ການປະເມີນໂຄງປະກອບຂອງດິນ ແລະ ການຕິດຕາມການບັນຈຸນ້ຳໃນດິນ ໂດຍການນຳໃຊ້ເຄື່ອງວັດແທກ (ERT) ໃນເຂດພູດອຍຂອງ ສ.ປ.ປ ລາວ

ອອງ ໂຣແບງ, ແຢນ ເລີໂຕແກ, ພາວີໄລ ສູນຍະວົງ, ບີຊິງ ຈາກົວ,
ເອມານຸ ບວກດົງ ແລະ ໂອລີວີເອ ຣິໂບຊີ

ບົດຄັດຫຍໍ້

ເຄື່ອງວັດແທກ (ERT) ໄດ້ນຳໃຊ້ເພື່ອຕິດຕາມນ້ຳບັນຈຸໃນດິນ ໃນເຂດອ່າງໂຕ່ງ ຫ້ວຍປ່ານໍ່ ແຂວງຫຼວງພະບາງ. ໄດ້ນຳໃຊ້ຂໍ້ມູນທີ່ໄດ້ມາຈາກເຄື່ອງວັດແທກ ແລະ ຈາກການເຈາະດິນຕາມໜ້າຕັດດິນມາສົມທຽບກັນ. ເຄື່ອງວັດແທກດັ່ງກ່າວ ສາມາດວັດແທກການຜັນແປຂອງລະດັບນ້ຳໃຕ້ດິນຕາມຄວາມຄ້ອຍຊັນຂອງພື້ນທີ່ໄດ້ຢ່າງຖືກຕ້ອງ. ຈາກການທົດລອງ ສາມາດຢືນຢັນໄດ້ວ່າ ປະລິມານ ຂອງນ້ຳຫ້ວຍແມ່ນຂຶ້ນກັບປະລິມານນ້ຳທີ່ສະສົມໄວ້ໃນດິນ ໂດຍຜ່ານການຊຶມລົງດິນຂອງນ້ຳຝົນ ແລະ ນ້ຳໃຕ້ດິນຈະປ່ອຍນ້ຳອອກມາຫຼາຍ ໃນເຂດດິນທີ່ມີປ່າເຫຼົ່າປົກຄຸມ ສ່ວນເຂດດິນທີ່ໄດ້ນຳເຂົ້າໃນການປູກຝັງ ຈະປ່ອຍນ້ຳໃຕ້ດິນອອກມາໜ້ອຍກວ່າ.

Assessment of soil organisation and monitoring of soil water content using Electrical Resistivity Tomography in the Uplands of Lao PDR

Henri ROBAIN[1], Yann LETROQUER[2], Phapvilay SOUNYAPHONG[3], Bee Xiong CHIAKOUA[3], Emmanuel BOURDON[2] and Olivier RIBOLZI[2]

Abstract

An Electrical Resistivity Tomography monitoring experiment was carried out in the uplands of Lao PDR in the Houay Pano experimental catchment. By comparing data obtained from the calculated cross section of electrical resistivity with hand auger observations, the detailed soil organisation in such a complex mountainous environment was characterised. By comparing the seasonal variation of ground electrical resistivity with the monitoring of groundwater level through a series of piezometer monitoring points, ground water fluxes along hillslopes can be measured precisely. Our study confirmed that stream water mainly corresponds to pre-event water stored in soils that is forced out by the infiltration of fresh rain water. The study also indicated that ground water recharge is larger for hillslopes with fallow vegetation than for cultivated hillslopes where soils are bare at the beginning of the rainy season suggesting the importance of surface cover on infiltration.

Key words: *Shallow groundwater resources; Geophysical measurement; Soil resistivity; Mountainous stream; Lao P.D.R*

---

[1]Centre IRD d'Ile de France – 32, avenue Henri Varagnat – 93143 Bondy cedex, France
[2]Institut de Recherche pour le Développement (IRD), International Water Management Institute (IWMI), National Agriculture and Forestry Research Institute (NAFRI) - c/o Ambassade de France – BP 06 Vientiane, Lao PDR
[3]NAFRI, Soil Survey and Land Classification Center (SSLCC)

Introduction

In the uplands of the Lao PDR population growth and resettlement policies have led to recent changes in land use. In this region, cultivated areas on marginal sloping lands have greatly increased, fallow periods have become shorter and new cash crops such as plants for biofuel (e.g. jathropha) or plantation timber (e.g. teak) are competing with former food-producing farmland or forest land.

