Practical use of a hydrological model for peatlands in Borneo

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Modelling the Sungai Sebangau catchment in Central Kalimantan, Indonesia

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ABSTRACT

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The value and vulnerability of tropical peatlands is nowadays widely recognised. To increase knowledge of the hydroloy of peat swamp forests and to promote sustainable management model studies can be a useful tool. In this study the Sebangau catchment in Kalimantan, Indonesia, is modelled in SIMGRO. By means of model input geohydrological data for the area were integrated. Model calculations give an impression of the spatial distrubution of groundwater levels and of fluctuations throughout the years. Further refining of the model however is a requisite to make the model suitable for simulation of landuse scenarios.

Keywords: peat swamp forest, peatlands, Sebangau catchment, Kalimantan, Indonesia, sustainable management, hydrology, landuse

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Preface

In two weeks time I made the decision to go to Kalimanton for my practical period. This was one of the fastest and less regretted decisions I have ever made. Though in the first week I discovered ‘culture shock’ is not a made up expression, I probably had the best three months of my life there.
Through this study I wanted to increase the hydrological knowledge of the system, to make a contribution to the sustainable management of the Sebangau catchment.
Having seen the peat swamp forest -including orang-utan!- I realised even more than I already did this is an ecosystem that has to be conservated. But not only I discovered the natural values of Kalimantan, I also learned a lot of the indigenous people of Kalimantan, the Dayak. Their culture, religion and general view on life are very intriguing.
As a Dayak elder once said:

In the past we depended on the forest,
Nowadays the forest depends on us.

(from Persoon and Aliayub, 2002)

Summary

Indonesia possesses the largest area of tropical peatlands in the world, of which one third is located in Kalimantan. These tropical peatlands are formed in sites of poor drainage, permanent waterlogging and substrate acidification due to which the vegetation litter accumulates faster than it decays. Decades ago these peatlands were considered as wastelands that had to be reclamated, but nowadays the values and functions are widely recognised. They are considered as an important reservoir of plant and animal diversity, play an important role in the provision and sustainability of water sources and function as a carbon sink.

Reclamation of peatlands for agricultural or forestry purposes usually starts with the digging of a drainage system. The main effect is a lowering groundwater table which results in subsidence. In this way hydrological conditions of the peat are permanently altered.

The Sebangau catchment is the last remaining large continuous block of peat swamp forest in Central Kalimantan. It is a very valuable and vulnerable ecosystem which provides habitat for a number of rare and endemic species, provides resources for local communities and has several other functions like carbon storage and water retention.

Illegal logging, agriculture and local forestry together with digging of canals is threatening the area by altering the hydrological conditions, which are they key factor for conservation of peat swamp forests.

To evaluate and visualise the effects of landuse changes on the hydrology of the Sebangau catchment a hydrological model can be a useful tool. In this study a model set-up is made in SIMGRO, a physically based regional groundwater flow model. Generating model input for SIMGRO was a useful tool for integrating the available geohydrological data for the model area. Initial model parameters were adjusted by comparing model output (groundwater levels) with measured groundwater levels.

Calculations were made with the best set of parameters which still gave groundwater levels that were slightly too low, but form a good picture of the spatial distribution of groundwater levels in the model area. Fluctuations of calculated groundwater levels were too strong, but still give an impression of the effect of rain events and dry spells.

After refining of model input and further adjustment of parameters the model as built and used in this study can be a useful tool to simulate and visualise landuse changes in the area.

Acknowledgements

During my stay in Palangka Raya, Kalimantan, Indonesia I received a lot of help from a lot of people. Not only in relation to the subject, but also they made my stay very pleasant in many ways. Therefore I would like to thank:

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Jyrki, for telling me about Indonesian and Dayak customs (!),
Wentin, for selling me the not-finished-yet ketambung and giving me a whistle,
and of course Erin, for being a friend.

With regard to the collection of data, providing general information about the catchment and setting up the model I would like to thank:

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Dr. Boehm, for sending me his peat thickness data,
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Gijsbert, for being there while everyone was on vacation.

1 Introduction

1.1 Background

Peatlands play a significant role in the biosphere, as they interact with fundamental life support processes. Tropical peatlands occur in Asia, the Caribbean, Central America, South America and Africa. An estimate of the total area of undeveloped tropical peatland is 30-45 million hectare of wich probably 30.000.000 hectare in South-east Asia. In this region Indonesia possesses the largest area of peatlands, of wich one third is located in Kalimantan (Andriesse, 1974; Page et al., 1996). Tropical lowland peatlands have an importance in the direct welfare of local communities, in biodiversity and in the maintainance of environmental quality (Maltby, 1997). They are directly linked to carbon sequestration affecting global climate change, and a provision of key habitats for a diverse range of the worlds flora and fauna. Tropical lowland peatlands have, different from other land types, a high diversity of physical, chemical and biological land conditions. Because of this great variation in land quality, topography and drainage capability there is a great variation in land productivity for local use.

In the past however, wetlands were generally considered as useless and, depending on local conditions and local policy, reclamation was a focus of attention. Purposes for tropical peatlands after reclamation can be agricultural practices, logging or agriculture-based transmigrant settlements (Andriesse, 1974; Radjagukguk, 1997). Almost 20% of the peatswamp forests of Indonesia have been developed by drainage, burning and deforestation (Rieley et al., 1997). These practices induce a rapid subsidence and mineralisation of the peat layers (Radjagukguk, 1997) and uncontrollable forest and peat fires.

On Borneo the province of Central Kalimantan contains about three million hectares of peatland, which is one of the largest continuous areas of tropical peatlands in the world. These peatlands are covered by a natural vegetation of peat swamp forest. In recent decades however the area of these peat swamp forests has been reduced due to logging and agricultural practices. If these forests are removed, either by this large scale cutting or by uncontrolled forest fires, as happened in 1982/83, 187, 1994, 1997 and 2002 it will take centuries for a new forest with a similar species diversity to revive. In 1996 the Indonesian Government commenced the One Million Hectare Mega Rice Project (MRP) for rice cultivation, linked to transmigration. The development of an area of one million hectares in Central Kalimantan, situated between the Sungai (= river) Sebangau in the west, the Sungai Kahayan, Sungai Kapuas and Sungai Barito in the east, and the Java sea in the south, was planned and realised. More than 4000 km of irrigation channels were laid out, because these sluices were not properly planned the peatland was drained severely. When in the summer hundreds of fires, which were started to clear deforested areas, spread out to natural forest areas both the surface vegetation and the underlying peat were ignated. Land-clearing, logging, drainage and fires caused a major loss of peat swamp forest.

In the area around Palangka Raya, the capital city of the province of Central Kalimantan, the peat swamp forest area was reduced from 2.406.732 ha in 1991 to 1.112.151 ha in 2000 (Boehm and Siegert, 2001; Boehm et al., 2001; Boehm et al., 2002).

Nowadays the value and functions of peatlands are becoming more and more recognised. Tropical peatlands function on a regional scale as water catchment and control system, stabilise landscapes, reducing erosion and flooding and maintaining water quality. They are an important habitat for biological diversity, as Orang-Utan populations on Borneo. Also these peatlands provide recources to local communities: food, fuel, timber and non-timber products (Sughandhy, 1997). On a global scale peatlands function as a carbon sink. Herefore their stability has important implications for climate change (Page et al., 2002). Thus the tropical peatland constitutes a fragile and valuable ecosystem and, hence, an appropriate management strategy should be developed to ensure its sustainable use. The peatlands should provide the above mentioned resources to generate food and income for local communities in a sustainable way. For agricultural purposes drainage has to be carried out which causes changes in moisture holding capaity and subsidence. These processes cause changes in the vegetation of the peat swamp forest and can be irreversible. Therefore controlling the groundwater level is closely related to peat conservation (Radjagukguk, 1997) and water management is the key to sustainable use of these peatlands for agriculture, forestry, and to conserve the natural ecosystem (Ritzema et al., 1998).

1.2 Problem formulation

The enforcement of the One Million Hectare Mega Rice Project in 1996 in Central Kalimantan caused a major loss of pristine peat swamp forest and induced severe burning of the forest and the underlying peat. West of the MRP-area, in between the Sungai Kahayan and the Sungai Sebangau, still exists a large, peat-covered catchment, the Sungai Sebangau catchment. This catchment is still covered by peat swamp forest, although illegal logging, transmigration projects and the fires of 1997 have had their impact. Because this area is the last remaining large continuous block of peat swamp forest in Kalimantan (Boehm and Siegert, 2001) it should be protected and agricultural practices near the catchment should be managed carefully. Digging of irrigation channels for agricultural purposes has far reaching consequences for the peat of which the Mega Rice Project is a harrowing example. To prevent the degradation of this vulnerable ecosystem due to irrigation the effects of different land-use forms should be visualised in order to make decisionmakers aware of the dangers.

1.3 Objectives

The EU-funded STRAPEAT project aims at the formulation of strategies for implementing sustainable management of peatlands in Borneo. Within this project the hydrology of peatlands is an important item. Developing measures such as drainage, burning and logging practices have a significant impact on the hydrology of these peat domes. To evaluate the effects of these practices and to predict the long-term impacts on groundwater table, peat surface and vegetation of a peat dome a hydrological model is applied on the Sungai Sebangau catchment in Central Kalimantan. Although this is a very large area, the entire catchment is used for the model. Management of complete catchments permits control of all activities likely to influence the beneficial functions of the system. Different land-use scenarios can be simulated and the effects of these scenarios on the groundwater table are presented in maps. These maps can be used as a communication tool among stakeholders and therefore function as a decision support system.

The aim of this study is to provide insight into the hydrology of the Sungai Sebangau catchment in Central Kalimantan and to bring together the hydrological data of the catchment that have already been collected. This is done by means of the hydrological model SIMGRO. After generation of model input and calibration impacts of realistic land-use scenarios such as growth of oil palm, sago and peat swamp forest can be evaluated and visualised.

The objectives are:
1. Collection of relevant available hydrological data of the study site.
2. Calibration of the model used on the study site
3. Simulation of different land-use scenarios
4. Presentation of the results in the form of maps generated by a GIS-application

of which 1 and 2 are attained in this study.

1.4 Methodology

First a literature review was conducted for outlining and understanding the system characteristics of tropical peatlands. During discussions with members of the STRAPEAT-team objectives and goals which the study should meet were fomulated and a study area was selected. The data needed to use a hydrological model were listed and compared to the list of data present for the study area. Some gaps occured, mainly in spatial distribution of the data, but these were not thought to be crucial and might be filled up by estimated values and extrapolation of data.

The next phase of the research was the collection of the data listed. This was done at the CIMTROP in Palangka Raya, which functions as a base of operation for many scientists while doing research on the peat swamp.

After the choice of a model was made the collected data had to be integrated and interpolated. Subsequently model input files were generated, the model was run and parameters were adjusted to obtain more realistic results.

Finally, the results are evaluated and the model is ready for simulating different scenarios.

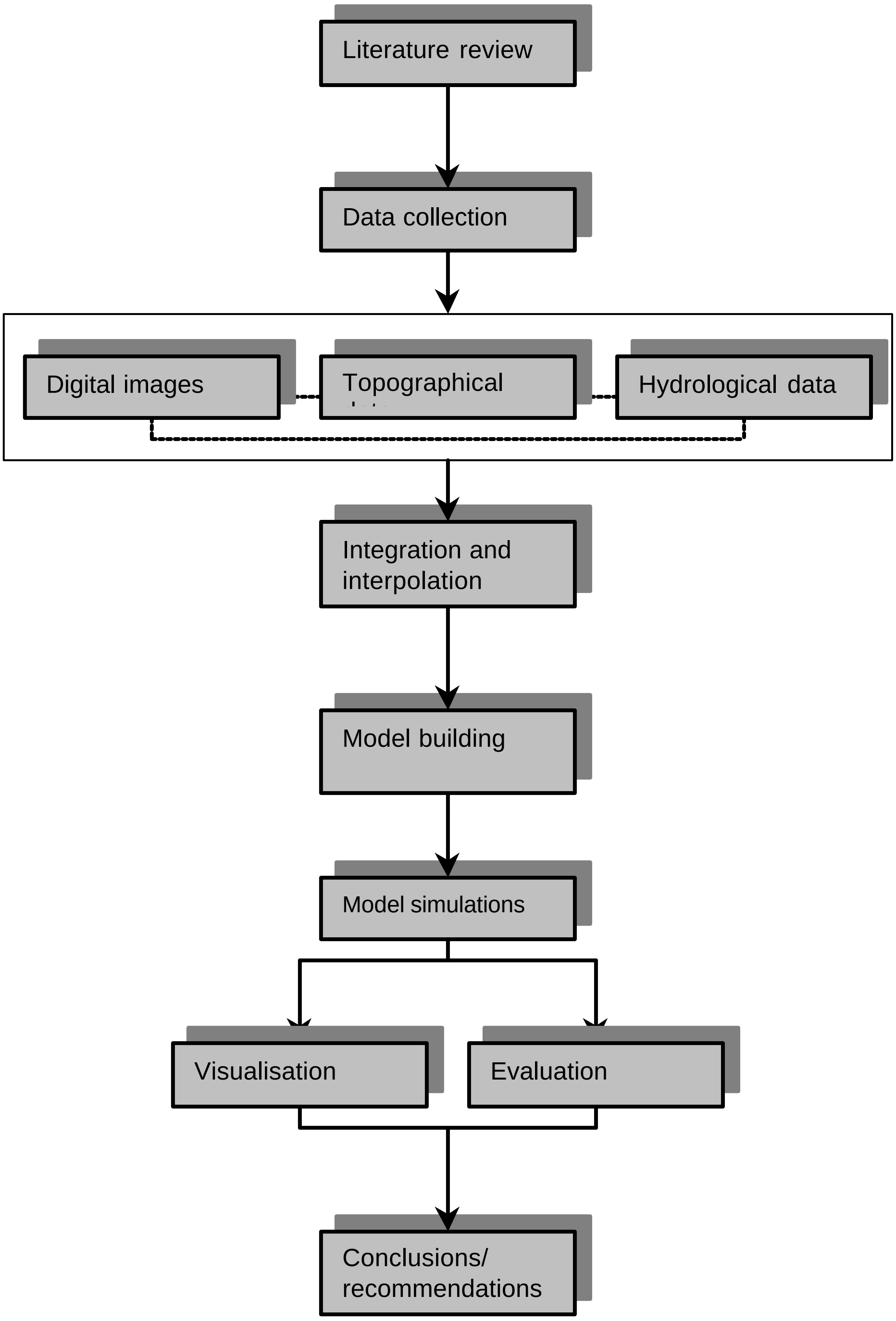

Figure 1.1. Flowchart of the study

2 Tropical peatlands in Kalimantan

2.1 Distribution of tropical peatlands

Tropical peatlands comprise approximately 10-15% of the total peatland area of the world. They occur in Central and South America, Africa and the Pacific, but far the greatest concentrations occur in Southeast Asia around the China Sea (Maltby, 1997). Indonesia possesses the largest area of peat in the tropics, with about one third of this area located in Kalimantan (Page et al., 1996).

2.2 Genesis

Peatland formation occurs in sites of poor drainage, permanent waterlogging and substrate acidification due to which the vegetation litter accumulates faster than it decays. These conditions were firstly revealed by Polak in the 1930s. In the 1970s Andriesse (1974) and Driessen (1978) conducted research on peat formation in Indonesia and Malaysia. Their findings have been summarised by Diemont et al.(1991) as follows:

- The fluctuations and rise of the late Pleistocene sea level stabilised about 5,000 years ago.
- During the following centuries, a rapid lateral deposition of coastal sediments took place which created extensive coastal tidal flats, notably in East Sumatera, Borneo and Southern Irian Jaya. Such flats were colonised by a mangrove plant community.
- The mangrove community stabilised the area so as to turn into more or less solid land making that in fact the coastline progressed into the shallow sea as the mangroves and lagoons under decreasing saline and increasing freshwater conditions became substituted by freshwater swamp forest and freshwater lakes, respectively.
- The shallow freshwater lakes gradually filled up with organic matter produced by the lake vegetation (fen peat), developing into a swamp forest peat influenced by the groundwater peat. This form of peat formation is called a topogenous peat as the conditions of its formation were a high watertable determined by topographic or geomorphological factors. Its composition is derived from a comparatively nutrient-rich plant community.
- On top of the topogenous peat, an ombrotrophic forest peat was formed.

Hence, peat formation in Indonesia started from 5,000 years BP, mainly from accumulation of woody materials. Initially topogenous peat was formed owing to anaerobic conditions maintained by river-flooding or tidal influences, overlying former marine sediments. These are the basin and coastal peatlands. In shallow depressions between the big rivers the accumulation of peat continued forming dome-shaped bogs (figure 2.2) (Radjagukguk, 1997). Diemont and Supardi (1987) however, found evidence that convex peat bogs in Sumatera and Kalimantan may have developed from the onset under ombrotrophic conditions. These high peats occur in more elevated watershed situations (15-50 m above sea level), overlying sandy, often deeply podzolised deposits (Rieley et al., 1992). The surface of these bogs is aerated from time to time and chemically enriched through litter fall from the trees. This promotes microbial activity and decomposition of the top layer. The surface becomes covered with young peat and the watertable rises, bringing the former surface horizon under permanent water saturation. In the permanently water-saturated subsoil decomposition is negligible and this part consists of loose, coarse fibric, lignin/wood-rich peat. On top of this layer a hemic and a sapric/hemic peat layer are situated (Driessen and Deckers, 2001; Moore et al., 1996). Figure 2.1 shows the different degrees of decomposition in a peat bog near Pontianak, Indonesia.

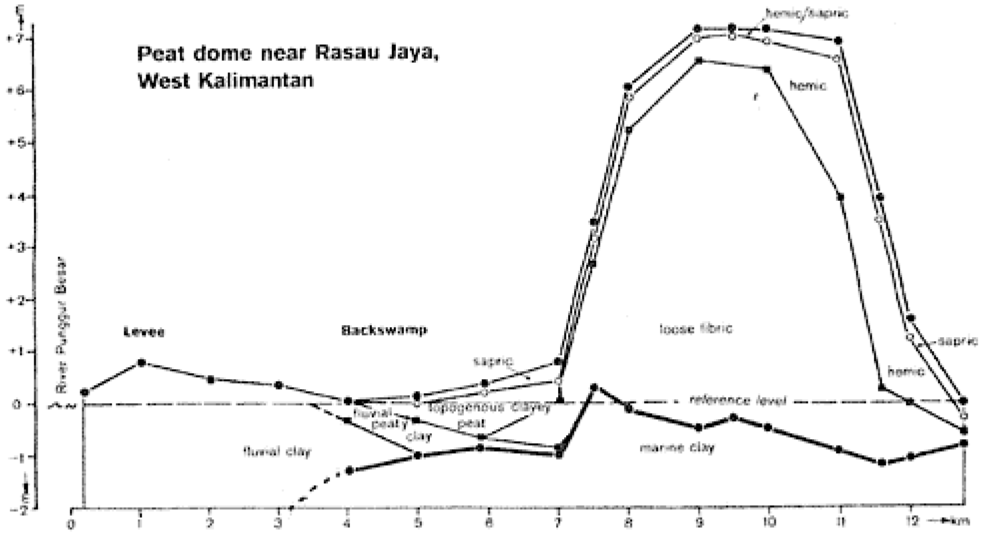

Figure 2.1. Cross-section of a small coastal "raised dome" near Pontianak, Indonesia (from Driessen and Deckers, 2001)

The net rate of vertical peat accumulation decreases with time in a roughly exponential pattern. Carbon datings of deep peat in Indonesia and Sarawak indicate an initial accumulation rate of 0.25 to 0.45 cm/year that decreased in the course of 3 to 5 milennia to 0.05 cm/year and less (Driessen and Deckers, 2001).
Radiocarbon dating of peats in Central Kalimantan shows variations in the age of coastal and basin peats from 800 to almost 5,000 yr BP. The high peats of the interior of Central Kalimantan however started to accumulate around 10,000 yr BP (Sieffermann et al., 1988).

