Integrated assessment of infiltration and overland flow for different rainfall events

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Abstract: This paper presents the results for infiltration and overland flow obtained according to the Morel - Seytoux & Khanji (1976) and Chu (1978) adaptation of the Green & Ampt (1911) model for steady and transient rainfalls, respectively. The study was carried out for the Córrego do Vaçununga basin, in the city of Luiz Antonio, state of São Paulo, Brazil. Ninety percent of the basin consists of aaeolian sandstones of the Botucatu Formation, which is the most important unconfined aquifer of Brazil, and residual unconsolidated materials. These two geological materials constitute the main aquifer of the region. Laboratory and in situ tests were performed to characterize the unconsolidated materials in terms of basic physical properties, potential infiltration, suction and hydraulic conductivity. Rainfall data were collected from January 2000 to December 2002 and twelve scenarios were defined on the basis of intensities and durations. The infiltration and overland flow ratio depend on the type of land use and associated management techniques, rather than high textural homogeneity of the unconsolidated materials The results showed that rainfall with high intensities and short duration does not produce the high overland flow ratios that we have observed for transient scenarios with long duration and low intensities.

Résumé: Cet article présente les résultats pour l'infiltration et l'écoulement de surface obtenus selon las adaptations de Seytoux et de Khanji (1976) et de Chu (des 1978) du modèles de Green et d'Ampt (1911) pour des précipitations régulières et passagères, respectivement. L'étude a été effectuée pour le bassin Córrego do Vaçununga, dans la ville de Luiz Antonio, état de São Paulo, Brésil. Quatre-vingt-dix pour cent du bassin se composent de grès éolien de la Formation Botucatu et le sol résiduel, le plus important aquifère du Brésil. Ces deux matériaux géologiques constituent l'aquifère principal de la région. Les essais en laboratoire et *in situ* ont été exécutés pour caractériser les sols en termes de propriétés physiques, infiltration potentielle, succion et conductivité hydraulique. Des données de précipitations ont été rassemblées de janvier 2000 à décembre 2002 et douze scénarios ont été définis compte tenu les intensités et les durées. Plutôt que l'homogénéité élevée en termes de texture de sol, l'infiltration et le rapport d'écoulement de surface dépendent du type d'utilisation et des techniques de gestion associées. Les résultats ont prouvé que les précipitations aux intensités élevées et la courte durée ne produisent pas de rapports élevés d'écoulement de surface comme nous l'avons observé pour les scénarios passagers à longue durée et basses intensités.

Keywords: Infiltration, overland flow, unconfined aquifer, Botucatu Formation, São Paulo, Brazil

INTRODUCTION

Studies to understand water dynamics have been developed according to two basic approaches. The most common approach is based on parameters related to water budget (Colenbrander, 1965; Dunne & Black, 1970; Giambelluca *et al.* 1996) and the other on specific parameters involving a grouping of natural components of the environment (Abu-taleb 1999; Ando *et al.* 1983; Morel-Seytoux 1984). Both cases consider specific aspects such as variability and heterogeneities of the geological materials, rainfall scenarios and human interference due to varying land use and occupation management practices. A third approach has been developed with the combination of field and laboratory procedures from the first two (Sullivan *et al.* 1996; Yang *et al.* 1999; LubczynsKi & Gurwin 2005; Jafar *et al.* 2005; Fazal *et al.*2005).

The population has increased very quickly in the northeast region of the state of São Paulo, Brazil, and water demand has increased at the same rate. In São Paulo State, aeolian sandstones of the Botucatu Formation occur in the south, southeast and west regions and are considered to represent the main groundwater source in Latin America. At the surface, the outcropping parts of these sandstones occur in two basic situations: 1 – outcrops of fractured and highly cemented sandstones on scarp features, and 2 – weakly cemented or very weakly cemented sandstones covered by sandy residual unconsolidated material and clayey sand. In the second type of situation, the unconsolidated residual material represents colluvial admixtures that are clay-rich where derived from basaltic rocks and sandy where sourced from sandstones. Here, the sandstones and unconsolidated superficial materials represent an unconfined aquifer with direct recharge. Thicknesses vary from a few meters to up to 100 meters and pollution susceptibility is higher than where the aquifer is semi-confined.

There have been several studies to evaluate water dynamics in hydrological basins, but integrated studies that consider different components of the environment are not common. Due to the importance of the infiltration rate in forecasting direct recharge and overland flow in an unconfined aquifer, the Córrego do Vaçununga basin was selected for this study. The basin is predominantly (90%) underlain by very weakly cemented sandstone and sandy residual unconsolidated materials, which together consequently represent a major part of the unconfined aquifer.

The relationship between rainfall and geological materials controls the infiltration and overland flow rate. According to Dykes & Thornes (2000), the more appropriate procedures to assess water dynamics are based on three groups of data: geological materials, rainfall, and interactions between rainfall and geological materials. The present study aims to present these procedures and evaluate the results obtained for the Córrego do Vaçununga basin considering a range of different rainfall events that are representative of conditions within that region.

