GIS FOR A GREENER BRAZIL: AUTOMATED DELINEATION OF NATURAL PRESERVES

Carlos Antonio Alvares Soares Ribeiro; Vicente Paulo Soares
Department of Forest Engineering, Federal University of Vicosa – Brazil

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Abstract

This paper shows how GIS is helping to bridge the gap between the theory and practice of environmental preservation in Brazil. As of May 13th, 2002, the Brazilian Forest Code has set new guidelines for the establishment of natural preserves on hilltops, along ridgelines and riparian zones, and on upland catchments, relying on key geographic features of watersheds. The new regulations of forest practice deter any commercial landuse on preserves, imposing severe restrictions on land availability for agricultural and cattle raising uses. These possibilities unavoidably undermine the necessary confidence of landowners to comply with these regulations and strategies for immediate compensation of income losses must be carefully sought. The first step for doing this is to accurately map and quantify potential landuse conflicts. The moment is propitious for using cutting-edge GIS technologies and Shuttle Radar Topographic Mission imagery to automatically delineated the natural preserves according to the Brazilian Forest Code, in a continental scale.

Introduction

In the last two decades there has been a growing concern about the alarming increase in the rate of deforestation of the tropical forests and its impact on their biodiversity. Although accounting for only approximately 7% of the total area, the tropical forests contain over 50% of the earth's biodiversity (RAVIKANTH et al., 2000). Between 1990 and 2000, the average rate of deforestation of tropical forests worldwide was estimated at 15.2 million ha/yr. In this same decade, deforestation rates on South America averaged 3.7 million ha/yr meanwhile Brazil saw its forest cover to be reduced from 567 million ha to 544 million ha (FAO, 2001).

Unquestionably the major agents of deforestation worldwide are farmers clearing land for cultivation and the main cause of deforestation keeps being agriculture (HOUGHTON, 1994). Shift cultivation has been a common practice in the initial stages of the economic development of many countries and still is part of the history of Brazil. Even when considering permanent cultivation, many land-use practices do contribute to diminish the soils capacity to support human enterprise. The declining on agricultural productivity forces landowners continuously to convert more and more forestland to agriculture, just abandoning the degraded areas.

Environmental preservation programs would benefit mostly the poor, rural communities that practice agriculture subsistence, which in turn has a strong dependency on natural soil fertility, water availability and on an ecologically sound environment. Over the last two decades too much has been said about environmental sustainability of production systems but too little has been effectively done to achieve it. Although there is a consensus that we cannot afford to lose what still remains from native ecosystems, the increasing pace of deforestation points to another direction and we are, in fact, losing them. During the last 500 years, the total deforested area considering the tree main biomes of Brazil – Amazon, Atlantic Forest and Savanna Woodland (*cerrados*) – was estimated as 270 million ha, i.e., about 32% of its territory. Today, the Atlantic Forest remnants account for only 7% of its original area. In the last 5 decades, the expansion of the agricultural frontier towards cerrados was responsible for removing 50% of this fragile biome and in half of this time, 15% of the Amazon were deforested. The intensive and increasing water usage for food and livestock production imposes immediate improvement of environmental policies towards heavier emphasis on protecting biodiversity, water and land, whilst promoting sustainable agriculture for food security.

Topography is a dominant control on earth surface processes. It is an agent that moderates spatial climate distribution, which in turn controls the biological systems' distribution and productivity (HUTCHINSON, 1996). This suffices to adopt the watershed as a natural unit of analysis for environmental planning. Furthermore, the possibilities of future conflicts over the water usage would be considerably reduced, since the problem of optimal resources allocation is confined to its natural domain. The traditional, manual derivation of basin physiographic characteristics from topographic maps is well known for its tediousness and labor intensity, indeed posing a major endurance to the analyst (GARBRECHT and MARTZ, 2000). Until the advent of GIS, any attempt to get more complex basin parameters, such as slope, stream length, flowpath, etc, was always hampered by the amount of work, thus limiting the potential applications of drainage analysis. Furthermore, the lack of standards made virtually impossible to store and share the derived information. Advantages of adopting automated approaches include process reliability and reproducibility and the digital results are much more easily shared (SAUNDERS, 1999).

The last 40 years have witnessed both the evolution of environmental awareness in Brazil and the stagnation on the delineation of permanent preservation areas as set by law. Concepts like natural preserves are the cornerstone of the Brazilian Forest Code of 1965. Up till now, the lack of appropriate countrywide topographic datasets and the expertise required for manually mapping the preserves, along with the difficulty in implementing the regulations 'on the ground', were used by landowners, state forest services and governmental agencies as the main excuse not to comply with the current environmental legislation.

