Visualization as a tool for assessing the potential climate impact in a potato-based system

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Visual representation could be a useful tool for enhancing information transfer and improving the understanding of complex data. In natural resources management work, visual interactive tools can be developed and applied as virtual laboratories for the communication of different agricultural scenarios and their impact on the environment. A case study on potential impact analysis conducted at Pacayas's watershed, located in Costa Rica, provided data to construct an example of the potential of coupling Geographic Information Systems (GIS) modeling and visualization techniques to facilitate decision making in potato based systems. In this study, the Soil and Water Assessment Tool (SWAT) was used for the prediction of the impact of surface runoff, soil erosion and nutrient losses in the system, based on climatic, topographic, edaphic, land use changes and management factors. Critical visual scenarios were simulated for climate extremes considering a hypothetical increase of the amount of rainfall and land use changes.

Keywords: Visual representation, Pacayas, SWAT, Costa Rica.

Introduction

After more than 30 years of application of computerized simulation in agronomic research (Sinclair and Seligman, 1996), the most important contributions of modeling include the enhancement of management decisions and the aid in education and policy issues concerning agricultural lands (Hammer *et al.*, 2002). These tools not only allow exploring hypothetical scenarios under specific conditions that in other way could be expensive or impossible to recreate, but some of them also give the potential of bringing together farmers and researchers during the development of the model to enhance farm management, among other advantages (Cox, 1996; Hammer *et al.*, 2002).

Nevertheless, some limitations arise in the adoption of complex information systems as aids and decision support systems (DSS) (Kuhlmann and Brodersen, 2001). The development of more user-friendly systems accessible and at low cost for users could contribute to solve some of these disadvantages (Engel *et al.*, 2003). In this context, this work describes an approach to visualize the results of a DSS, SWAT, in a 3D virtual reality environment as a friendly interface for the exploration of critical scenarios in a case study carried out in one of the most important horticultural watersheds of Costa Rica.

Virtual worlds for sharing and communicating research results

For improving the communication of scenarios, in the present work, we used a tool for building virtual worlds called CIPWorlds. Three-dimensional virtual worlds are a type of immersive virtual reality (VR) based on networked desktop platforms. Virtual worlds allow their users to interact in simulated 3D environments that usually mix text-based chat tools with a 3D graphical interface. So these tools provide multi-user synchronous communicative advantages found in chat-type applications such as Multiple User Domains Object Oriented (MOOs) and features of VR immersion through 3D representations (Dickey, 2005).

In this regard, CIPWorlds is an on-line multiuser virtual environment which groups a complex of virtual worlds centered on a primary world. The current virtual worlds found in CIPWorlds are related to the study areas of the project "Desarrollo de Bases para el Análisis de la Vulnerabilidad en Agro-Ecosistemas de Montaña", which receives the financial support of INIA-Spain and is developed by CIP and other institutions of Iberoamerica such as INTA of Costa Rica.

CIPWorlds is based on the Active Worlds client/server environment (Tatum, 2000). Currently, it uses a U1000 server so it allows 50 simultaneous users and a virtual land size of 1,000,000 sq. meters. Users interact with the system through a browser which renders compressed files in Renderware file format. Being a multiuser virtual environment, users can interact through the visual interface making use of an avatar which shows behaviors and expressions based on sequences of animated 3D movements.

In order to run CIPWorlds, the installation of a free plug-in is required. This is accessible over the internet (http://inrm.cip.cgiar.org) and it runs under Microsoft Windows operating system.

A case study

The study area of Plantón-Pacayas is located in the province of Cartago, Costa Rica. This micro watershed has an intervention area of roughly 561 has. It exhibits altitudes between 1720-2900 m.a.s.l. and an annual precipitation of 2227 mm (meteorological station of Pacayas). About 50% is classified as pastures. The land dedicated to crops is about 25%, where potato is one of the most important crops (about 10% of the total area in Plantón-Pacayas) in rotation with other horticultural crops such as broccoli and cauliflower. There is also an important area of forest which covers around 19% of the area (Arroyo *et al.*, 2006).

A particular feature of the area is the slopes patterns, which goes from moderate to highly undulating (i.e. approximately 44% of the area shows slopes of 30-50%, while 31% and 18% of the area show slopes of 15-30% and 50-75%, respectively) (Arroyo *et al.*, 2006).

Developing scenarios of extreme events

The Standardized Precipitation Index (SPI) was used to characterize extreme wet or dry climatic events for the case study. Originally, McKee *et al.* (1993) developed the SPI to quantify precipitation deficits on multiple time scales. The SPI is the transformation of the precipitation time series into a standardized normal distribution (z-distribution). National Drought Mitigation Center (NDMC) classifies SPI in seven categories as seen in Table 1 (Hayes, 2006). In this study we used the SPI_SL_6, program developed by NDMC (2006), to calculate the index with Pacayas' meteorological station rainfall data (monthly data from 1979 to 2006). The classification of the rainfall events for Plantón-Pacayas, over a time series of 28 years are shown in Table 1. Years 1999, 1997 and 1990 were chosen as extremely wet (Yearly SPI = 2.01), moderately wet (Yearly SPI = 1.22) and near normal years (Yearly SPI = 0.01), respectively (Figure 1). Making use of the Soil and Water Assessment Tool (SWAT), these years were used to simulate an extremely wet, moderately wet and near normal scenarios and its possible impacts on soil erosion, surface runoff and nutrient losses. SWAT is a hydrologic free distributed model developed by the USDA-ARS Laboratory developed to study the watershed impact of the management of water, sediment and agricultural chemical yields (Di Luzio *et al.*, 2002). A review of this model is beyond the scope of the present paper but for a complete review see references listed in http://www.brc.tamus.edu/swat.

