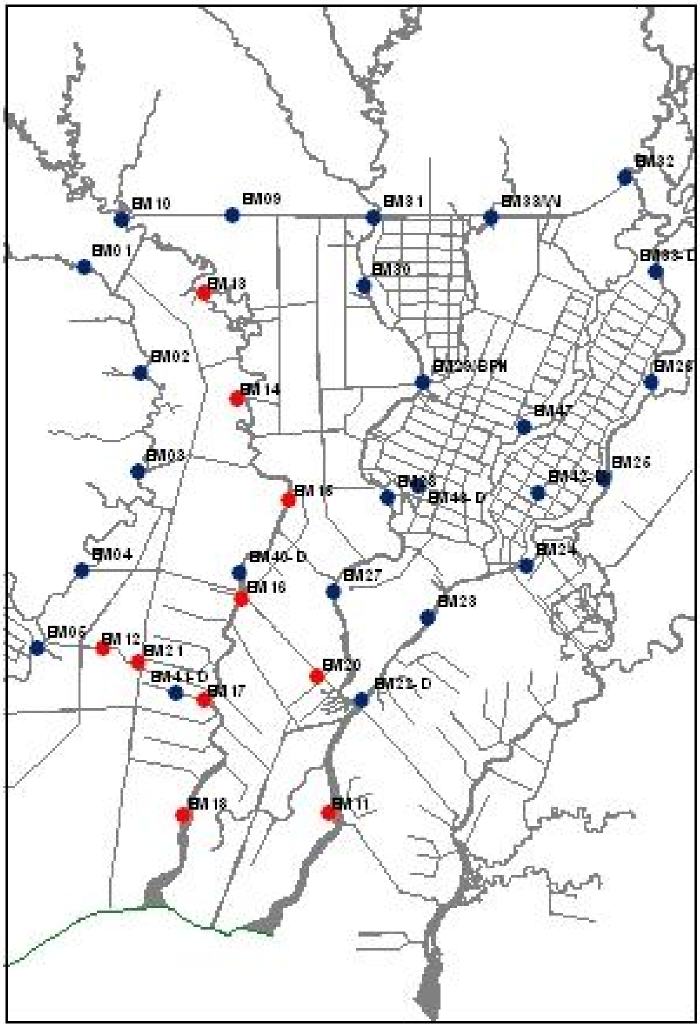

Figure 11.7 DGPS BM locations. The red dots indicate wrong BM Id's (and consequently also wrong elevation).