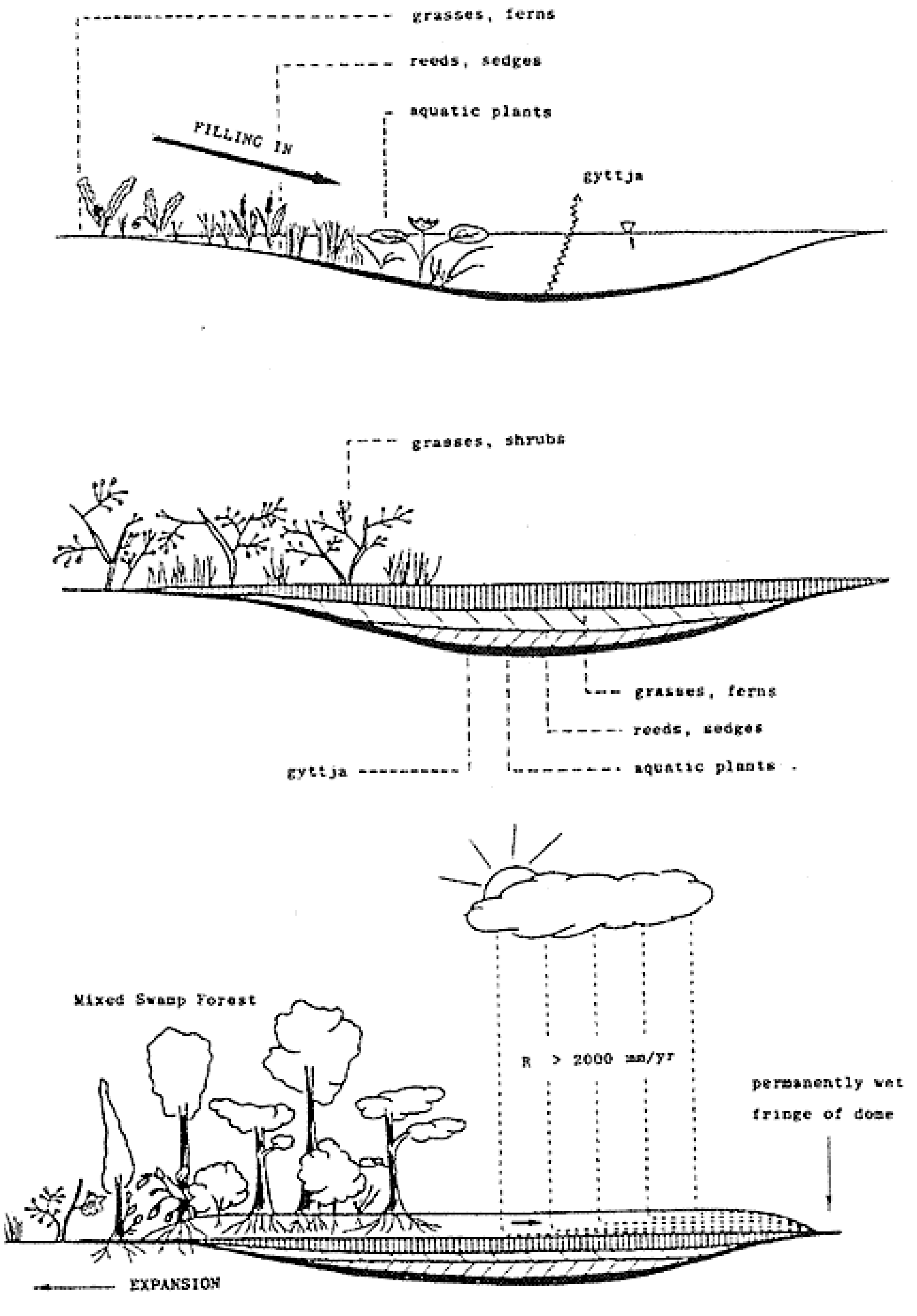

Figure 2.2. A depression is gradually filled in with topogenous peat, which is then overgrown by a laterally expanding ombrogenous peat mass (from Driessen and Deckers, 2001)

2.3 Climate

According to the Köppen classification system, which is based on temperature and precipitation, the climate in Kalimantan is a tropical rain climate without a dry season and a long term mean precipitation in the driest month higher than 60 mm (class Af). The climate is influenced by two monsoon winds, the Northeast Monsoon from November to February and the Southwest Monsoon from April to September. Average evaporation throughout the year is fairly constant and has a total of almost 1500 mm per year in Banjarmasin, South Kalimantan. Annual rainfall is much higher than annual evaporation, but much more irregular in time. During the driest months evaporation exceeds rainfall (figure 2.3) (Ritzema and Wösten, 2002). Central Kalimantan around Palangka Raya has 2.3 m/yr rainfall and experiences a mild dry season of three months and in some years there can be 4-6 months with a moisture deficit (Neuzil, 1997).

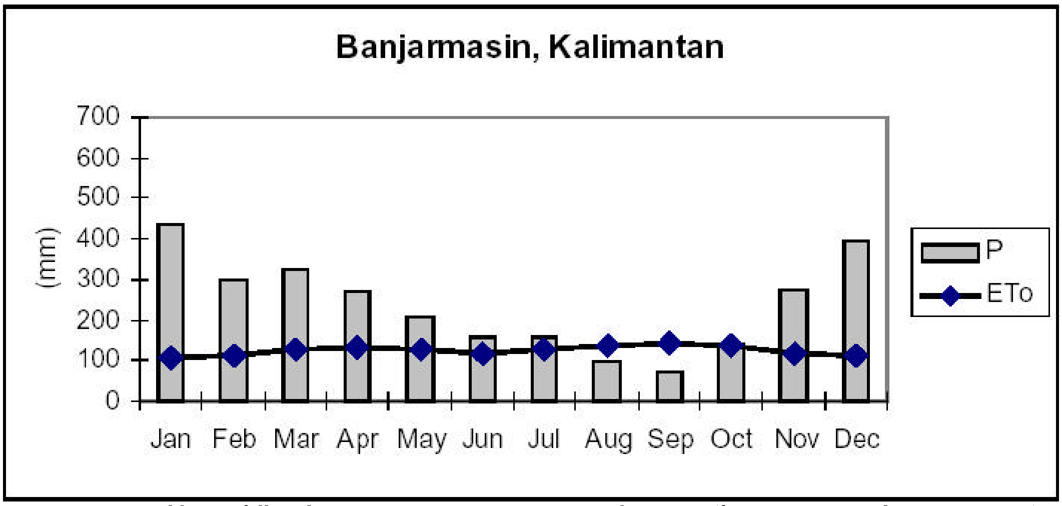

Figure 2.3. Monthly rainfall and evaporation in Banjarmasin, Kalimantan (from Ritzema and Wösten, 2002)

2.4 Soil characteristics

Soils with an organic matter content of more than 30% occuring in a 40 cm layer within the upper 80 cm of the soil profile are classified as Histosol by the FAO-UNESCO Classification System (Radjagukguk, 1997). Histosols are formed in 'organic soil marerial', with physical, chemical and mechanical properties that differ strongly from those of mineral soil material. Organic soil material accumulates in conditions where plant matter is produced by an adapted ('climax') vegetation, and where decomposition of litter is slowed by:

- persistent water saturation,
- extreme acidic conditions or nutrient deficiency,
- high levels of electrolytes or organic toxins.

In the tropics these so-called raised bogs consist mainly of slightly or partially decomposed trunks, branches and roots of trees within a matrix of structureless decomposed material (Rieley et al., 1996). Dry bulk density is about 0.1 g/cm^3 and ash content very low (<2%).

2.5 Hydrology

The hydrology of tropical peat swamps is determined by the climate, topographic conditions, natural subsoil and drainage base. In general, the development of peat domes depends on permanent waterlogged conditions due to a precipitation surplus (Spieksma, 1998; Ritzema and Wösten, 2002). The domes of these ombrogenous peatlands are situated topographically above the highest limit of wet season river flooding. Therefore water tables of the peat swamp fluctuate with rainfall.
The water tables are lowest during the dry season or periods of drought Surface water run-off occurs along an anastomosing system of water tracks, from the centre to the perimeter, flowing into streams and rivers that drain the peat covered watersheds. Water also flows laterally through the upper peat layers within the zone of water table fluctuation.
The overall properties of these tropical peatlands are a result of wood content, degree of decompostion, mineral content, bulk density, hydraulic conductivity and water holding capacity (Rieley et al., 1997). There are various parameters that are important for ombrogeneous lowland peat swamps and that have to be specified in order to understand their hydrology.

Topography
Peat swamps are bordered by the sea and by rivers. On the seaward sise the borders consist of sand deposits or mudflats, along the rivers they consist of levees of mineral soil. From these levees to the centre of the swamp the subsoil genltly drops, and this is what causes the typical lens-shaped cross-section of a peat dome. In old peat swamps the edges can have a convexity of up to 6 meters over the first 250 meter. The centre of the bog is almost flat and can be situated up to 20m above sea level (Ritzema and Wösten, 2002).

Evapotranspiration
Average evapotranspiration in tropical peatlands is fairly constant during the year, and only during the driest months evapotranspiration exceeds precipitation (Ritzema and Wösten, 2002).

Rainfall
Together with evapotranspiration rainfall is the most important factor influencing ground water level change in a peat swamp forest. If the precipitation is less than evapotranspiration the ground water level will fall and the surface peat layer will become dry (Takahasi et al., 2002). Ground water levels rise sharply after each heavy rain event, and drop step-wise during dry periods (Takahashi and Yonetani, 1997).

Hydraulic conductivity
Hydraulic conductivity is a measure of the rate at which water moves through the soil and is an important parameter in peat swamp hydrology. It indicates the amount of water stored in a peat deposit and that can be released to the surface in natural or artificial drainage, and therefore determines the water table response to rainfall.
Several soil characteristics influence hydraulic conductivity and therefore it is closely related to land-use. Total pore space and permeabilty (interconnected pore space) determine hydraulic conductivity and water retention capacity of the peat soil. These characteristics are functions of degree of decomposistion and bulk density. After drainage, the degree of decomposition of organic matter increases – and therefore also bulk density increases – and hydraulic conductivity decreases (Nugroho et al., 1997).

Storage capacity
The peat layer functions as a buffer during periods of heavy rainfall, because rainfall can easily infiltrate in the peat soil. However, storage can only take place in the unsaturated zone, and therefore is limited because of the high ground water tables in peat (Ritzema and Wösten, 2002).

Discharge/run-off
In natural peat catchments there are three routes of water outflow:
- surface run-off or depression flow,
- sub-surface flow,
- groundwater flow.

Surface run-off is caused by a series of hollows or even by “blackwater” channels, and accounts for the largest part of the natural outflow. Subsurface flow occurs in the top layer of the peat (acrotelm), which has a very high hydraulic conductivity, and also accounts for a large part of the outflow (Hooijer, 2003; Ritzema and Wösten, 2002; Bragg, 1997; Takahashi and Yonetani, 1997).

2.6 Functions

Although peat swamp forest vegetation is less diverse than the vegetation of rain forest growing on mineral soil, it has been recognised as an important regional reservoir of plant diversity in South-east Asia. Large tropical peatlands usually support a number af different forest sub-types, which vary in their species complement and structure in response to changes in peat depth and hydrology.
Also primate diversities are said to be less diverse than in lowland dipterocarp forest. Nevertheless, tropical peat swamp forest function as a habitat for many globally threatened bird and mammal species (Sebastian, 2001). For example, Malaysian peat swamp forests are the habitat of the Sumatran rhinoceros and the proboscis monkey. In Borneo they are one of the most important habitats for the orang-utan. Ornithological importance of the peat swamp forests also becomes more and more recognised (Page et al., 1996).
Large peat-covered catchments also play an important role in the provision and sustainability of water recources. Functions that are performed by these tropical

wetland systems are water storage, groundwater recharge, storm protection, flood mitigation, shoreline stabilisation and erosion control. Other functions are retention of carbon, nutrients, sediments and pollutants (Page et al., 1996; Rieley and Page, 2001). Tropical peatlands are a major sink of carbon and hence play an important role in the global carion cycle. The ability of peatlands to accumulate and store carbon is related to hydrology and associated water table, geomorphology and climate (Rieley and Page, 2001). During the 1997 El Nino event, which caused widespread fires throughout the forested peatlands in Indonesia, between 0.81 and 2.57 Gt of carbon were released to the atmosphere. This is equivalent to 13-40% of the mean annual global carbon emissions from fossil fuels (Page et al., 2002).
Furthermore, peat deposits may conserve valuable pollen,spores and macrofossils, which hold a detailed record not only of the peatlands themselves but also of the adjacent and regional vegetation. They contain a record of tectonic events and ancient tropical agricultural activities (Bellamy, 1997).
In addition to these more or less intrinsic values, peatlands also have an important economic role. They contain several timber species of high commercial value. Also the peat swamp forest provide several sources of income and resource provision for local communities. They supply non-timber forest product such as *gemur*, rubber, fruits, bush meat, *damar* and *jelutung* (Persoon and Aliayub, 2002). Also peat forests are a breeding ground for several commercially important species of river fish (Page et al., 1996). Furthermore, the peat swamp forest houses an increasing number of plant species recognised as of medicinal value (Maltby, 1997).

In the past scientists emphasised mostly ecological functions to promote conservation of tropical peatlands.
In recent years a new appraoch has been advocated to formulate new strategies and policy for the wise use of tropical lowland peatlands. This appraoch not only considers ecological aspects but also utilitarian aspects of the ecosystem. The concept is called wetland ecosystem functioning, and this approach may be much more appealing to politicians and decision-makers than the traditionally more restricted arguments for conservation (Maltby, 1997).

2.7 Current and prospective uses of peatlands in Indonesia

There are many options for utilising peat and peatlands, which can be divided into non-extractive and extractive use, see box 2.1. Only few of these options however are relevant for the current and prospective near-future situation in Indonesia. Some of Indonesia's peatlands are preserved but the remainder are utilised for some productive function. The remainder of these utilised peatlands has been cleared for cultivation and extraction. They are used for anual and perennial crop production, the establishment of plantation forests or extraction like providing seedling substrates for forest nurseries. Uncleared peatlands which are used for productive functions are designated either as unlimited or limited production forests for timber. See table xx for the functions of Indonsesia's peatlands.

Table 2.4. Breakdown of Indonesia's peatlands on the basis of land use (Radjakgukguk, 1993)

Land use types	**Area (ha)**	**% of total**
Convertible forest	3,951,875	19.7
Protected forest	578,525	2.9
Nature conservation forest	1,375,265	6.9
Unlimited production forest	5,249,560	26.1
Limited production forest	1,243,300	6.2
Unclassified	7,674,300	38.2
Total	**20,072,825**	**100.0**

The utilisation of Indonesia's peatlands for agriculture is now top priority in Indonesia. The government fully realises the importance of the peatland resource in sustaining the counties self-sufficiency in rice and in increasing the production of estate crops for export.

So far, paddy cropping has been restricted to shallow peat soils, particularly at the edges of the peat domes. On peat thicker than 60 cm, yields of paddy apparantly fall sharp compared to yields on thinner peats. The cultivation of upland crops, in particular cash crops, have been attempted with varying success, and the cultivation of vegetable and fruit crops has almost always been very succesful. In recent years, the cultivation of estate crops such as cocnut and oil palm, has rapidly expanded on lowland deep peats. Also ramin, spices and medicinal crops seem to have good prospects (Radjagukguk, 1997).

Box 2.1: Use options of peatlands (Radjagukguk, 1997)

Non-extractive
Natural peatlands

- **Ecological/environmental functions**
- **Recreation**
- **Education and research**
- **Aesthetics and heritage**

Modified/managed peatlands

- **Agriculture**
- **Forestry**
- **Other plant harvests (food, fibre, medicine)**
- **Waterfowl production**
- **Fishing**
- **Aquaculture**

- **Waste disposal**
- **Transportation**
- **Residential/industrial**
- **Harbour development**
- **Channel development**
- **Hydropower**

Extractive
Fuel peat
Hortocultural peat
Soil improvement material
Industrial peat (chemical extraction)
Insulation and packaging material
Effluent treatment material
Fertilizer base
Ceramic type material

2.8 Effects of changing land-use

2.8.1 Reclamation

Reclamation of peatlands generally has single sector puposes such as agriculture and forestry (Maltby et al., 1996). Natural peat bogs must be drained and normally also limed and fertilised to permit cultivation of “normal” crops. Therefore reclamation of peat bogs nearly always starts with the construction of shallow drainage ditches. Usually the natural vegetation is left standing for a few years because it accelerates drying of the peat. Woody dome peat formations do not require very narrow spacing of the drains. The drainage system however will have to be adjusted after several years because of the changing soil properties (Driessen and Deckers, 2001).

2.8.2 Subsidence

The lowering of the groundwater table after drainage causes subsidence of the peat layer. The initial phase involves the loss of buoyancy of the peat and compaction of the organic column under its own weight. This compaction results in changes in bulk density, water content, pore volume and hydraulic conductivity. The dominant processes in the second phase are biological oxidation, wind and water erosion and leaching of soluble organic materials (Nugroho et al., 1997). Subsidence in the first year(s) of drainage can be as much as 500 mm and proceeds at rates of 10-100 mm depending on local conditions, providing the watertable is progressively lowered (Maltby, 1997; Wösten et al., 1997).
Wösten et al. (1997) give a subdivision of subsidence into three components:

Consolidation: mechanical compression of permanently saturated peat layers. This is the very rapid subsidence that occurs when virgin peat swamps are drained. In the beginning it basically equals the rate at which the groundwater table is lowered (PS Konsultant & LAWOO, 2001).

Oxidation: volume reduction of peat above the grounwater table resulting from loss of organic matter due to decompostion biochemnical processes.

Shrinkage: volume reduction of peat above the groundwater level due to irreversible loss of water at highly negative water pressures.

Cultivation practices may also contribute to subsidence. For instance, when small farmers burn the vegetation and the top layer of the peat to “liberate” nutrients for crop growth and to raise the pH, or to remove crop residues, an increased oxidation occurs (Driessen and Deckers, 2001). Use of fertilisers influences the biological activity in peat soils and thereby also contributes to subsidence. On the other hand, subsidence can be reduced by compaction with heavy machinery to allow anchorage of trees and to increase the bearing capacity of the land (Wösten et al., 1997).
Long-term average subsidence rates as a function of watertable depths can be calculated from observed peat subsidence in different areas of the world. Figure 2.4 shows subsidence rate versus groundwater level for different areas in the world. Subsidence rates in the tropics are much higher than rates in temperate areas. This can be explained from an increase in soil temperature and the absence of summer-winter periodicity (Wösten et al., 1997). For Sarawak the following relationship can be derived (PS Konsultant & LAWOO, 2001):

Subsidence rate (cm/year) = 0.1 * watertable level (cm)

Linear regression of the data for IADP area in peninsular Malaysia show that the long-term effect of each 10 cm lowering of the groundwater table is an increased subsidence of 0.7 cm per year. However, this relation decreases with time and during the last phase the increase has been reduced to 0.4 cm per year. Therefore the relation Wösten et al. (1997) derive is:

Subsidence rate (cm/year) = 0.04 * watertable level (cm)

An empirical model derived by Stephens and Stewart (1976) for Florida can also be used to describe the relationship for subsidence versus groundwater level. The contants have been calibrated for circumstances in Malaysia by Wösten et al. (1997), the resulting equation is:

$$\text{Subsidence rate (cm/year)} = (0.093 + 0.00524 * GL) * 2^{(T-5)/10}$$

In which GL is the groundwatertable level (cm) and T is the soil temperature (ºC) at 10 cm soil depth. The last term is based on the assumption that the reaction rate doubles for each 10ºC rise in temperature.
However, because of the parabolic-shaped watertable between drainage canals, additional subsidence occurs close to these canals. The additional subsidence can be estimated as up to 30%.
Using the Peat OXidation And Permanent Shrinkage (POXAPS) model the extent to which oxidation and shrinkage contribute to total subsidence can be estimated. Calculations for several locations resulted in an average of 60% for subsidence caused by oxidation and an average of 40% for shrinkage (Wösten et al., 1997).

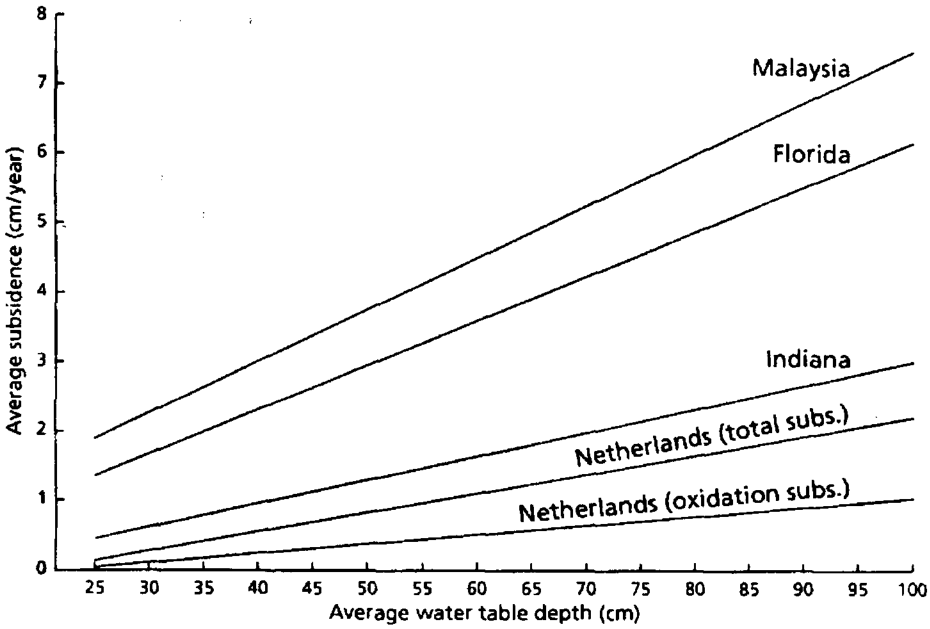

Figure 2.4. Subsidence rate versus groundwater level relationships for different areas in the world (after Wösten et al., 1997)

It may be clear that drainage and overall site hydrology in peat bogs is very difficult to manage. Not only technical problems are encountered as a result of drainage but also alteration of environmental quality such as water quality, a decline in previously "free goods" from the forest such as fisheries and other natural harvests. Thus a perception of the importance of the peat swamp forest as a vital economic and social resource is acknowledged (Immirzi et al., 1996).

3 Study area

3.1 Topography

The main study area selected is the catchment of Sungai Sebangau in Central Kalimantan. The province of Central Kalimantan is situated in the middle of Kalimantan, the Indonesian part of Borneo (see figure 3.1).

