Deposit structure, water mineralization and groundwater recharge of a rubber-tree-planted watershed in Northeast Thailand

Jean-Pierre Montoroi[A], Olivier Grünberger[B], Onjamala Elarimisa[C], Jean-Luc Michelot[C], and Wanpen Wiriyakitnateekul[D]

[A]Institut of Research for Development, UMR Bioemco, Bondy, France, Email jean-pierre.montoroi@ird.fr
[B]Institut of Research for Development, UMR Lisah, Montpellier, France, Email olivier.grunberger@ird.fr
[C]University of Paris-Sud, UMR Ides, Orsay, France, Email elarimisa@yahoo.fr, jean-luc.michelot@u-psud.fr
[D]Land Development Department, Bangkok, Thailand, Email wwanphen@gmail.com

Abstract
In Northeast Thailand rubber-tree cropping is widespread according to economy market and in spite of climate constraints. A study was undertaken in farmer's plantation to characterize the pedological and geological deposits within a 2 km^2 watershed, to monitor groundwater fluctuations within shallow and deep aquifers and to assess water mineralization and water chemistry composition. The soil profile comprises a more or less thick clayey layer above the bedrock (sandstone-siltstone), the top depth of which is less than one meter at slope summit and increases along the slope until few meters. The sandy layer is a temporary aquifer where a shallow perched groundwater is flowing laterally towards lowlands owing to the underlying and low impermeable clay layer. The sandstone-siltstone bedrock is a fractured and permanent aquifer which is most often at the same elevation in uplands than in lowlands and is recharged from the upland summit. The deep groundwater mineralization is saline-contaminated whereas the shallow groundwater origin is meteoric. The study leads to the conclusion that variability in deposit structure and groundwater functioning should be taken into account in management of rubber-tree plantations.

Key Words
Tropical soil, Sandstone, Water chemistry, Watershed, Rubber-tree, Thailand.

Introduction
The landscapes of North Eastern Thailand (NT) are dominated by undulating hills with elevation ranging from 170 m (lowlands) to 240 m (uplands). The lowlands are managed for rain-fed and flooded paddy rice fields which are nowadays severely affected by salinity. *Dipterocarpus* forest natively occupied the uplands but was massively cleared over the last mid-century. Forest area decreases from 70,400 km^2 in 1961 to 21,370 km^2 in 1993, namely from 41% to 13% of the NT area (Wannakomol 2005). Intensive wood-cutting propelled on the farming of cash crops including cassava, sugar cane, kenaf and maize. It is arguing that the ancient and widespread land use change leads to a comprehensive change of hydrology balance in NT including a groundwater rise up due to a deep aquifer recharge increase, an evapotranspiration inefficiency of seasonal crops and an extension of saline seepage on lower slopes and valley floors (Ilstedt 2007). Lowland salinity features are visually displayed in dry season as discrete patches of various sizes (from some m^2 to some ten m^2) and shapes which cover soil surface with white efflorescences, mainly halite. Salinity contamination comes from the artesian rise up of the regional groundwater which is enriched with dissolved salts by flowing through the Cretaceous Maha Sarakham evaporite deposits embedded within siliclastic formations (El Tabakh *et al.* 1998, Williamson *et al.* 1989, Imaizumi *et al.* 2001). An area of 28,400 km^2, namely 17% of the NT region, is salt-affected from slightly to severely stages (Arunin 1992). Last cultivated cash crop in NT is rubber-tree (*Hevea brasiliensis*), which is intensively developing (from 30,965 ha in 1990 to 94,450 ha in 2003) and economically following the increasing demand for manufactured rubber devices as tyres. The recent land use change, which is expected to last over several decades, is likely to modify aquifer recharge leading to a water infiltration decrease, as deep rooted trees contribute more efficiently than shallow rooted crops towards evapotranspiration, a groundwater fall and a slightly decrease of lowland salinization. However, NT is not as suitable for rubber-tree cropping as other Thai regions. Climate is highly variable in time and space, constraining the plant growth and the latex production. The objective of the study is (i) to evaluate the relationships between aquifer recharge and water mineralization at a small watershed scale, which is partly five-year rubber-tree planted, by deposit surveying, groundwater monitoring and conceptual modelling; (ii) to assess the rubber-tree cropping sustainability on a long-term basis.

Methods

Experimental site

Located nearby Ban Non Tun village (16°20’N; 102°44’30”E), the 2 km^2 studied watershed is about 20 km southwest of the city of Khon Kaen in the district of Phra Yun. The Tropical Savannah climate is influenced by Asian monsoon and marked by distinct rainy season (from May to October) with a mean annual rainfall of 1,212 mm and 107 rainy days per year in average (Wada 1994) and dry season (from November to April). Soils are classified along a toposequence as Typic Haplustult (upland summit), Arenic Paleustalfs (from upper to lower slope) and Typic Paleustult (toe slope). Clay and silt contents increase with depth ranging from 3% to 28% for clay fraction and from 5.6 to 14.3% for silt fraction. Sandy layer displays iron oxide features which attest iron mobility under reduced conditions. Clayey layer underlines a highly fractured bedrock which is described as sandstone and siltstone. Quartz, smectite and kaolinite are the predominant constituents in the clay fraction with some illite and trace amounts of feldspar and goethite. Quartz is the major component in the silt fraction with small amount of feldspar and trace of goethite. Formation of poorly crystalline kaolinite along the slope may formed by pedogenesis under an intermediate to poorly drainage whereas a dense clay layer at 50-70 cm depth produced a waterlogging in rainy season (Wiriyakitnateekul 2009).