STUDY AREA CHARACTERISTICS

The Córrego do Vaçununga Basin occupies an area of 80.53 Km^2 located in the region surrounding the city of Luiz Antonio, in the north-eastern portion of the state of São Paulo (Figure 1). According to the Koppen classification the climatic type falls between categories A and C, with dry winters and hot summers and temperatures varying from 13^o C to 30^o C (average 23º C). The average annual rainfall is 1,300 mm, and annual potential evapotranspiration is around 920 mm; altitudes vary between 600 to 800 m.

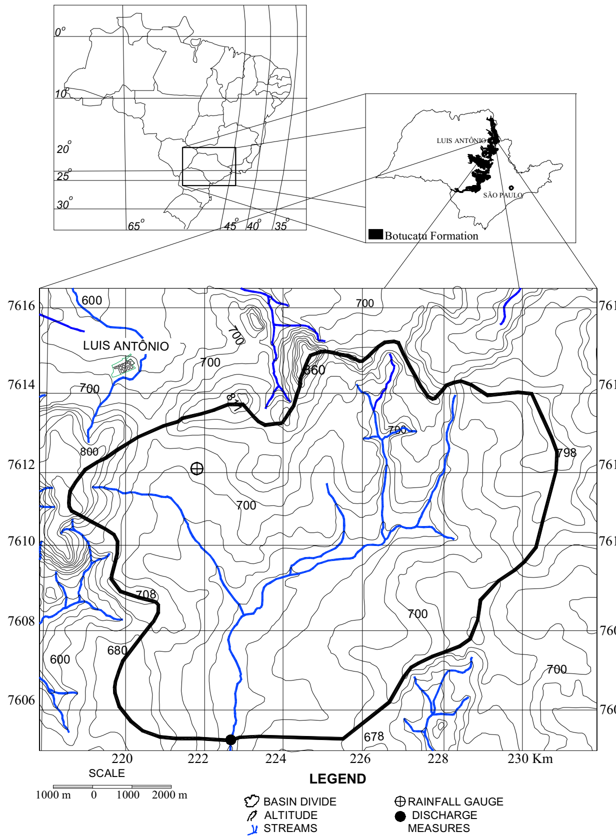

Figure 1. Location of the Córrego do Vaçununga Basin (UTM Zone – 23 South).

METHODOLOGY

This study was carried out following the recommendations of Dykes & Thornes (2000) previously described in the introduction. The specific procedures adopted were as follows:

- Geological units were mapped at a scale of 1:10,000. Their physical properties were characterized by laboratory studies and field tests.
- A group of laboratory and field tests were performed for selected sites in order to obtain suction and infiltration rates and also hydraulic conductivity parameters of the geological materials.
- The filter paper method (Whatman No. 42) was used to obtain data with which to plot the water retention curves for unconsolidated materials, following the recommendations of Marinho (1994). Calibration was according to equation (1) of Chandler et al. (1992)

In situ infiltration tests

The infiltration rate depends on several attributes related to geological materials as well as slope, vegetation, land use and land management practices and bedrock depth. This study adopted unsteady infiltration conditions and considered that the land surface is continuously flooded with a very small depth of water at a time, t>= 0 (the surface soil will be saturated); an initial moisture content was assumed. The in situ double ring infiltrometer and instantaneous profile method proposed by Libardi (1980) were used to obtain the infiltration curve and hydraulic properties of the geological materials.

Equation 1 was used to obtain the saturated hydraulic conductivity (constant head):

$$k_{fs} = \frac{Q}{\left(\frac{H+Z_W}{Z_W}\right) A.t} \tag{1}$$

Where: k_{fs} = in situ saturated hydraulic conductivity (m/h); Z_W = saturated water front depth (m); A = ring area (m^2); t = time (H); Q = water volume (m^3); H = constant water depth into the internal ring (m).

The main advantage of the instantaneous profile method proposed by Libardi (1980), as opposed to the double ring infiltrometer, is to enable the calculation of the hydraulic conductivity for different volumetric moisture contents at a range of depths, as in the following general equation (2):

$$K(\theta) = Ko.e^{\gamma(\theta - \theta o)} \tag{2}$$

Where: K(θ) = unsaturated hydraulic conductivity related to volumetric moisture content (θ), K_o = a saturated hydraulic conductivity, θ = volumetric moisture content, e θ_o = saturated volumetric moisture content. The infiltration tests must be long enough to allow water to reach depths greater than the effective root depths and to minimize the presence of macropores and preferential flow.

The infiltration test, combined with the instantaneous profile method carried out in the region to characterize the sandy residual unconsolidated material, was developed in sites prepared as follows. A circular earthfill was constructed in order to preserve natural conditions. An area 9 m^2 across and 7 m^3 was then infiltrated, maintaining a minimum water depth of 10cm to avoid problems with water velocity and soil structures. After the tests, samples were taken at 20 cm depth intervals for several time periods to obtain the moisture content and consequently, the water distribution.

