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# PILOT PLAN ON GROUNDWATER RECHARGE

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## Introduction

Fresh water resources are limited, and the demand for it is constantly increasing with the population increase, resulting in disputes on how to share them (Boken et al., 2004). According to Gomes (2009), Brazil has about 12% of the water reserves of the planet, possessing one of the world's largest water resources, be them surface (Amazon, San Francisco and Paraná River Hydrographic Basins) as well as underground (Paraná, Piauí and Maranhão Sedimentary Basins). That whole potential has the reinforcement of abundant rains (between one thousand and 3 thousand mm year$^{-1}$) in more than 90% of the territory (Rebouças, 2006), allied to dominant geological formations that favor the generation of important water surpluses and immense underground reservoirs, that feed one of the most extensive and dense drainage networks, generating water courses of great importance (Rebouças, 2006; Gomes, 2009). However, this hydric potential is irregularly distributed throughout the country. The Amazonian area basins - Amazon and Tocantins, for instance, where there are the lowest population densities, possess 78% of the surface water. Meanwhile, in the

Southeast (Posses Sub-basin area), that relationship is inverted: the highest population density areas of the country have about only 6% of the total available water (Gomes, 2009).

The inadequate land use and soil management systems for tropical environment, predominant in Brazil, are directly responsible for aquifer recharge capacity loss (Freitas, 2005). Furthermore, natural resources degradation, mainly vegetation, soil and water, is growing in an alarming way, reaching critical levels that result in bodies of water sedimentation and in environment deterioration.

Few ecosystems in Brazil present a degradation situation similar to that which occurs in the extensive formation known as Atlantic Forest. Among these, South region of Minas Gerais state has been submitted to physical and environmental pressure of factors determined by the slopes orientation and soil historical occupation. The soil occupation in this region has been influencing directly in the water production.

Studies on the land use and soil occupation in water recharge areas are more and more necessary, considering that currently, studies regarding water dynamics in these areas are still quite scarce (Junqueira Júnior, 2006). The land use can alter water quality and quantity, besides influencing underground water storage, spring water organization, and bodies of water (Pinto et al., 2004). The soil acts as a dynamic water reservoir, where its physical-hydric attributes can influence water partition system, especially infiltration, affecting aquifer recharge process in a direct way (Rezende et al., 1999). Besides land use, physiographic conditions associated to pedologic and topographical conditions should be considered (Menezes et al., 2009).

The appropriate management of hydrographic basins, especially in environmentally fragile areas, such as the South of Minas Gerais, is of great importance for the maintenance of their underground drainage, this being fundamental in the maintenance of the bodies of water perenniality, whose existence is a function of satisfactory surface aquifer recharge conditions and as a consequence, spring water production. However, some soils which are in an advanced degradation stage, represented by occurrence of sheet and rill erosion that, although shallow, are quite frequent. Besides erosion, in some places the stream flow reduction is observed during water shortage periods. In such areas, inadequate land use and management eventually affect its quality, causing the soil to be less permeable and impeding it from exercising its role as driver and filter water. As a result, a great volume of water stops infiltrating into the soils due to inadequate management and the vegetable covering reduction. This implies in lowering the systems recharge contribution, decreasing base level and as consequence the water availability and its multiple uses in the region and downstream (Freitas et al., 2001).

The land use with extensive pasture and absence of conservationist practices has been altering the landscape in the South region of Minas Gerais state, exposing soil to erosive agents, modifying water infiltration conditions, providing soil and water losses by surface runoff, compromising aquifer recharge and producing bodies of water sedimentation at their lowest extremities. In the state, the Extrema County is considered a priority area for national water production, in the away that its hydrographic sub-basins are preferential targets of water erosion reduction programs, such as the Water Producer Program, elaborated by the Brazil's National Water Agency (ANA, 2007).

Given the above, in this text a look at the research is presented as to the importance of the edaphic-environmental knowledge and monitoring of the soil-water management and natural resources conservation practices, seeking to the water recharge. Furthermore, this chapter contains preliminary results of the Water Producer Program in the Posses Sub-basin located at Extrema County, Minas Gerais - Brazil.

**Groundwater Recharge**

Groundwater recharge can be defined as the rate at which infiltrating water moves across the water table of a non-confined aquifer, forming an additional water reservoir for the underground waters (Diodato and Ceccarelli, 2006). The aquifer recharge can take place by diffuse infiltration the soil, or by discrete infiltration through drainage wells, dry valleys and some sinkholes (Jones and Banner, 2003). Groundwater recharge quantification is a basic prerequisite for efficient underground water resource management, and it is particularly vital in semi-arid areas where such resources are frequently the key to economic development (Melo et al., 2006).

