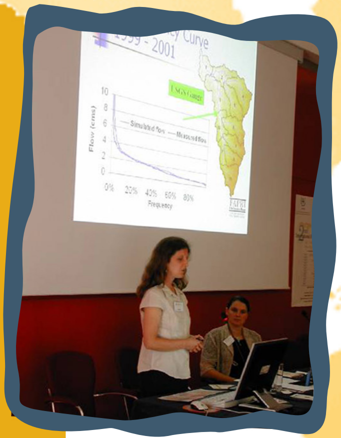
SWAT2003

2nd International SWAT Conference

Proceedings

July 1-4, 2003
Bari, Italy



TWRI Technical Report 266

2003 International SWAT Conference

Edited by

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Foreword

This book of proceedings presents papers that were given at the 2nd International SWAT Conference, SWAT 2003, that convened in 2003 in Bari, Italy.

The focus of this conference was to allow an international community of researchers and scholars to discuss the latest advances in the use of the SWAT (Soil Water Assessment Tool) model to assess water quality trends.

The SWAT model was developed by researchers Jeff Arnold of the United States Department of Agriculture Research Service (USDA-ARS) in Temple, Texas and Raghavan Srinivasan at the Texas Agricultural Experiment Station (TAES), who is the Director of the Texas A&M University Spatial Sciences Laboratory.

SWAT is a comprehensive computer simulation tool that can be used to simulate the effects of point and nonpoint source pollution from watersheds, in the streams, and rivers. SWAT is integrated with several readily available databases and Geographic Information Systems (GIS).

Because of the versatility of SWAT, the model has been utilized to study a wide range of phenomena throughout the world. At the same time, the research community is actively engaged in developing new improvements to SWAT for site-specific needs and linking SWAT results to other simulation models.

This conference provided an opportunity for the international research community to gather and share information about the latest innovations developed for SWAT and to discuss challenges that still need to be resolved.

This proceedings includes papers covering a variety of themes, including new developments associated with SWAT, applications of the SWAT model, the use of related modeling tools, how SWAT can be calibrated or compared to other models, the use of other simulation models and tools, and integrating SWAT with other models. In addition to papers presented at SWAT 2003, posters shown at the conference are also included in this proceeding.

The organizers of the conference--- Antonio Lo Porto (IRSA-CNR), Arnold and Srinivasan —want to express thanks to organizations and individuals who made this conference successful. Organizations that played a key role in this conference include USDA-ARS, TAES, Texas A&M University, the Water Research Institute of Italy (IRSA), the National Research Council of Italy (CNR), the EU Project EuroHarp (an effort to evaluate quantitative tools at European scale for the assessment of nutrients in water resources), the EU

TEMPQSIM project (which is improving water quality models to adapt them to intermittent streams in southern Europe), and the municipality and province of Bari, Italy (where the conference was held). Companies that assisted in the conference include SIT and s.r.l. GIS technologies of Italy, ESRI Italia.

Individuals that should be acknowledged in this proceedings include Ric Jensen of the Texas Water Resources Institute and Jennifer Jacobs of SSL, who helped to edit the proceedings, and Kellie Potucek of TWRI, who assembled the papers into an online technical report.

These proceedings can be referenced as TWRI technical report 266.

The 3rd International SWAT conference is scheduled for July 11-15, 2005, in Zurich, Switzerland. To learn more about SWAT, go on the web to http://www.brc.tamus.edu/swat/ or contact Srinivasan at r-srinivasan@tamu.edu

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Soil Erosion Evaluation and Multi-temporal Analysis in Two Brazilian Basins

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Abstract

The aim of this work, performed in the framework of a European Union Project (INCO-DC), was to evaluate the soil erosion in the Pantanal area, the largest wetland in the world (South-Central Brazil, Mato Grosso do Sul). The land use changes during the last 30 years in the highlands, in particular from native vegetation to agriculture and cultivated pasture, caused extended erosion processes, resulting in heavy sedimentation in rivers and streams, as well as in the occurrence of large gullies. Areas with high risk of environmental degradation were identified by the application of the SWAT model, by simulating different scenarios and foreseeing short-term and long-term evolution, by means of a multi-temporal analysis. The analysis was based on land uses related to 1966, 1985 and 1996 years, derived from digitizing and processing of topographic maps and satellite images; the digital elevation model (DEM) came from digitizing of topographic maps.