Field surveying and water sampling

A field survey was performed using outcrop observations, manual auger soundings until bedrock along transects (90 samples) and an electromagnetic conductivimeter (EM38 from Geonics^{TM}) (Figure 1). Soil of each sounding was sampled every 10 cm within one meter and every 20 cm depth below. Soil samples were analysed in field for manual particle size distribution. Depth and thickness of sandy, clayey and bedrock were assessed and mass soil water content was measured at laboratory by gravimetric method.
A piezometer network was installed in lowlands and along two transects to localize the shallow (< 3 m in depth) and deep (from 10 m to 32 m in depth) aquifers by manual and mechanical drilling, to ascertain the magnitude of groundwater fluctuations by monitoring in time and to determine the chemical types of underground waters by laboratory analyses. Piezometers were base-screened from one meter (shallow ones) and two meters (deep ones) to avoid aquifer mixture. Surface waters stored in small ponds and aquifer waters were sampled at late dry season (March) and at rainy season (September) for chemical and isotopic analyses.

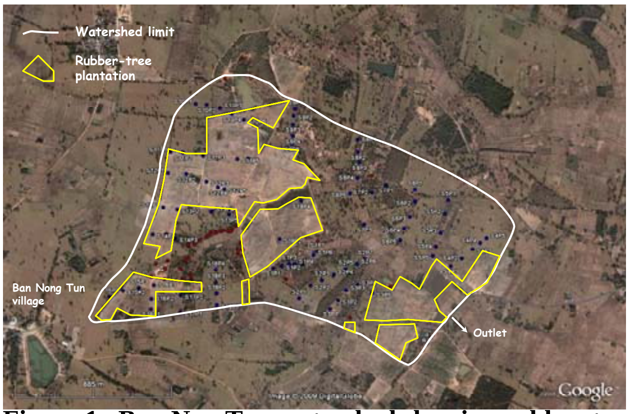

Figure 1. Ban Non Tun watershed showing rubber-tree plantation area and soil sampling location

Results

Characterization of soil and deposit features

The thickness of the sandy and clayey layers is highly variable showing a regular increase towards down slope and lowlands. The spatial distribution of the bedrock (sandstone-siltstone) top elevation is closely related to the watershed topography (Figure 2). These results are confirmed by EM38 measurements. The general distribution of the clayey layer is a key point to control groundwater recharge. The distribution of the soil mass water content is spatially clay content-related.

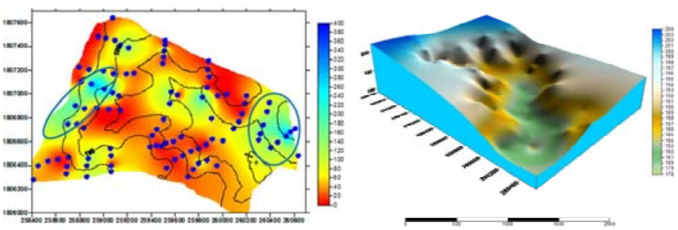

Figure 2. Spatial distribution of clayey layer thickness (in cm) and bedrock top elevation (in m)

Groundwater monitoring
Figure 3 shows a slightly trend to a groundwater recharge of the deep aquifer where groundwater level elevation is ranging from 177 m to 179 m. Only the piezometer located at slope summit (PB1K) quickly reacts at any heavy rainy event indicating that a preferential vertical recharge by direct infiltration occurs through the sandy later and the fractured bedrock (lack of clayey layer at this location). All the shallow piezometers react when rain is falling.

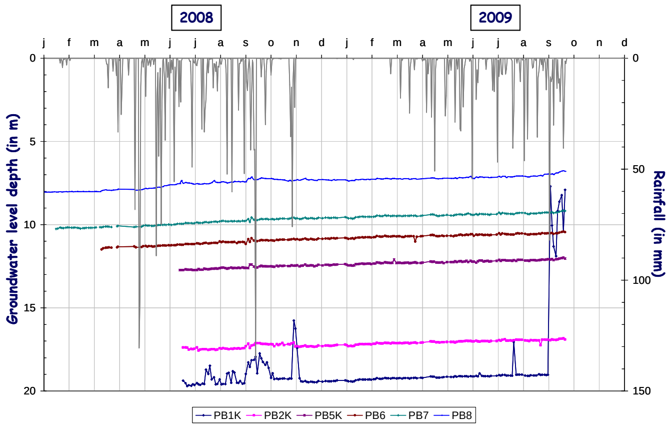

Figure 3. Time evolution of deep groundwater and daily rainfall amount

Mineralization and stable isotope features of groundwaters
Three groundwater types are distinguished taking in account the electrical conductivity parameter, the chemical composition and the groundwater elevation assessed at the screening piezometer base. The shallow groundwater of the sandy layer aquifer is weakly mineralized and Na-HCO_3 type whereas the deep groundwater of the sandstone-siltstone aquifer is highly mineralized (up to 6.5 dS/m) and Na-Cl type assuming a saline contamination. An intermediate type which is related to the shallow groundwater of the sandy layer aquifer located in paddy fields has an average mineralization and type (Figure 4).