Aquifer recharge is conditioned mainly by the following factors: climate, topography, soil, vegetation and land use (Keese et al., 2005; Menezes et al., 2009), making it necessary that the land use planning be accomplished at the level of physiographic units, not only being executed at rural property level, since these units reveal a global panorama of the affected ecosystem. Thus, the hydrographic basin has been recognized as the natural unit for water resource administration (Heathcote, 1998), in which the hydrological processes and their constituent elements, which are unevenly distributed in the area, constitute ideal ecosystems for external impacts evaluation in the water quality and quantity (Baruqui and Fernandes, 1985).

Within the factors that condition the aquifer recharge, those related to soil physical-hydric attributes should be well elucidated, since water infiltration process in the soil is a decisive component of the water availability, occurrence and magnitude of runoff and aquifer recharge

(Cecílio et al., 2003). Therefore, in urban areas, in rural constructions, or even in poorly managed agricultural areas, a widespread sealing due to pavements, paved roads, residential coverings or soil compactation usually occurs, that minimize the natural recharge responsible for the dynamic balance maintenance of the underlying aquifers and excessively increase the runoff, causing significant water surplus losses during the rainy season (Cadamuro and Campos, 2005). Besides, under similar conditions, steeper the slope, higher runoff and, lower water infiltration, consequently, lower soil capacity regarding the promotion of aquifer recharge. The opposite happens on flatter reliefs (Menezes et al., 2009).

The water infiltration capacity in the soil is seen as an integrator process of the soil properties, modified by the land use and management system. The conservationist land use and management planning includes the group of technologies and practices that allow to improve soil infiltration capacity and, consequently, groundwater recharge (Freitas, 2005). In the Posses Sub-basin, Minas Gerais, Brazil, in an area of undulating and strongly undulating relief, integrated planning has been conducted, considering the pedologic, physical-hydric and, the agricultural land suitability, seeking a land use plan, the technologies indication and best management practices to provide an aquifer recharge increase and guarantee the bodies of water continuity.

## Main Factors that Control Groundwater Recharge

The main factors related to aquifer recharge are the climate, topography, soil classes, vegetation and land use (Keese et al., 2005; Menezes et al., 2009). Besides these, the soil depth (Arnold et al., 2000; Menezes et al., 2009) and rock characteristic above the water table (Arnold et al., 2000) can also alter aquifer recharge potential. Groundwater recharge occurs in varied manners, spatial as well as temporal as a consequence of variation in climatic conditions, land use, irrigation and hydrogeological heterogeneity (Sharma, 1986).

The role that vegetation plays on aquifer recharge potential varies. In a study conducted by Keese et al. (2005) in 13 regions in Texas (USA), with different climate, vegetation and soil classes, the researchers found that in forested areas, the aquifer recharge was reduced when compared with grassy areas due to the tree's deeper roots. The fact that the vegetation diminishes recharge is explained by Finch (1998): when roots depth increases, aquifer recharge decreases as larger soil moisture deficits develop and need to be replenished before soil reaches field capacity, when soil will start to drain. However, the plants water demand should also be considered (Carrera-Hernandez and Gaskin, 2008). Plants that require a smaller water amount from soil will leave a larger water available amount for recharge.

The organic matter contribution due to vegetation type can also modify recharge potential (Moraes et al., 2003), since organic matter is directly linked to the soil aggregation, altering pore distribution, facilitating the infiltration and consequently creating favorable aquifer recharge conditions (Junqueira Júnior et al., 2008). The organic matter is of paramount importance for mitigation of direct rain drops impact, avoiding crusting and soil particles splashing, altering pore distribution, and therefore, facilitating water infiltration (Moraes et al., 2003). The presence of trees increases soil organic matter contribution, conserving moisture, increasing absorption and water infiltration capacity, reducing erosion risk and stimulating biological activity (Barbera-Castillo, 2001; Mendonça et al., 2009).

The soil physical attributes affect the way in which rainfall is partitioned into runoff and water that enters the soil water balance, as well as the soil's available water quantity. Soils with low conductivity values and elevated water retention capacity will experience low recharge rates since a larger amount of water will be used to replenish the soil's water deficit to reach the field capacity (Carrera-Hernandez and Gaskin, 2008). Field and modeling studies have shown that recharge is higher in sandy versus clay textured soils (Cook and Kilty, 1992; Menezes et al., 2009). It stands out that, independent of Latosols (Oxisols) texture, these present a good aquifer recharge potential due to higher permeability, effective depth and their position on the landscape (Menezes, 2007).