In this paper, the application of SWAT for two basins is presented: the first one (Rio Taquarizinho) is smaller (150,000 ha) and suffered more land use changes; the second (Rio Aquidauana) is bigger (1,520,000 ha) and less anthropized. The model simulations, supported by extended calibration using local data, gave satisfactory results and showed the importance of management practices. In particular it was found a high specific soil loss (about 40-50 t/ha) for a single crop versus strong reductions (2-8 t/ha) on areas with crop rotations. Similarly, a correct management of pasture areas resulted in decreases of specific soil loss (from 12 to 0.6 t/ha).

KEYWORDS: agriculture, basins, best management practices, environmental control, erosion, image processing, land management, land use, model calibration, multi-temporal analysis, Pantanal, pastures, satellite imagery, sediments, soil types.

Introduction

The present work was performed in the framework of an EU project (INCO-DC, 2000). Its aim was to evaluate the sediment load in the Pantanal area, the largest wetland in the world (South-Central Brazil, Mato Grosso do Sul, see Figure 1) during the last 30 years and to suggest territorial management guidelines.

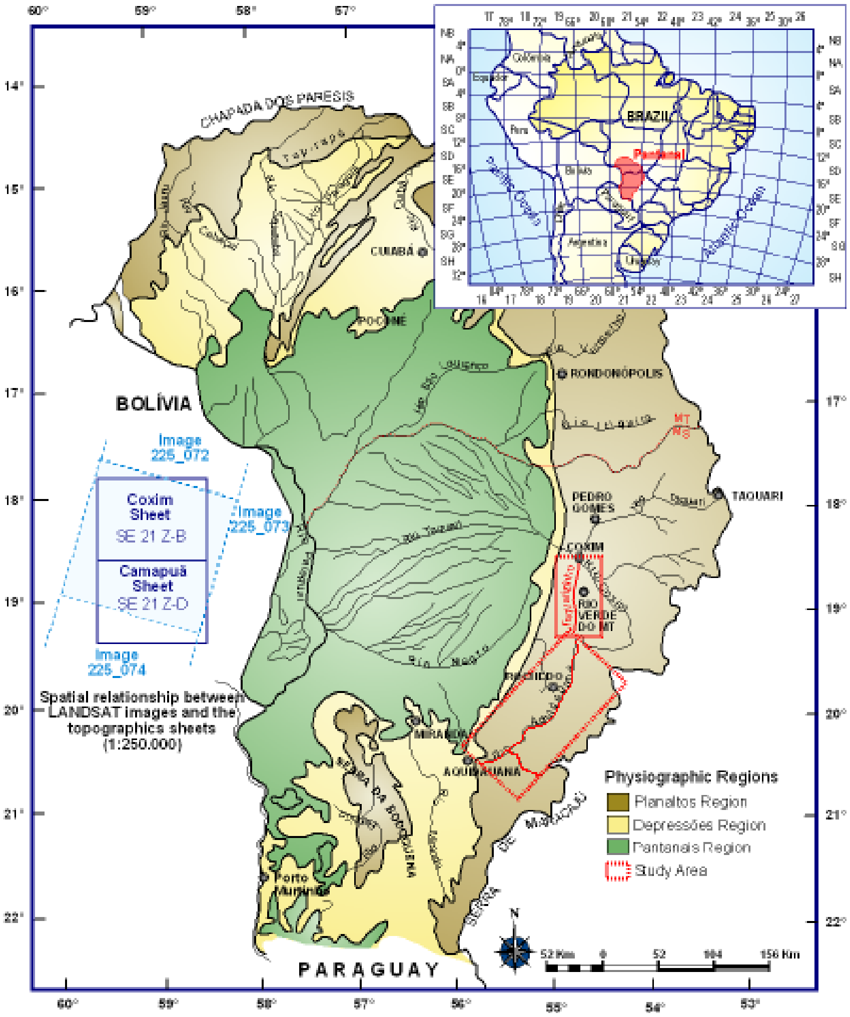


Figure 1. Study Area.