In this context, knowledge of soil water content is of major importance to implement new sustainable agricultural practices that conserve soil ecological services. It is well known that within a small catchment, the soil water content may vary considerably both in space and time. In an agricultural context, these variations are controlled by complex interactions between i) surface water inputs (rainfall and streams), ii) soil structure which controls water infiltration and storage and iii) water uptake by plants. The last two factors are strongly influenced by changes in land use and agricultural practices.

Generally, variations in soil water content are measured using invasive methods which disturb soil conditions (e.g. measurements of the gravimetric water content require sample removal, water content measurements with Time Domain Reflectometry or neutron probes require that holes are drilled). Furthermore it is often difficult to establish generalities concerning large areas based on these local measurements.

Due to improvements in the feasibility of performing intensive calculations with personal computers, Electrical Resistivity Tomography (ERT) has been used in many recent soil research studies (e.g. Dahlin, 1996; Reynolds, 1997, Samouëlian et al. 2005). Indeed, this innovative geophysical method operated from the soil surface is not invasive, easily reproduced and the different soil layers can be rapidly characterised with very dense sampling. The measured parameter is ground electrical resistivity which depends on i) the type, size and arrangement of solid constituents; ii) water content; iii) the ion concentration in soil water and iv) soil temperature (Campbell et al., 1948; Rhoades et al., 1976; Kalinski and Kelly, 1993). The different soil layers are delineated by measuring variations in electrical resistivity along a cross section (e.g. Griffiths and Barker, 1993; Robain et al. 1996; Tabbagh et al., 2000), and water content changes in each layer are characterised by determining variations in electrical resistivity with time (e.g. Daily et al. 1992; Ramirez et al. 1993; Benderitter and Schott, 1999; Hahesy et al., 2000; Aaltonen, 2001; Zhou et al., 2001; Michot et al., 2003).

This paper presents some results obtained in the Houay Pano experimental catchment using an integrated approach combining high resolution non-invasive ERT measurements and low resolution invasive measurements made with auger holes and piezometers. The study aimed to i) assess the detailed soil organisation and ii) obtain a comprehensive understanding of the connexions and fluxes between groundwater in hillslopes and river banks, on the one hand, and stream surface water, on the other hand.

Material and methods

Site Description

The biophysical characteristics of the surveyed site, namely the Houay Pano catchment, are described in detail by Valentin et al (this issue).

The traverse RIB48 presented in this article is located in the central part of the catchment (Figure 1a) where the valley is rather large and corresponds to a swampy area. The land use on the right hillslope was fallow and the left hillslope was cultivated (rice). The geographical coordinates of the traverse were recorded with a hand GPS (GARMIN XL12) and the topography determined with a laser theodolite (NIKON DTM 332). The elevation AMSL of the traverse was referenced to a DGPS survey (TRIMBLE 5700) undertaken along the Houay Pano stream in 2006.

The groundwater level variations presented in this article were measured with 4 piezometers (Figure 1b) located approximately 0.5 m and 1 m above the stream base level on the right and left banks, respectively. Groundwater level monitoring was made with a manual probe, weekly until mid May 2007 and then daily after that.

Electrical Resistivity Tomography (ERT)

ERT is based on the measurement of ground electrical apparent resistivity. To perform the measurements, an electrical current of known intensity (I in Amperes) is released into the ground using a pair of metallic electrodes (C_1 and C_2) and then the resulting difference of electrical potential (ΔV in Volts) is measured between another pair of electrodes (P_1 and P_2). The electrical resistivity is given by the following equation:

$$\rho_a = K \cdot \frac{\Delta V}{I} \text{ (in } \Omega\text{.m)}$$

with $$K = \frac{2\pi}{\frac{1}{C_1P_1} - \frac{1}{C_1P_2} - \frac{1}{C_2P_1} + \frac{1}{C_2P_2}}$$

with C_1P_1, C_1P_2, C_2P_1 and C_2P_2 the distances (in m) between the electrodes of the measurement quadrupole.

P_a corresponds to a value normalised by the geometrical characteristic of the measurement array and is called the apparent resistivity. For homogeneous ground it is equal to the actual ground resistivity. For heterogeneous ground it is a convolution of the different resistivities. A set of measurements using quadrupoles with increasing size is required to calculate the distribution of actual resistivities. The curve of apparent resistivity as a function of array size is known as the Direct Current Vertical Electrical Sounding (DCVES). This curve allows a 1D geoelectrical model to be calculated (i.e. the variation of electrical resistivity along a vertical axe) using specific software. ERT consists of measuring numerous soundings close to one another along a linear traverse. This data set allows a 2D model of ground resistivity variation to be calculated - i.e. the variations of electrical resistivity along a cross section (Lines and Treitel, 1984; Ellis and Oldenburg, 1994; Loke and Dahlin, 2002).