The water infiltration is one of the most important processes of the hydrological cycle, mainly for being fundamental for aquifer recharge and for being affected by the land use and management practices to which soils are submitted (Gaspar et al., 2007). The infiltration is influenced by natural and anthropic factors. Natural factors include mineralogy, texture, structure, initial moisture, stoniness, porosity and relief, which are attributes related to soil classes and their location on the landscape (Gaspar et al., 2007). Areas of gentle relief propitiate the infiltration of large amounts of water with low runoff rates, thus guaranteeing aquifer recharge (Menezes, 2007).

The non-natural factors are related to land use and management - compaction, sealing, removal of vegetation etc. (Gaspar et al., 2007). Frequently, these affect water infiltration processes in the soils in a negative way. For instance, in deforested areas, aquifer recharge decreases significantly due to low infiltration capacity associated to soil moisture losses (Mendonça et al., 2009).

In the Posses Sub-basin, such factors are being characterized and interpreted, so as to evaluate their contribution to water recharge potential of the Cantareira System. Thus, this work is being employed in the Posses Sub-basin in order to interpret physical-hydric and pedologic attributes, as well as land use in groundwater recharge potential for the Cantareira System.

## Water Resource Conservation in the Cantareira System

Water resource is extremely complex due to different points of view, perspectives, interests, perceptions and alternatives for its use, such as: i) rural populations are direct water consumers, while the urban population obtains water through suppliers; ii) water issues are related to income (the higher the income the higher the use); iii) water shortage is differently perceived, according to individual consumption; iv) water issues are uneven in time and space within a basin, quantitatively as well as qualitatively; and v) water is an essential resource for life and society. Therefore, increasing interests in its conservation and correct use is in constant development (Sánchez-Román et al., 2009).

In Brazil, the government sanctioned the Law No. 9,433/97, which instituted the National Water Resources Policy and created the National Water Resources Management System. This was done with the objective of minimizing the already existent problems, besides reflecting the deep change in the water resources management conception (Machado, 2003). The main instruments of that Policy are: to elaborate water resources planning per hydrographic basin and by State; to frame bodies of water into classes, according to preponderant water uses; to grant the use rights; and to charge the water resource use (Brasil, 1997). The Brazil's National Water Agency (NWA) was created (Law No. 9,984/2000) to implement the National Plan for Water Resources. Such agency is under the Union domain (Machado, 2003; Senra, 2007). The National Plan for Water Resources is the most important instrument of National Water Resources Policy (NWRP), being elaborated at federal and state levels and per hydrographic basin (Brasil, 2000). It establishes the protection and recuperation actions of a watershed and water use control. In the scope of a hydrographic basin, the Plan establishes the water policies in the basin, guiding the water uses and establishing the priority actions (Machado, 2003).

In this context, the payment for environmental services is now the world tendency in agriculture-environmental programs (Pagiola and Plantis, 2003; Chaves, 2004; FAO, 2007). This mechanism provides incentives for the rural producers in the sense that they exercise the role of natural resources protectors, eliminating or minimizing the main problems related to inappropriate land use, improving water flow regulation and erosion control (May, 2006).

The payment for environmental services has been implemented by the Brazil's National Water Agency through the Water Producer Program (ANA, 2003), in partnership with the State Secretary of the Environment of São Paulo, Integral Technical Support Coordination - CATI SP and The Nature Conservancy NGO to recruit technical and financial support for implementation of such program in strategic hydrographic basins of the country, in this case the basins of the rivers Piracicaba, Capivari and Jundiaí (ANA, 2007).

According to National Plan of Water Resources, the Extrema County, MG, is considered a priority area for the water production (ANA, 2007), so that the sub-basins selected for the accomplishment of this pilot project are located in this region, where the Posses Sub-basin has being the first one in the program (Figure 1).