The revision of the Brazilian Forest Code, as of May 13th, 2002, sets the guidelines for the establishment of natural preserves on hilltops, along ridgelines and riparian zones, and on upland catchments, relying on key geographic features of watersheds. The new regulations of forest practice deter any commercial landuse on preserves, therefore imposing severe restrictions on land availability for agricultural use. Although representing a remarkable advance on environmental legislation, these accomplishments remained on paper. The recent technological advances on GIS and high-resolution topographic imagery allowed this issue to be revisited.

The accuracy of the existing digital datasets for Brazil does not match the standards required for mapping the permanent preservation areas according to the current technical specifications. The moment is propitious for evaluating cutting-edge GIS technologies and highly accurate digital topographic datasets to automatically delineate the natural preserves.

Objective

The higher order development goal of this research, through the use of a new generation of accurate digital elevation models, was to demonstrate how effective is GIS technology for establishing natural preserves in Brazil according to its environmental legislation.

Methodology

The selected study area was the Paraíso Creek basin, encompassing an area of 212 ha and situated nearby the city of Viçosa, State of Minas Gerais, Brazil. As a reference, the geographic coordinates of its centroid are 20º48’S and 42º53’WGr. The basin’s altitude ranges from 680m to 850m and its average slope is 30% ± 20%. The database used (contour lines with vertical equidistance of 10m and stream network), shown in figure 1, was produced by manual restitution of 1:10.000 scale aerial photographs (SOARES et al., 2002) and then converted to digital format.

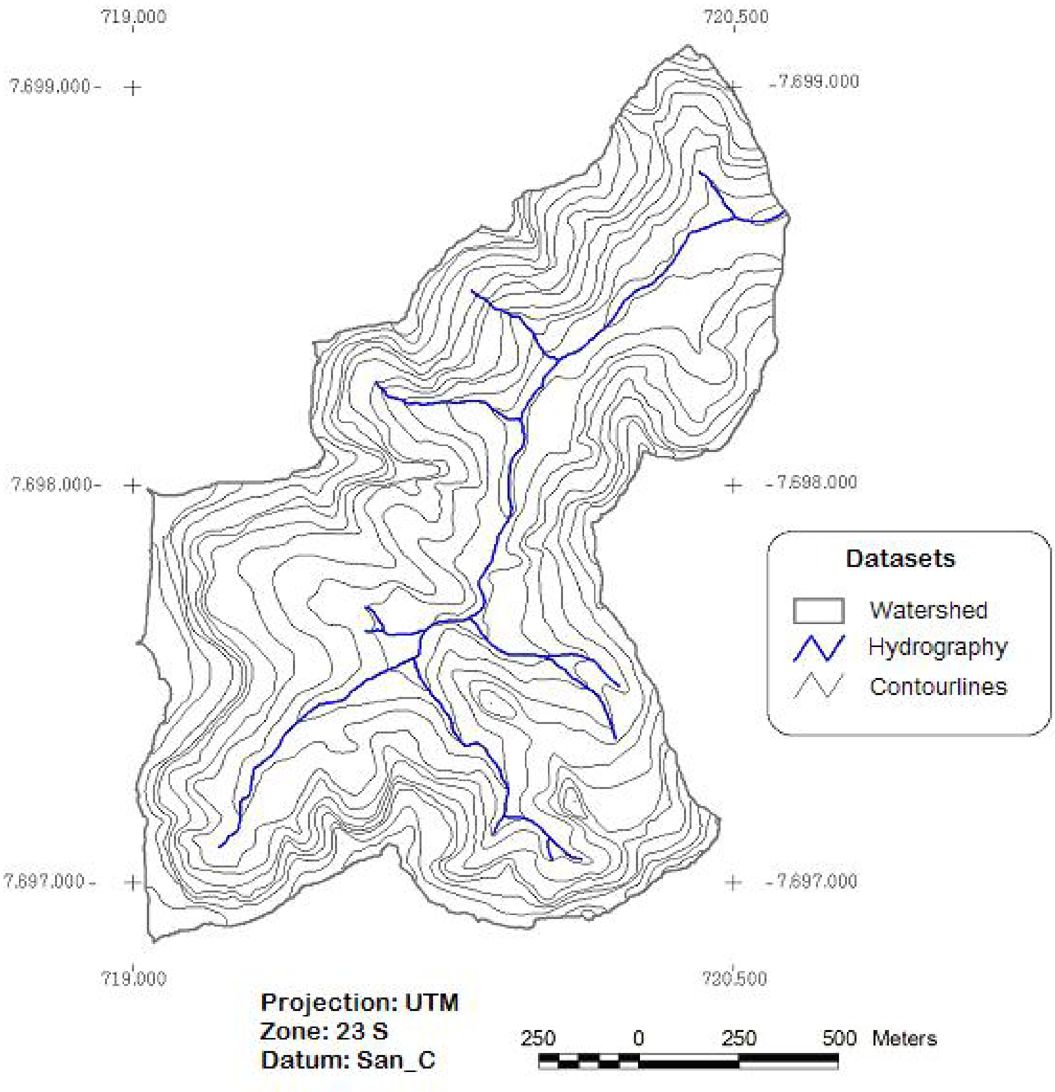

Figure 1. Location of the study area.

