



# **Land-Water Linkages in Rural Watersheds Case Study Series**

## **Valuation of land use and management impacts on water resources in the Lajeado São José micro-watershed Chapecó, Santa Catarina State, Brazil**

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April 2002

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS  
Rome, Italy

## **Abstract**

As a cause of improper land use and management and inadequate disposal of organic manure within the watershed, erosion processes are increased, which have on-site impacts like soil impoverishment and gradual decrease in crop yields, loss of biodiversity and reducing farmers income. Off-site impacts are related to river sedimentation, lost of water storage capacity, flood hazards, reducing water quality, increasing in water treatment cost and damage to aquatic life.

Correct land use and management lead to important on-site benefits such as: Reduction in soil erosion; increase in crop productivity; improvement in physical, chemical and biological soil conditions; increasing farms income and leading to better quality of life. Even considering the importance of the on-site benefits, the present case study is concentrated on off site benefits of land management of watershed, in term of water quality and reduction in water treatment costs.

As a consequence of better management practices, improved by farmers, including zero and minimum tillage, contour-tillage, crop rotation, cover crops, green and organic manure, level terracing and forestation, the suspended sediment concentration in river dropped 69 percent and the savings in water treatment cost for domestic supply, was 2 445 US\$ per month.

Important lessons, related to technical strategy, participatory methodology, research and extension service , monitoring system and externalities were learned, with the study case, which are of significant relevance for new management projects in micro-watersheds.

## **Introduction**

Considering agriculture and environment, the main issues are natural resources degradation processes, including soil erosion, mving as immediate causes improper land uses and management and inadequate disposal of animal waste and sewage wastewater in the watershed. Direct consequences are: soil impoverishment and gradual decrease in crop yields and reduced water quality and quantity in rivers and springs, loss of biodiversity and quality of life.

In economic terms, effects are felt in the reduced income of families who reside in the watershed, causing them to abandon and sell their properties. This contributes to an increase in social problems in the outskirts of urban areas where many of these families settle.

The correct land use and management within the watershed lead to important on-site benefits such as: Reduction in soil erosion; increase in crop productivity; improvement in

physical, chemical and biological soil conditions; leading to increasing farms income and better quality of life.

Even though these on-site benefits are important, they will not be the focus of this study. The objective of this paper is to present downstream, or off-site benefits in terms of water quality and quantity and the reduction in treatment costs, obtained through the implementation of Better management Practices (BMP), in Lajeado São José micro-watershed by the World Bank's Land management II Project. The watershed was monitored from 1988 to 1997. The management plan of the watershed started in the beginning of 1992.

Important lessons learned from micro-watershed management project are:

- (i) to deal with widespread problems of natural resource degradation, it is necessary to adopt new strategies based on modern soil erosion and conservation concepts, based more on land management than on isolated conservation practices which often do not combat the causes of erosion but rather their effects;
- (ii) the technical strategy must seek to both combat the causes of the problem and bring immediate economic results to the farmers involved;
- (iii) land use and management when focused in a holistic way, by organizing all the farmers in the watershed bring to very important benefits on- and off-site;
- (iv) the intervention methodology should be based on participatory planning, which is focused on people rather than things.

The valuation included measurement of: rainfall; water discharge; coliform bacteria concentration; water turbidity; suspended sediment concentration and the costs for downstream water treatment for domestic use.

## **Background information on the study area**

### **Biophysical setting**

Lajeado São José watershed lies between 53°35'31" and 52°41'34" West longitude and 26°58'40" and 27°07'00" South latitude. The total area is 7 744 m and the study area, above the water treatment station of CASAN, (Water Supply and Sanitation Company of Santa Catarina) is of 6 348 m. Average slope is 12.3 percent and average altitude is 659 m.

[\[Click to view Figure 1: Location of the Lajeado São José watershed\]](#)

The main part of Lajeado São José river (11 km) lies between the level curves of 600 m and 650 m, where the topography is mainly flat or gently sloping and soil are deep. In the

upstream areas close to the drainage divide the slope is about 20 percent, the soil is shallow, stony and younger.

Primary vegetation is of perennial sub-tropical forest, including: *Araucaria angustifolia*, *Ocotea spp*, *Ilex paraguariensis*, *Apuleia leiocarpa*, *Paraptadenia rigida* and *Balfordodendron riedelianium*. Other land uses comparing 1990 to 1996 are shown in **Table 1**.