Extrema makes up part of the Jaguari river basin, the Cantareira System's biggest contributor. The Cantareira System is a group of several dams formed at the head-basin Piracicaba river's main contributors with the purpose of reinforcing the water reception for São Paulo Metropolitan Area (SPMA), being responsible for the provisioning of 19 million people in SPMA and for that counts on one of the largest drinking water productions in the world (33 $m^3$ $s^{-1}$). With an area of approximately

228,000 hectares covering twelve counties, four of them in the Minas Gerais (Camanducaia, Extrema, Itapeva and Sapucaí-Mirim), and eight in São Paulo state (Bragança Paulista, Caieiras, Franco da Rocha, Joanópolis, Nazaré Paulista, Mairiporã, Piracaia and Vargem). Minas Gerais contributes with 45% of the water producing area (ISA, 2007). Within Cantareira System limits, the Jaguari river basin encompasses totally or partially, the municipal districts of Camanducaia, Extrema, Itapeva, Sapucaí-Mirim, Joanópolis and Vargem.

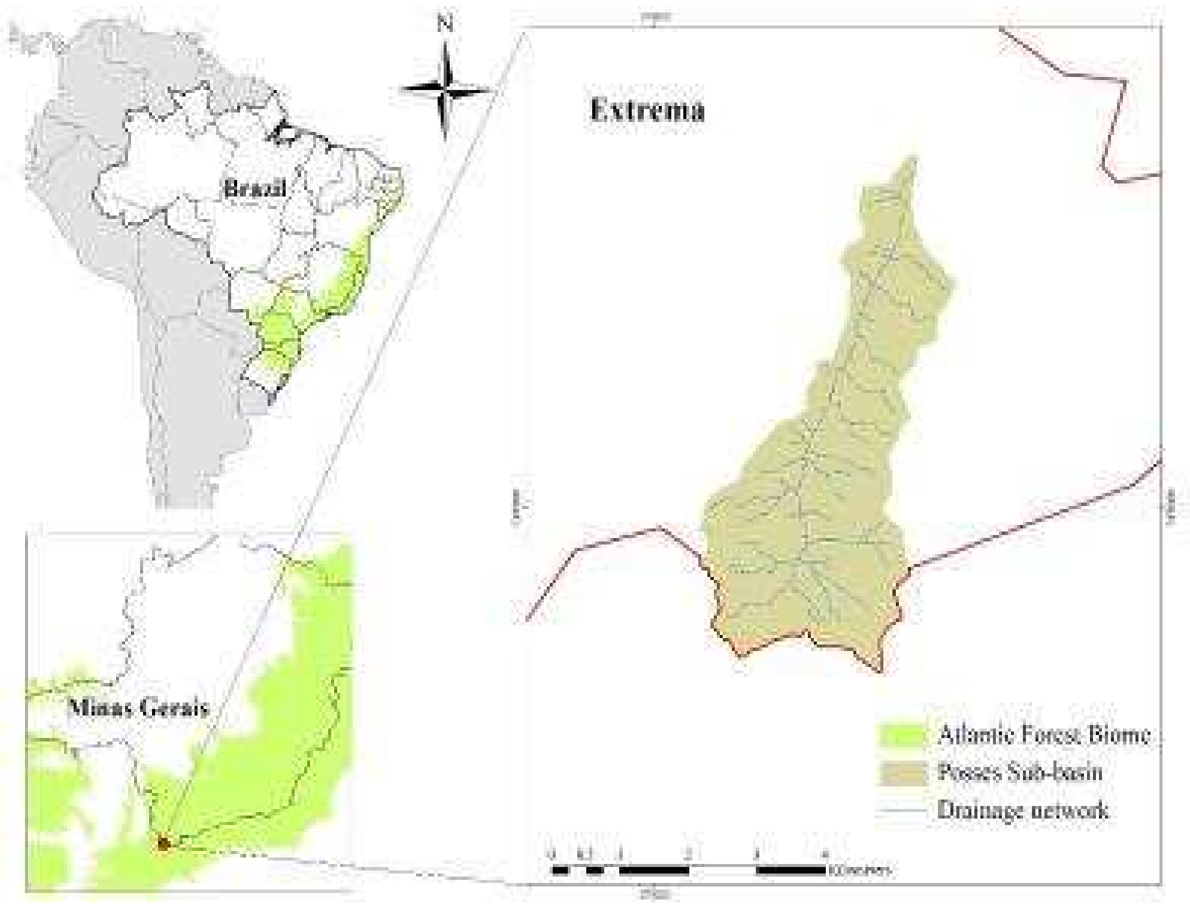


Figure 1. Posses Sub-basin localization.

The sub-basins which form the System are Jaguari-Jacareí, Juquerí, Cachoeira and Atibainha, being 22 $m^3 s^{-1}$ of the production originating from Jaguari-Jacareí Sub-basins, where the most part is inserted in Minas Gerais state (ISA, 2007). Considering the Jaguari river contribution, the different alterations that this undergoes will be reflected in the System as a whole. In recent years, the Jaguari reservoir presented a reduction in the volume of stored water, caused by the lack of effective water resource conservation policies and by climatic instabilities. The situation generated serious supply problems, provoking intense regional debates and conflicts on the use of water and soil resources (Hoeffel et al., 2008).