The proposed methodology relies on the relatively new concept of hydrologically consistent digital elevation models (HC-DEM). A HC-DEM has a high coincidence between its numerically derived drainage network and the real hydrography, being completely free of spurious sinks that otherwise would block the surface flow (HUTCHINSON, 1989). The software used for generating the HC-DEM, with a 2m-cellsize resolution, was the Arc/INFO version 8.2 running on Windows XP. A significant amount of preprocessing was required to prepare the vector data for input to TOPOGRID, the interpolation routine used by Arc/INFO. The utmost objective of TOPOGRID is to produce a depressionless DEM, the foundation for automated extraction of drainage basin physiographic parameters as well as automated watershed and drainage network delineation. However, for relatively flat valleys, it was detected a severe discrepancy between the original vector stream data and its numerically derived drainage network. A stream burning technique (HELLWEGER, 1997) was used for reconditioning the DEM surface within a 5-cell wide buffer (10m) along the rivers for consistency with the stream vector coverage. Flowdirection is the first step in deriving hydrologic information about a surface and this dataset should be as accurate as possible. Thus the resulting flowdirection grid was post-processed to ensure the surface water within the buffer would converge to the stream cells and that all the stream cells would flow to the basin outlet (RIBEIRO et al., 2002a).

Automated delineation procedures were developed to map the following types of natural preserves: on hilltops, along ridgelines and on upland catchments (RIBEIRO et al., 2002b).

- Natural preserves on hilltops

  CONAMA (Brazilian National Council for the Environment) adopts the following definitions:

  * *"hill – land rise with base-top height between 50m and 300m, having hillsides with slopes of at least 30% along its steepest descent"* and
  * *"mountain – land rise with base-top height over 300m"*.

  After isolating every hill or mountain that matched these criteria, the corresponding upper thirds were then delineated.

- Natural preserves along ridgelines

  Determining natural preserves along ridgelines (watershed divides) is based on the contributing area of each stream segment. Segments are the sections of a stream channel connecting two successive junctions, a junction and the outlet, or a junction and the drainage divide. In order to map the upper third of a hillside, for each cell in the landscape one needs to know what is the elevation of its closest cell to the divide and also what is the elevation of its closest cell to the hydrography. These three cells must lie along the same flowpath. Only after that it is possible to identify if a cell belongs or not to the hillside's upper third. Since CONAMA's ridgelines definition is bound to hill and mountain definitions, the upper third calculations will be done only for hillsides at least 50m high.

- Natural preserves on upland catchments

  According to CONAMA, the area of a circle having a minimum radius of 50m around any given spring, as well as its contributing area, constitutes a natural permanent preserve.

RESULTS AND DISCUSSION

Implementing these procedures was done using Arc/INFO's Grid Module version 8.2 for Windows. In the first phase of this work natural preserves on hilltops were located. Seventy eight hilltops in the study basin were identified. Observe that part (a) in figure 2 shows how most of the hills are situated close to the stream network. Figure 2 (b) shows 8 hills that satisfy the first condition: an elevation must have more than 50m of height and less than 300m to be considered a hill, thus being object of analysis in the process of delineating environmental natural preserves. Figure 2 (c) illustrates that only 5 hills are at least 50m high and also attend to the second requirement necessary to be considered a hill: having most of its slopes higher than 30%.