Table 1. SPI classification and the occurrence percentage in Plantón-Pacayas Subbasin

SPI Values	Category	Occurrence percentage
> 2.0	Extremely wet	3.57
1.5 to 1.99	Very wet	7.14
1.0 to 1.49	Moderately wet	7.14
-0.99 to 0.99	Near normal	64.29
-1.0 to -1.49	Moderately dry	7.14
-1.5 to -1.99	Severely dry	10.71
< -2	Extremely dry	0.00

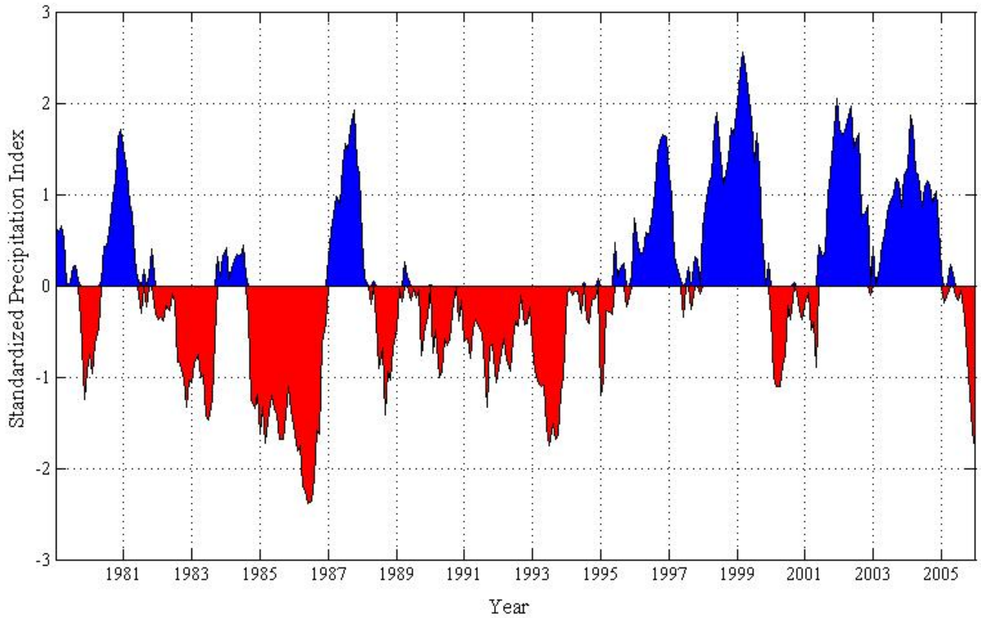
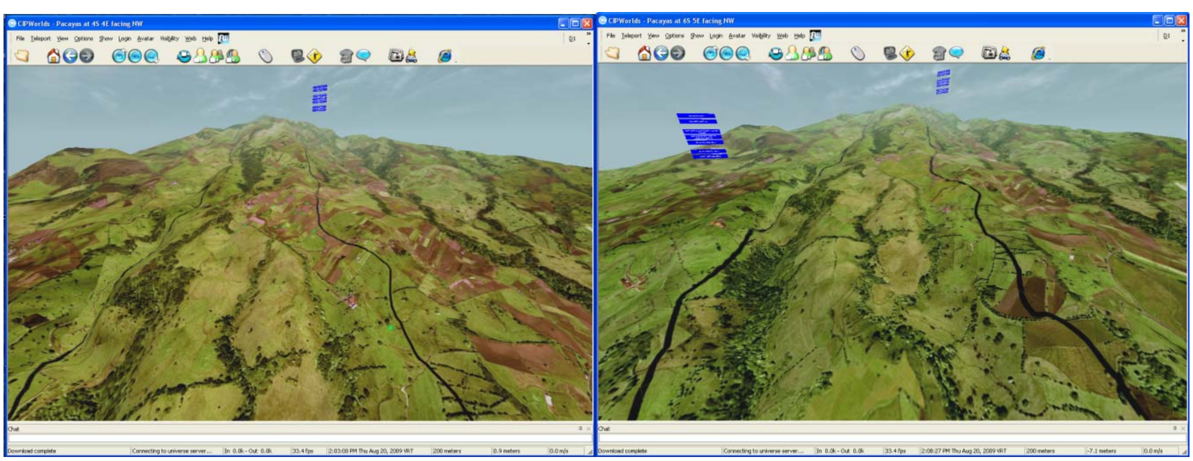