The data set presented in this study was obtained with a multi-electrode resistivity meter (SYSCAL R2 – MULTINODE equipment, Iris Instruments). With this device the apparent resistivity for numerous quadrupoles of increasing size can be measured automatically with an array of 64 equidistant electrodes. For this study the unit inter electrode spacing was 1.5 m which corresponds to a traverse total length of 94.5 m.

The quadrupole configuration used is known as the Wenner-Schlumberger configuration. It corresponds to a quadrupole $C_1P_1P_2C_2$ where the distances C_1P_1 and P_2C_2 are equal and where distance P_1P_2 is a fraction of distance C_1C_2. When this fraction is equal to 1/3, the configuration is called Wenner *a*.

SYSCAL R2 uses a commutation program to connect sequentially chosen $C_1P_1P_2C_2$ quadrupoles among the 64 electrodes. The 828 apparent resistivity measurements obtained are represented on a conventional graph (Figure 2). For the Wenner-Schlumberger array, the X coordinate is the centre of bipole P_1P_2. The Y coordinate is a pseudo-depth equal to half distance between C_1 and C_2.

Each resistivity measurement was repeated at least 3 times and up to 6 times, when the experimental deviation was greater than 1%. Measurements that still had an error factor of more than 1% were not used in the analysis. In the most unfavourable cases, the rejected measurement points represented approximately 5% of the total set of measurements along the traverse.

This paper presents ERT measurements obtained in 2007 at the end of the dry season (19/01), at the beginning of the rainy season (24/04), and the middle of the rainy season (01/08) (Figure 3). This data set was processed using the commercial software RES2DINV (Geotomo Software, Malaysia). Since measurements were made in the same location at different dates, a 2D model of the underground resistivity distribution as well as its variation with time could be calculated (Loke, 1999; Leroux and Dahlin, 2006).

Results

Variations in the groundwater level

Rainfalls and groundwater levels monitored during the period are presented in Figure 4. Groundwater fluctuations appear to be strongly influenced by rainfall events with very rapid rises in the groundwater level upon rain and then sharp exponential decays. This behaviour is linked to the storm floods observed in the stream.

Readings from the piezometers close to the stream (48R2 and T3A2), showed that groundwater levels were almost constant and lower than the stream baseline until mid June. After this date, levels increased gently and only surpassed the stream baseline after the heaviest rainfall events. A strong difference between readings from distant piezometers placed on the left and right banks was observed. For the right bank (48R1), the fluctuations were the same as those observed with the close piezometers. For the left bank (T3A3) the variation amplitude was much larger. A decrease starting above the stream baseline was seen until the end of the dry season. Then increases were observed just after the beginning of the rainy season, at first these were gradual (until the end of June) and then became more rapid with very sharp fluctuations of more than 0.5 m in amplitude.

ERT monitoring

The 2D models calculated from the resistivity data are shown in Figure 5. Three main layers can be seen in the cross sections: a top resistive layer, a conductive intermediate layer and a resistive layer at the bottom. The more complex soil organisation is also included on the models. Important differences were observed between the right and left bank of the stream. These differences concern both the shape and resistivity of the layers.

The cross section shows several anomalies of high resistivity deviating from the general resistivity pattern along hillslopes in the top layer. These were more pronounced on the right bank than on the left bank. The conductive layer extends over the whole cross section and reaches the surface under the swampy area. The resistivities are lower under the hillslopes than under the swampy area. An anomaly of low resistivity is observed in the intermediate layer at the foot of the right hillslope. The top of the bottom resistive layer rises at the right end of the swampy area.

Variations in resistivity with time did not significantly change the general aspect of the cross sections. Nevertheless the differences relative to the initial resistivities are significant. Their statistical characteristics are presented in Table 2. The mean measured apparent resistivities did not vary between January and April (transition between dry and rainy season) but decreased between April and August (transition between the beginning and the middle of rainy season). On the other hand, the standard deviations of measured apparent resistivities decreased for both time intervals with a larger drop between January and April than between April and August.

The mean calculated resistivity decreased for both time intervals. The drop was lower between January and April than between April and August. The standard deviations also decreased for both time intervals but, as in the case of the measured apparent resistivities, the drop was larger between January and April than between April and August.