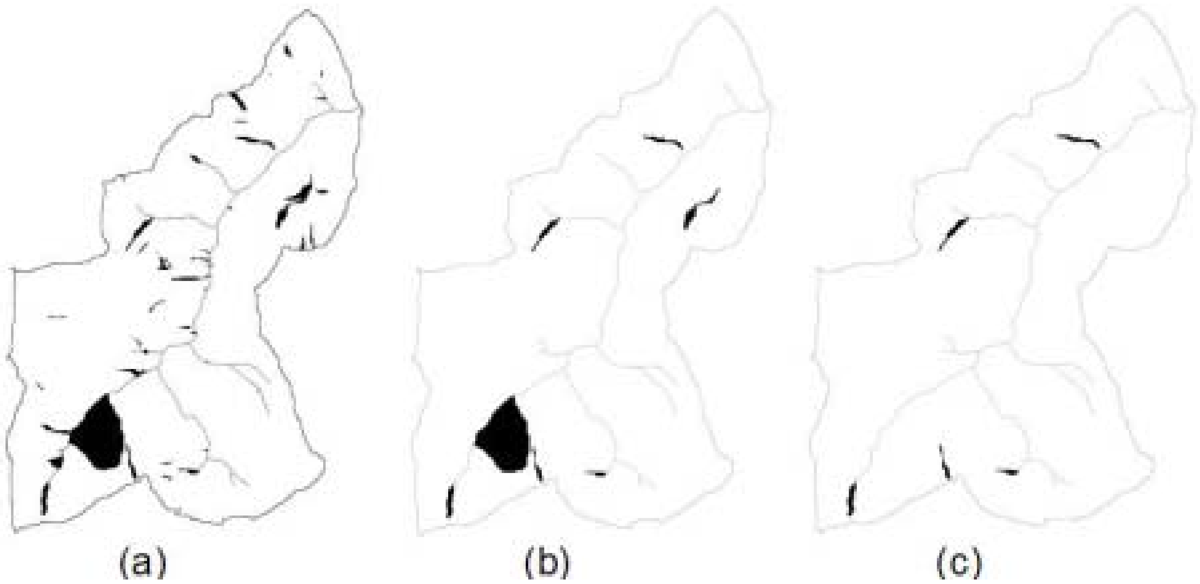

Figure 2. (a) Location of the hills identified within the watershed; (b) hills at least 50m high; (c) hills at least 50m high and with majority slopes above 30%.

Natural preserves on hilltops at the Paraíso Creek basin are shown in figure 3. The sum of all areas on the upper third of these five hills is 2,840m^2, which represents only 0.13% of this basin's total area.

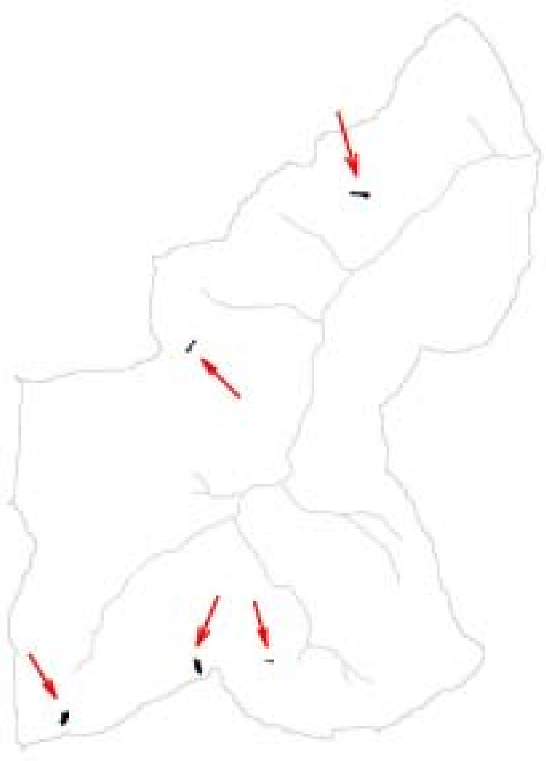

Figure 3. Identification of natural preserves on hilltops (upper third).

Determining natural preserves along ridgelines starts by identifying the contributing areas for all segments of the stream network as shown in figure 4. Thicker lines portray hydrography.