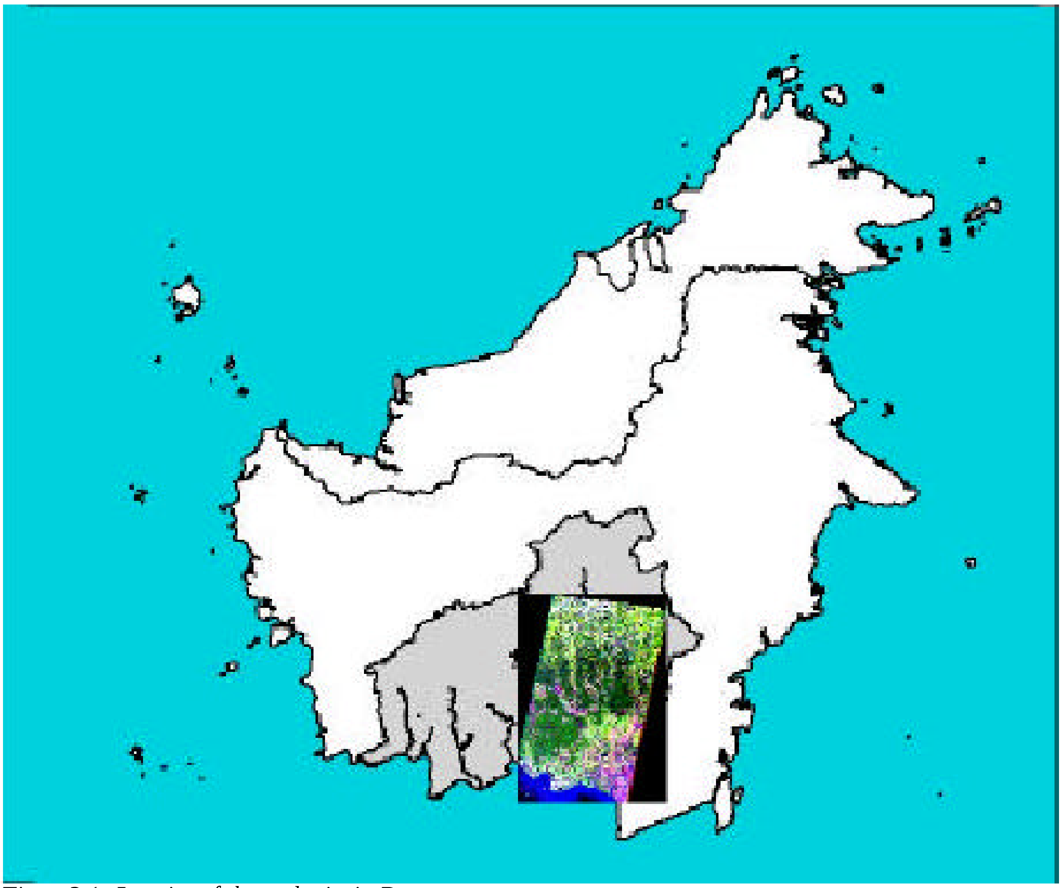

Figure 3.1. Location of the study site in Borneo

The Sebangau River is a blackwater river that originates in, and drains, a densely forested 15,000 km^2 large peat swamp in the floodplains between the Kahayan and Katingan rivers in Central Kalimantan (Muhamad and Rieley, 2001). The Sungai Sebangau catchment is a large watershed area of undisturbed peatland, located between the Sungai Sebangau and the Sungai Katingan, stretching 200 km north from the Java Sea. This area is the last remaining large continuous block of peat swamp forest in Kalimantan (Boehm and Siegert, 2001). It is an area of low relief with small, granite hills that rise above the peat-covered landscape. The mineral underground below the peat consists mainly of quartz sand (podzol) (Boehm et al., 2002). This layer is often more than 5 m thick and under it there is a hard pan of about 2 m thick (Rieley et al., 1992). The Sungai Sebangau is a slow-flowing “blackwater” river which rises over the 200 km that it is stretched inland only about 20 meters above sea level. In its upper catchment there are extensive ares of high peat, which are replaced by shallower coastal peat nearer to the sea (Page et al., 1996). Peat thickness increases with the distance from the river and varies between 1 and 10 meters. Peat surface elevation from the river to the center of the peat dome varies between 1 and 20 meters.

Very little permanent habitation occurs within the catchment and only along the main rivers, the principal land-uses are small-scale agriculture, timber and river-fishing. Despite of the low accessibility of the interior some transmigration settlements have been established along the Sungai Sebangau. Along the Sungai Katingan, Sungai Bulan and Sungai Klaru some agricultural settlements are situated, which differ from the transmigration settlements in the sense that the fields are not irrigated. Also canals have been dug to provide transport for (il)legal logging practices.

East of the Sungai Sebangau the MRP area is situated. The area between the Sungai Sebangau and the Sungai Kahayan is generally referred to as ‘Block C’. In this area almost all the peat swamp forest has disappeared because of the implementation of the Mega Rice Project. Trees have been removed, irrigation channels have been dug and due to these measures in the dry periods forest fires destroyed the remaining forest and the top layer of the peat deposit. Irrigation, drying and burning caused shrinkage and subsidence of the peat. In this area more habitation occurs, mainly along the rivers and channels transmigration settlements are located (see figure 3.2).

Figure 3.2. Map of the study area in Central Kalimantan. Left the Sungai Katingan, right the Sungai Kahayan and in the middle the Sungai Sebangau. Palangka Raya is the capital of Central Kalimantan

3.2 Genesis

Peat accumulation in the Sungai Sebangau catchment was initiated at 22,120 ^{14}C yr BP, dated at the peat-sediment interface at 840 cm. This is the oldest age reported for any SE Asian peat deposit (Weiss et al., 2002). In the center of the peat dome however the peat can be up to 13 m thick (Page et al., 1996), which implies even older ages of the peat deposit (Wust, pers. comm.). Peat accumulation in the late Pleistocene was very low but during the early Holocene increased nearly threefold. In the mid Holocene accumulation decreased and in the late Holocene between 6070 ^{14}C yr BP and the present peat accumulation rates decreased to 0.001 $g/cm^2/yr$ (Weiss et al., 2002).

3.3 Soil characteristics

Conditions are very acidic, pH varies between 3 and 4. The peat water is dark brown to a murky black and contains dissolved organic acids. Dry bulk density and ash content are low compared to mineral soils. Dry bulk density of a peat core sampled in the Sebangau catchment under low pole forest ranges from 0.02 to 0.21 g/cm^3. Ash contents in the same core vary between 0.33% and 1% and pH is 3.2 ± 0.4 (Weiss et al., 2002).
On top of the silty substrate a clayey peat layer is situated. The largest part of the peat dome consists of coarse hemic (fibric) peat. This layer is covered by a hemic/sapric layer. The level of the watertable is approximately coincident with the bottom of this layer (Moore et al., 1996).

3.4 Vegetation

Along the gradient in peat thickness and elevation of the peat surface there are distinct differences in forest structure (Page et al., 1999, Shepherd et al., 1997). These shifts in vegetation type are also connected with the depth of the water table below the peat surface.

Riverine forest
In the upper catchment the edge of the peat swamp forest is at a distance of about 1,5 km from the river, because the original riverine forest has ben removed. In the middle catchment however, some forest still persists on the river bank. Here the peat is shallow (up to 1,5 m thick) and, during the dry season, shallow pools are present on the forest floor. Canopy trees achieve heights between 25 and 35 m. The principal canopy tree is *Shorea balangeran*, which is the only tree that exceeds a hight of 35 m. The sedge *Thorachostachyum bancanum* is characteristic of the ground vegetation. In places where the riverine forest has been destroyed due to logging and burning it is replaced by low-growing, species-poor sedge swamp.

Transition forest (riverine-mixed swamp forest)
Slightly further from the river, on a peat layer up to 2 m thick, transistion forest is found, which is influenced mostly by the outflow from the interior peat catchment. Also here the principal canopy tree is *Shorea balangeran*.

Mixed swamp forest
Mixed swamp forest extends up to a distance of 4 km from the river. It is located beyond the limit of river flowing and the peat thickness increases from 2 to 6 m. The

forest is stratified, with an upper canopy height of 35 m, then a closed layer between 15 and 25 m and then a more open layer with trees form 7 to 12 m in height. The trees grow on large hummocks formed by root plates and that are interspersed with hollows that fill with water during the wet season. This forest type contains several commercial tree species, like *Calophyllum sclerophyllum*, *Cratoxylum glaucum*, *Dactylocladus stenostachys*, *Gonystylus bancanus*, *Shorea balangeran* and *S. Teysmanniana*. There is a wide range of other tree species. The forest floor is covered by a dense growth of seedlings and saplings, the sedge *Thorachostachyum bancanum* and a few shrubs and herbs. Several climbers, epiphytes, insectivorous pitcher plants and orchids occur in this forest type.

Transistion forest (mixed swamp forest-low pole forest)
Between 4 and 6 km from the margin of the peat dome there is a slow transistion from mixed swamp to low pole forest. The canopy reaches a height of 25-30 m. This type has a similar range of species to that of the mixed swamp forest. Pandans form an almost continuous ground cover.

Low pole forest
This forest occurs between 6 and 11 km from the river on peat that is from 7 to 10 m thick. The groundwater table is permanently high. The forest floor is uneven and the trees grow on island-like hummocks that are separated by deep, waterfilled depressions in which the water persists during the dry season. A dense mat of tree roots is formed in the surface peat. The upper canopy reaches a height of 20 m and is open, the lower canopy reaches hieghts between 12 and 15 m and is more closed. This type contains very few commercial trees and no good timber species. Here pandans form a dense ground cover.

Tall interior forest
This forest occupies most of the upper regions of the peat dome, with peat thicknesses of at least 9 m. The water table is below the surface throughout the year, during the dry period water tables of –1,5 m can be measured.. Upper canopy heights reach up to 45 m, the lower two layers reach up to 15-25 m and 8-15 m. The upper canopy is dominated by *Agathis dammara*, *Calophyllum hosei*, *C lowii*, *Cratoxylum glaucum*, *Dactylocladus stenostachys*, *Dipterocarpus coriaceus*, *Dyera cotulata*, *Eugenia havilandii*, *Gonystylus bancanus*, *Gymnostoma sumatrana*, *Koompassia malaccensis*, *Mezzetia leptopoda*, *Palaquium* spp., *Shorea teysmanniana*, *S. platycarpa*, *Tristania grandifolia*, *Vatica mangachopai*, *Xantophyllum* spp.. and *Xylopia* spp. The forest floor is relatively flat and owing to the low light levels the ground flora is poorly developed. There is a greater abundance of climbers and epiphytes.

Very low canopy forest
The area where this forest type occurs has a permanently high water table and is characterised by very large pools. It is situated on the highest point of the catchment between the two river systems. Few of the trees exceed 1,5 m in height. The commonest species are *Calophyllum* spp., *Combretocarpus rotundatus*, *Cratoxylum* spp., *Dactylocladus stenostachys*, *Litsea* spp., *Ploiarium alternifolium* and *Tristania* spp. Because of the very open structure there is a great diversity in ground-covering vegetation. No

Pandanus spp. occur, the sedge *Thorachostachyum bancanum* is the most frequent vascular plant on the forest floor.

3.4.1 Fauna

Mammals
Highest diversity of mammals was recorded in the mixed swamp forest (26 species) and the tall interior forest (20 species). Only 8 species were recorded in the low pole forest. In total, 35 species have been identified, of which 5 primates: agile gibbon, pig-tailed and long-tailed macaques, orang utan and red leaf monkey. Some mammal species in the Sungai Sebangau occur outside their previously known ranges on the island of Borneo, such as marbled cat, grey tree rat, black flying squirrel and slender tree shrew (Page et al., 1997).

Orang utan
The tropical peat swamp forest is an important habitat for orang-utan. They are present in all forest types that occur in the catchment, but achieve highest densities in the marginal mixed swamp forest and the tall interior forest. The overall density of orang utan in the upper Sungai Sebangau catchment is estimated to be 1.7 individuals per square km. Density is much lower in areas of high disurbance. The total population in Sebangau is likely to appraoch 4,000 individuals, so it exceeds the minum population size of 2,000 individuals which is necessary to be self-sustaining (Page et al., 1997). Although the importance of the catchment for the conservation of orang utan populations is acknowledged, the population in Sungai Sebangau is not under official protection (Meijaard, 1997). Orang-utan densities in the Sebangau catchment have altered since 1996. This shift coincided with the commencement of illegal logging activity. A higher orang-utan density in the low pole forest indicates that many orang-utans have moved away from logging areas. If the distribution does not return to normal, a substantial decline in numbers will result (Husson et al., 2002).

Birds
A total of 150 bird species are identified, of which 106 occur in the mixed swamp forest and 77 in the tall interior forest. Some rare peat swamp forest specialists are recorded, and six species are Red Data Book Species. This outlines that the avian species diversity is considerable and the importance of this habitat as a refuge for a number af rare and threatened species. Eighty percent of all species recorded can survive in selectively logged forest, however the long-term effects of selective logging have not been determined yet (Page et al., 1997).

Fish
Fish species have been recorded in the Sungai Sebangau and its tributaries, in the sedge swamp and in pools on the forest floor. A total of 34 species was recorded, of which twelve are endemic to Borneo and seven have not been recorded previously from Central Kalimantan, which stresses the importance of this habitat. Blackwater

fish communities are not only of scientific interest, but also they are renewable resources of important economic value to local communities (Page et al., 1997).

3.5 Hydrology

Water tables in the Sebangau catchment are generally lower than in other Indo-Malesian peats (Moore et al., 1996). During the dry season water level in the tall interior forest (see 3.4) can drop to 1.5 m below the soil surface. Here the water table never rises above the peat surface, whilst in the other forest types the water table is almost continuously above the peat surface during the rainy season (Page et al., 1999). Actual daily evapotranspiration in the peat swamp forest of the Sebangau catchment varies between 3.2 and 3.6 mm/day (Takahashi et al., 2002).
Hydraulic conductivities in the area vary with landuse and peat depth. According to a recent study conducted by Sajarwan (2001) hydraulic conductivities in the area range from 0.48 to 12.48 m/day (Radjagukguk, 2002). In the top layer of the peat they exceed values of 10 m/day (Takahashi and Yonetani, 1997). Under agricultural land hydraulic conductivities are lower than under forest and can be as low as 0.00195 m/day (data collected by Adi Jaya and several students).

3.6 Current and potential land use forms in the Sebangau catchment.

Peatland areas in Central Kalimantan can be classified into three types according to the intensity of human activtities; 1) the native peat swamp forest, 2) the destroyed, abandoned and fire-damaged area, 3) cultivated areas. Villages are situated along the main rivers: Sungai Kahayan, Sungai Sebangau, Sungai Katingan and Sungai Bulan. The main sources of income in the region are (illegal) logging, fishing, agriculture and local forestry. Appendix 1 gives the locations of potential products and main threats in the area.

3.6.1 Logging

Various types of logging occur in the Sebangau catchment.
Riverbank logging is a relatively small-scale activity wich is used particularly along the Sungai Katingan during the dry season. It involves cutting of the trees, the transporting of the logs to the main river trhough a path consisting of small beams over which a kind of sledge carrying one log of four meters length can be pulled and pushed at the time. The density of these sites along the river can be very high. This type of logging destroys the riverine forest.
Logging with the use of canals, of which some reach 25 km into the forest, opens up the interior forest and is particularly used for the more valuable species. The canals can be about one meter wide and not more than one meter deep, or might be up tio 8 meters wide and 5 or 6 meters deep. There are many of these canals, not only connecting the swamp forest directly with the Sungai Sebangau and Katingan, but also along the tributaries of these rivers webs of canals are dug. According to a self-

made map of a Javanese transmigrant the density of the canal system along the Danau Panjang river in the southern part of the Sebangau forest is very high.
The canals have an incredibly important ecological effect. Due to the continuous drainage through the canals, in particular during the dry season, the top soil of the peat quickly dries out. Also during the rainy season the groundwater table is lowered due to an increased run-off.
The third system is logging using a railway., which requires very high investments. It is a system based on a railway through the forest with a locomotive that can pull about 40 m^3 at a time.This system has been used in the early phase of logging in the area by large companies, nowadays only one contractor uses this system. Old railways have been removed though the leftovers can still be seen. The peat below the railway is compressed and the trail functions as a canal (Persoon and Aliayub, 2002).

3.6.2 Fishing

Fishing is the occupation of mainly local people, in particular Dayak and Banjarese. In the sea fishing for shrimp and other small fish occurs with nets. Near the coast shrimp ponds are established by cleaning the area of all vegetation, building a dyke and a drainage system to supply the pond with seawater. For freshwater fishing in the rivers nets are used but also the very controversial form which uses electricity.

3.6.3 Agriculture and local forestry

Along the Sungai Kahayan, between Maliku and Pankuh, a high density of transmigration villages is situated. The main crop cultivated here is dry rice, which is grown in the dry season because during the wet season the fields are flooded with the (acidic) peat water. Also to the north along the Sungai Kahayan, south-east of Palangka Raya, transmigration settlements can be found growing mainly rice. The only settlements along the Sungai Sebangau are located in the south: Paduran I, II and III. Here also rice is the main crop. Other crops grown in transmigration settlements are cassava, corn and bananas (pers. comm., Ma'mun).
Also some Dayak villages are situated along the Sungai Sebangau but their main income comes from local forestry activities and hunting and gathering. Dayaks are familiar with cultivating rattan in their forest fields for a long time. The cultivation of rubber trees is difficult because of the regular flooding but it does happen on small scale. Sago cultivation does hardly occur , it is not considered as an agricultural crop anymore because people prefer rice as a staple food. In the past the starch of this palm is known to have been eaten and the leaves functioned as roofing material. Now the sago stands are cleared as a result of expanding vegetable gardens. Drainage of these fields is also detrimental to the palms. Therefore the sago palm is actually a potentially valuable crop, very suited for the ecological conditions of the Sebangau area. It grows very well in swampy conditions, can easily withstand extensive flooding and it is one of the very few agricultural crops that does not require drainage of swamps (Yonebayashi et al., 1997). According to farmers experiences and the results of various studies, horticultural crops are also suitable to be grown on peat

(Radjagukguk, 1997). Dayak villages further upstream use shifting agriculture for growing non-irrigated upland rice species for a couple of years after clearing and burning. The next phase can be rattan or fruit trees. Products from the forest gathered can be *gemor, damar* and *jelutung*. Animals hunted for are birds, *kura-kura* and *kalong* (Persoon and Aliayub, 2002).

4 Hydrological modelling

4.1 Description of the SIMGRO model

The model used for the study is the regional groundwater flow model SIMGRO (SIMulation of GROundwater flow and surface water levels). This model is physically-based and simulates the water flow in the saturated zone, the unsaturated zone and the surface water (figure 4.1). The model takes into account the effects of irrigation, drainage and groundwater use. Because SIMGRO is physically based it can be used in situations with changing hydrological conditions. See Appendix 2 for the schematisation of water flows in SIMGRO.

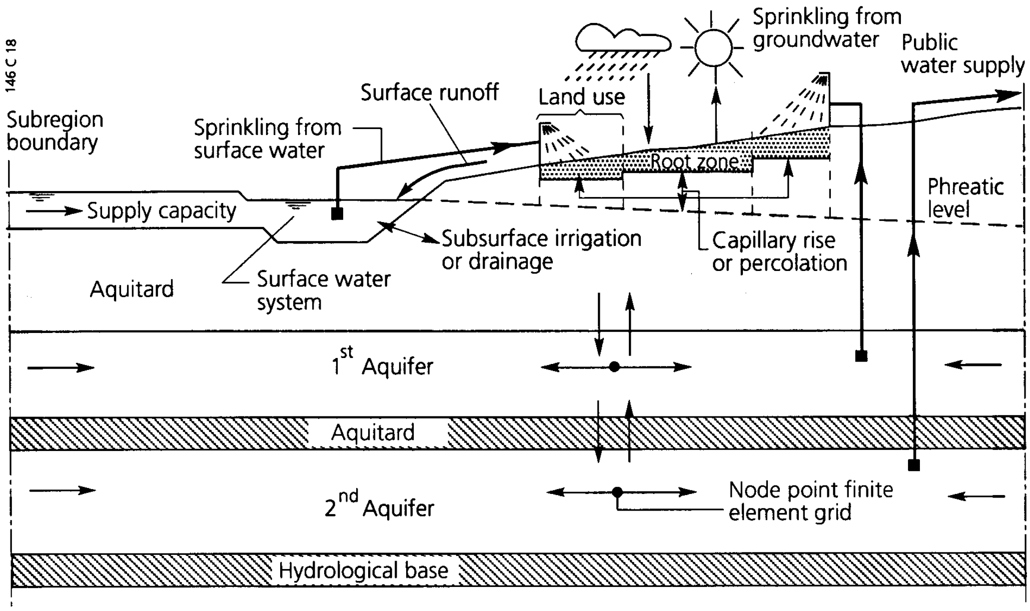

Figure 4.1. Schematisation in SIMGRO of the hydrological system by means of an intergration of saturated zone, unsaurated zone and the surface water (Querner and Van Bakel, 1989)

4.1.1 Saturated zone

Saturated groundwater flow is modelled by means of the finite element method, for which the region is divided into a network of nodal points. Quasi-three dimensional flow is considered, which means horizontal flow in water-bearing layers (aquifers) and vertical flow in the less permeable layers (aquitards). Ecohydrological information such as hydraulic transmittivity, vertical resistance, layer thickness, storage coefficient and porosity, is required for each layer. Groundwater levels and fluxes are calculated per nodal point.