Intensity and duration of the rainfall were assessed over a period of 3 years, beginning in January 2000 through December 2002. Measurements were made at 5 minute intervals for 12 rainfall scenarios (intensity and duration) that were selected as representative of conditions in the basin. Due to the short time duration of these scenarios, as well as the high relative air humidity, the evapotranspiration was not considered in the modelling.

The Green & Ampt (1911) model was modified and used to assess the water and geological material interaction for the 12 rainfall scenarios. This model was chosen because it is based on physical properties and can be applied to a range of different natural conditions. The basic version of the model is mainly applicable to geologically homogeneous terrains and considers that the wetting front presents a well-defined limit between saturated and unsaturated zones (piston-like).

From this model other versions were developed, in order to adapt the basic model to the more complex conditions that typically occur naturally. In this study the Morel – Seytoux & Khanji (1976) and Chu (1978) modified models were used for steady and transient rainfall events, respectively, and some representative equations (5, 6 and 7) are now presented:

For Morel – Seytoux & Khanji (1976) model: tp = [(θ-θi).Hb(θ-θi)] / r (r/K – 1) (5)	Where: tp: Ponding time θ: Saturated volumetric moisture content (m^3/m^3); θi: Initial volumetric moisture content (m^3/m^3); Hb: Effective capillarity (m); K: Saturated hydraulic conductivity (m/h); r: Rainfall intensity (m/h);

The potential water infiltration depth (W) was calculated according to the Morel – Seytoux & Khanji (1976) model from mathematical expression (6) proposed by Abdulaziz & Turbak (1996), which considers the following parameters:

$$W = i_r t_p + \left[2(\theta - \theta i)H_c K\right]^{1/2} \frac{i_r^*}{i_r^* - 1}\left[(t - t_p) + \frac{t_p}{2}(\frac{i_r^*}{i_r^* - 1})^3\right]^{\frac{1}{2}}$$ $$-\left[\frac{t_p}{2}(\frac{i_r^*}{i_r^* - 1})^3\right]^{\frac{1}{2}} + K(t - t_p)$$ (6)	Where: W: Potential water infiltration depth (mm) ir: Rainfall intensity (m); ir*: Normalized Rainfall intensity (m); K : Saturated hydraulic conductivity (m/h); t: Rainfall duration (h); θ: Saturated volumetric moisture content (m^3/m^3); θi: Initial volumetric moisture content (m^3/m^3); tp: Ponding time (h); and Hc: Capillarity (m).

For Chu (1978) model tp = {[KSM/(I-K) – $P_{(t_{n-1})}$ + $R_{(t_{n-1})}$]/I}+tn-1 (7)	Where: tp: Ponding time K: Saturated hydraulic conductivity (m/h); S: Difference between initial and final potential capillarity (m); M: Difference between initial and final volumetric moisture contents; I: Rainfall intensity (m/h); P: Accumulated precipitation to t_{n-1} (m); and R: Overland flow depth for t_{n-1} (m).

According to Chu (1978), model water infiltration depth for each scenario represents the total quantity of water infiltrated during the rainfall event.

P = F + R

When R = 0 → F = P.

Where:

P: Precipitation (m);

F: Infiltration rainfall depth (m);

R: Overland flow depth (m).

RESULTS AND ANALYSIS

Geologically, the study basin consists of very weakly cemented or weakly cemented aeolian sandstones of the Botucatu Formation (> 90%), and in some areas (less than 10%) these sandstones are overlain by basalt of the Serra Geral Formation. The sandstones present low heterogeneity in terms of texture and mineralogy (mainly quartz), contain well-rounded grains with worn surfaces, and have colours varying from red to yellow. They are of somewhat variable thickness, but are predominantly less than 50 m.

Unconsolidated materials

The unconsolidated materials were classified into 2 groups: residual and transported. Their distribution within the basin is shown in Figure 2, and their basic geotechnical characteristics are presented in Table 1.

Residual group

The sandy unconsolidated materials derived from sandstones of the Botucatu Formation occur in most parts of the basin and are between 5 and 20 m thick. They are characterized by high lateral and vertical homogeneity.

The residual unconsolidated materials from basalts of Serra Geral Formation are thin, and are texturally classified as clays and silts. Mineralogically they consist of kaolinite, gibbsite, magnetite, hematite, ilmenite, limonite and goethite. These are joined by feldspar and other primary minerals in the saprolitic zone of relatively less weathered rock.

Transported group

The transported unconsolidated materials represent colluvium that has resulted from the natural mixture of clayey and sandy unconsolidated materials derived from basalts and sandstones, respectively. The characteristics of these materials depend on their thickness and spatial extent, and upon the extent of local basalt outcrops. In addition, alluvial deposits are found in valley floors close to drainage channels; they are characterized by vertical and lateral heterogeneity and variable thickness, with an average saturated hydraulic conductivity of around 10^{-3}cm/s. In the floor of the Córrego do Vaçununga basin the depth to ground water level from the surface is variable; on the flanks it is in excess of 10 m.

Table 1. Basic geotechnical characteristics of the unconsolidated materials.