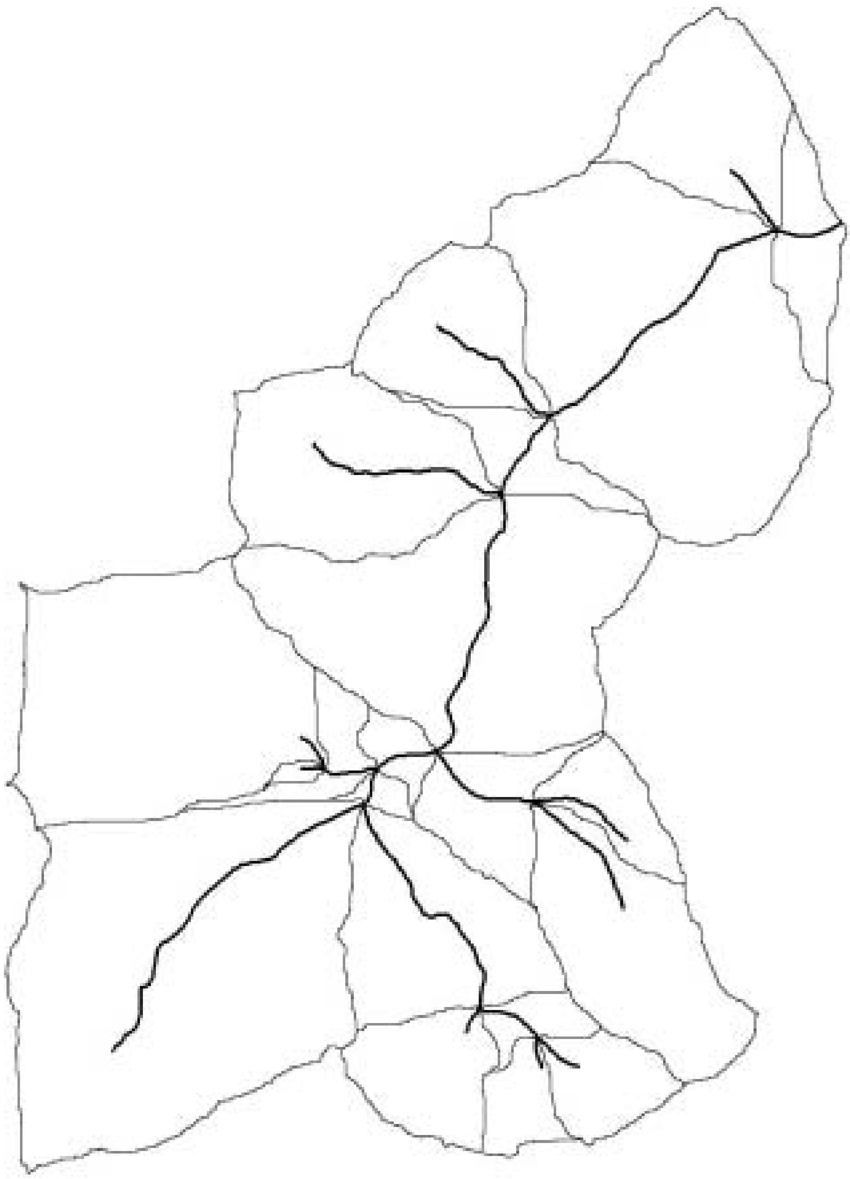

Figure 4. Sub-basin divides for the Paraíso Creek watershed.

Figure 5 presents areas located in the upper third of each sub-basin depicting ridgelines and the associated stream network. Part (a) shows the upper third in each sub-basin without restrictions of any kind. For legal purposes, part (b) eliminates the areas in which ridgelines have a height less than 50m. Note that regions designated as natural preserves are not continuous in both cases. Some of the gaps are due to hills whose bases are situated on a hillside's upper third.