Regarding the distribution of the changes in resistivity in the cross section relative to dry season, some general trends can be inferred:

- The transition between the dry and rainy seasons corresponded to a decrease in resistivity at the top of the cross section, a more or less pronounced increase at intermediate depth and a complex pattern at the bottom of the cross section. It is also noted that increases in resistivity in the intermediate layer were connected with the soil surface between the high resistivity anomalies observed along hillslopes in the top layer. This indicates that the pattern of the resistivity variations with time is influenced by the differentiations in the top layer of soils which are shown by the anomalies in resistivity.

• The transition between the beginning and the middle of the rainy season corresponded to an extension, both in amplitude and in thickness, of decrease in resistivity at the top of the cross section, a diminution of the increase observed at intermediate depth and a conservation of the complex pattern observed at the bottom.

• Important differences were observed for the increase in resistivity at intermediate depth between the left and right banks. At the beginning of the rainy season, the increase in resistivity was continuous across the whole section and extended to depth under the swampy area. The amplitude of the increase was more pronounced for the right bank than for the left bank. At the middle of the rainy season, the resistivity increase almost disappeared for the left bank and was confined to several areas for the right bank.

Conclusion

This study shows that ERT provides relevant data to address the spatial variations of soils in a complex context such as a mountainous environment. In particular it appears that using this technique, landslides and bedrock inhomogeneities, which strongly influence the organisation of soils along hillslopes, are clearly detected. This information is very useful to guide the implementation of observation and/or experimentation plots.

By monitoring resistivity variations with time the water fluxes can be assessed in this type of environment. On one hand, it confirms that in this catchment rain water infiltrates very rapidly and pushes out the pre-event groundwater which principally contributes to the storm floods observed in the stream. On the other hand, it appears that the general pattern of water content variations in the top layers is strongly influenced by plant cover. High levels of water uptake occur in vegetated soils and hence water content during the rainy season is highly variable. Bare soils present lower variations in water content and consequently are more subject to surface runoff which decreases the budget of catchment groundwater recharge.

Acknowledgments

This work was supported by the department DRV (Dépàrtement des Ressources Vivantes), the research unit SOLUTIONS of IRD (Institut de Recherche pour le Développement), IWMI (International Water Management Institute) and ECO_2CO Cytrix (project 71, ONDINE).

References

Aaltonen J., 2001. Seasonal resistivity variations in some different swedish soils. Eur J Environ Eng Geophys 6, 33–45.

Benderitter, Y., Schott J.J., 1999. Short time variation of the resistivity in an unsaturated soil: the relationship with rainfall. Eur. J. Environ. Eng. Geophys. 4, 37–49.

Bernstone, C., Dahlin, T., Ohlsson, T., Hogland, W., 1998. DC resistivity mapping of internal landfill structures: two pre-excavation surveys. Environ. Geol. 39, 360–371.

Campbell, R.B., Bower, C.A., Richards, L.A., 1948. Change of electrical conductivity with temperature and the relation of osmotic pressure to electrical conductivity and ion concentration for soil extracts. Soil Sci. Soc. Proc. 66–69.

Daily, W., Ramirez, A., Labrecque, D., Nitao, J., 1992. Electrical-resistivity tomography of vadose water-movement. Water Resour. Res. 28(5), 1429– 1442.
Dahlin T., 1996, 2D resistivity surveying for environmental and engineering applications, First Break 14, 275–283.

Ellis, R.G., Oldenburg, D.W., 1994. Applied geophysical inversion. Geophys. J. Int. 116(1), 5 –11.

Griffiths, D.H., Barker, R.D., 1993. Two-dimensional resistivity imaging and modelling in areas of complex geology. J. Appl. Geophys. 29, 211–226.

Hahesy, P., Heinson, G., Endres, A.L., Hutson J.L.: 2000, Geophysical signature of moisture distributions in the vadose zone, in Proceedings for SAGEEP 2000, Washington D.C., 233–242.

Kalinski R.J., Kelly W.E., 1993. Estimating water content of soils from electrical resistivity. Geotech. Test. J. 16, 323–329.

Leroux, V., Dahlin, T., 2006. Time-lapse resistivity investigations for imaging saltwater transport in glaciofluvial deposits. Environ. Geol. 49, 347–358

Lines, L.R., Treitel, S., 1984. Tutorial - A review of least-squares inversion and its application to geophysical problems. Geophys. Prospect. 32(2), 159– 186.

Loke, M.H., 1999. Time lapse resistivity imaging inversion. Proceedings of the 5th Meeting of the EEGS European Section,. 6-9/10/1999, Budapest, Hungary

Loke, M.H., Dahlin, T., 2002. A comparison of the Gauss–Newton and quasi-Newton methods in resistivity imaging inversion. J. Appl. Geophys. 49(3), 149–162.