The land use changes in the highlands, in particular from native vegetation to agriculture and cultivated pasture, caused extended erosion processes, resulting in heavy sedimentation in rivers and streams in the plateaus surrounding the Pantanal (Planalto), as well as in the occurrence of gullies (canyons up to 1 Km long and 30-40 m deep). For this reason, two sample river basins in the Planalto area were studied, namely the Rio Taquarizinho (150,000 ha, highly anthropized) and the Rio Aquidauana (1,520,000 ha, little anthropized).

Input Data for SWAT Simulations

GIS data: The Digital Elevation Model (DEM) of the two basins was obtained by digitizing Brazilian topographic maps at a scale of 1:100,000 (based on aerial photos of the years 1964-1966). The maps provide elevation, hydrographic and land cover data, representing the oldest homogeneous land cover documentation for the whole study area. The maps were rasterized and georeferenced, and then elevation contour lines, spot heights and land cover were vectored in order to obtain the geographic databases of topography and land cover (year 1966). The DEM (with a 10 m resolution, improved for a correct delineation) was built by processing the database of topography through the TIN and “topogrid” procedures implemented in the ESRI ARC/INFO software.

Landsat 5 TM images of the dry season (July - October) of the years 1985 and 1996 were pre-processed through spatial registering to the topographic maps and topographic normalization based on the Lambertian reflectance model (ERDAS, 1982-1999) to reduce the difference in illumination due to the slope and aspect of the terrain. The land cover databases for the years 1985 and 1996 were created by performing the following steps: Landsat 5 TM image segmentation based on function of soil properties (in order to minimize the occurrence of land use classes having similar spectral properties), maximum likelihood classification of image segments, segment mosaicing, raster to vector conversion, accuracy assessment and photointerpretation check based on fieldwork data. The three land cover databases (1966, 1985 and 1996) were finally codified according to the E.U. CORINE land cover nomenclature (Heymann Y. et al., 1994) , then transcoded according to the SWAT land use database. Post-classification topological intersection allowed researchers to obtain the land cover multi-temporal data base and the statistics of changes from 1966 to 1985 to 1996.

The soil map and its vertical profile were taken from a Brazilian work (PCBAP, 1997). The soil types of the basins and their related coding are as follows:

AQa: Quartzose alic sandstone;
PVa: Yellow-red podzolic alic;
PVd: Yellow-red podzolic distrophic;
PVe: Yellow-red podzolic eutrophic;
LEa: Dark red alic latosol;

LRd: Red distrophic latosol;
LVa: Yellow-red alic latosol;
HGPd: Little humic “glei” distrophic;
HGPe: Little humic “glei” eutrophic;
Ra: Litholic alic;
V: Vertisol.

Agricultural data: On-site interviews of local agricultural organizations allowed set-up of the following site-related suitable management schedules for soybean monocrop, soy-soy-corn rotation and pasture, equal for both basins.

Rotation Soybean – Soybean – Corn (3 years)

Year 1-2

1st March	Pesticide application (insecticide)
20th April	Corn (Soya bean) harvest and kill
1st November	Tillage operation (plowing)
10th November	Fertilizer application
11th and 20th November	Tillage operation (harrowing)
21st November	Soya bean planting
6th and 20th December	Pesticide application (herbicide + insecticide)

Year 3

15th May	Soya bean harvest and kill
20th October	Tillage operation (plowing)
1st November	Fertilizer application
2nd November	Tillage operation (harrowing)
16th November	Fertilizer application
17th November	Tillage operation (harrowing)
18th November	Corn planting
28th November	Pesticide application (herbicide)