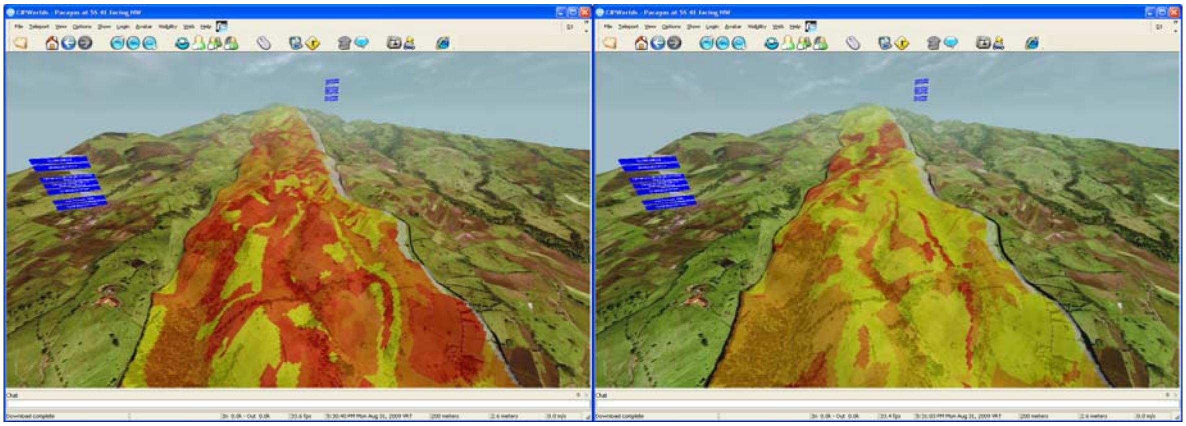
Figure 1. Standardized Precipitation Index (Yearly time-scale)

A 3D model of Plantón-Pacayas was then developed based on a 10 m elevation data obtained from contour lines provided by INTA, Costa Rica and upload to CIPWorlds. The 3D model was texture-mapped with an image from Proyecto Carta 2005 – CENAT, 1:15000. Likewise, a photo-simulation of a hypothetical scenario of an alternative land use was generated replacing crop areas in unsuitable areas for agriculture with pastures (Figure 2). The scenarios generated previously with SWAT were also incorporated as textures upon the 3D model (figure 3). Finally, interactive panels and an assistant bot were programmed for accessing the different layers of information within the 3D environment and panoramic views of several landmarks were linked.



(a) (b)

Figure 2. 3D representation of Plantón-Pacayas. (a) Land use in 2005;
(b) Hypothetical scenario of crop replacement by pastures



(a) (b)

Figure 3. SWAT soil erosion scenarios during an extremely wet year (a) with land use in 2005; and (b) hypothetical scenario of land use replacing crops by pasture

Discussion

One of the first features to be identified in the results of the case study is that Plantón-Pacayas shows high levels of surface runoff, soil erosion and nutrient losses, even in typical years. Furthermore, as expected, erosion was exacerbated during moderate (1997) and extremely wet (1999) years. The negative impact on soil erosion and nutrients loss can be reduced by applying an alternative land use to those areas that should be protected due to their steep slope. In that case, for instance, the results obtained with the SWAT model suggest that the change of horticultural crop areas in Plantón-Pacayas, to a different management option such as pastures reduces the surface runoff, soil erosion and nutrient losses considerably. These results highlight the problem commonly found in tropical highlands where horticultural crops are produced (Bouma et al., 2007). Producing horticultural products in steep slopes demand a comprehensive approach; i.e. tradeoffs between production and environmental deterioration must be included in the economic analysis of policy makers, since the present generation might be consuming the resources of the future generations. It also poses a new challenge for horticultural scientists. Conservation agriculture technologies for steep slopes in tropical highlands are a must, since food should be produced but the damage to the environment should be minimized.

One of the advantages in the use of a 3D representation in this case study was that it allowed visualizing the effect of cultivating steep slopes in Plantón-Pacayas. Figure 3b shows that even in a hypothetical scenario in which horticultural crops are replaced by pastures; there are critical areas that remain affected due to the slope. Moreover, the inclusion of 3D information gives the user new ways of visual analysis since different layers of information can be linked to current views of the area. In addition, the researcher can visit in a virtual way the exact place that the model identifies as a critical area and where high levels of surface runoff, soil erosion and/or nutrient losses are expected.

In the case study, the use of virtual worlds as a tool for 3D representation not only offers new capabilities of visualization, but also provides an interactive environment where immersive experience is highlighted. As a platform for virtual worlds, CIPWorlds also give the tools for scientific collaboration online. Consequently, in the case study, researchers and stakeholders can meet in the virtual representation of Plantón-Pacayas and they can use the tool to analyze together the different scenarios and discuss the course of action in critical events.

Conclusion

The use of virtual worlds for scientific visualization and collaboration provides promising possibilities for increasing the communication and analysis of DSS scenarios. The multi-dimensional data visualization in virtual worlds offers new advantages for visual analyzing complex information and data sets as well as provides the network tools for increasing participation and collaboration among scientists and land managers.

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