4.1.2 Unsaturated zone

The unsaturated zone is modelled at the nodal subdomain level. A nodal subdomain can be described as a ‘node with the associated land surface area’. Within it, soil physical properties are uniformly distributed. Various types of landuse and root zone depths may occur within one nodal subdomain, of which relative surface areas are present in the SIMGRO database. The unsaturated zone is modelled by means of two reservoirs, one for the root zone and one for the subsoil. The root zone has inflows and outflows: precipitation, evapotranspiration, irigation, percolation and capillary rise. An excess of water in the root zone percolates, and the actual evapotranspiration depends on the moisture content in the root zone. The groundwater level is calculated from the water balance of the subsoil below the root zone, using a storage coefficient dependent on the depth of the groundwater level below the soil surface and on soil characteristics. Within a nodal subdomain, calculations of unsaturated groundwater flow are performed for each landuse type.

4.1.3 Surface water

The surface water system is modelled as a network of reservoirs, in which the outflow from one reservoir is the incoming flow to the next reservoir. The area that is drained by all conduits within a reservoir is called a subcatchment. These subcatchments are linked, forming catchments, thus allowing the surface water to follow its natural discharge route. Subcatchments comprise at least one nodal subdomain. Open water conduits are classified on the basis of their sizes.

4.1.4 Plant-atmosphere

Potential evapotranspiration is calculated using potential evapotranspiration of a reference crop. Actual evapotranspiration is calculated from soil moisture storage in the root zone. Calculations are performed per landuse type per nodal subdomain.

4.1.5 Drainage and subirrigation

The exchange between surface waters and groundwater is calculated at each time stpe of the surface water calculation procedure. The surface water interacts with groundwater in the phreatic aquifer, deeper aquifers into which surface water conduits are (partially) penetrating, or aquifers below aquitards that are partially penetrated by surface water conduits.
The spatial distribution of the various classes of open water conduits within a nodal subdomain is unknown, and each class of open water conduits is assumed to drain independently from the others. The interaction between groundwater and surface waters depends on the differences between locally abutting groundwater- and surface water levels.

4.1.6 Sprinkler irrigation

This module was specifically developed for the Dutch situation and is not applicable for this study.

4.1.7 Capillary rise and percolation

Soil moisture flow is calculated during each groundwater time step, for every landuse form and for each nodal subdomain. If the moisture storage in the root zone exceeds the equilibrium content, percolation occurs, otherwise an upward flux is simulated.

4.1.8 Surface runoff

Surface runoff is the process in which an excess of precipitation is routed to the surface water system via the ground surface. Surface runoff takes place in case the precipitation exceeds the infiltration capacity of the soil. This is a complex process that is modelled in SIMGRO by a depression storage. When the depression reservoir is full, the excess is modelled as surface runoff. The infiltration capacity at the bottom is dependent on soil physical characteristics (Querner and Van Bakel, 1989; Querner et al., 1994; Dik and Van der Bolt, 1998; Kupper et al., 2002).

4.2 AlterrAqua

AlterrAqua is an Arcview 3.2 GIS application developed around the SIMGRO model. The purpose of this application is to make regional groundwater models easily accessible. The application enables the use of SIMGRO within the GIS environment of ArcView. SIMGRO input is generated stepwise in the separate AlterrAqua modules. For the flowchart of the model-building see Appendix 10. Because AlterrAqua was developed for the Dutch situation specifically, default values are used in standard input files and look up tables.
For a detailed description of SIMGRO input and output files, read Dik and Van der Bolt, 1998.

4.3 Schematisation and input data

4.3.1 Model boundary and nodal network

The model area is the entire riverbasin of the Sungai Sebangau. This includes the Sebangau catchment peat dome and the Block C peat dome as well as the adjacent rivers; Sungai Katingan in the east and Sungai Kahayan in the west. In the north the model boundary is situated just above Palangka Raya.

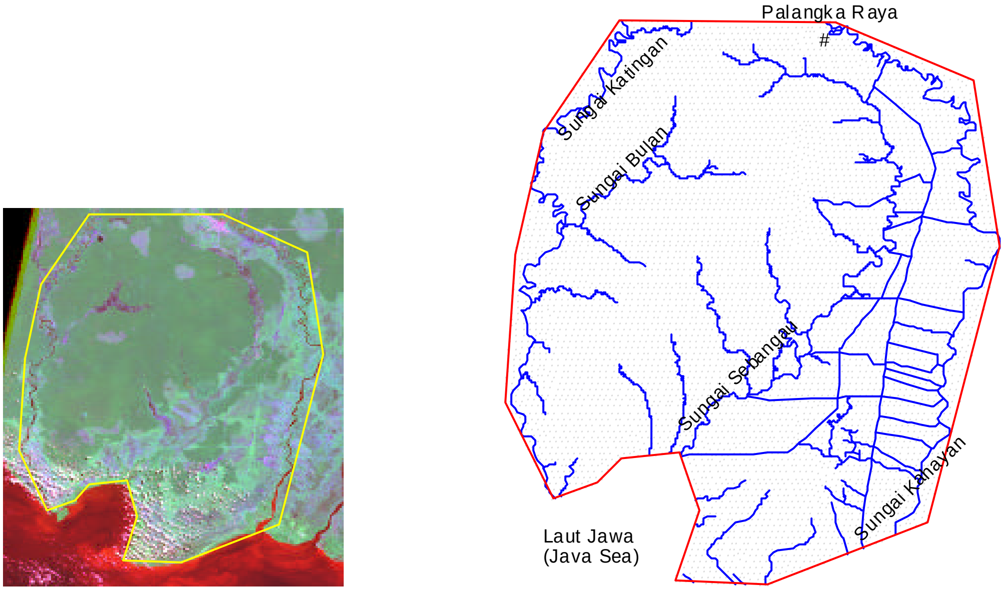

Figure 4.2. Left: landsat TM image showing model boundary. Right: model area with rivers and canals

The nodal network was generated using FemGrid, the grid generator of MicroFem. The distance between nodes was set to 1500m, this resulted in a network comprising 5791 nodes.

4.3.2 Geohydrological data

Because geohydrological data for the model area were very marginal much of the data required had to be generated manually from (satellite) images. All files were generated using ArcView. The generation of the geohydrological data needed for the model is considered as a useful and important tool for integration of the fragmented available data.

4.3.2.1 Surface water

A dtm (digital terrain model) was generated using a soil elevation map. The original soil elevation map is shown in Appendix 3.

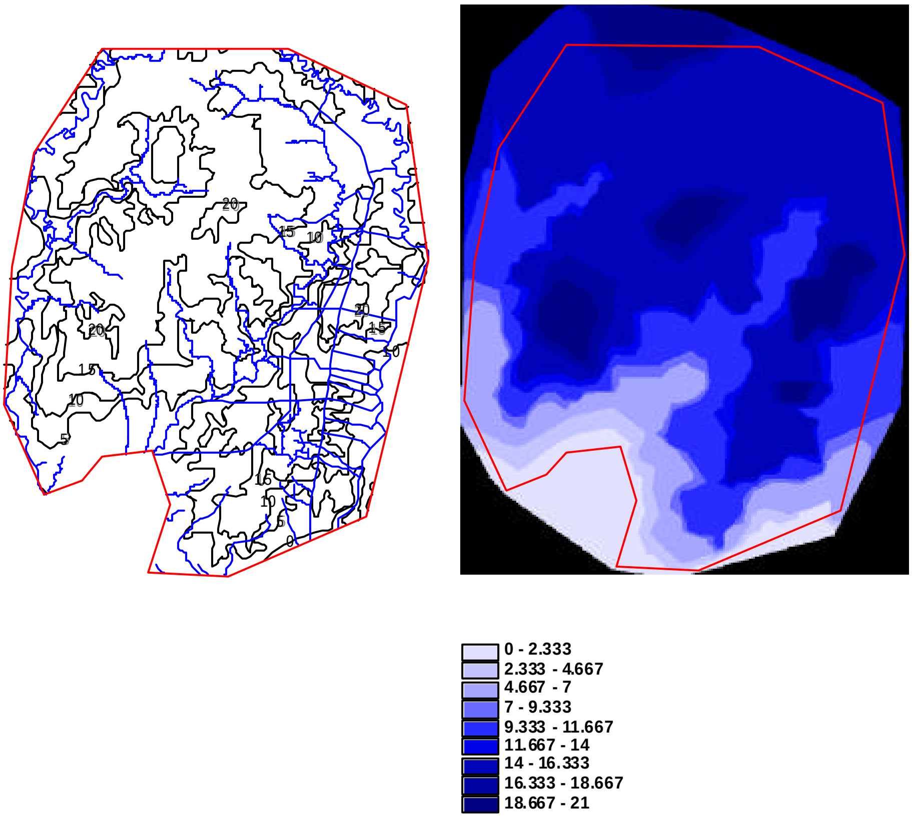

Figure 4.3. Soil elevation map and derived dtm. Classes in meters above mean sea level (msl)

A line-shapefile containing 2nd order open water conduits (rivers and canals, see figure 4.2) was drawn using a detailed satellite-image. Code, description and dimensions were defined. Of the three large rivers in the area the Sungai Kahayan and the Sungai Katingan have their origin outside of the model area. Therefore inflow rates at the model boundary were specified in these two rivers at day 244 of 1993, see table 4.1.

Table 4.1. Initial inflow rates at model boundary.

River	**Width at model boundary (m)**	**Depth (m)**	**Inflow (m^3/day)**
Katingan	200	1.6	9788235
Kahayan	200	2	14192284

Location and dimensions of smaller canals and streams were defined in a polygon-shapefile (4th order conduits). Five different systems were distinguished, of which the dimensions had to be specified (figure 4.4 and table 4.2).

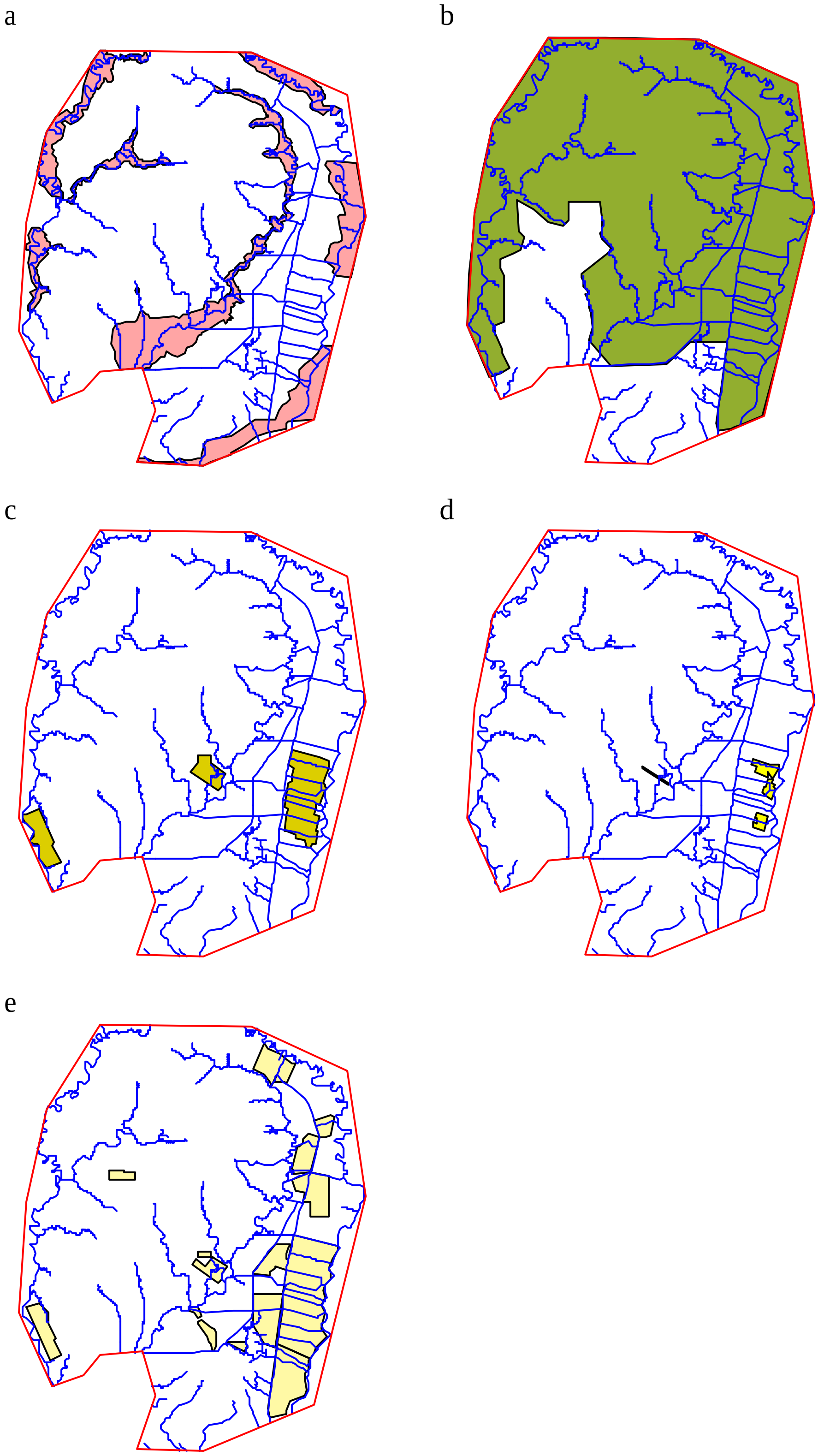

Figure 4.4a-4.4e. Drainage polygons as defined for SIMGRO calculations. See table 4.2 for dimensions

Table 4.2. Spacing and depth of drainage ploygons as shown in figures 4.4a–4.4e.

Polygon in figure.	Drain spacing (m)	Drain depth (m)
4.4a	1000	0.5
4.4b	1000	1
4.4c	400	0.75
4.4d	200	0.5
4.4e	100	0.5

Watersheds were created using the water conduits file and the dtm. With this file, the water conduits file and the network files, SIMGRO-watersheds could be created.

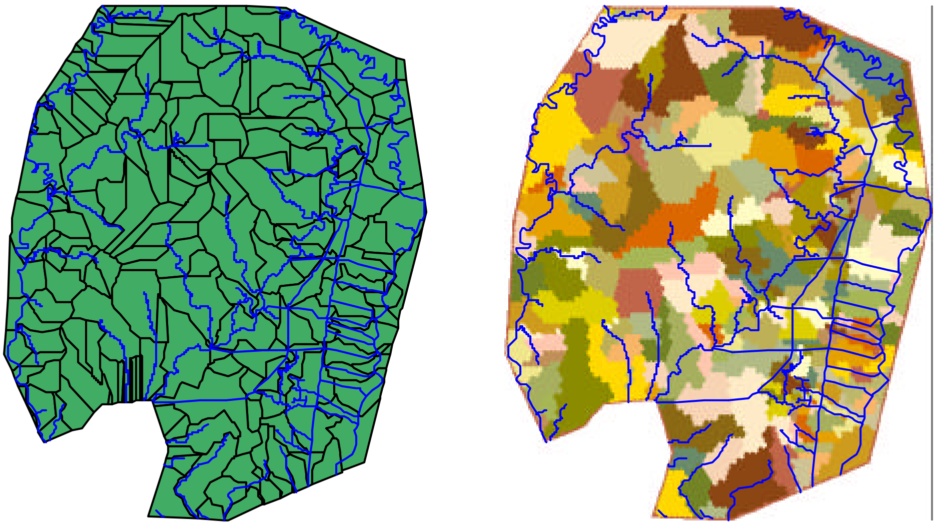

Figure 4.5. Left: watersheds created by ArcView. Right: SIMGRO-watersheds created by AlterrAqua

In SIMGRO also a 5th order trench system is included, which simulates small ditches, trenches and streams which are omnipresent in the peat surface. From the three surface water systems used (the 2nd, the 4th and the 5th) the drainage of the area is calculated.

4.3.2.2 Saturated zone

Using peat thickness data from the CIMTROP (Appendix 4) a peat thickness map was generated. Based on expert judgement and literature (refs) the geohydrology was schematised as summarised in table 4.3. The top aquifer is formed by the peat with varying thickness and a high hydraulic conductivity (k). The bottom aquifer is a sand layer with a thickness of 7m. Betweeen the aquifers an aquitard is situated, which can be considered as a transition layer. Hydraulic conductivity of the layers was estimated. Ong and Yogeswaren (1991) reported hydraulic conductivities in a peat deposit in Sarawak, Malaysia of 10-30 m/day. These data were obtained using long-duration pumping tests. Takahashi and Yonetani (1997) however measured far lower hydraulic conductivities, but these values were determined by the piezometer

method. Radjakgukguk (2002) reports that Sajarwan (2001) found hydraulic conductivities ranging from 0.48 to 12.48 m/day, but does not give a reference for this study.
For the model initially the choice was made for an intermediate hydraulic conductivity of 20 m/day, independent of depth and landuse. The transistion layer is supposed to have no influence on groundwater levels and therefore given a low but numerical stable value for thickness and k. The bottom layer consists of quartz sand and therefore has a relatively large k of 10 m/day.

Table 4.3. Specification of layers used in the model

Nr. of layer	Type	Soil type	Thickness (m)	k (m/day)
1	aquifer	peat	variable	20
2	aquitard	transition	0.5	0.01
3	aquifer	sand	7	10

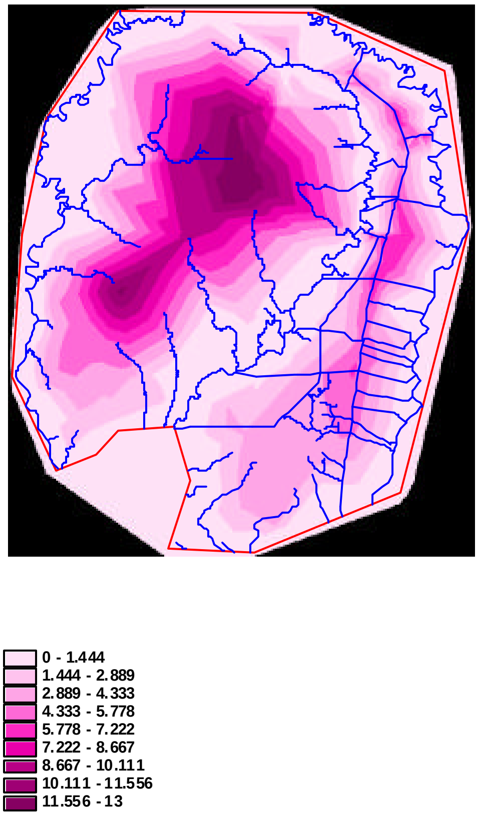

Figure 4.6. Peat thickness map, classes in m

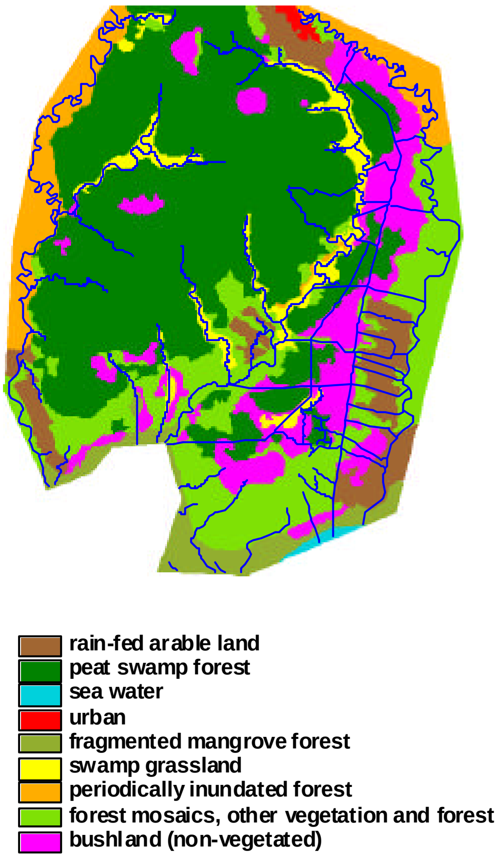

Figure 4.7. Landuse map.

4.3.2.3 Unsaturated zone

A soil map of the area was composed, which contains soil physical units. These units refer to soil physical characteristics summarised in a SIMGRO look up table. Because no soil maps of the modelling area were available, the entire area was set to peat (code 1 in the look up table, deep peat) , with the exception of the coastal area which was set to sand (code 9, loamy fine sand). The landuse map of the area was simplified to make it compatible with the landuse types used in AlterrAqua, see figure 4.7 and compare the original landuse map in Appendix 5. The landuse map derived from this map refers to a look up table containing evaporation and interception factors.
These files discretisise the water flow in the unsaturated zone. Some of the standard look up tables were modified to make them applicable for the Indonesian situation.
The land use types that occur in the study area were converted to the Dutch land use codes that are used in the look up tables. Evapotranspiration factors, growing season, Leaf Area Index and interception were changed for crops:

- Considering an actual evapotranspiration of forest (E_{forest}) of 3.5 mm/day (Takahashi et al., 2001) and a evapotranspirationfactor for forest (f_{forest}) of 1.3, the grass reference evapotranspiration (E_{ref}) was set to 2.7 mm/day.
- The Indonesian growing season was set to 365 days/year

In the meteo file the grass-reference evapotranspiration, to which the crop evapotransipiration factors refer, was modified into a realistic value for the area. In this meteo file precipitation data for the study area were mannually inserted, which cover the period from September 1993 to September 2002.