Meteorological data: Rainfall histories and statistical data were collected (and/or evaluated) for two weather stations within the basins. The statistical parameters were particularly difficult to evaluate (lacking official data), e.g. the parameters RAIN_HH and RAIN_6H (10-year frequency 0.5 and 6 h rainfall) were estimated by means of the following formula, commonly used in that area (T is the return time in years, t is the rainfall duration in minutes and the I is the rainfall intensity).

$$I = \frac{(43019)\,T^{0.55}}{(t+62)^{1.405T^{0.053}}}$$

Hydrology: To keep into account the hydrologic characteristics of the Planalto region, with an aquifer sustaining the streams, it was decided to set the deep aquifer percolation fraction (RCHRG_DP) and the threshold depth of water in the shallow aquifer required for return flow to occur (GWQMN) to 0.

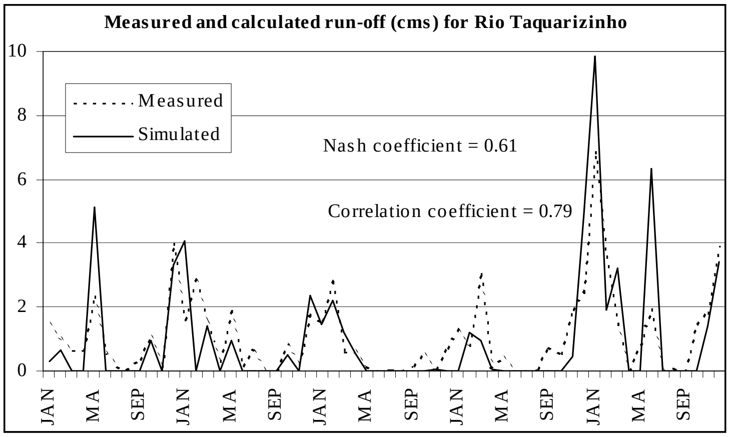
SWAT Calibration

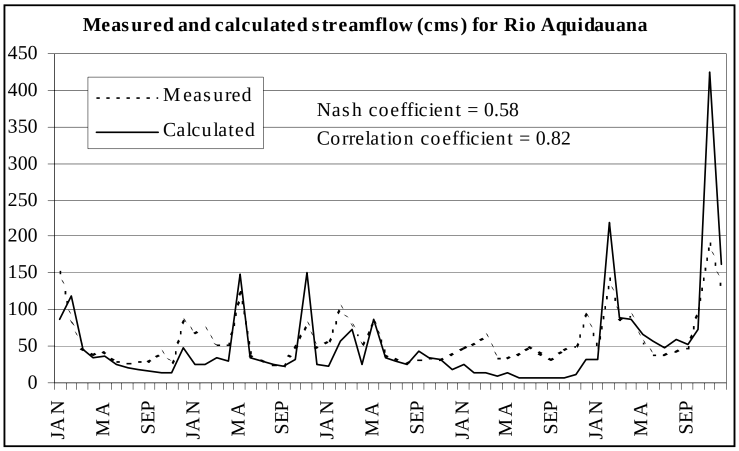
The calibration was performed in three steps:

Step 1: Run-off and total streamflow

1. Acquisition of daily total flow data from ANEEL (Agencia Nacional de Energia Eletrica, Report, 1996);
2. Use of USGS HYSEP software (Sloto R. A. et al., 1996) to separate run-off and base flow from total flow;
3. SWAT run and confrontation with HYSEP results (monthly averages, see Figure 2 below);
4. Use of the calibration tool to modify the following parameters: Curve number, available water capacity and soil evaporation compensation factor.

Figure 2. Confrontation between calculated and measured run-off and total flow.