**Table 1 – Main land uses in Lajeado São José micro-watershed, comparing the situation in 1990 with 1996**

Sub systems	Area(ha)	
	1990	1996
1 – Economic crops		
1.1. maize	1,183.4	1199.0
1.2. Soya bean	876.1	702.9
1.3. Bean	479.4	390.0
1.4. Tobacco (*)	85.0	40.0
1.5. Wheat (**)	647.6	280.0
2 - Forestation (mainly <i>Eucaliptus spp</i> and <i>Ilex paraguariensis</i> )	437.0	664.0
3 - Native forest (primary and secondary forests)	538.8	512.5
4 - Pasture area	952.5	947.0
5 - Other uses (***)	1,880.8	1,932.6

(\*) Same area used for maize and bean

(\*\*) Winter crop, using the same area of maize and soya bean

(\*\*\*) Include: Urban areas; roads; construction; horticulture; fruticulture; recreation areas.

The climate is influenced by cold mass coming from Antarctica, by rain regime and by win blowing mainly from southeast. From Thornthwaite classification which consider hydric index and annual potential evapotranspiration, the climate in the watershed is mesotermic with no water deficiency in any season (SANTA CATARINA, 1986)<sup>1</sup>.

Precipitation data, which were collected in the EPAGRI's meteorological station located in the micro-watershed, show that the average monthly rainfall is 157 mm. Annual average rainfall in the period from 1970 to 1996 is 2 039 mm. Lowest monthly rainfall occurs in March (115.6 mm) and the highest monthly rainfall occurs in May (179.2 mm). The second highest monthly rainfall is October and the third is November. The strongest rains occur at the soil preparation period for winter and summer crops, giving more importance to the kind of tillage and soil management system, impacting directly on soil erosion.

Rainfall data collected by EPAGRI/CPMP in the last three decades reveal that the total annual rainfall in the West region of Santa Catarina State increased from 1 856 mm in the 70's to 2 429 mm in the 90's.

<sup>1</sup> SANTA CATARINA. Gabinete de Planejamento e Coordenação Geral. *Atlas de Santa catarina*. Rio de janeiro: Aerofoto Cruzeiro, 1986. 173p.

## Socio-economic setting

The total population of the watershed is estimated in 28 375, been 1 075 in the rural area side and 27 300 in the urban area. The number of rural families is about 215 (GONÇALVES, 2000)<sup>2</sup>.

Considering the rural area of the watershed, the main economic activities are presented in **Table 2**. Milk production; cattle meat production and tea production (from *ilex paraguariensis*), are of less economic relevance. In the urban area, which was not considered in this study, the prominence is for factoring, industries and storage buildings.

**Table 2 – Economic value for different activities in the rural area of Lajeado São José micro-watershed, Chapecó-SC, Brazil**

Activity	Production value/year	Permanent population
1 – Grain production		
1.1. maize	320.9	-
1.2. Soya bean	212.7	-
1.3. Bean	139.8	-
1.4. Wheat	77.7	-
2 - Animal production		
2.1. Chicken production	2 100	516 000
2.2. Turkey production	4 800	420 000
2.3. Pig production	1 000	15 000

The watershed is occupied mainly by annual crops (yellow), followed by pasture (beige) and forests (green). Few changes happened in the rural area during the monitoring period from 1988 to 2000, but a significant urbanization process took place during this period (grey area). The very important changes in watershed happened in the tillage system, where the farmers change from conventional to zero and minimum tillage.

[\[Click to view Figure 2: Land use in the Lajeado São José watershed, 1978\]](#)

[\[Click to view Figure 3: Land use in the Lajeado São José watershed, 2000\]](#)

The Lajeado São José watershed has particular importance as the water supply for Chapecó city. Every month, 750 000 cubic meter of water are treated. The existing Water Supply and Sanitation Company of Santa Catarina (CASAN) and meteorological station of the Rural Research and Extension Service of Santa Catarina (EPAGRI) in the watershed facilitated the data collection and monitoring process.

The main urban water uses are domestic and industrial supply. In the rural zone, the river water is used for animal and fish production, while for domestic consumption, water comes from wells (37 families) and from surface springs (167 families).

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<sup>2</sup> GONÇALVES, O. C. L. *Uso e ocupação do solo na microbacia do Lajeado São José – Chapecó/SC e seus reflexos na qualidade da água*. 2000. (Dissertação de mestrado em Geografia da UFSC).