4.4 Simulation and results

4.4.1 Sensitivity and adjustment of parameters

Dimensions of the initial surface water system were not sufficient for drainage of the model area. Therefore small water courses were widened and deepened.
The k-value of layer 2 was raised to 0.02 m/day (which corresponds with c = 25 days) because this layer is not supposed to have a large influence on groundwater levels and should be easily permeable. This adjustment does not have a large influence on model output.
Also dimensions of the surface water system 5, k of the peat and sand layer and drainage resistances of the surface water system were modified, see table 4.4 for effects on model output (groundwater levels). The set of parameters in modification 7 appeared to give the most realistic groundwater levels and therefore was used for model simulations.

Table 4.4. Adjustment of parameters during the modelling process and the effects on model output

Modification	Surface water system modified	k	Drainage resistance (redr and rein)	Output groundwater levels
1	initial	initial	default	too high
2	initial	k sand = 5	default	no effect
3	initial	k peat = 30	default	no effect
4	system 5	initial	default	slightly lower
5	system 2	initial	default	lower
6	both system 2 and system 5	initial	default	lower, but too high at edges of peat dome
7	system 2	k transition layer = 0.02	default	realistic, but slightly too low
8	system 2	k transition layer = 0.02	+ 20%	exploding
9	system 2	k transition layer = 0.02	+ 10%	exploding
10	system 2	k transition layer = 0.02	+ 5%	exploding
11	system 2	k transition layer = 0.02	+ 1%	no effect
12	system 2	k transition layer = 0.02	+ 2.5%	no effect
13	system 2	k transition layer = 0.02 k peat = 8	default	no effect

4.4.2 Groundwater

4.4.2.1 Calculated and measured groundwater tables

Although groundwater table data of the area are very marginal, calculated groundwater tables can be compared with measured groundwater tables in plot1B. For this plot groundwater data were present from December 1993 untill December 2000. Figure 4.8 shows calculated and measured groundwater tables in plot1B (for location of plot1B see figure 4.12) in time. Groundwater tables were measured every ten days, while calculations are made on a daily base. Calculated values are lower than measured values, with dips during the dry season and especially during the dry spells in 1994 and 1997, see figure 4.9, which shows rainfall in plot1B. Fluctuations of the calculated values follow the pattern of the measured water tables.

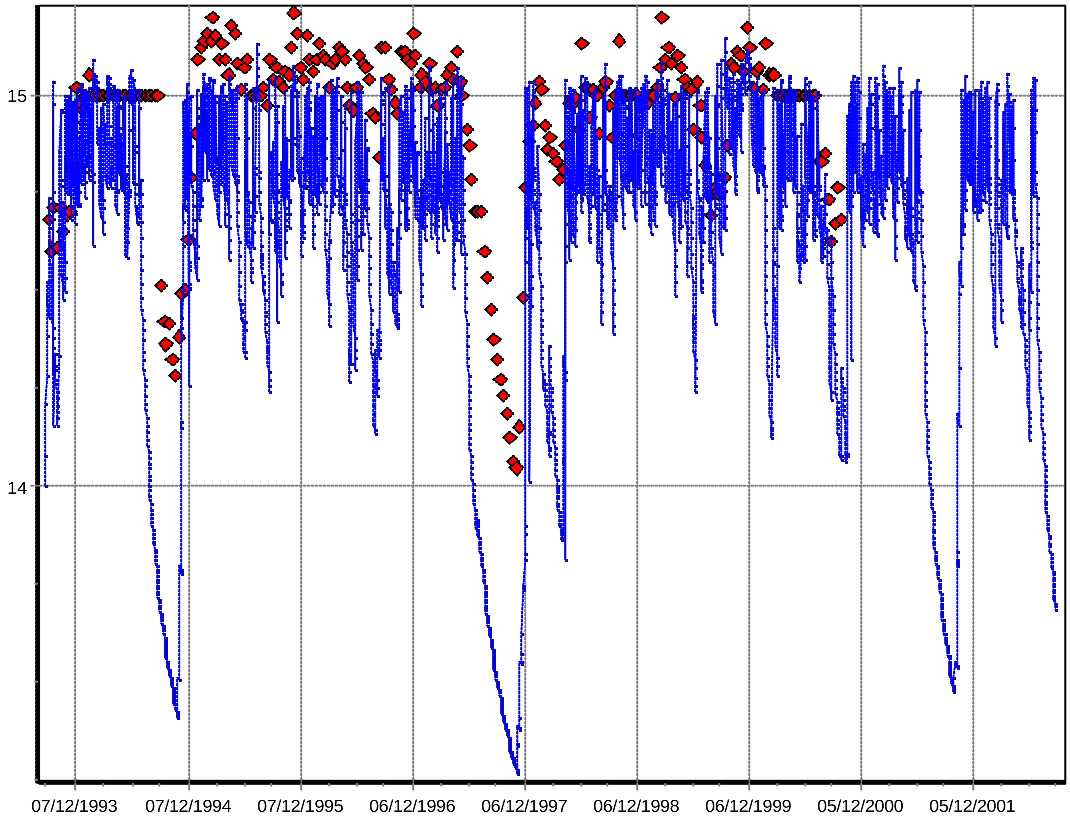

Figure 4.8. Calculated (blue line) and measured (red dots)groundwater tables. X-axis represents days, Y-axis represents groundwater tables in m above msl. Groundsurface is situated at 15 m

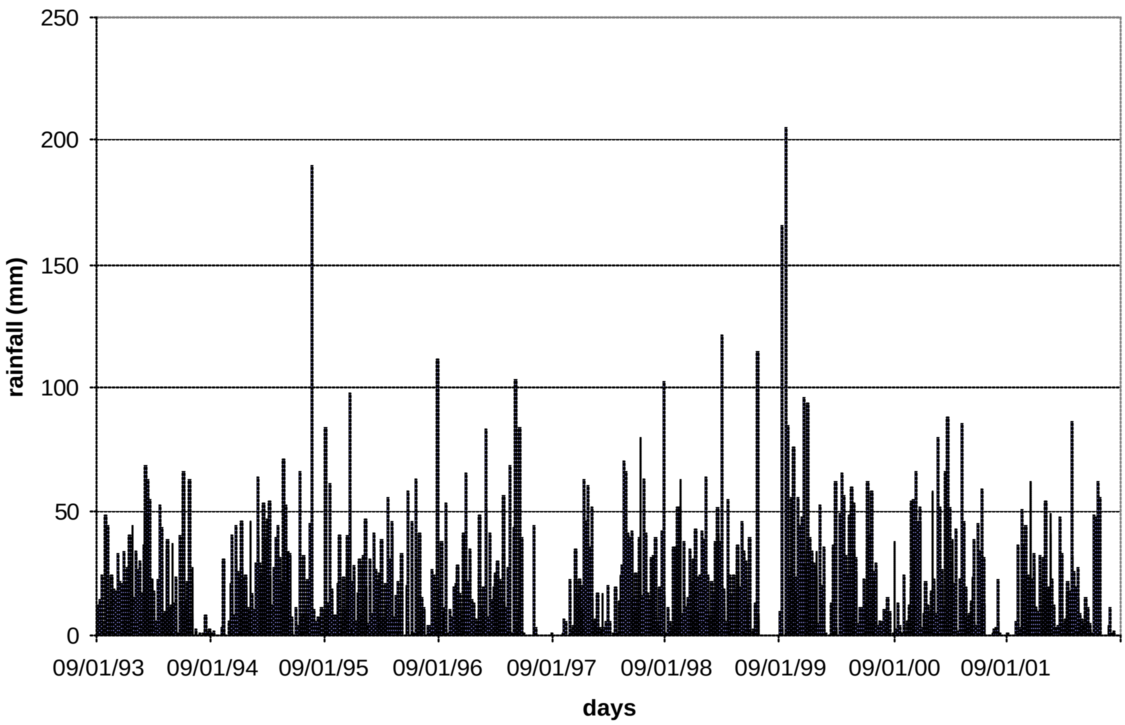

Figure 4.9. Daily rainfall in plot1B

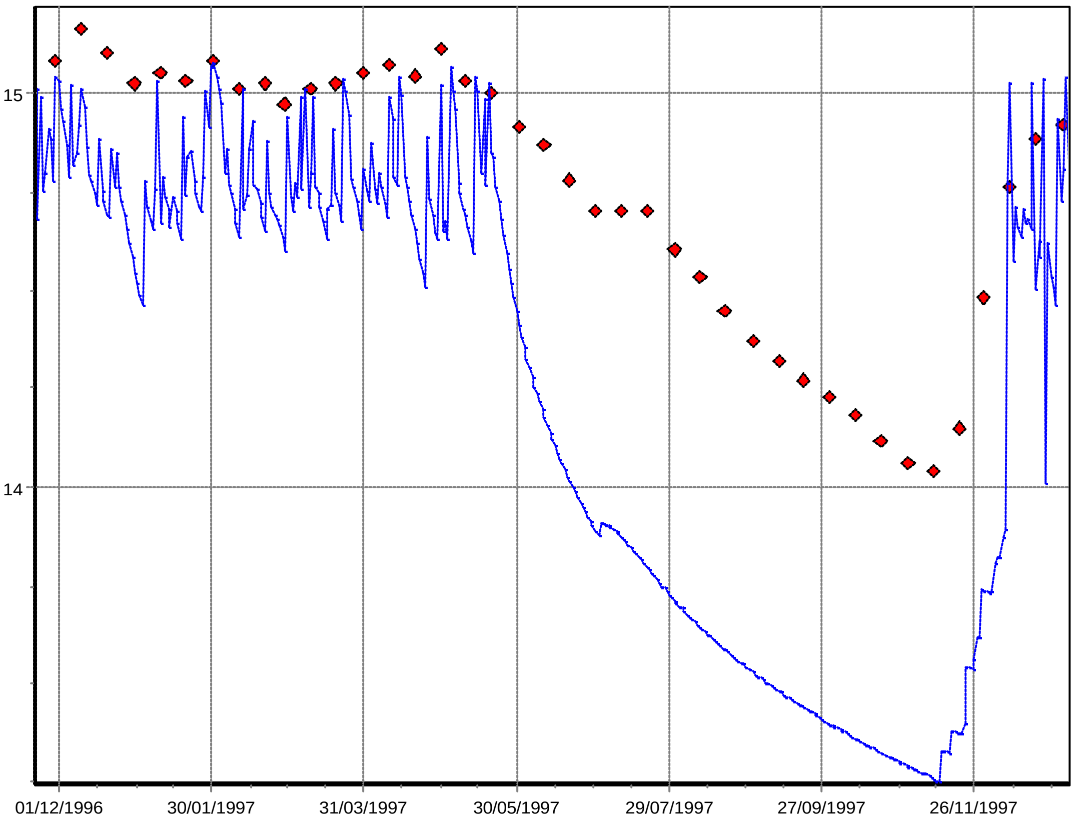

Figure 4.10. Calculated (blue line) and measured (red dots)groundwater tables in 1997

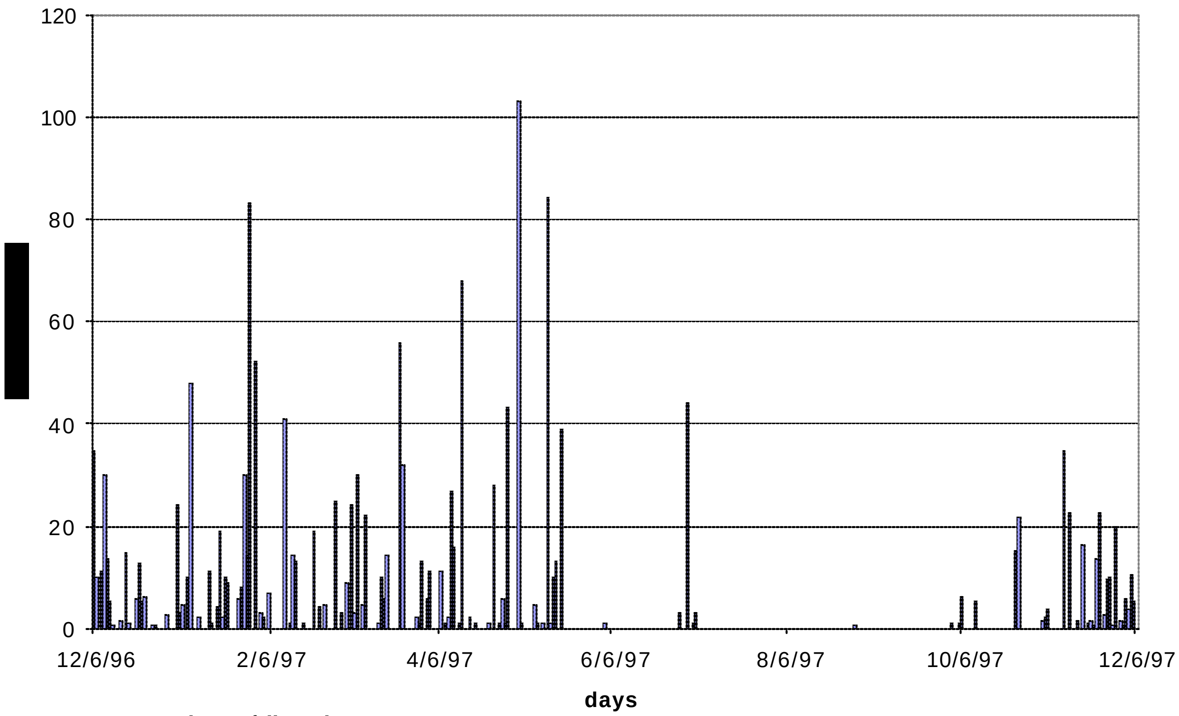

Figure 4.11. Daily rainfall in plot1B in 1997

In Appendix 6 calculated groundwater levels versus time are shown for six nodes, see figure 4.12 for locations and table 4.5 for details.

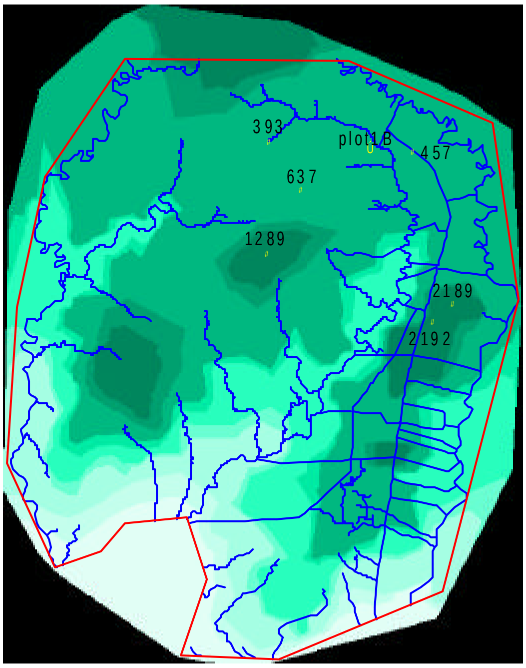

Figure 4.12. Location of plot1B and six nodes of which groundwater tables are shown in Aappendix 6

Table 4.5. Characteristics of six nodes of which groundwater tables are shown in Appendix 6

Node number	Groundsurface (m+msl)	Approx. distance to surface water	Landuse
1289	20	7	Closed PSF
2192	20	2	Fragmented PSF
2189	20.9	5.5	Closed PSF
457	15	0.2	Closed PSF
637	15	11.5	Closed PSF
393	15	0	Closed PSF

In nodes 1289 and 2192 calculated groundwater levels vary between groundsurface and almost 2.5 meters below groundsurface, showing extreme daily fluctuations. Especially during dry days groundwater levels drop even more than in plot1B (compare fig. 4.8).
Groundwater levels in 2189, which is also situated above 20 m+msl follow a more normal pattern, comparable with groundwater levels in node 457.
However, groundwater levels in all nodes drop below 2 m during dry spells, and in node 457 even below 3 m.
Groundwater levels in node 393 are very differnet from levels in the other nodes. In this point levels are between 0.1 and 1.5 m above the soil surface, with the exception of the groundwater levels during the dry spell of 1997.

4.4.2.2 Groundwater level maps

Figures 4.13 – 4.16 show maps of average groundwater level, average spring groundwater level, average lowest groundwater level and average highest groundwater level in the period from September 1st 1993 untill August 31st 2002. Although overall groundwater levels are quite low, there are some very wet spots. Most of these locations coincide with depressions or "steep" slopes, compare the dtm in figure 4.3. Locations with low groundwater levels can be found in topographically higher situated areas and along rivers and canals, with the exception of the Sungai Sebangau, along which relatively high groudwater levels occur. Some large wet spots occur in upstream watersheds of tributaries of the Sungai Sebangau and along the Sungai Bulan, see picture 4.15.
In general, groundwater levels in Block C of the MRP are lower than groundwater levels in the Sebangau catchment.