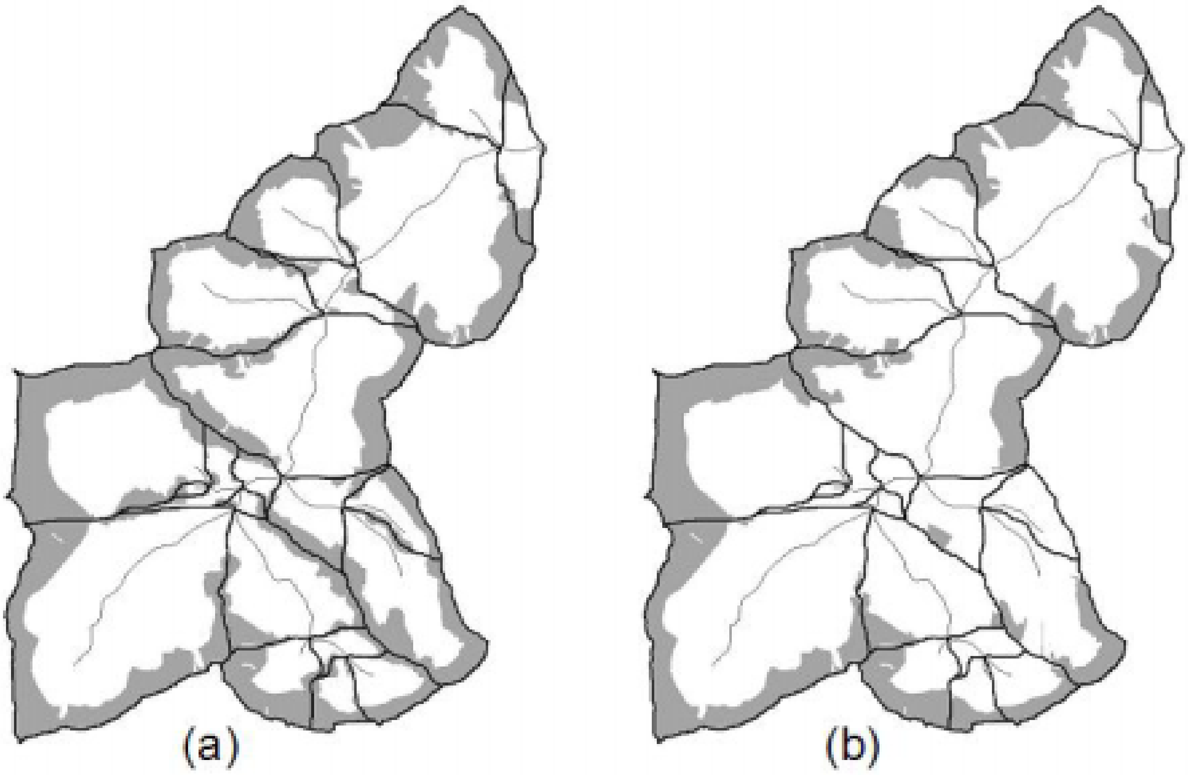

Figure 5. (a) The upper third of the hillsides; (b) natural preserves along ridgelines limited to hillsides at least 50m high.

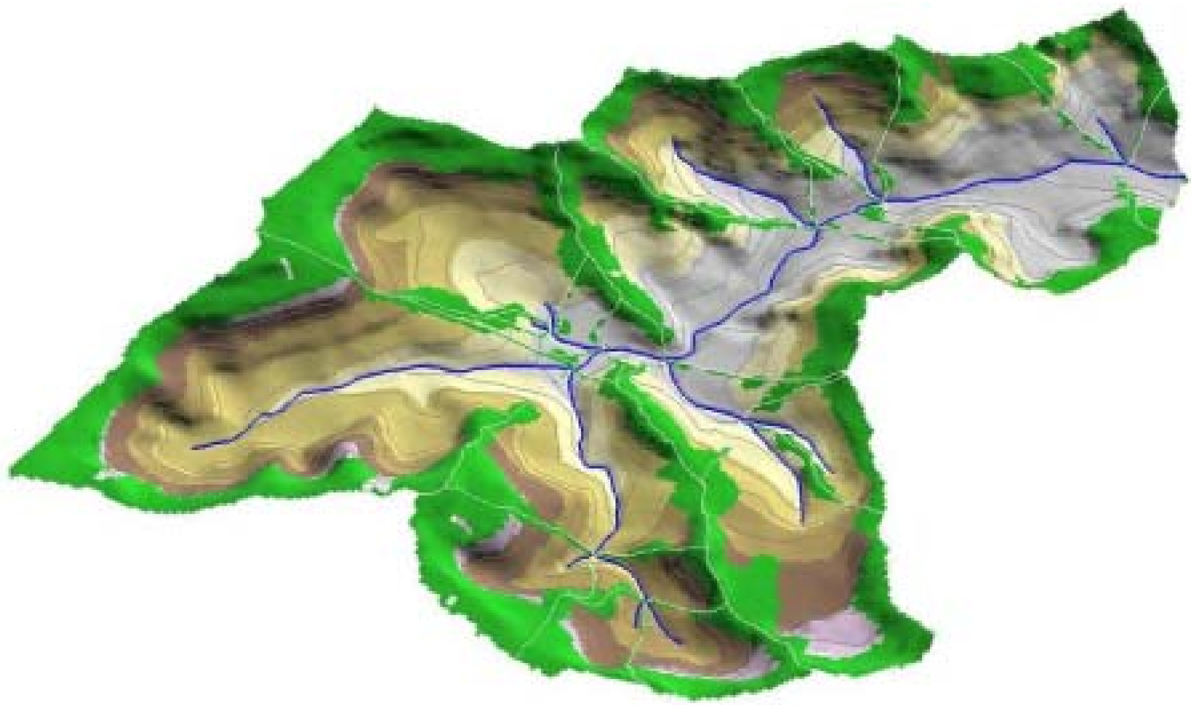

Figure 6. Perspective view of the upper third of hillsides.