Unconsolidated materials	γs * (KN/m^3)	Clay (%)	Silt (%)	Fine sand (%)	Intermediate Sand (%)	Coarse sand (%)	Porosity (%)	γd ** (KN/m^3)
Botucatu Sandstone	26.71 to 27.60	0 to 5	8 to 18	35 to 41	38 to 49	0 to 3	41 to 54	11.7 to 15.1
Serra Geral Formation	2789 to 28.73	40 to 44	30 to 35	15 to 21	3 to 5	0 to 4	36 to 51	14.7 to 16.3
Mixture transported	26.70 to 27.99	31 to 37	20 to 25	11 to 29	10 to 29	3 to 6	44 to 49	13.1 to 15.7
Alluvial	27.10	0 to 4	7 to 31	11 to 39	15 to 41	0 to 6	40 to 50	14.2 to 15.3

* Specific gravity; ** Natural dry density

Land use

The land use and occupation map was prepared using satellite and aerial images augmented by fieldwork. Basically more than 90% of the basin is occupied by sugar cane and eucalyptus cultivations and pasture (Figure 2). Sugar cane cultivation involves 2 well-defined crop-cycle phases. First, the soil structures and compacted beds are destroyed by deep tillage methods used to improve agricultural conditions (12 months); water is held in channels produced by the deep tillage. The second phase is related to land use management practices over a period of 48 months. Eucalyptus forestry has been practiced in one area for 30 years, but because the position of the trees is changed after each 8-year period, compaction of materials near to the surface is not common.

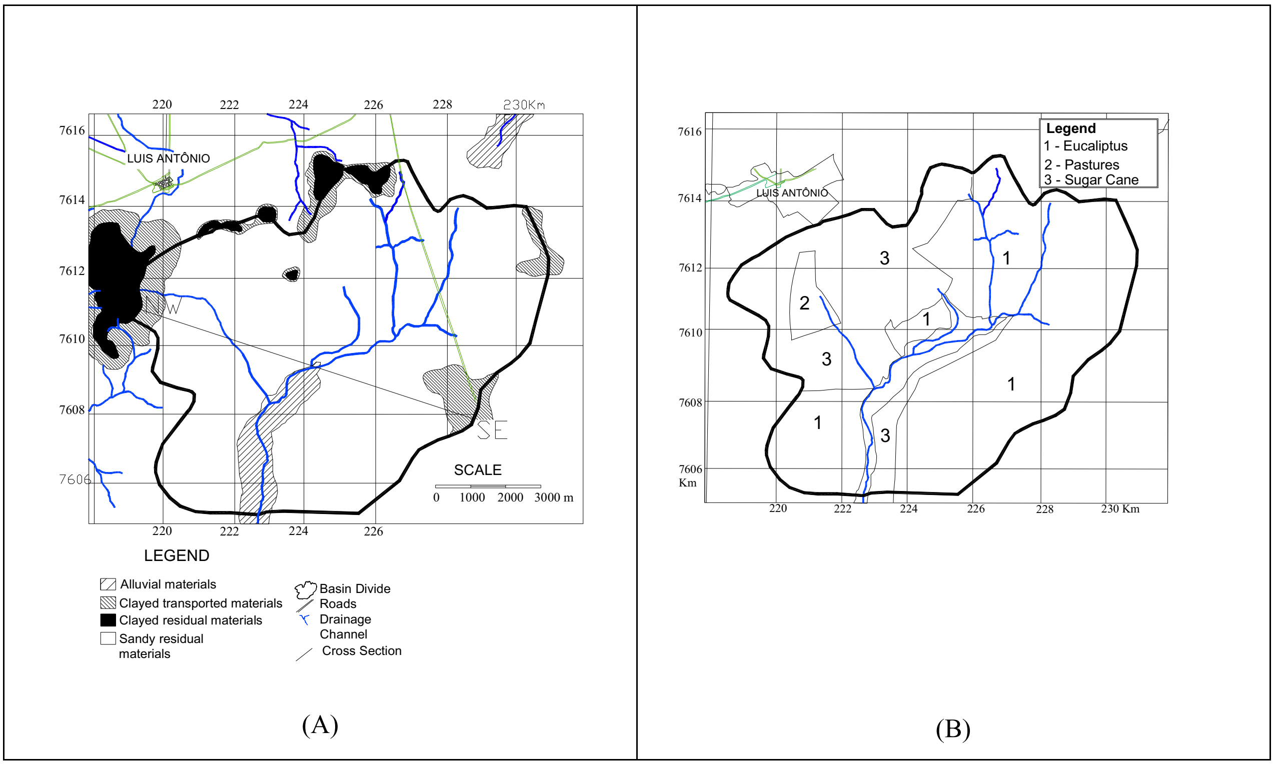

Figure 2. (A) Unconsolidated material map and (B) Land Uses and Occupation distribution map.

The land use and unconsolidated materials maps were used in combination to select the sites for in situ infiltration tests. The sandy unconsolidated materials were carefully investigated to reveal the basic characteristics of the unconfined aquifer in the larger region.