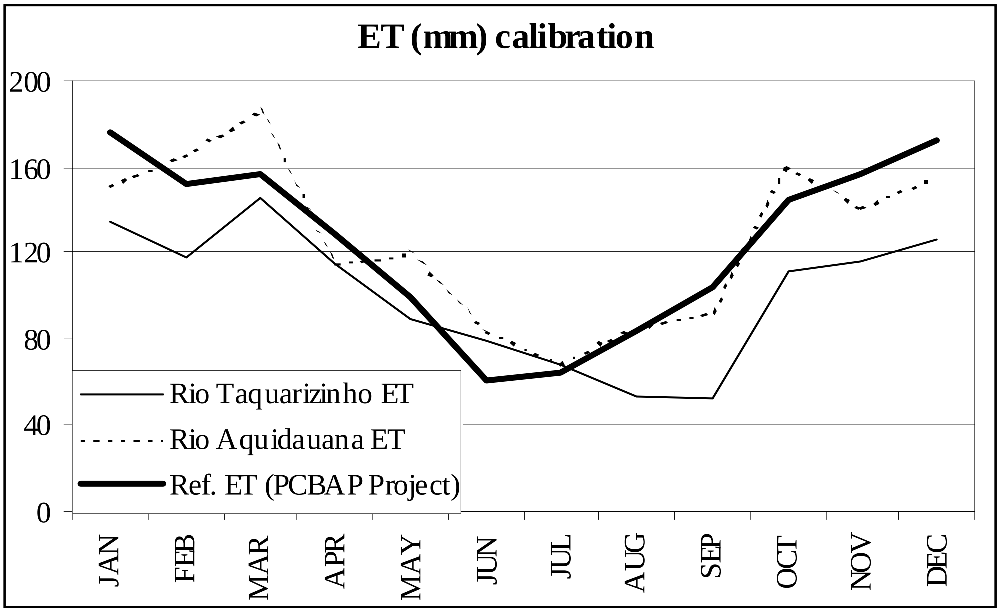




Step 2: Evapotranspiration (ET)

The PCBAP Project performed an evaluation of the monthly averages of ET for an area in the proximity of the basins so that values could be used for the confrontation with SWAT results (see Figure 3 below). The modified parameters were the groundwater “revap” coefficient (also influences run-off) and threshold depth in the shallow aquifer for “revap” to occur.

Figure 3. Confrontation between calculated and literature ET.



Step 3: Sediment flow

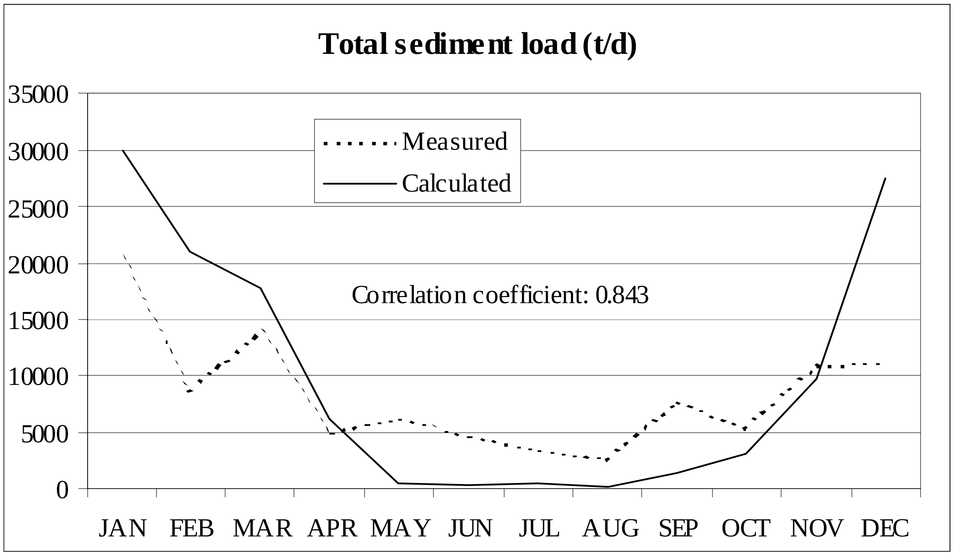
Due to lack of data two different methods were used for the basins.