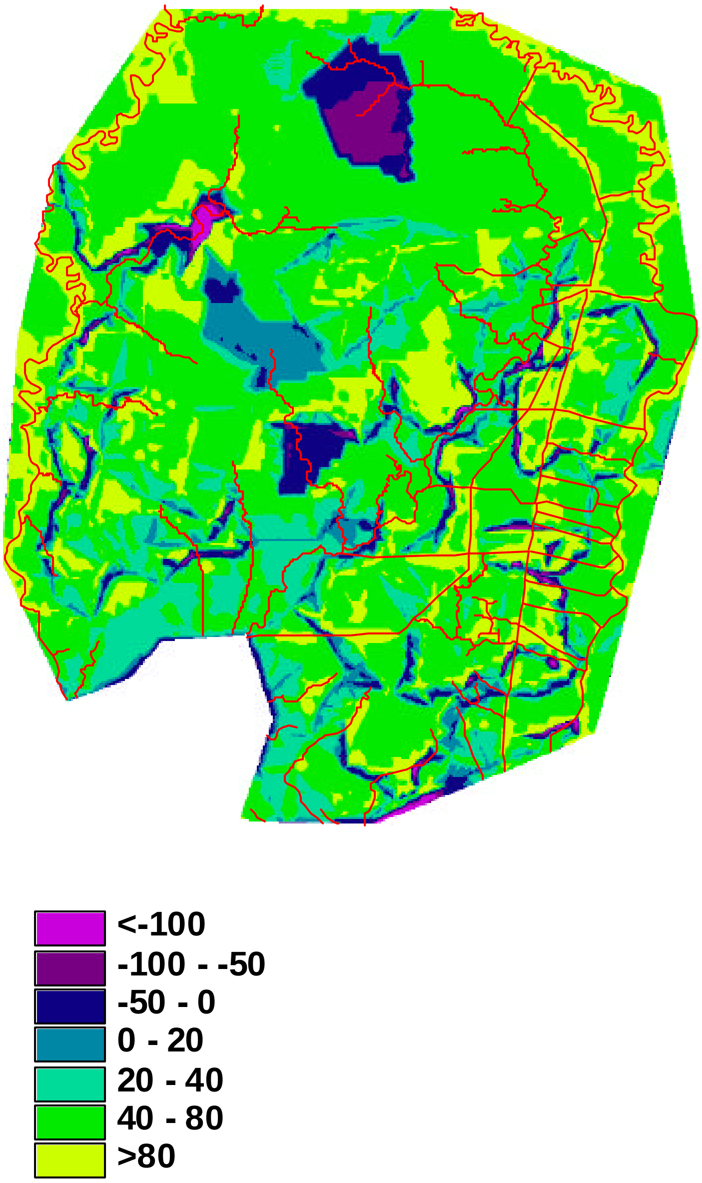

Figure 4.13. Average groundwater level map for the period 1993-2002

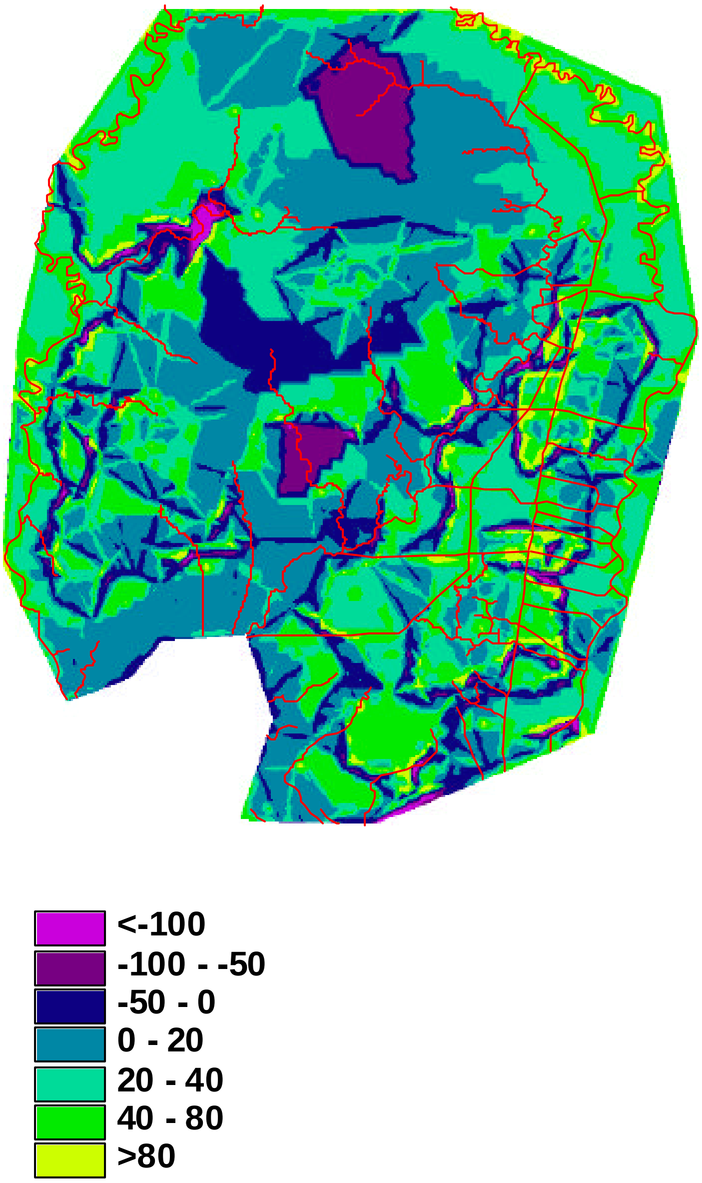

Figure 4.14. Average spring groundwater level map for the period 1993-2002

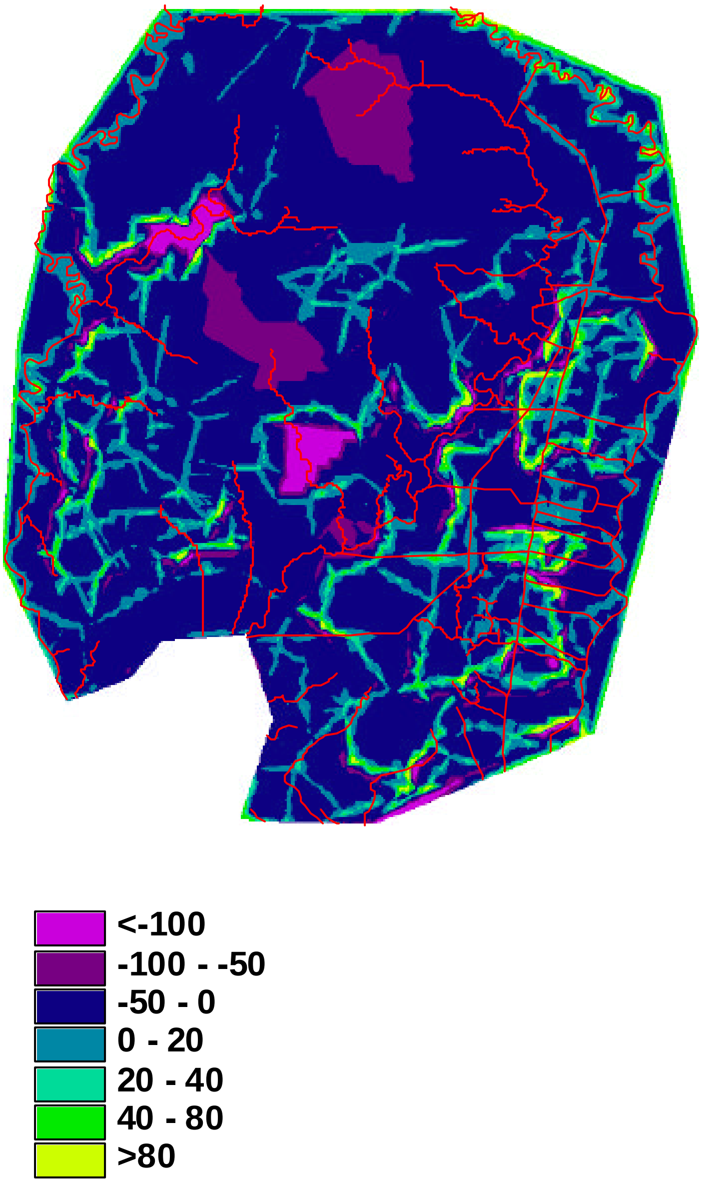

Figure 4.15. Average highest groundwater level map for the period 1993-2002

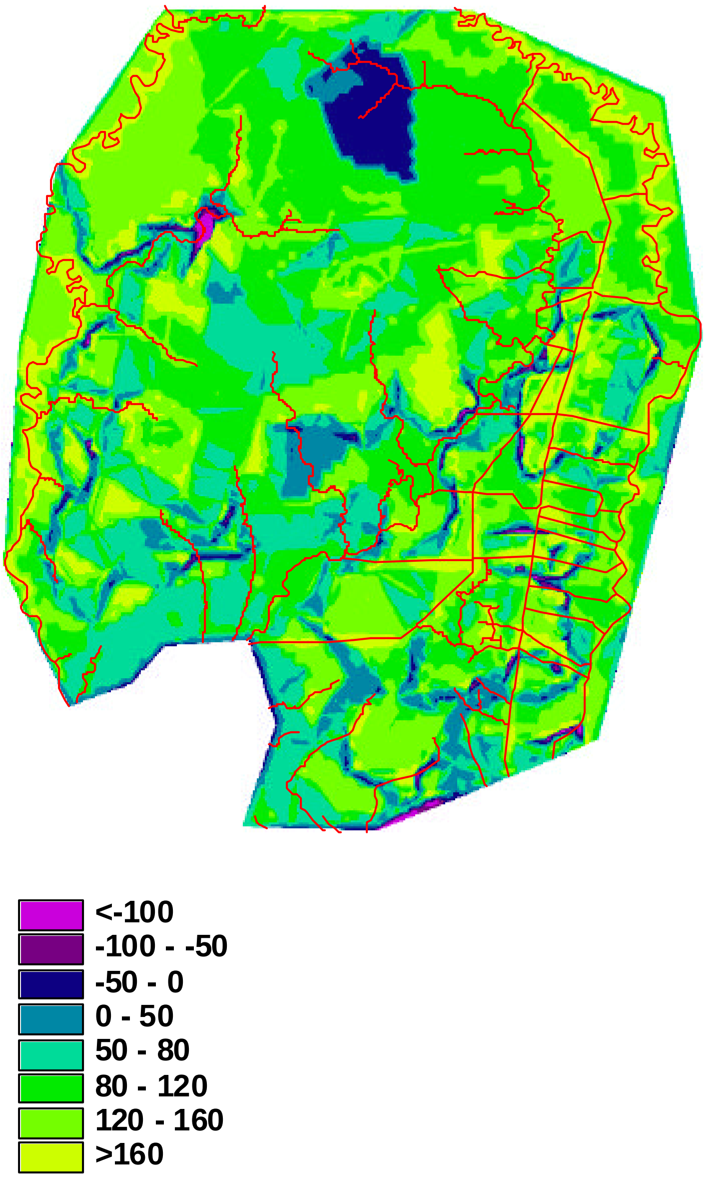

Figure 4.16. Average lowest groundwater level map for the period 1993-2002

4.4.3 Surface water

4.4.3.1 Water levels

Water levels in the Sungai Sebangau off Plot1B are shown in figure 4.18. Because no water level data of this point were available no comparison can be made with measured values. It is very clear however that water levels calculated by the model are too high.

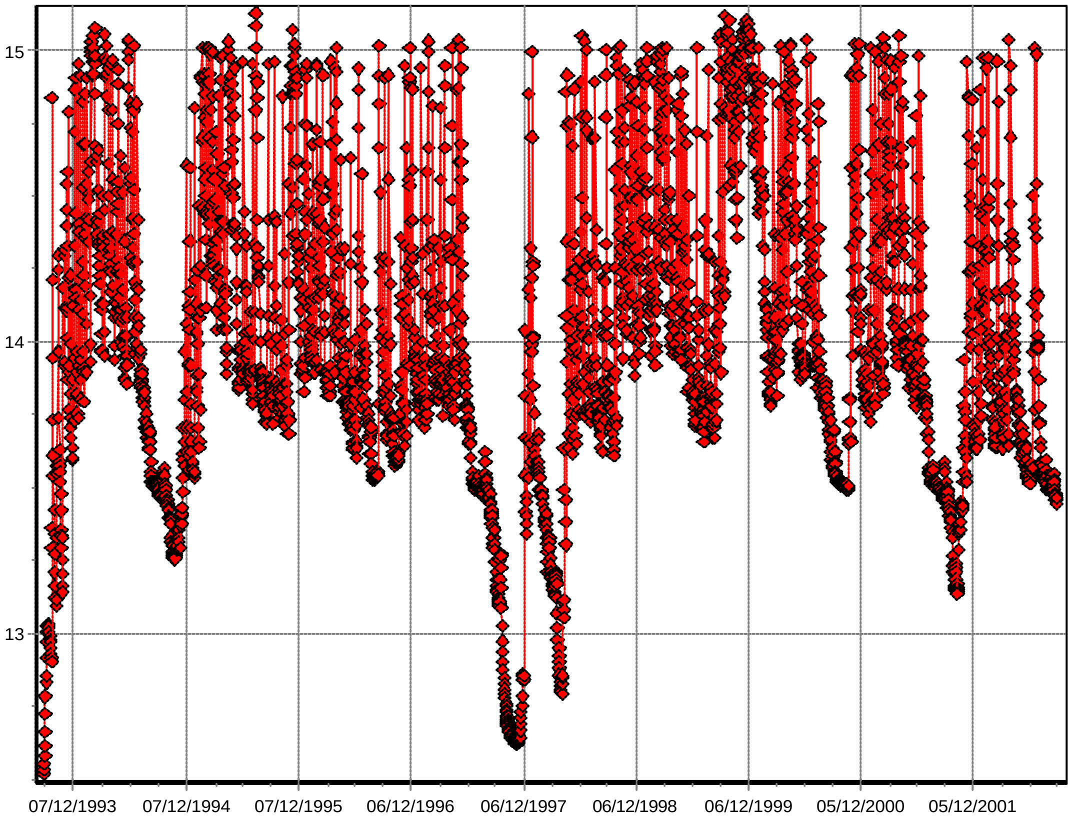

Figure 4.18. X-axis: calculated water levels in the Sungai Sebangau off Plot1B (m +msl). Y-axis: days. Bottom of the river is situated at 12.5 m +msl, riverside at 15 m +msl

Figure 4.19 shows calculated water levels at the same point for the period from December 1st 1996 untill May 25th 1998, which includes the dry spell of 1997. This figure shows that calculated water tables can fluctuate up to 1m a day, which is not realistic.

Figure 4.19. X-axis: calculated water levels in the Sungai Sebangau off Plot1B (m +msl) in 1997. Y-axis: days

4.4.3.2 Discharges

Discharge data in the Sungai Sebangau at Kereng Benkirai were available for the period from August 17th 1998 untill March 23rd 2000. Calculated and measured discharges at this point are compared in figure 4.20. Both calculated and measureed values are daily, which outlines that calculated discharges fluctuate far more than measured discharges. As can be expected from the high calculated waterlevels, calculated discharges are higher than measured discharges. Especially calculated peak values deviate from measured values.

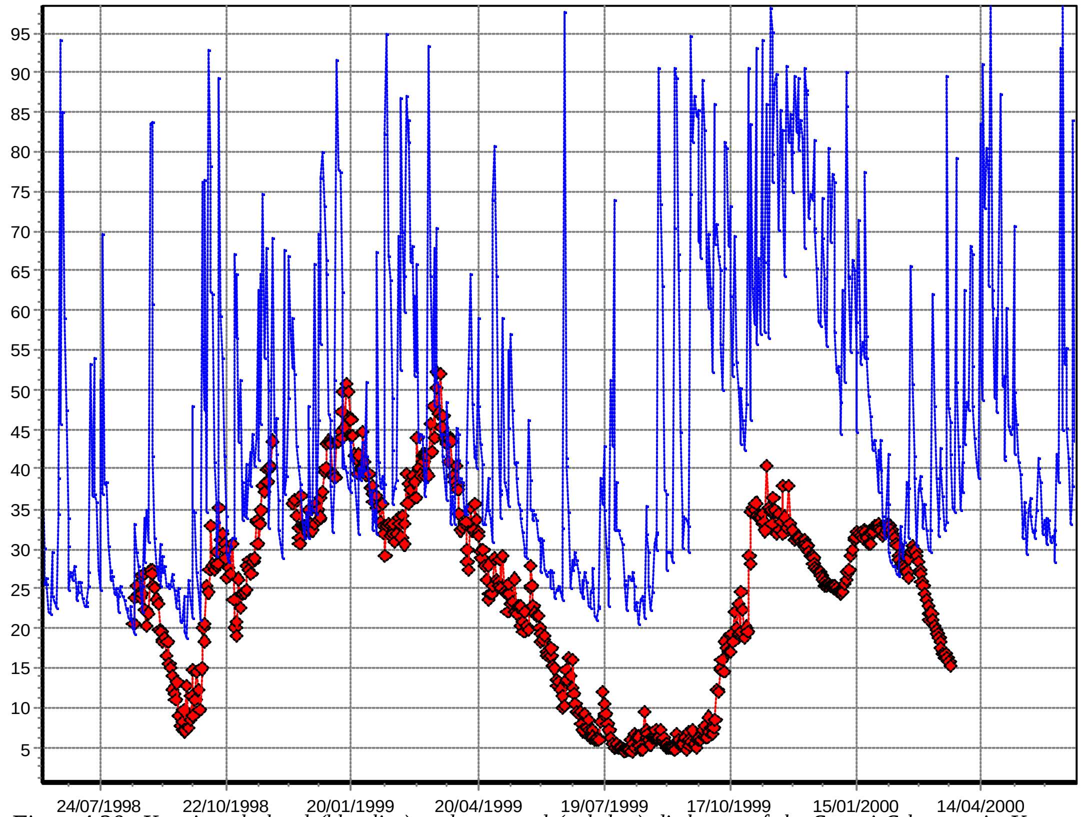

Figure 4.20. X-axis: calculated (blue line) and measured (red dots) discharges of the Sungai Sebangau in Kereng Benkirai (m^3/s). Y-axis: days

Appendices 7 and 8 show calculated waterlevels and discharges in the upper course of the Sungai Kahayan and the Sungai Katingan. In these rivers water level fluctuations are less extreme than in the Sungai Sebangau. Discharges follow these patterns but are most of the time lower than the inflow rates at the model boundary of 164 m^3/s for the Sungai Kahayan and 113 m^3/s for the Sungai Katingan. In the Sungai Katingan even negative discharges occur.

5 Discussion

5.1 Schematisation and input data

Because the model area is very large compared to other studies conducted with AlterrAqua and SIMGRO and the number of nodes is low because of the limited calculation time, spatial accuracy is relatively low.
As mentioned before, geohydrological data of the study area were very marginal. The landsat TM image (figure 4.2) functioned as a data source for the surface water system, of which dimensions had to be estimated. The dtm was generated using a soil elevation picture which was found in the CIMTROP, and of which the source is unknown. Generation of the peat thickness map followed the same procedure, using an image of which the source is unknown. Composition and thickness of the mineral subsoil was based on literature, and a soil map was composed relying on literature and expert judgement.
Furthermore AlterrAqua is concentrated on the Dutch situation and therefore uses default values and look-up tabels that are not very suitable for the Indonesian situation, for example for soil physical characteristics.
As a consequence of these limited data, model input could not be expected very accurate and in some cases was doubtful.

5.2 Sensitivity and adjustment of parameters

Layout and dimensions of the surface water system appeared to be an important determining factor for model output. An enlargement of the drainage capacity of a surface water system resulted in lower groundwater levels throughout the catchment.
Also drainage resistances of the surface water system were adjusted. An increase of up to 2.5% did not have any effect on groundwater levels, while an increase of over 5% led to exploding groundwater levels. Probably this parameter has a numerical effect on model calculations
Hydraulic conductivity, which is an important hydrological parameter according to many researches, did not have an effect on groundwater levels. For the peat layer the value for k was adjusted from 8 m/day to 30 m/day but no changes in groundwater levels could be seen.
Because of the limited time available only a small amount of parameter adjustments could be evaluated. The choice was made to continue with the set of parameters that gave most realistic model output at that time.

5.3 Groundwater levels

Although very little data were available for comparison some remarks can be made on rightness of calculated groundwaterlevels. In general, calculated groundwater levels in the model area were a bit too low. Especially average lowest groundwater levels were very low and during dry spells calculated groundwater levels lowered dramatically. Groundwater level fluctuations are very strong.
Adjustment of the surface water system does have an effect on groundwater levels but does not mitigate these fluctuations.
Groundwater levels maps show the lowest groundwater levels on top of the peat dome and highest groundwater levels just below the relatively steep edges and in depressions. Page et al., 1999 reported that below the tall pole forest, which occurs on the deepest peat, the mean groundwater table is 150 cm below the peat surface. Shepherd et al., 1997 state that rain water which falls onto the most elevated part of the catchment, where the tall interior forest is located, moves laterally through the unwaterlogged peat surface towards the low pole forest which is at a lower elevation within the catchment. Along the Sungai Katingan and Sungai Kahayan, as well as near the canals in Block C, groundwater level are low as a result of drainage. Along the typical "blackwater" rivers that drain the Sebangau catchment water levels are high. This high-groundwater zone can be regarded as a discharge zone where upward seepage occurs (Grobbe, 2003).
During dry days groundwater levels drop and as the dry period lasts longer groundwater level steps are reduced. This is a logical consequence of the smaller influence of evapotranspiration deeper from the soil surface. After rain events the groundwater table rises quickly. Hooijer (2003) writes that due to the limited depth of the unsaturated zone (limited storage capacity), there is very little delay in the response of the water table to changes in storage. However, calculated levels seem to react stronger than measured levels. Adjustment of parameters of the unsatured zone module probably could decrease these oscillations, for instance (Dutch) soil physical characteristics, evapotranspiration and crop factors.
According to Hooijer (2003), groundwater levels fluctuate uniformly throughout the catchment. The area of the study site in this research however was much smaller than the model area of the Sebangau catchment. As can be seen in Appendix 6 fluctuation pattern differs greatly within the model area.

5.4 Surface water

In contrast with groundwater levels surface water levels and discharges in the Sungai Sebangau are too high. Compared to measured discharges fluctuations are very strong.
In the other two rivers, the Sungai Kahayan and Sungai Katingan, discharges and water levels are more realistic, which isn't very surprising because inflow rates at day 244 1993 were specified. Nevertheless, fluctuations in these rivers are still very strong and even stronger than in the Sungai Sebangau.
It is to be expected that river water levels react even faster and stronger on rain fall than groundwater levels, because no changes in storage can occur. In addition not

only rain water that actually falls on the river water surface causes a water level rise, but also rain water that falls on the peat surface and reaches the river through surface run-off and subsurface flow.
Discharges and waterlevels are very much dependent on width and depth of watercourses, of which values are estimated in this study.

6 Conclusions and recommendations

This study was conducted to increase the knowledge of the hydrology of the Sebangau catchment, determine the consequences of changing landuse and thereby contribute to a more sustainable managment of the system.
The aim of this study was to provide insight into the hydrology of the Sungai Sebangau catchment in Central Kalimantan and to bring together the hydrological data of the catchment that have already been collected.
This was supposed to result in a of model set-up in SIMGRO, which can be used to predict impacts of land-use scenarios.
Several conclusions can be drawn from the different phases of the study. First, findings during the differnet phases of the study will be presented, and recommendations are added. After this will be concluded whether this study meets the aim mentioned above.

Literature review
The detailed literature review confirmed the value and special status of the peat swamp forest in Central Kalimantan. A summary was given of genesis, soil characteristics, hydrology, present status and threats. The importance of the hydrology for the survival of peat swamp forests is widely recognised. However, no detailed studies have been conducted on the effects of peripheral drainage on groundwater tables in the centre of the catchment. Management on catchment-level is promoted, but very view studies focus on the hydrology of an entire catchment. Apparently there is a need for this kind of hydrological studies.

? Model studies on catchment level can be a useful tool to understand the hydrology of peat swamp forests and the effect of landuse changes.

Collection of available data
A lot of research has been done on the Sebangau catchment in the past ten years. One of the difficulties for hydrological research is the low accessibility of the area, which limits the posibilities for field measurments and experiments. As a consequnce hydrological data are very marginal, and are in posession of different research groups around the world. There is little coordination regarding the collection and sharing of data, and even within the STRAPEAT project it is often very difficult to trace existing data. Methods and equipment vary which hampers integration of data.

? Communication, coordination and tuning within the hydrologists working in the same area would increase the accessibility and usability of hydrological data.

Integration and interpolation of geohydrological data
The application AlterrAqua, in which the SIMGRO model input had to be generated, was developed primarily for the Dutch situation. Therefore a lot of default files had to be modified, and files that are ready to use in The Netherlands had to be generated manually. These procedures were very time consuming.

However, despite of the low accuracy and limited availability of spatial data, sufficient model input was generated. These products not only have a value in the modelling process, but on themselves function as very valuable spatial information on the Sebangau catchment, although in some cases accuracy is low.

? Probably a lot more spatial and hydrological data than used in this study is available somewhere. Especially the surface water system, peat thickness map and soil map could be improved. A lot of SIMGRO input files use default values for the Dutch situation. In this study the effects of these values are not evaluated, but it is recommended to

Model simulation results

- Layout and dimensions of the surface water system are an important factor in the calculation of groundwater levels.
- The model is insensitive for changes in hydraulic conductivity.
- Reaction of model output on increased drainage resistances implies numerical instability.
- Generally, groundwater levels calculated by the model are too low, while surface water levels are rather too high.
- Groundwater and surface water levels react very fast on rainfall.
- Groundwater level maps show a realistic spatial pattern.
- Groundwater levels as well as surface water levels show extreme oscillation.
- Despite of these oscillation problems groundwater levels give an impression of the effects of rain events and dry spells.
- Apart from the extreme values, calculated groundwater levels as well as calculated surface water levels show a time-curve that is similar to measured levels.