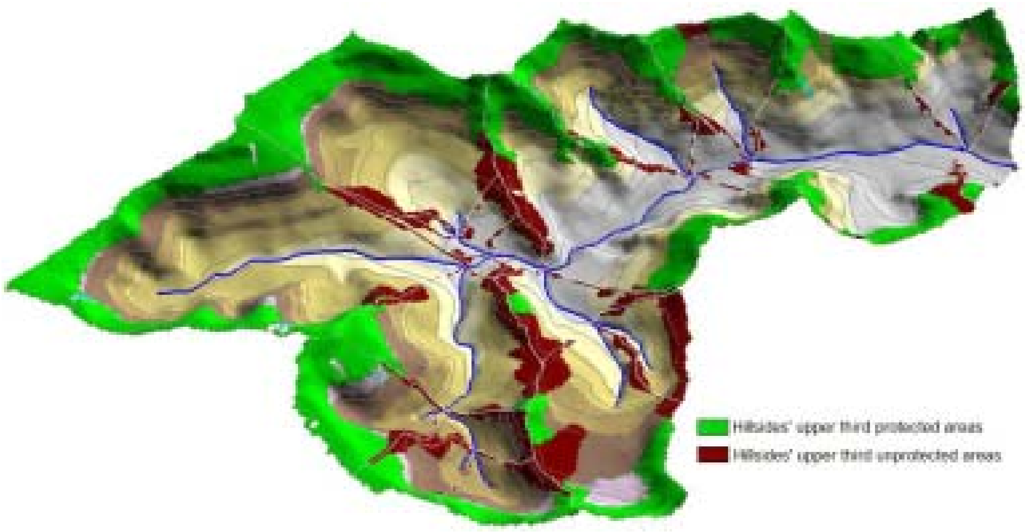

Figure 7. Perspective view of the natural preserves along ridgelines (green) highlighting the excluded areas (brown) of the upper third of the hillsides due to legislation.

Hillside's upper third in Paraíso Creek watershed such as shown in figures 5 (a) and 6 occupies an area of 75 ha, accounting for approximately 35% of the basin's area. The actual area that needs to be protected attending to the current legislation, as figures 5 (b) and 7 present, is much lower (55 ha), corresponding to approximately 26% of this basin's surface.

The 50m-radius area around all the Paraíso Creek's springs totals 8 ha. However, since the respective contributing areas are also classified as natural permanent preserves, this adds another 62 ha, as shown in figure 8.

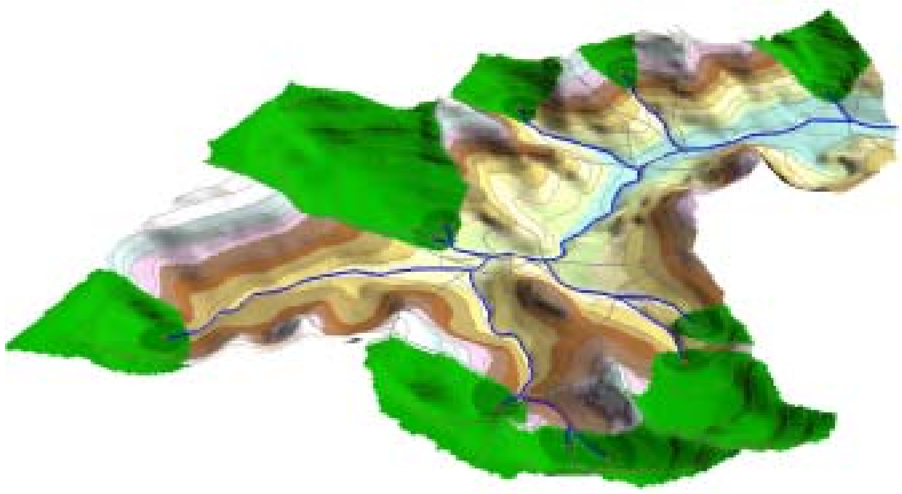

Figure 8. Natural preserves on upland catchments, highlighting the 50m-radius circles(darker green) around springs (red dots).

The Brazilian Forest Code includes yet other areas as natural preserves. Riparian zones, whose sizes depend on floodplains widths and lakes surface areas, and hillsides with slopes above 100% are also designated as natural preserves. Due to the easiness of delineating them, they constitute most of the existing natural preserves on rural properties. Including these areas, the natural preserves for the Paraíso Creek basin cover an extension of 123 ha, or approximately 58% of its total area, as shown in figure 9.