For Rio Taquarizinho, the confrontation data were evaluated from literature measurements of sediment flow (Padovani C. R. et al., 1998; Walling D. E. et al., 1998) on similar watersheds with the following procedure:

1. Acquisition of literature data of sediments loads and stream flows in Rio Taquarì streams (period 1995-1997);
2. Calculation of coefficients a and b of the equation expressing the relation between *suspended* sediments loads (Qs, t/d) and stream flow (P, m^3/s): $\ln Qs = a + b \cdot \ln P$ using the above data;
3. Evaluation of the mean annual Rio Taquarizinho water flow at the outlet, by means of the conservation of the specific flow measured at an intermediate gauged station; calculation of the mean annual *suspended* sediment flow using the previous correlation (point 2);
4. Evaluation of mean annual total sediment load from the ratios “total load”/”suspended load” taken from the literature data at point 1.;
5. Confrontation with SWAT results;

For the Rio Aquidauana, the confrontation was made more straightforwardly with monthly averages reported in the PCBAP Project (see Fig. 4 below).

Figure 4. Confrontation between calculated and measured sediment flow for Rio Aquidauana.



For both basins, the parameters modified were those related to the sediment re-entrainment in channel routing phase.

SIMULATIONS AND MULTI-TEMPORAL ANALYSIS

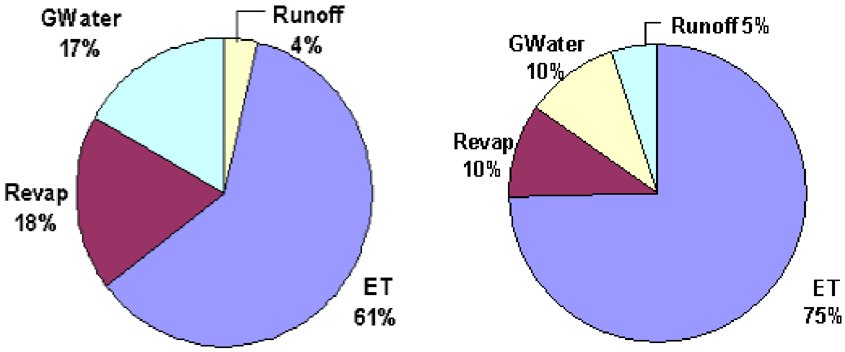
In simulations performed are summarized in Table 1 (* yearly averages).

Table 1 – SWAT Simulations

Basin	Subbasins	HRUs	Sim. Years	Rain (mm)*	Runoff (mm)*
Rio Taquarizinho	113	215	1969-1972	1325.5	22.0
		337	1981-1983	1439.0	60.3
		285	1993-1997	1296.8	50.8
Rio Aquidauana	184	467	1968-1972	1,264.9	50.5
		453	1978-1982	1,528.0	81.0
		434	1994-1998	994.8	26.7

The first result checked was the hydrologic balance that showed, in both basins, relatively high values for ET and revap (see Fig. 5). Further interviews with Brazilian researchers confirmed this situation.

Figure 5 – Hydrologic Balance: Rio Taquarizinho (left), Aquidauana (right).



The target of the multi-temporal analysis is to investigate some of the links between human-induced land use modifications and the soil erosion trend. It is important to stress and precisely define an important concept: as expressed by the USLE equation: The main factors influencing output parameters indicating soil erosion are the quantity and quality of rainfall (duration, intensity, etc.), and the coupling between soil types and land use. Obviously, they change from the various scenarios. That means that it is difficult to compare and say what is “best” and what is “worst.” One cannot merely read the run-off and sediment output data and understand these complex relationships.

Some environmental variations associated with the climatic changes (the “greenhouse effect”) can introduce further elements of uncertainty in the analysis, in particular for the meteorological data).