In spite of the inaccuracies, the model as built and used for calculations in this study represents the global hydrological processes in a peat swamp forest.

? Because of the limited time available sensitivity of the model for the most important parameters is only marginally tested. Effects of hydraulic conductivity and drainage resistance can not be completely understood. Therefore it is recommended to perform a sensitivity analysis, not only on these parameters but, for example, as well on evapotranspiration and crop factors.
The prime interest of this study were groundwater levels, therefore this is the only model output that is used. In the continuation of this study it might be interesting to use waterbalance output data as well.

In this study a useful integration of hydrological and spatial data of the Sebangau catchment has been brought about. A model set-up in SIMGRO has been made that gives insight in the spatial distribution of groundwater levels throughout the entire catchment. After subsequent calibration and sensitivity analysis this model can be used for simulation of different landuse scenarios. AlterrAqua offers adequate tools for presentation of the hydrological effects of these scenarios.

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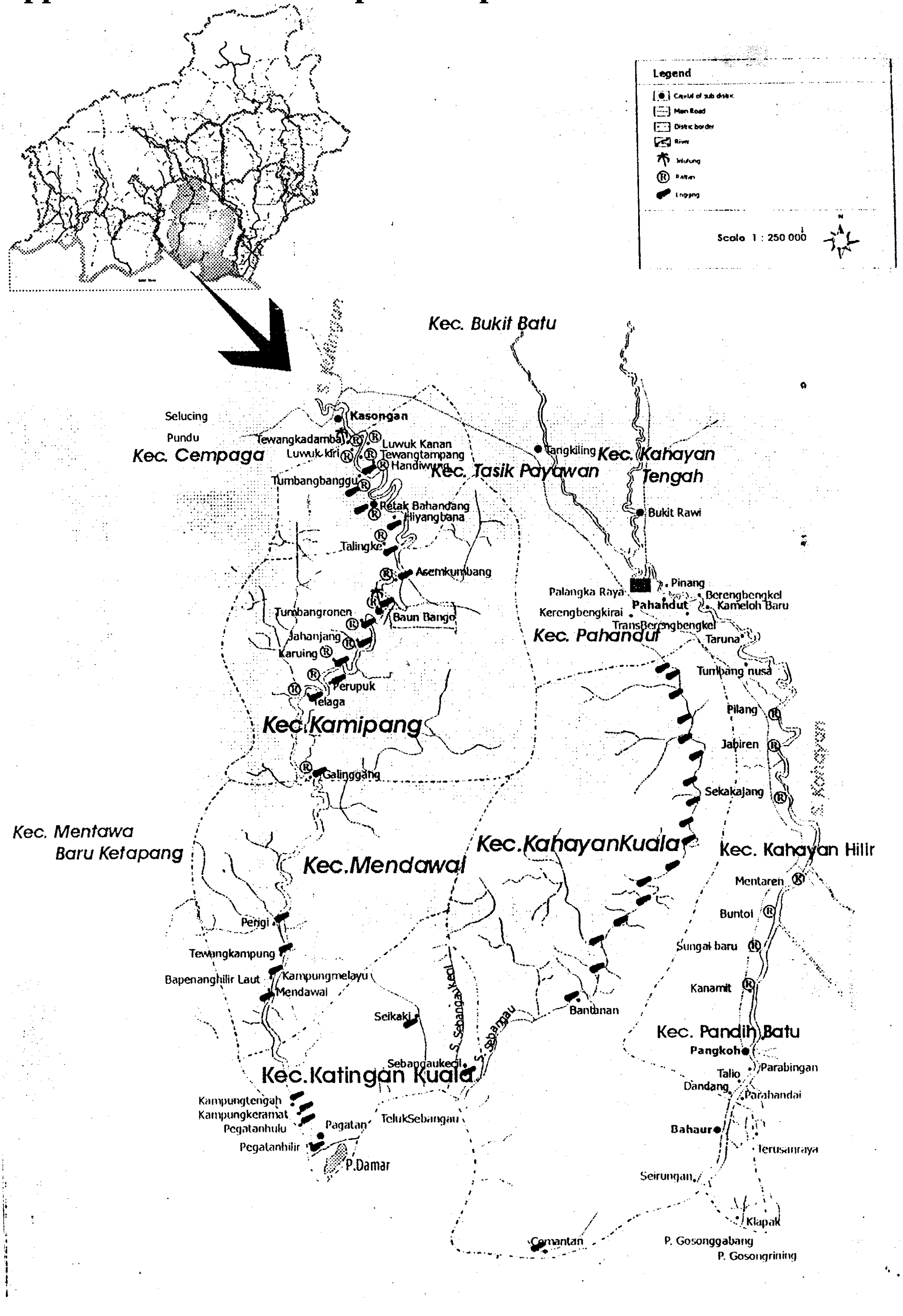
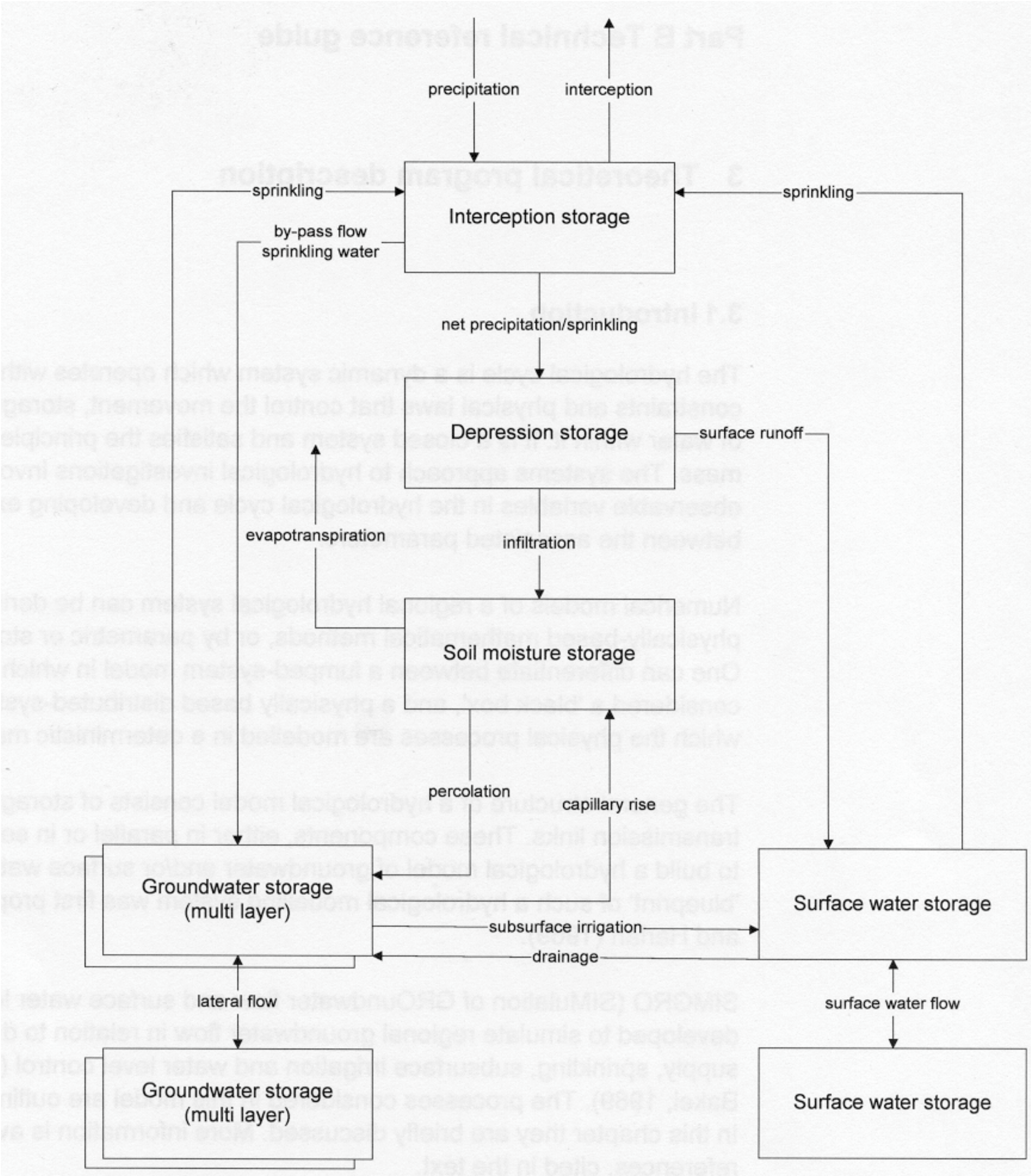
List of Appendices

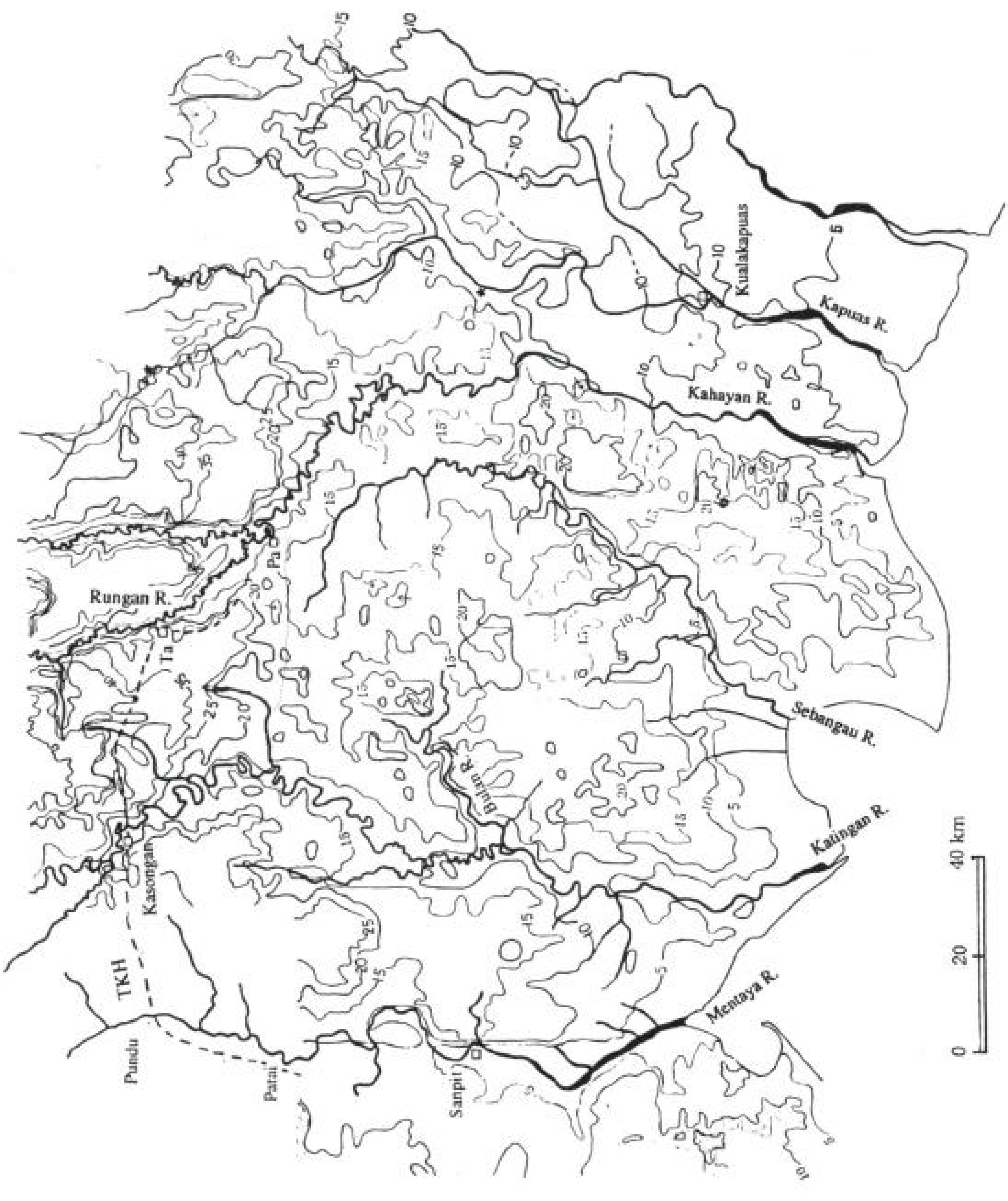
Appendix 1 : Locations of potential products and main threats



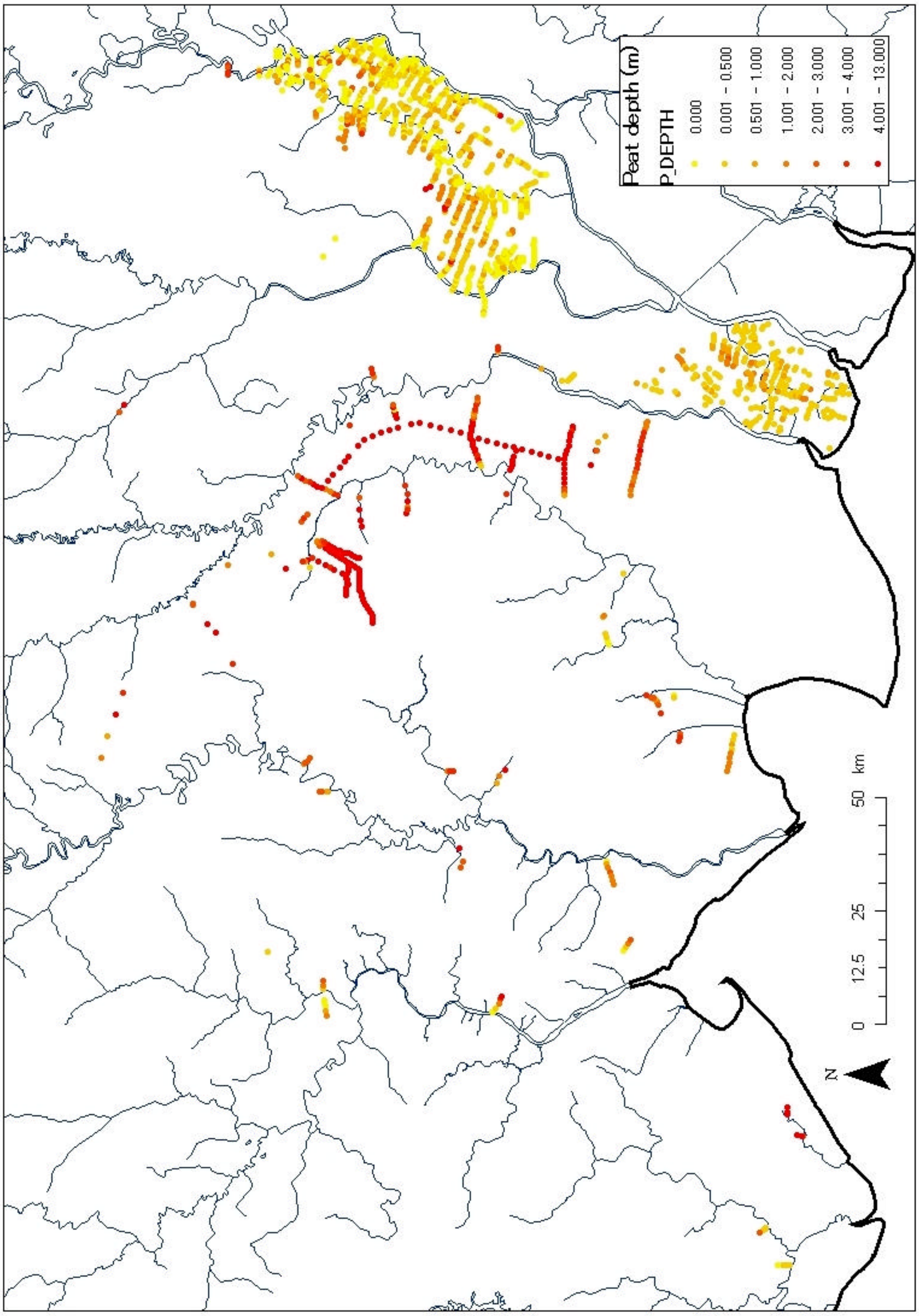
Appendix 2 Schematisation of water flows in SIMGRO



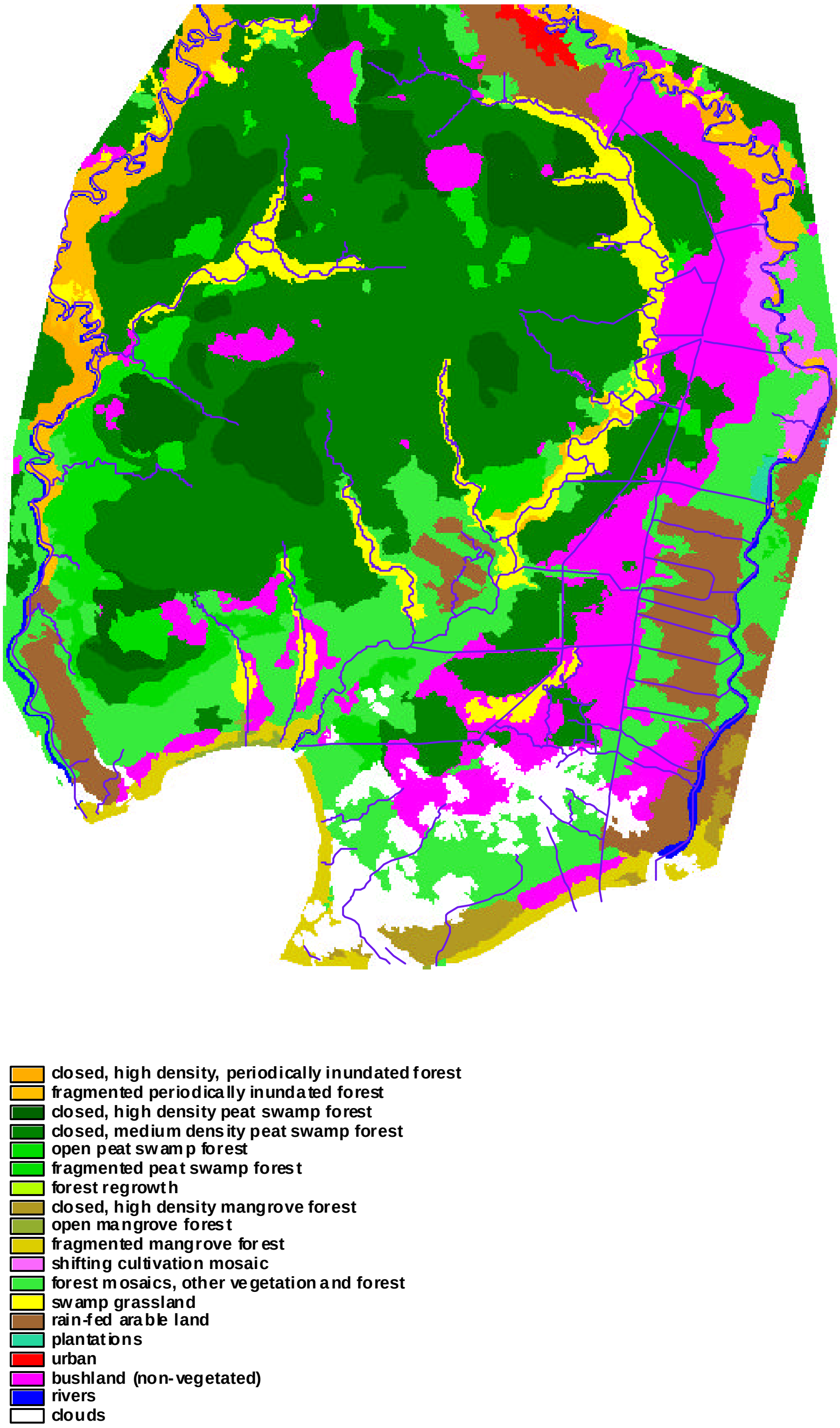
Appendix 3 Soil elevation map of Central Kalimantan



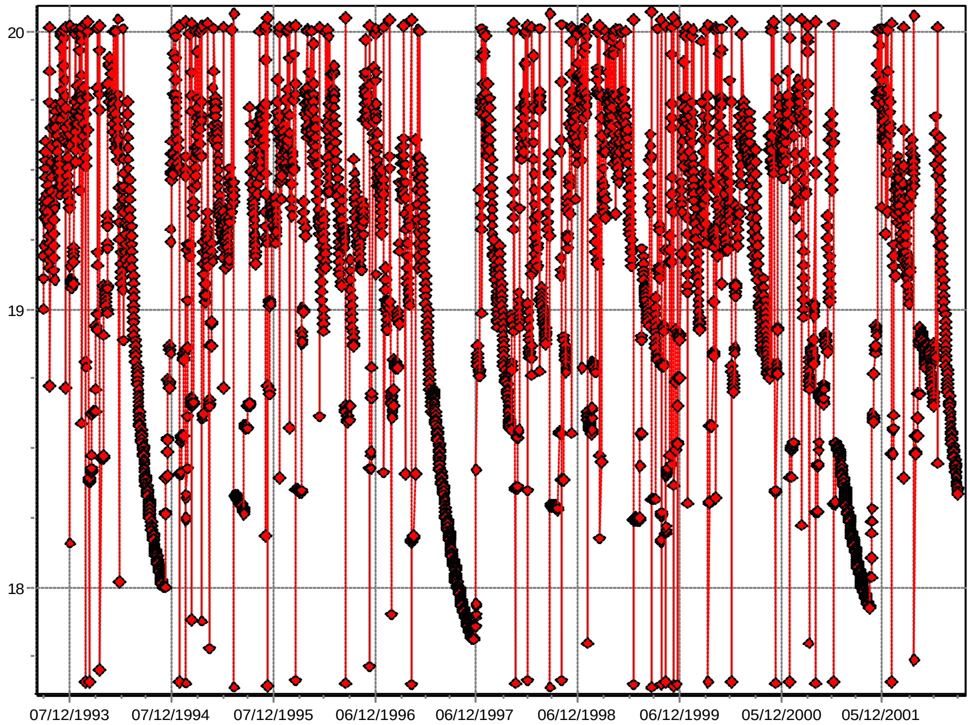
Appendix 4 Peat thickness measurement points in Central Kalimantan