DEM of the Ex-Mega Rice Area in Central Kalimantan

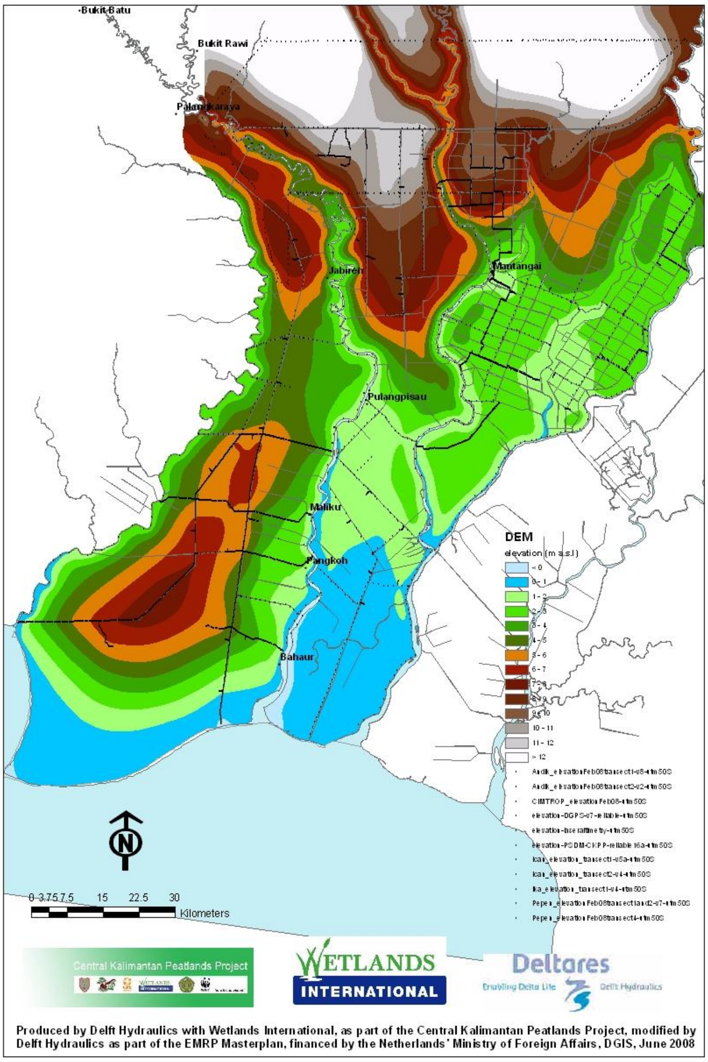

Figure 11.8 Final DEM with all measuring points. Not shown on the map are the extra points derived from SRTM in unforested areas on the basis of 'visual' interpretation.

11.2.4 Peat

In addition to the existing data sets described in paragraph 2.1.4, peat depth measurements were made in Blocks A and C (114 in total), mostly at the locations where dipwells were installed but also at locations where additional vegetation observations were made. Bulk density samples were taken in Block A NW at 9 locations at 2 depths (1 and 2 meter) and results are shown in Table 11.8.

Table 11.8 Bulk density (ρ_b, g cm^{-3}) of peat sampled in Block A NW. Layer 1 sampled at 1 m depth, Layer 2 at 2 m depth. Fibric (< 0.09 g cm^{-3}), hemic (0.09 – 0.20 g cm^{-3}), and sapric peat (>0.20 g cm^{-3}).

				ρ_b	ρ_b
Location	*Latitude*	*Longitude*	*Sampling date*	*Layer 1*	*Layer 2*
TA02	-2.30390	114.48338	21-Apr-08	0.26	0.20
PS01	-2.29545	114.48355	21-Apr-08	0.19	0.21
TA07	-2.28713	114.48375	21-Apr-08	0.18	0.20
TB02	-2.30586	114.52169	15-Apr-08	0.14	0.16
PS02	-2.29667	114.52132	15-Apr-08	0.23	0.23
TB09	-2.28783	114.52127	14-Apr-08	0.19	0.20
TD02	-2.37218	114.52088	11-Apr-08	0.12	0.09
PS03	-2.36228	114.52077	11-Apr-08	0.10	0.13
TD09	-2.35210	114.52036	11-Apr-08	0.15	0.14

Uncertainties

It was found that significant differences exist between the datasets, where they have peat depth measurements in (nearly) the same location. These differences are partly due to errors that can never be excluded, but largely due to differences in methods and in interpretation of what is ‘peat’. Especially the ‘soupy’ layer of organic+mineral material between peat and mineral substrate causes problems in this respect. After due deliberations and discussions with Mr Lili Muslihat (Puslitanak) and Dr. Jack Rieley (Restorpeat) we have decided to not make choices on which dataset to use in the peat depth map but to simply use all data, only excluding points that were clearly erroneous. Where different peat depths are found on nearby locations, the peat depth map will present a smoothed average. An evaluation of the peat depth survey methods and uncertainties is given in Annex 14 of the PSDM-CKPP report.

Because hardly any peat depth measurements were available for Block E it was decided to use the Kalimantan Peat Atlas (Wetlands International, 2006) for this area by adding some points to the peat map as derived from the peat atlas. We have not been succesful in obtaining the metadata and methods report of the Peat Atlas, so can not tell how accurate this data is.

Interpolation technique

The *Topo to Raster* interpolation technique available within ArcGIS was used to create the peat depth map using the complete available datasets, setting peat depth along the rivers at 0 as levees always have mineral soils and with further settings ‘no drainage enforcement’ and ‘spot heights’ as primary input data. A few additional points were added manually to improve automatic interpolation. A polygon with all the blocks, including rivers was used as boundary, the same which was used for the DEM generation.