Michot, D., Benderitter, Y., Dorigny, A., Nicoullaud, B., King, D., Tabbagh, A., 2003. Spatial and temporal monitoring of soil water content with an irrigated corn crop cover using electrical resistivity tomography. Water Resour. Res. 39, 11-38.

Nobes, D.C.: 1996, Troubled waters: Environmental applications of electrical and electromagnetic methods, Surveys in Geophysics, 17, 393–454.

Ramirez, A., Daily, W., LaBrecque D., Owen, E., and Chesnut, D., 1993, Monitoring an underground steam injection process using electrical resistance tomography: Water Resources Research, 29, 73-87.

Rhoades, J.D., Raats, P.A.C., Prather, R.J., 1976. Effect of liquid phase electrical conductivity, water content, and surface conductivity on bulk soil electrical conductivity. Soil Sci. Soci. Am. J. 40, 651–655.

Reynolds, J.M., 1997. An Introduction to Applied and Environmental Geophysics. Wiley, Chichester. 796 pp.

Robain, H., Descloitres, M., Ritz, M., Yene Atangana, Q. 1996. A multiscale electrical survey of a lateritic soil in the rain forest of Cameroon. Journal of Applied Geophysics 34, 237-253

Samouëlian, A., Cousin, I., Tabbagh, A., Bruand, A., Richard, G., 2005. Electrical resistivity survey in soil science: a review. Soil & Tillage Research 83, 173–193.

Tabbagh A., Dabas M., Hesse A., Panissod C., 2000. Soil resistivity: a non-invasive tool to map soil structure horizonation. Geoderma 97, 393–404.

Zhou Q.Y., Shimada J., Sato A., 2001. Three-dimensional spatial and temporal monitoring of soil water content using electrical resistivity tomography. Water Resour. Res. 37, 273–285.

Table 1 – *Elevation of piezometers relative to the local stream base level*

Piezometer	Elevation	Delta Elev
T3A3	525.92	1.42
T3A2	524.81	0.31
Stream	524.50	
48R2	524.94	0.44
48R1	525.57	1.07

Table 2 – *Statistical parameters of measured and calculated electrical resistivities. The changes in resistivity models are both calculated relative to January.*

Date		19/01/2007	24/04/2007	01/08/2007
Data : Apparent Resistivity (Ohm.m)	Number	828	828	828
	Number	836.6	463.8	403.3
	Max	24.0	22.0	20.4
	Mean	69.8	69.9	61.5
	STD	78.4	59.5	46.3
Model : Calculated Resistivity (Ohm.m)	Number	1344	1344	1344
	Max	1189.6	591.2	495.9
	Min	7.8	8.5	8.3
	Mean	107.5	95.0	79.3
	STD	174.1	117.5	94.0
Model Changes (%)	Max		146.4	103.1
	Min		-62.2	-65.1
	Mean		3.2	-9.8
	STD		24.2	21.6