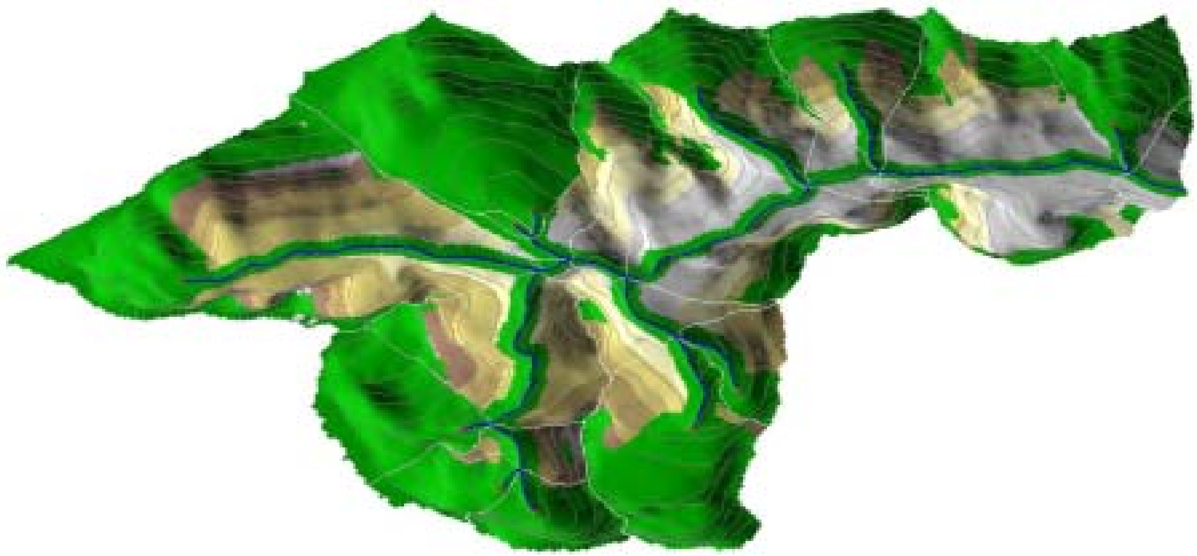

Figura 9. Perspective view of the natural permanent preservation areas for the Paraíso Creek basin.

Table 1 summarizes the contribution of each category of permanent preservation areas, taken individually.

Table 1. Protected surface in the Paraíso Creek basin by category of permanent preservation area.

Category	Area (ha)	Percentage of basin's area
Upland catchments	70	33%
Along ridgelines	55	26%
Riparian zones	30	14%
Steep slopes	2	1%
Upper third of hills	0,28	0,13%

CONCLUSIONS

The Paraíso Creek basin topography is very representative of the relief of this region. Therefore, the findings of this case study may be safely extrapolated to a broader area. For hilly topography it means that permanent preservation areas would account for more than half of watershed's total surface.

Due to the inherent difficulty of on-the-ground delineation and their percent contribution as shown in Table 1, the natural preserves associated to upland catchments and along ridgelines are likely to house most landuse conflicts. This possibility certainly undermines the willingness of farmers, regional planners and politicians to comply with these regulations. The solution for this problem relies on accurately mapping and quantifying current and potential landuse conflicts on a regional basis, therefore enabling a reliable evaluation of its political and economic scope. The moment is propitious for using cutting-edge GIS technologies and Shuttle Radar Topographic Mission imagery to automatically delineate natural preserves according to the Brazilian Forest Code, in a continental scale.

The results shown in this work prove that our environmental legislation can be fulfilled at last. It is just a matter of political willingness. Time is arrived to face the moral obligation of either to revoke this Chapter of our Forest Code or to fully enforce it. The bill 1364/2003, currently under analysis by the Brazilian Congress, obliges all landowners to delineate the natural permanent preservation areas located in their lands and to rehabilitate conflicting areas using native species in a timeframe of 5 years. Mapping permanent preservation areas will also allow for identifying places where landuse change is legally allowed. Where some see quarrels, others see opportunities. It's a good starting point.

Brazilian National Council for the Environment's act no. 303 strengthens population's worries in environmental problems. As can been seen in this article, the Brazilian Forest Code provides a robust and clever framework to establish natural preserves countrywide based on solid grounds. Much more than just protecting ecosystems, these regulations will surely lead to healthier watersheds, protecting their soils from erosion and improving water quality and quantity. If and when enforced, this environmental legislation will create a huge network of ecological corridors, connecting all biomes and effectively protecting our biodiversity. As suspected, Brazilian constitution is, in fact, green!

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Carlos Antonio Alvares Soares Ribeiro, Ph.D.
Associate Professor
Department of Forest Engineering
Federal University of Vicosa
36571-000 Vicosa, MG – Brazil
Phone: (+55-31)3899-1186
e-mail: cribeiro@ufv.br

Vicente Paulo Soares, Ph.D.
Associate Professor
Department of Forest Engineering
Federal University of Vicosa
36571-000 Vicosa, MG – Brazil
Phone: (+55-31)3899-1225
e-mail: vicente@ufv.br