Peat map

The peat map is shown in Figure 11.9. Despite uncertainties resulting from differences found in the respective datasets and lack of data in certain areas (the south of Block C and the whole of Block E) we have confidence in the location of the 1m and 3m peat depth boundaries in the rest of the area, which is most . In Blocks A and B (and D) the uncertainty in the location of the 1m boundary is generally within 1km, and of the 3m boundary generally within 2km. In Block C the uncertainty in these lines can be up to 5km. Additional peat depth data for Block C, collected in the Master Plan project, came in too late and were therefore not used in generating the peat map. They are however included in the database.

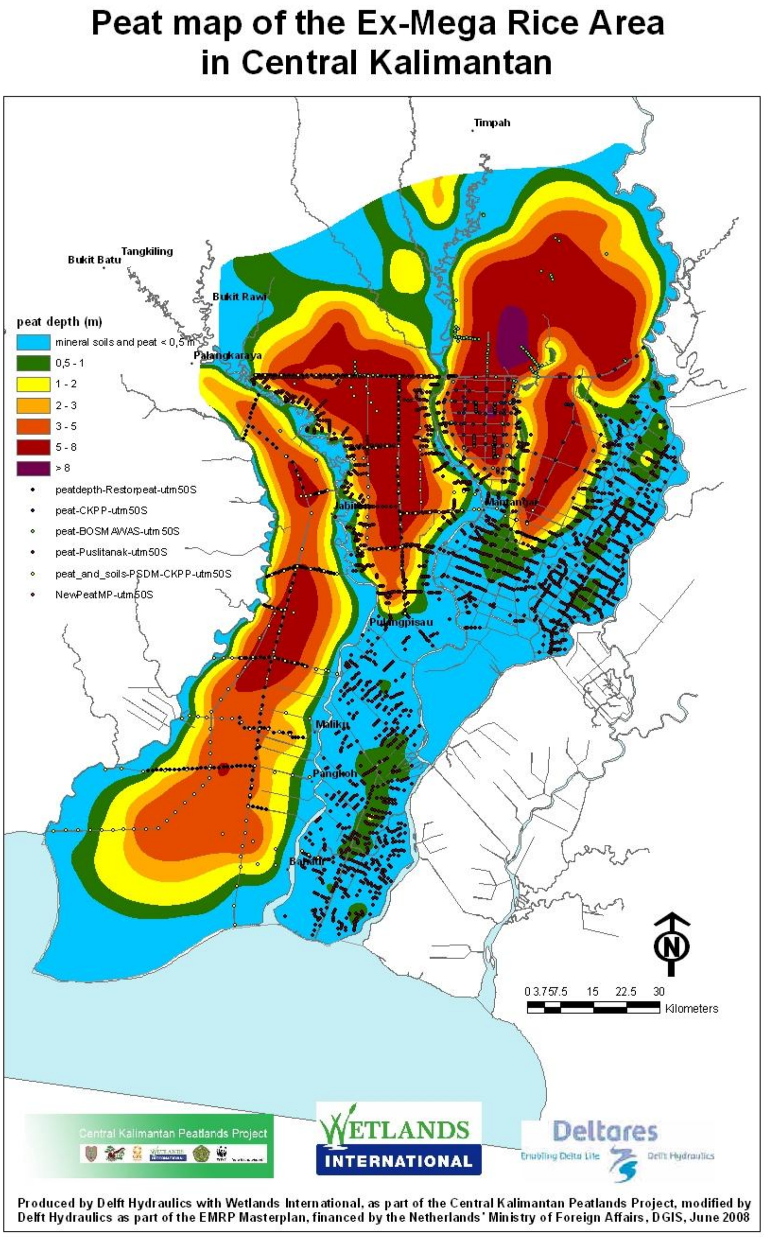

Figure 11.9 Peat depth map with sampling locations for the EMRP area.

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