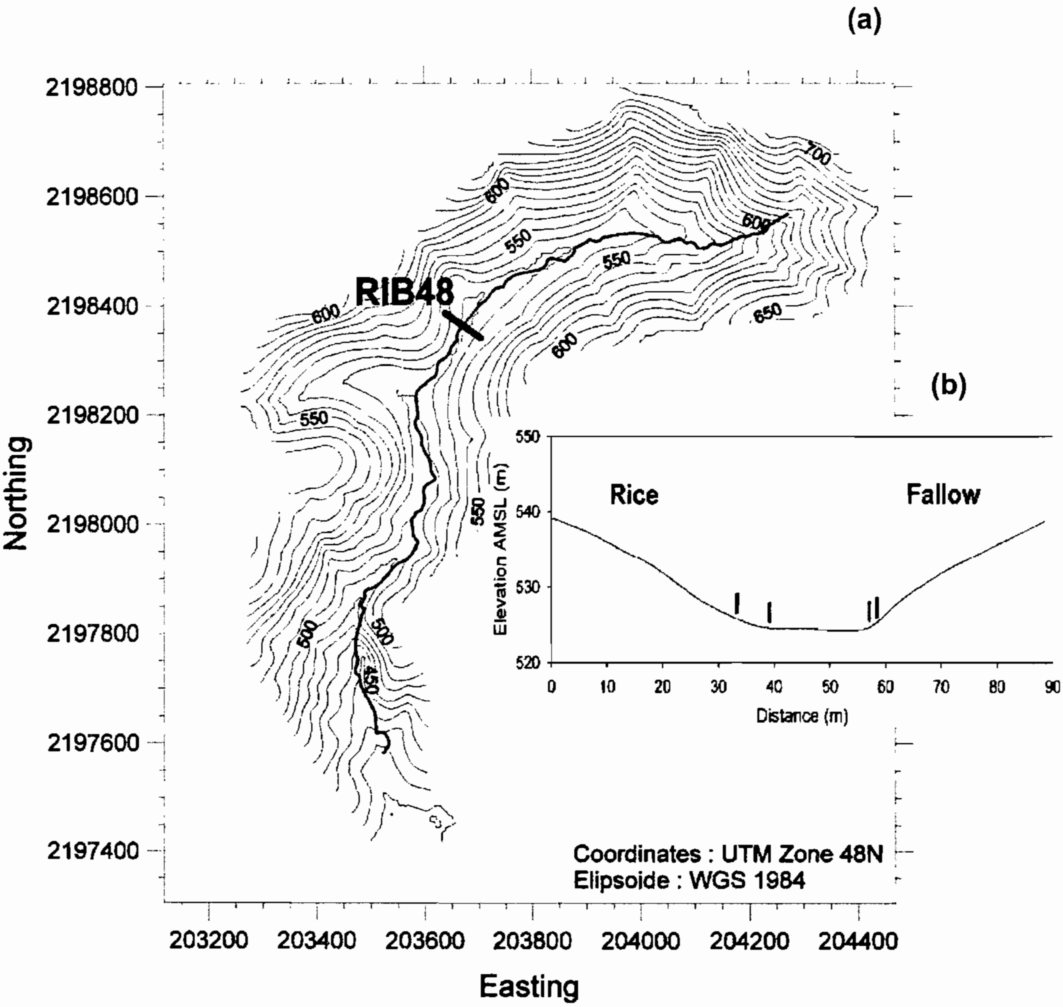

Figure 1 – ***(a)*** *Traverse RIB48 location and topography.* ***(b)*** *Elevation profile showing the location of piezometers (blue vertical lines).*

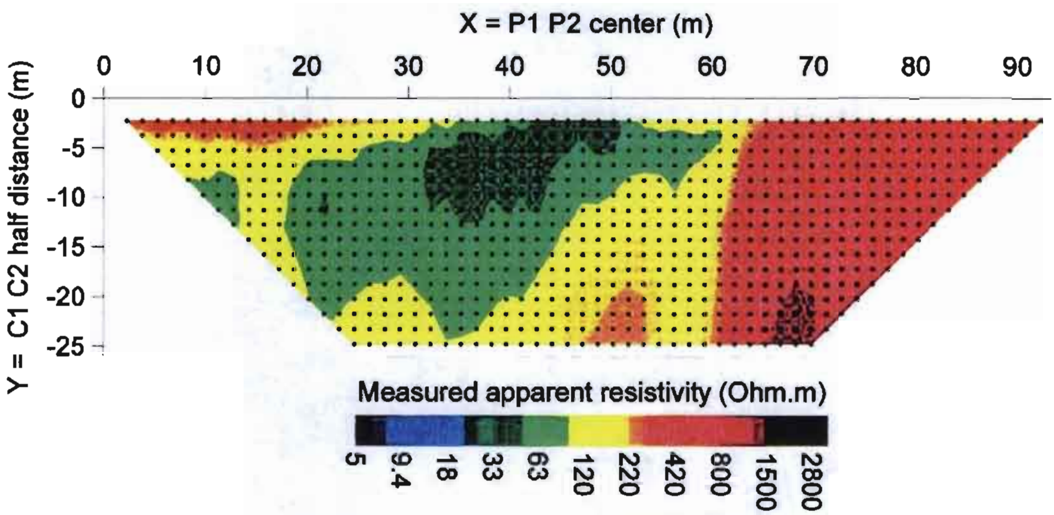

Figure 2 – *Conventional representation of a set of apparent resistivity measurements.*