Suction tests

Suction values for 12 samples collected for each unconsolidated material were obtained according to the recommendations of Marinho (1994) and the representative water retention curves are shown in Figure 3. Even though the physical parameters of the sandy residual unconsolidated material show low variability, the water retention curves present different types of behaviour because suction depends on void size distribution and electrochemical forces. The water retention curve for the final period of the sugar cane cycle shows the influence of compaction conditions due to the heavy machinery used for fertilizer application.

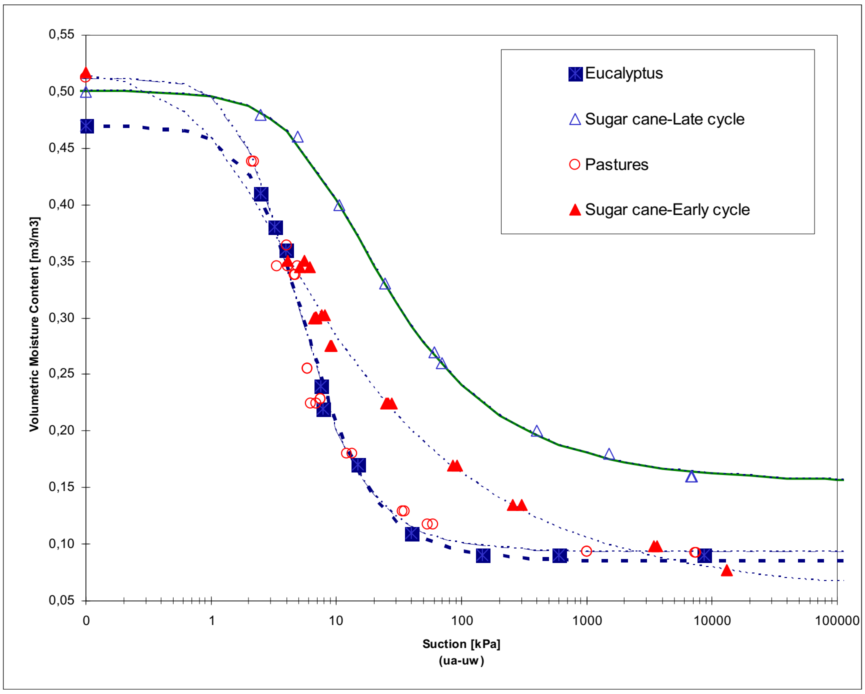

Figure 3. Representative Water Retention Curves for sandy unconsolidated materials with different land uses.

Infiltration tests

Double ring tests

Considering the different geological materials and land uses, 12 tests (9 in sandy residual unconsolidated material of the Botucatu Formation, 2 in clayey residual unconsolidated material of Serra Geral Formation and 1 in alluvial material) were performed according the procedures of the ASTM.

From these tests were obtained the following saturated hydraulic conductivity values: between 3.65 10^{-5} to 1.48 10^{6}cm/s for clayed residual unconsolidated materials from basalts; 3.65 10^{-5} to 1.48 10^{-6}cm/s for sandy residual unconsolidated materials; around 4.52 10^{-4}cm/s for alluvial materials; and 5.18 10^{-5}cm/s for colluvial unconsolidated materials.

Infiltration tests – Instantaneous profile method.

Sandy Residual Unconsolidated Materials with eucalyptus cultivation. The typical physical properties for a site where the in situ infiltration test was carried out were: specific gravity 27.419 to 27.580 KN/m^3, natural dry density 14.191 to 15.572 KN/m^3 and Porosity 0.4321 to 0.4902 %. The results from the infiltration tests (Figure 4) show a high velocity of water distribution a few minutes after the test had finished. 21 hours after, however, the velocity is low because the volumetric moisture is similar to field capacity (0.13 m^3/m^3) in that this condition continues for a long period. The saturated (Ko) and unsaturated hydraulic K(θ) conductivity obtained for different depths are in Table 2.

Table 2. Saturated and unsaturated hydraulic conductivity equations for sandy residual unconsolidated materials - Eucalyptus Cultivation.

Depths (cm)	**Saturated hydraulic conductivity (cm/s)**	**Unsaturated hydraulic conductivity equation (cm/s)**
0 - 20	0.00771	$K(\theta) = 0.00771548 \,.\, e^{46.5116\,(\theta - 0.429)}$
20 - 40	0.0099	$K(\theta) = 0.00998281 \,.\, e^{47.6190\,(\theta - 0..372)}$
60-120	0.001647	$K(\theta) = 0.001647715.\, e^{52.9101\,(\theta - 0.427)}$
> 120	0.0078236	$K(\theta) = 0.00782366 \,.\, e^{41,6667\,(\theta - 0,442)}$

θ – Volumetric moisture content

Sandy Residual Unconsolidated Materials with sugar cane cultivation. In this case it is important to note that this type of cultivation is managed in 2 very distinct phases related to the age of plant:

(1) Related to soil preparation to plant, deep tillage (~1m deep) is carried out to break the compacted strata, improve water infiltration, and facilitate root penetration. During the first 12 months the values of the saturated hydraulic conductivity (Ko) are around 1x10^{-3}cm/s.
(2) From the 12th until 60th month there is no deep tillage. In this phase, heavy tractors and machinery are used for harvest and management practices, leading to the onset of the compaction process. The basic physical properties for a site where the in situ infiltration test was carried out are: Specific Gravity 27.231 to 27.547

KN/m^3; Natural Dry Density 14.183 to 15.600 KN/m^3; and Porosity 0.4337 to 0.4792 %. Volumetric moistures for the period between 12 and 60 months are shown Figure 5.