Due to the great interaction between water and soil and considering the land use and occupation effects on the hydrographic basin water quality and quantity, the conservation of these resources have deep importance for water resources administration. Besides making supply management possible, increasing available water amount in the basins for the appropriate aquifer recharge and improvement of its quality, conservation practices also promotes the water demand administration, when stimulating rational use and reutilization of water in the various sectors, therefore reducing captured outflow and effluents volume released in the bodies of water (ANA, 2008).

The water situation in the System forming basins is one of concern, because anthropic uses altered a large part of the region (69.4%). The areas covered by Atlantic Forest, essential for water production and purification, occupy only 21% of Cantareira System area (ISA, 2007). In Piracicaba river basin, the dominant land uses are pasture (45%), agriculture (31%), natural forest and forestry (16%) and urban areas (6%). In the last 20 years, urban and agricultural areas had a steady growth over pastures and natural forests areas (Filoso et al., 2003). In the same way, around Jaguari-Jacareí dam endures with anthropic pressure of recent decades, originating from occupation and land use modification, conditioned mainly by the population increase (ISA, 2007). The most impactful uses in the area are: livestock, swine breeding, brickworks, pottery, mining activities, urbanization process and growth of the tourism segment (Hoeffel et al., 2008).

Water Producer Program is focused on reduction erosion, through soil conservation practices, redesign unpaved roads and construction of septic tanks on rural areas. These actions directly influence perennial river flows and enhance their flow besides their quality. The program also foresees the recovery permanent conservation areas, with ciliary forests recomposition and hill tops revegetation, besides the incentive for maintenance already vegetated areas (ANA, 2007). Agricultural producers volunteers are financially motivated to participate through the sale of environmental benefits generated by incorporation of sustainable practices into production and resources management. Such practices should include sedimentation reduction and increase of water infiltration (Chaves, 2004).

## Preliminary Results in the Posses Sub-basin

The water erosion is responsible for innumerous environmental problems throughout the world, transporting sediments that may pollute bodies of water, siltation of reservoirs and reducing water infiltration. It also causes losses of nutrients, organic carbon, agrochemical and seeds, carried together with the sediments removed by runoff, besides environmental hazards related to water availability and quality, favoring floods in the rainy period and increasing water shortage in the drought period (Pruski, 1997).

Factors such as rainfall intensity, soil erosion potential, topography, cover and cropping management practices influence soil and water loss rates. With the dynamics knowledge of those factors in the hydrographic basin it is possible to verify the main points on the landscape where water erosion can be a problem and how to act towards its reduction, avoiding that runoff and sediments transport cause damage to the farmers, rivers, wellsprings and reservoirs. Thus, the Posses Sub-basin located in South region of Minas Gerais, has been investigated to evaluate the main factors responsible for water erosion as well as to avoid that such factors interfere in the water quantity and quality generated by this basin, which is responsible for water supply of other regions.

The Posses Sub-basin includes an area of 11.96 km², with average altitude of 1,134 m and gently undulating to mountainous relief. This sub-basin is the first practical experience from Brazil's National Water Agency through Water Producer Program that begun in 2006 (ANA, 2008). Since then, some results have already been obtained.

The dominant soils are Lithic and Fluvic Neosols (Entisols), Haplic and Humic Cambisols (Inceptisols), and Red-Yellow Argisols (Ultisols) (Silva et al., 2008). Considering water recharge potential from soils in that basin, Fluvic Neosols and Humic Cambisols possesses high recharge potential, the former for being present in privileged position on the landscape (flat to gently undulating relief) and close to the drainage network; and the latter for presenting a relatively thick surface horizon rich in organic matter, which contributes to better water infiltration. Red-Yellow Argisols are responsible for areas with good recharge, while Haplic Cambisols and Lithic Neosols are related to areas with low recharge potential, mainly due to steeper relief, low depth and low permeability.