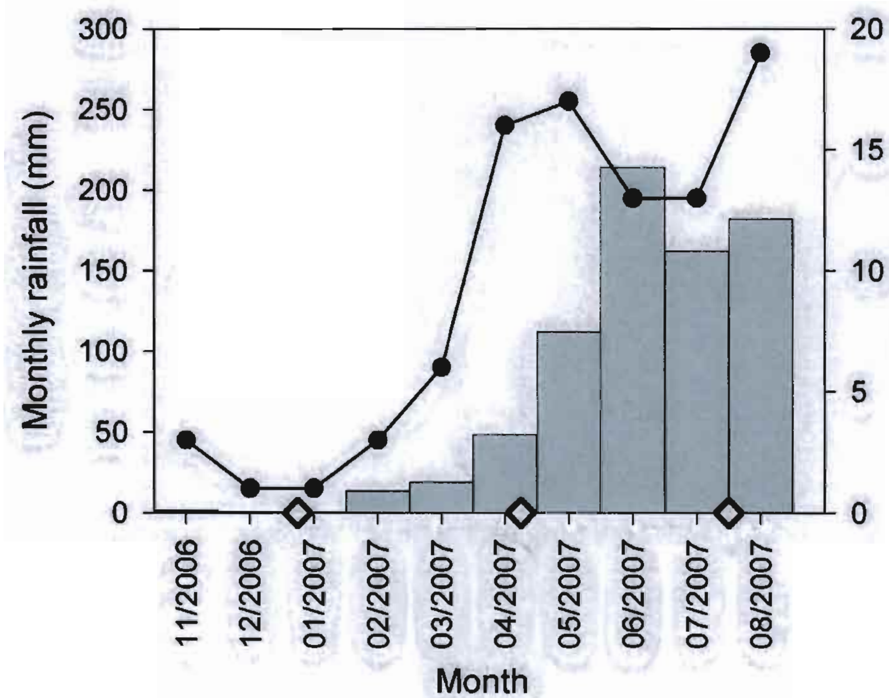

Figure 3 – *Monthly rainfall in the Houay Pano catchment. The bar chart represents monthly rainfall; the line plot, the number of rainy days; the three dates on which ERT measurements were made are indicated along x axis by the diamond symbols.*