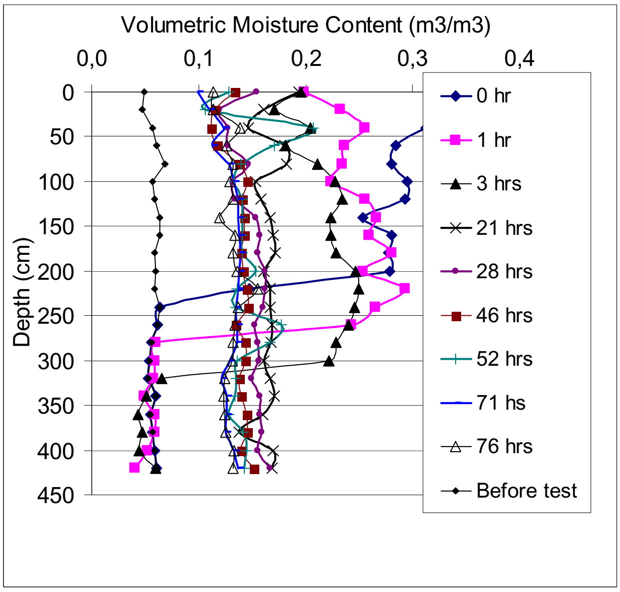

Figure 4. Water moisture content during redistribution after infiltration in the Sandy residual unconsolidated material with eucalyptus cultivation.

For the sandy residual unconsolidated materials occupied by sugar cane cultivations, 2 different intervals were defined with unsaturated hydraulic conductivity equations:

- from the surface to 80cm depth the Ko varies from 0.000113 to 0.00066 cm/s, and the unsaturated hydraulic conductivity equations are: $K(\theta) = 0.00011\ e^{26..5252(\theta - 0.3071)}$ (minimum) and $K(\theta) = 0.000657\ e^{62.1118\ (\theta - 0.35)}$ (maximum).
- for depths greater than 80cm Ko varies from 0.00201 cm/s to 0.00298 cm/s, and the unsaturated hydraulic conductivity equations are: $K(\theta) = 0.002012\ e^{32.0513\ (\theta - 0.3454)}$ (minimum), and $K(\theta) = 0.00298\ e^{45.6621\ (\theta - 0.3898)}$ (maximum).

The volumetric moisture values measured over periods in excess of 24 hours after the infiltration test were around 0.2m^3/m^3 and, 21 hr the water distribution was stable until 4.5 m depth.

Sandy Residual Unconsolidated Materials occupied by pasture. The typical physical properties for a site where the in situ infiltration test was carried out are: specific gravity 25.85 to 26.15 KN/m^3; natural dry density 14.22 to 16.10 KN/m^3; and Porosity 0.4212 to 0.4880 %. The results obtained for 6 different periods after the infiltration test are in shown in Figure 6 (volumetric moisture content).

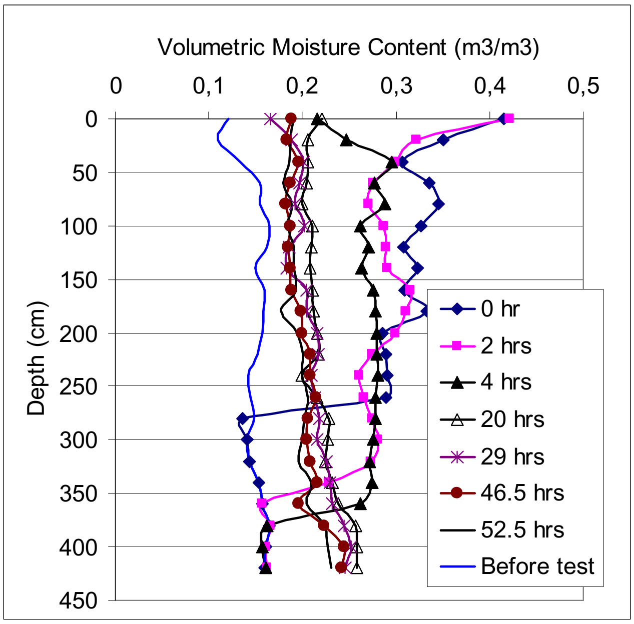

Figure 5. Water moisture content during redistribution after infiltration in the Sandy residual unconsolidated material with sugar cane cultivation.