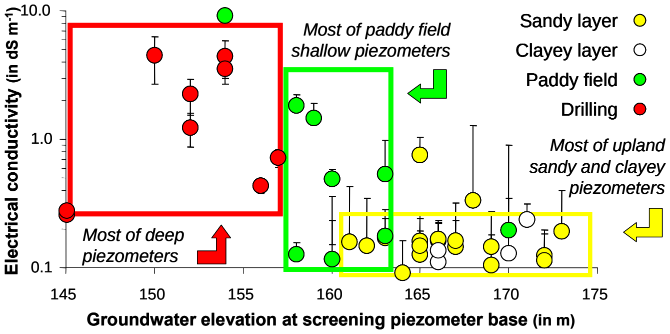

Figure 4. Mineralization patterns of shallow and deep groundwaters

Deep groundwaters are not evaporated assuming that they are meteoric in origin. A slight evaporated pattern is observed for some shallow groundwaters. Pond surface waters contributing to groundwater recharge are slightly evaporated according to isotope values (Figure 5).

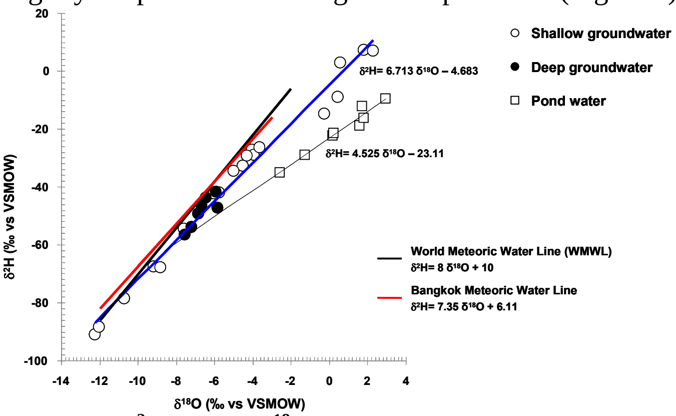

Figure 5. ^{2}H versus ^{18}O relationship for all sampled waters within Ban Non Tun watershed

Conceptual modelling
Figure 6 summarizes the recharge pathways and the chemical features of groundwaters using a synthetic scheme. The evolution with time (dry and wet seasons) is assumed for groundwater movement .

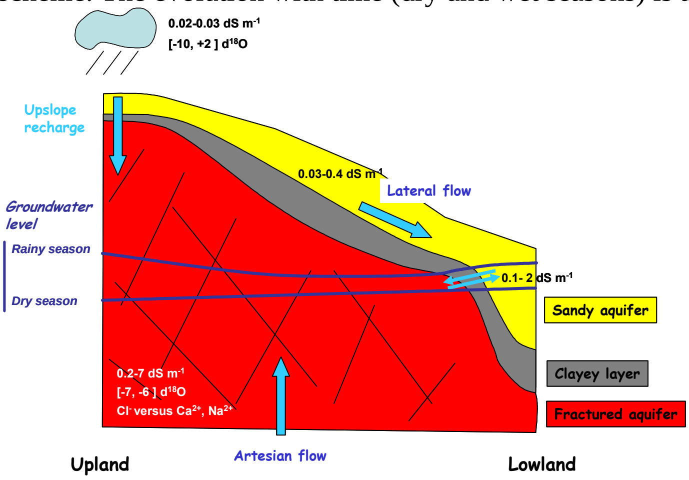

Figure 6. Conceptal model of groundwater pathways within deposit toposequence. Chemical and isotopic data ranges of groundwaters sampled at late dry season are included.

Conclusion
The field study performed at a small watershed scale leads shows (i) the presence of an impermeable clayey layer which has a double role as controlling the recharge distribution of the upland groundwater and protecting the shallow groundwater flowing within the sandy top layer; (ii) a high downwards recharge and a weak upwards recharge for both sandy layer and sandstone-siltstone aquifers; (iii) a deep deposit origin of groundwater mineralization with a slightly contamination of the shallow sandy aquifer and a strongly contamination of the deep sandstone-siltstone aquifer by saline and artesian flow uprising.
The present study site has lower annual precipitation rate and rainy day amount than the suitable values for rubber-tree cropping (1,250 mm and 120-150 rainy days) inferring a severe climate constraint. Moreover root system growth might be interfered according to the tree position along the slope. Soil layer thickness, clay layer barrier and waterlogging duration are determinant factors leading to increase the biomass variability within rubber-tree plantations. Soil and water resources need to be properly managed by smallholders and rubber production would be improved using inter-rank cropping and water harvesting.

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