As an example, the greater amounts of runoff and the soil loss in the 1978-1982 period is strictly linked to the total amount of rainfall in this period. Conversely, their reduction in the 1994-1998 period is linked to the decrease of rainfall (see Table 2). So a simple comparison of parameters (runoff, revap, evapotranspiration, total soil loss) does not produce useful elements for a multi-temporal analysis for the reasons listed above.

Table 2 – Results of Simulations.

		Simulation periods			
River Basins	Parameters	1968-1972	1978-1982	1994-1998	1978-1982 l. u. 1996
Rio Aquidauana	Rainfall (mm)	1,264.9	1,528.0	994.8	1,528.0
	Runoff (mm)	50.48	80.98	26.70	87.75
	Total soil loss (t/y)	67,000	118,000	44,000	143,600
	Tot. stream flow (mm)	106.32	253.07	40.51	248.4
Rio Taquarizinho	Rainfall (mm)	1325.5	1439.0	1296.8	----
	Runoff (mm)	22.0	60.3	50.8	----
	Tot. soil loss (t/y)	28,280	94,330	75,640	----
	Tot. stream flow (mm)	159.5	337.4	219.6	----

Then, in order to have some clues on the correct interpretation of Table 2 data, it was decided to perform a test simulation, not necessarily conform to the reality for Rio Aquidauana, keeping the rain of the 1978-82 period and the land use of 1996. The examination of results (see Tab.2) allowed to hypothesize a growing trend for the total sediment load.

Figures 6 and 7 show the land use changes for the two basins in three simulation periods. The effect of the anthropization is clear: increasing of pasture (Brachiaria grass areas) and noticeable decrease of forested areas (FRSD, RGNB and RNGE).

Figures 6 and 7 – Land Uses Trends

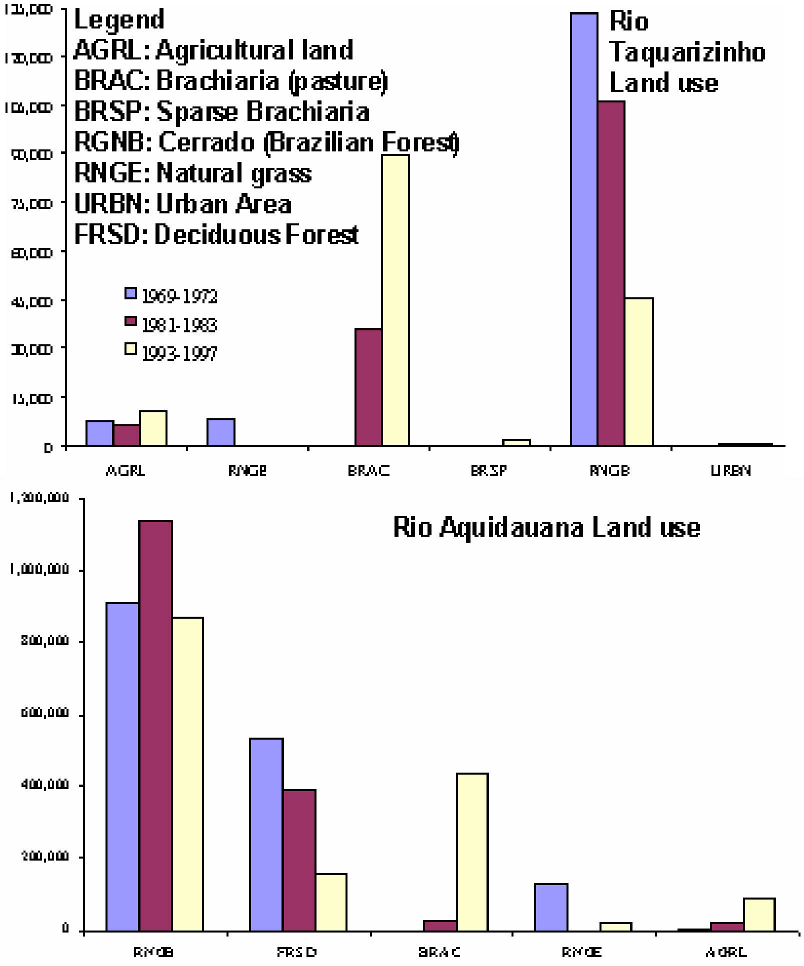


Table 3 shows the changes occurred in the simulation periods by aggregating the SWAT tabular data related to “anthropized” lands (namely agricultural and pastured lands) and the “natural” ones (namely forests and prairies):

Table 3 – Simulation Results.