Appendix 5 Landuse map of the model area



Appendix 6 Groundwater levels in six nodes



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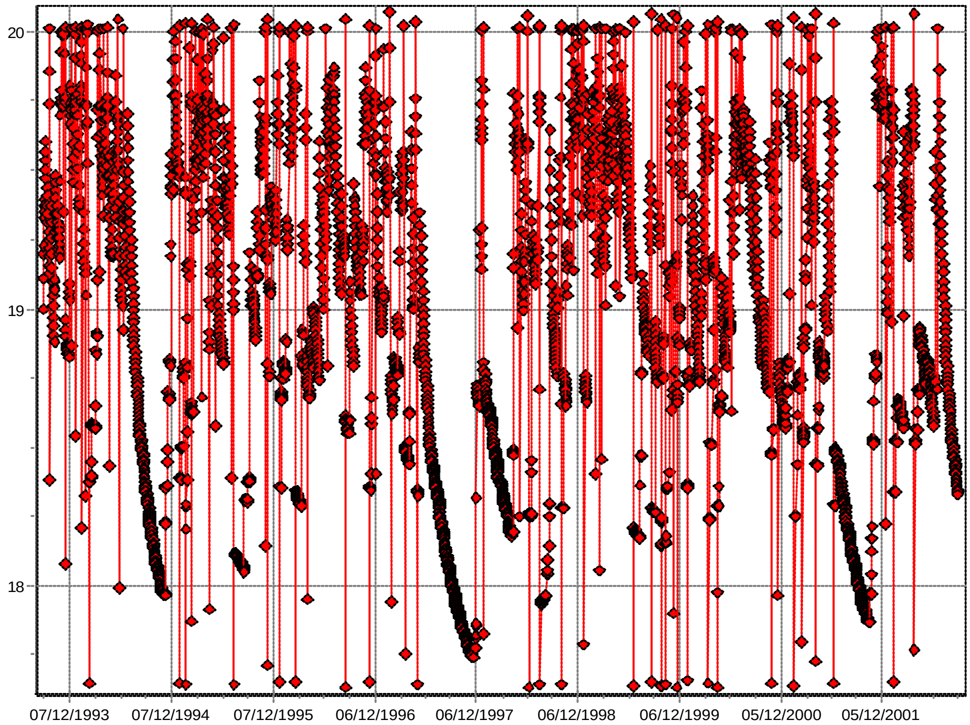

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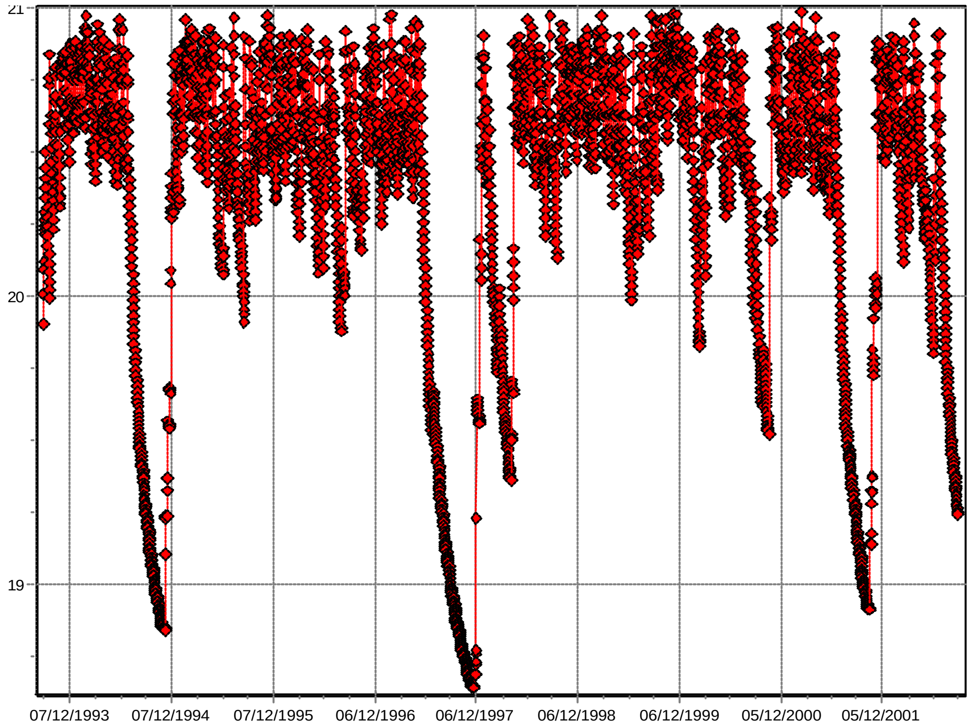

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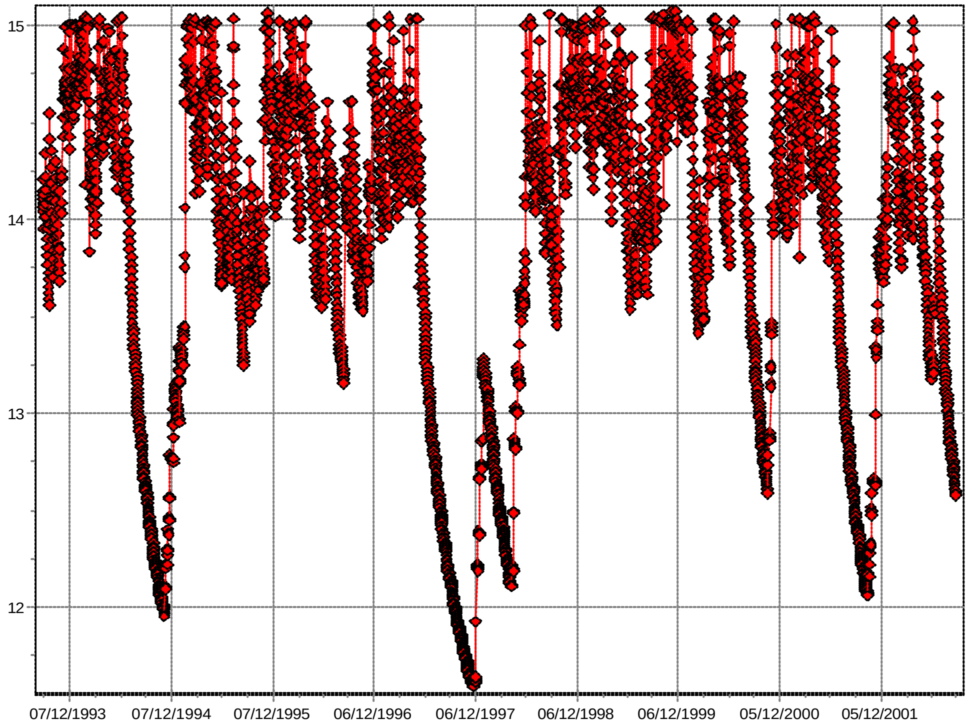

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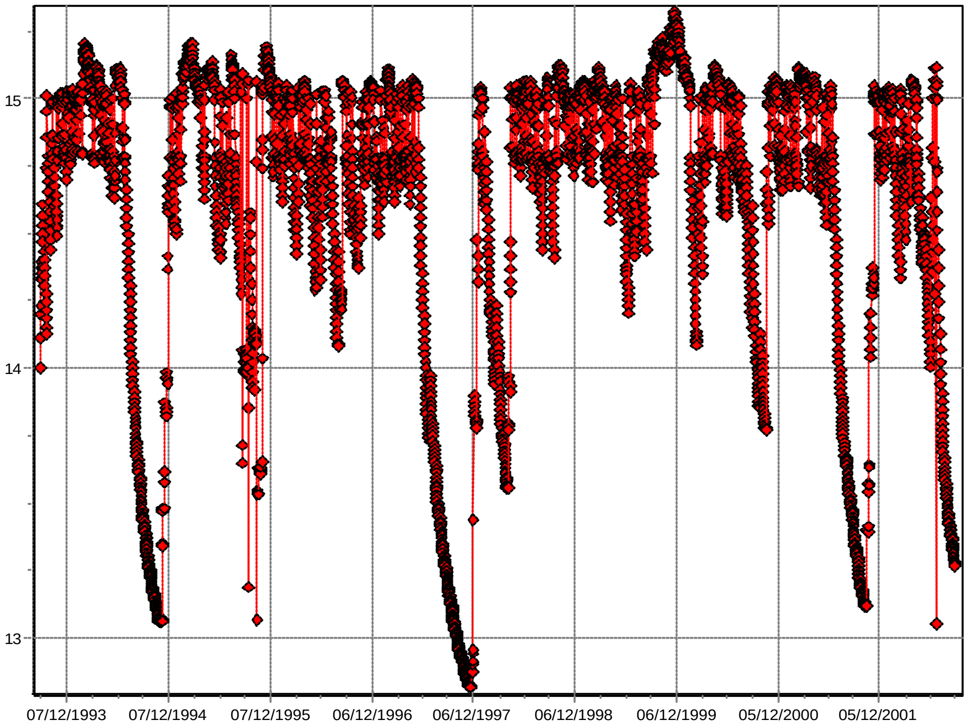

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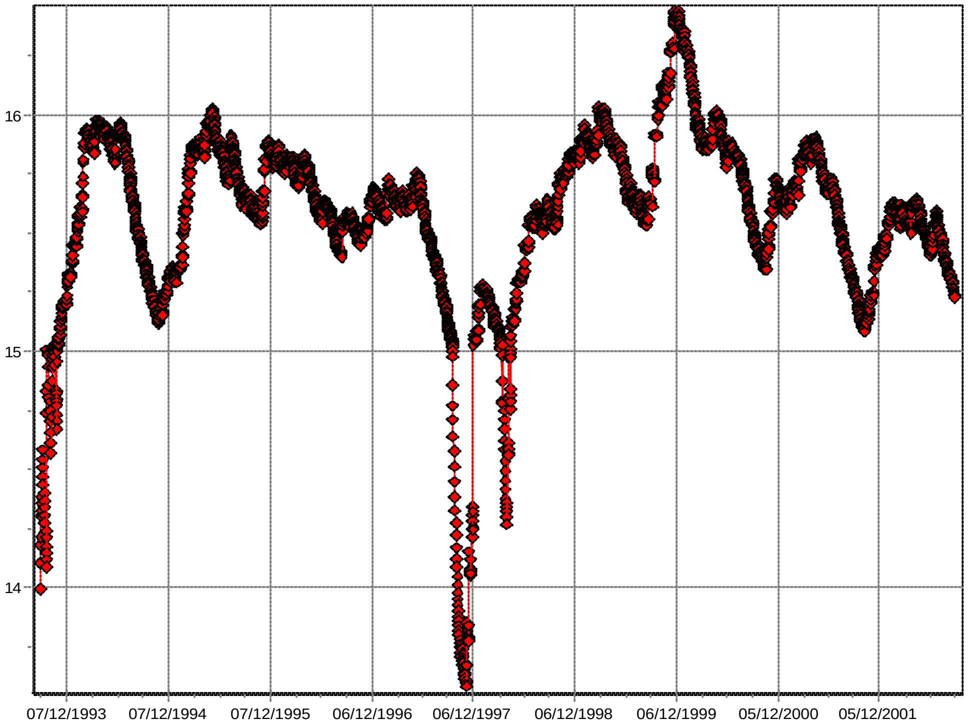
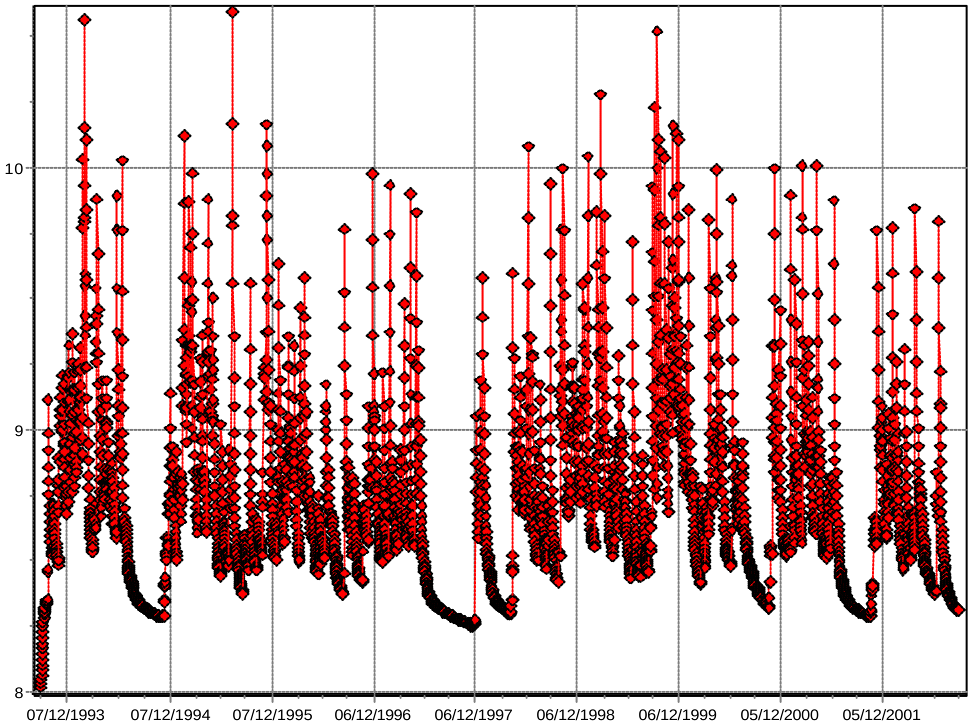
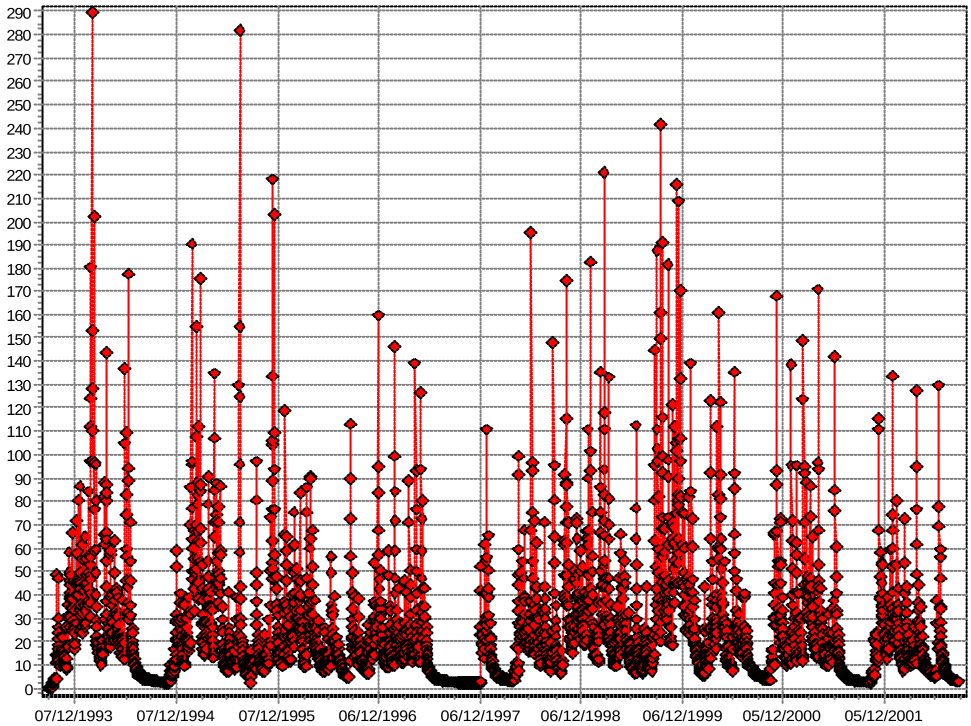


Node 393

Appendix 7 Water levels and discharges in the Sungai Kahayan

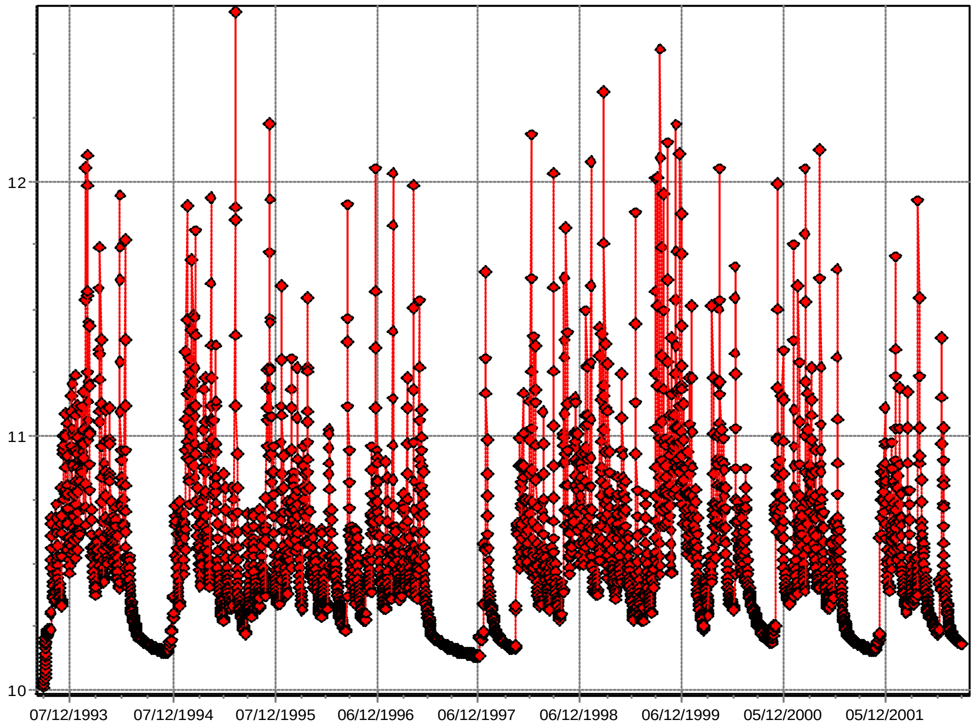


Waterlevels

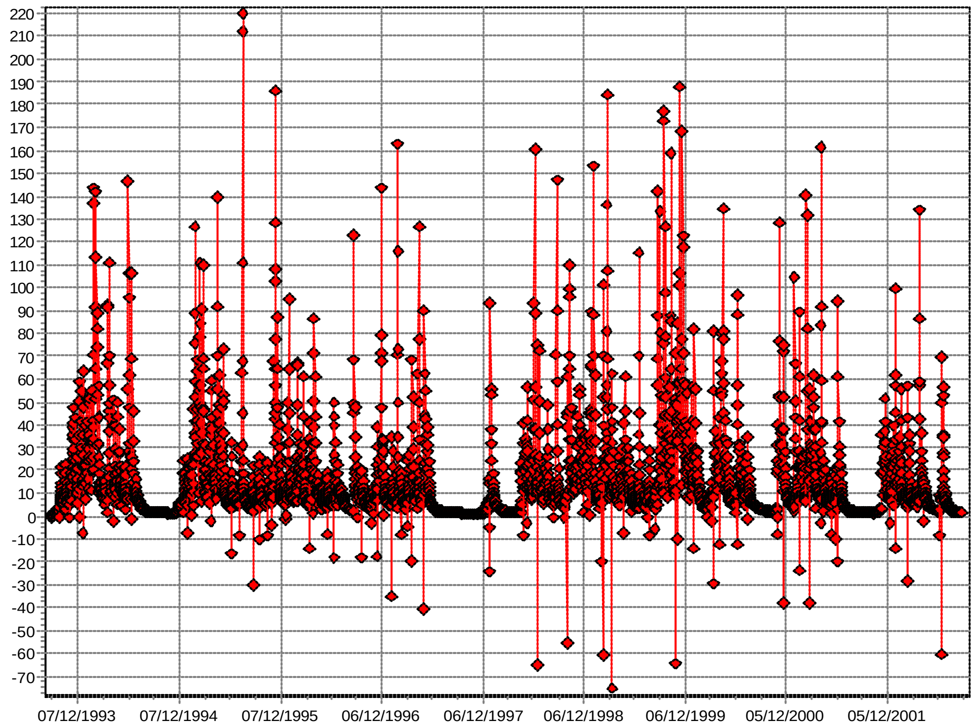


Discharges

Appendix 8 Waterlevels and discharges in the Sungai katingan



Waterlevels



Discharges