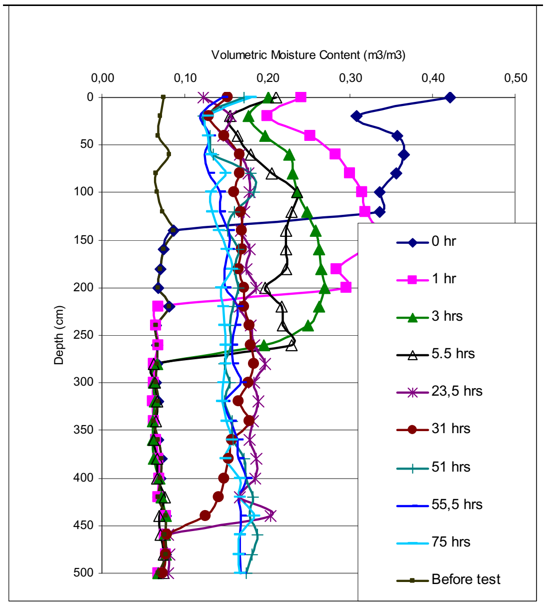

Figure 6. Water moisture content during redistribution after infiltration in the Sandy residual unconsolidated materials with pasture.

The saturated (K_o) and unsaturated hydraulic K(θ) conductivity obtained for different depths are shown in Table 3; field capacity is 0.15 m^3/m^3.

Table 3. Saturated and Unsaturated Hydraulic Conductivity equations for sandy residual unconsolidated materials with pasture.

Depths (cm)	**Saturated hydraulic conductivity (cm/s)**	**Unsaturated hydraulic conductivity equation (cm/s)**
0 - 20	0.0024865	$K(\theta) = 0.0024865 \cdot e^{52.91005\,(\theta-0.3079)}$
20 - 80	0.004615	$K(\theta) = 0.0046154 \cdot e^{56.4971\,(\theta-0.3575)}$
> 80	0.00162	$K(\theta) = 0.001623 \cdot e^{31.15265\,(\theta-0.3361)}$

θ – Volumetric moisture content

The unsaturated hydraulic conductivity equations obtained from in situ tests show good compatibility with the variation of the physical properties at depth due to management practices. The unsaturated hydraulic conductivity results were considerably influenced by land use and land management practices despite the low variability (< 5%) of the basic physical properties of the unconsolidated materials.

RAINFALL AND GEOLOGICAL MATERIALS INTERACTION

Table 4 shows the rainfall scenarios based on registers obtained for 5 minute intervals. Twelve rainfall scenarios were defined on the basis of the intensity and duration of the rainfall events, and these were combined with three types of land use (sugar cane and eucalyptus cultivations and pasture). This produced 36 different interaction scenarios for modelling. The results obtained from field and laboratory studies were adopted as parameters for modelling. A value for initial moisture content of $0.2m^3/m^3$, and a capillarity head of 10 cm were adopted, based on laboratory and geological characteristics of the unconsolidated materials. For each scenario, ponding time and infiltration rates were obtained by the modified models of Chu (1978) for transient rainfall conditions (Table 4) and Morel – Seytoux & Khanji (1976) for integral events (Figure 7).

In general, a similarity of results obtained for ponding time was found for areas occupied by sugar cane cultivations. The different values of ponding time are due to the initial moistures and rainfall intensities considered by the models. For scenarios 1, 2, 4, 8 and 10 considering pastures and eucalyptus cultivations, ponding time is not observed because the rainfall intensities are less than the infiltration capacity.

Table 4. Intensity and duration of the rainfall scenarios.

Scenario	**Partial Duration**	**Intensity**	**Scenario**	**Partial duration**	**Intensity**
	(h)	(m/h)		(h)	(m/h)
1	0,166	0,012	6	0,166	0,0204
	0,333	0,036		0,499	0,0740
	1,333	0		1	0,0090
	1,666	0,009		2	0,0130
2	0,166	0,024	7	0,166	0,0564
	1,166	0,008		0,333	0,0234
3	0,333	0,0174		1,333	0,0019
4	0,333	0,0024	8	2	0,0037
	0,833	0,0036		2,166	0,0096
	1,833	0,002	9	0,166	0,0168
	2,333	0,024		0,333	0,0384
	3,333	0,002		1	0,0540
	4,333	0,0008	10	3,5	0,0020
5	0,083	0,1056	11	0,333	0,0420
			12	0,166	0,0684
				1,499	0,0405