		Land use Scenarios		
		1966	1985	1996
"Anthropised" Land Uses Rio Taq.	Surface (ha)	7,160	43,020	103,210
	Total soil loss (t)	309,672	488,774	467,705
	Specific soil loss (t/ha)	43.2	11.4	4.5
"Natural" Land Uses Rio Taq.	Surface (ha)	141,860	106,000	45,810
	Total soil loss (t)	18,686	542,471	31,693
	Specific soil loss (t/ha)	0.1	5.1	0.7
"Anthropised" Land Uses Rio Aquid.	Surface (ha)	3,014	48,222	572,846
	Total soil loss (t)	5,632	908,297	1,167,524
	Specific soil loss (t/ha)	1.9	18.8	2.2
"Natural" Land Uses Rio Aquid.	Surface (ha)	1,570,742	1,525,479	1,046,741
	Total soil loss (t)	2,472,388	3,315,230	656,492
	Specific soil loss (t/ha)	1.6	2.2	0.6

With the aid of the above table the following considerations were made:

Rio Taquarizinho:

- A significant decrease of natural areas from 95% (1969-1972) to 31% (1993-1997) of the total basin area.
- The deforested areas became mainly pasture areas (Brachiaria grass).
- The extension of the agricultural areas is relatively small, about 5% of the total basin area, with no significant variation in the three simulation periods, even if the agricultural lands migrated from PVe (the most erodible soil) to LEa soil types, with a consistent reduction of soil loss, also due to the change in agricultural management.
- In the period 1993-1997 the land use BRSP (sparse Brachiaria) takes into account that the pasture areas have lower spatial density, either because they are neglected or because the soils are not suitable for an optimal growing of that grass.

Rio Aquidauana:

- The “natural” areas gradually decrease from the 1968-1972 period, when they practically covered almost the whole basin to the 1994-1998 period when they are about two thirds of the basin extension. That can be considered an always increasing anthropization of the basin, most of which occurs from the second to the third simulation period. In particular the extension of the agricultural areas is relatively small: it varies from about 0.2% of the total basin area in the 1968-1972 period, to about 6% of the total basin area in the 1994-1998 period.
- The soil loss shows a noticeable increase already in the 1978-1982 period, in spite of the small anthropized surface, because of the agricultural activities are performed on soils highly sensitive to erosion (AQa soil type).
- In the 1994-1998 period it can be noticed that, for the first time, the anthropized section of the land (about one third of the total) causes a soil loss equal at almost the double of that coming from the “natural” lands.
- The deforested areas became mainly pasture areas (Brachiaria grass).

Conclusions

Recently in the Planalto (Boddey R. M. et Al., 1996) it was observed that Brachiaria pastures (that are increasing in area) are often degrading in productivity with time. Such a degradation and its causes are at present poorly described and understood and that, more than the deforestation itself, have a negative impact on the environment in terms of soil erosion.

The calculation results confirm that the erosion effectively increases with the decreasing of grass density. That may be prevented with the rotation of Brachiaria with legumes since that improves the fixation of nutrients in the soil (this practice is increasing).

The use of the model allowed to perform good estimations to evaluate the correct choice of soils and management practices.

We presented above two ways for describing simulation results in multi-temporal analysis. However, in order to try to describe a scenario of soil erosion and allow easier confrontations among different ones, further investigations are necessary, in our opinion. For instance, it would be useful to define some synthetic parameters, independent (as far as possible) from the natural phenomena (like rainfalls) and capable to lead to the determination of a threshold for a “sustainable” erosion both from the economic and environmental point of view.

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