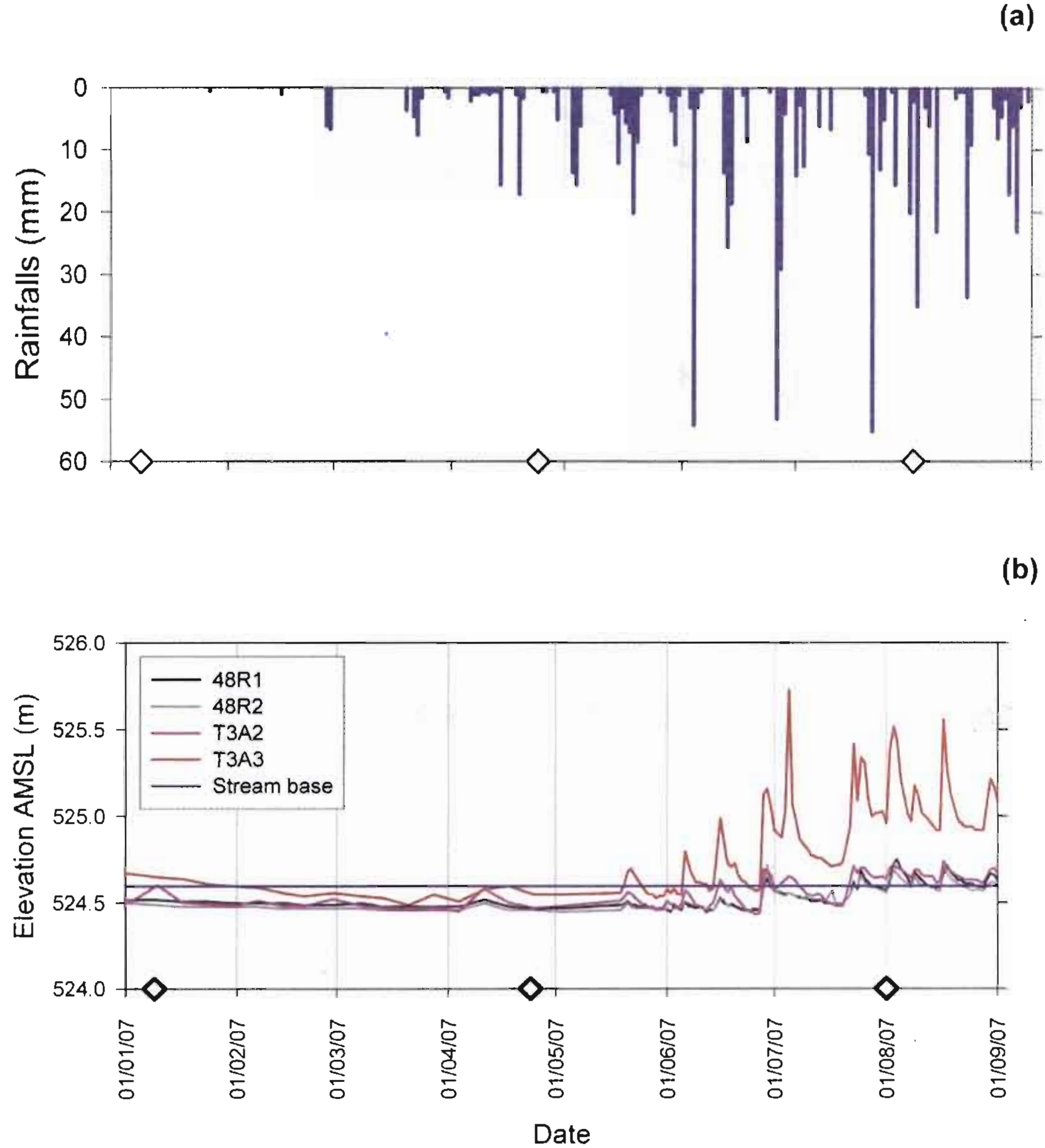

Figure 4 – *Daily rainfall **(a)** and groundwater level variations **(b)**.*

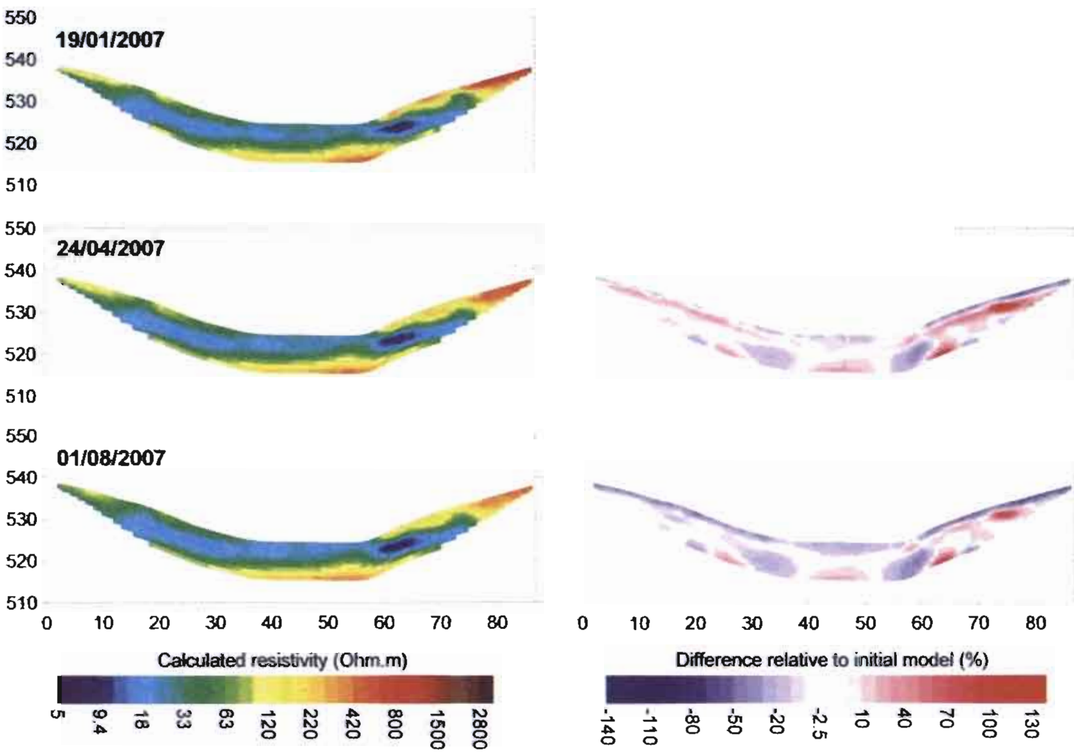

Figure 5 – *Calculated 2D resistivity models (left) and variations relative to the end of dry season (right).*

THE LAO JOURNAL OF AGRICULTURE AND FORESTRY

MSEC special issue No. 17, September 2008

Management of Soil Erosion and Water Resources in the Uplands of Lao P.D.R.

IRD Institut de recherche pour le développement
International Water Management Institute
MSEC
NAFRI

THE LAO JOURNAL OF AGRICULTURE AND FORESTRY

MSEC special issue No. 17, September 2008

Management of Soil Erosion and Water Resources in the Uplands of Lao P.D.R.

Designed and Layout by: Khanhkham Ouneoudom, Information Center, NAFRI

ອອກແບບ ແລະ ຈັດໜ້າ ໂດຍ: ຂັນຄຳ ອ້ວນອຸດົມ, ສູນຂໍ້ມູນຂ່າວສານ, ສຄກປ