It is important to emphasize that the rainfall data are fundamental for the water recharge control, as well as to forecast the accumulated water amount. It is not enough that land has favorable conditions, without having a satisfactory rainfall contribution (Souza et al., 2003). In the Posses Sub-basin, the rainfall regime is not a limiting factor due to high annual average precipitation with well distributed rains throughout the year, thus the water surpluses, considerably high, contribute to the underground drainage in the region (Lima et al., 2008). Another important point, in relation to the rainfall events in this region, is the high intensity with which they occur, presenting high erosivity values, in order of 7,709 MJ mm $ha^{-1}$ $h^{-1}$ $yr^{-1}$ (Lima et al., 2009). The erosivity is related to the rainfall intensity and kinetic energy that the raindrop reaches the soil surface. Under these conditions, the vegetal cover will exercise a direct influence on the water recharge capacity, as dense vegetation reduces the raindrop impact on the soil, favoring water infiltration thereby reducing runoff.

According to Freitas et al. (2008), the Posses Sub-basin can be divided into three classes of agricultural lands suitability. One of them includes agricultural lands suitability for short/long cycle farming, with some constraints to agricultural management, representing Red-Yellow Argisol areas and corresponding to 31.7% of total sub-basin area. Another one, represented by Haplic Cambisol, which represents 41.2% of sub-basin area, corresponds to agricultural lands with regular suitability for natural pasture and inept for forestry. The last class includes areas with Lithic and Fluvic Neosols and Humic Cambisols, which are framed in the areas without agricultural lands suitability, representing 27.1% of total sub-basin area.

In compensation, the dominant land use verified is pasture, which occupies 76.2% of the total sub-basin area and is characterized by pasturing above its support capacity with high degradation state. According to erosive processes typology and distribution, it was observed sheet, shallow and deep rill, piping and gully erosion and mass displacement distributed in different areas of the drainage network (Oliveira et al., 2008a). Therefore, for effective water erosion control the conservationist management practices should be considered, which seek to reduce and prevent direct raindrop impact on the soil surface, to improve the soil fertility and to increase water infiltration from rainfall (Oliveira et al., 2008b).

The conservationist management practices recommended for this sub-basin are: i) area isolation, soil scarification, grasses and legumes planting after liming and fertilization, for areas presenting sheet erosion; ii) area isolation, utilization of protections with eucalyptus and grasses and legumes plating after liming and fertilization for areas presenting rill erosion; and iii) area isolation, with stakes, reforestation preferentially with native species, embankment smoothing, and redesign of adjacent roads for areas presenting gully erosion. Prevention areas should be assigned to areas with rockiness/stoniness, steeper relief, low support capacity, and associate with drainage network and wellsprings. For pasture, agriculture and forestry areas, the narrow base type terracing is recommended, associated with water reception and/or drain channel (Oliveira et al., 2008b).

For implantation of conservationist practices on roads, it is recommended the location redefinition, parceling of length slopes with bedding and directing and distribution of runoff into water receptors constructed across the roads.

Besides soils properties and sub-basin natural capacity to store water, the employment of appropriate conservationist management practices, the maintenance of an efficient vegetable covering and land use according to its agricultural land suitability, act towards the reduction of sediment volume carried to the rivers, the increase of water infiltration, thus improving water recharge capacity in the sub-basin and the rational environmental resources use also favors the rural producers who are paid for environmental services rendered.

## Final Remarks

The main natural order factors related to aquifer recharge are climate, topography and soil classes. The vegetable covering and land use are called non-natural order factors, because they are related to land use kind. The Posses Sub-basin presents favorable characteristics for erosive processes increase, directly reflecting upon water recharge, because it changes infiltration conditions, provides water and soil losses by runoff, and produces bodies of water siltation in lower parts of the landscape.

The Fluvic Neosols and Humic Cambisols are responsible for high potential recharge sub-basin areas, followed by Red-Yellow Argisols with intermediate potential, and Haplic Cambisols and Lithic Neosols related to areas of low potential. In the latter two areas, special attention to management practices is needed, in order to avoid soil degradation and, consequently, loss of water quality. Even presenting pedologic characteristics that denote low water recharge potential, the water surpluses are considerably high in the region, contributing to underground drainage.

In relation to dominant land use, a large part is covered by pastures under management practices above soil support capacity. In this context, intervention is recommended, such as reforestation and mechanical conservationist practices, in order to guarantee the water resources conservation in the region. It is fundamental to keep preservation areas (high and good recharge potential), together with correct adoption of land use and conservationist management practices in the agricultural, pasture, forestry, plus the unpaved roads, factors that will act towards sediments volume reduction carried to rivers and increase water infiltration.

Water Producer Program, allied to the best land use planning, will positively reduce water erosion, as a consequence, increasing groundwater recharge, guaranteeing water supply for São Paulo Metropolitan Area.

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