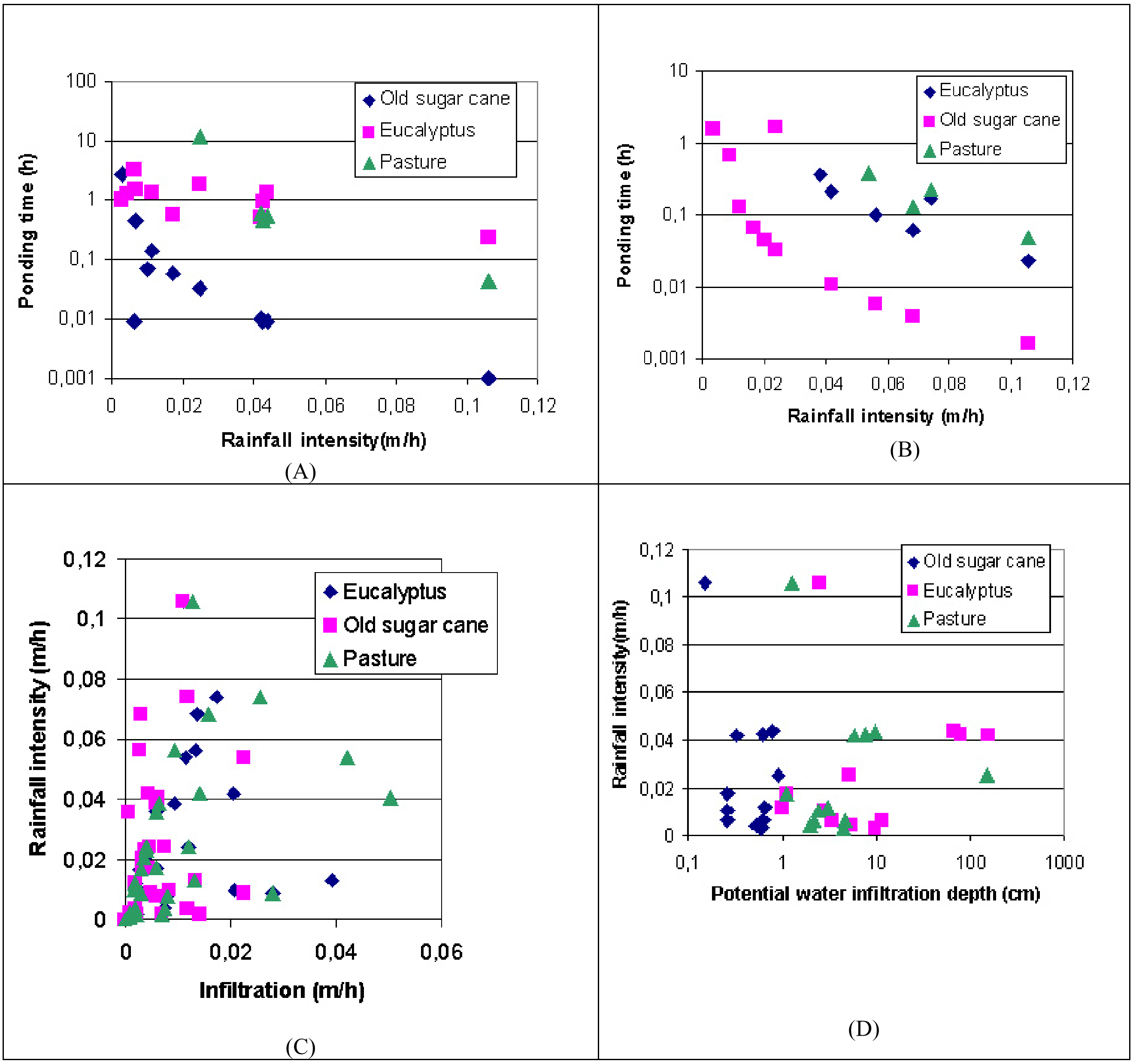

Figure 7. Ponding time and infiltration obtained for different scenarios.

CONCLUSION

The saturated hydraulic conductivity obtained by double ring test and instantaneous profile showed good agreement. With the unconsolidated materials the following values were adopted for modelling: 5.2×10^{-4} cm/s; 4.52×10^{-4} cm/s; and 1.82×10^{-5} cm/s, the land uses being for eucalyptus, pasture and sugar cane respectively.

Land uses and associated management practices control the overland flow and infiltration rates in terrain underlain by sandstones of the Botucatu Formation capped by sandy residual unconsolidated materials. The behavioural characteristics of the surface stratum are controlled by land uses, as well as by different intensities and types of management practices carried out during the crop cycles.

Even though the sandy residual unconsolidated material is homogeneous in texture and other physical properties, the results of laboratory and in situ tests demonstrate that unsaturated hydraulic conductivity, water retention curve and diffusivity vary in the surface stratum as a result of differing land uses and land management practices.

The results obtained from modelling show that overland flow occurs in parts of the basin, and that it depends on cultivation types and management practices. For sugar cane cultivation areas, the initial moisture content is less important than for situations with pasture and eucalyptus cultivation because the infiltration rate is also inferior. However, the overland flow/infiltration rate varies continually during the sugar cane cycle. When the rainfall period coincides with the soil tillage phase, the total precipitation infiltrates into the soil for each of the 12 rainfall scenarios. The instantaneous profile test presented good and representative results for sandy residual unconsolidated materials, over periods of time less than 21 hours. The total water distribution had occurred mainly in the first 5 hrs. The different results obtained from Morel-Seitoux (1976) and Chu (1978) models are directly related to moisture content and rainfall intensity considered.

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