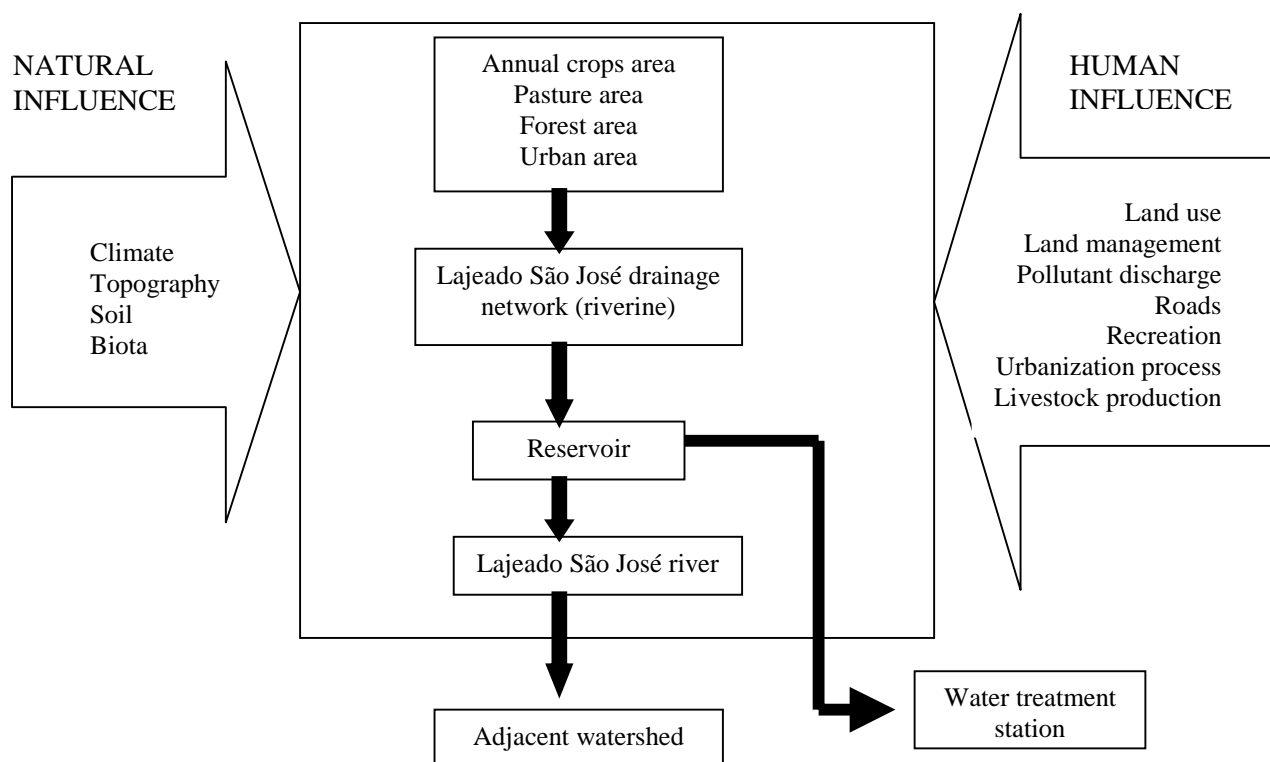
The main Institutions acting in the micro-watershed are: i) Extension Service (EPAGRI); ii) Prefecture; iii) Chicken and turkey industry; iv) Tobacco industry. EPAGRI conducts many different validation experiments, together with farmers, mainly regarding to soil and water conservation technologies.

Stimulated by the institutions as a strategy of project intervention, farmers organized many different groups for different purposes. Farmers organization is very important to continue the watershed management plan and to reduce costs through the common use of equipment, buying and selling products together, discussing and solving common problems.

### Main linkages between land uses and water resources

The micro-watershed converts large amounts of rain to streamflow. In case of Lajeado São José, where the total average annual precipitation is of about 1 800 mm each square meter receives 1.8 t of water per year. The total studied area of 6 348 ha, thus receives 112 264 000 t of water per year. In the orderly runoff of this high amount of water, every piece of ground plays a very important function which can be modified by the different land uses and management.

In **Figure 4**, a conceptual model is presented illustrating the transport of sediment, biota, nutrient, organic and chemical pollutants in the Lajeado São José watershed. *Major sources and sinks of sediment and other pollutants are represented by the boxes. The flow of material from one system to another is shown by arrows.*



**Figure 4 – Conceptual model for sediment and other pollutants in Lajeado São José micro-watershed**

The process of soil erosion and sedimentation are controlled by natural and human influences exerted on the entire micro-watershed. The erosion process within the watershed besides of reducing the soil productivity also influences the hydrologic regime and water quality.

Reduction in soil productivity is due to the loss of topsoil, including organic matter and mineral particles. Together with these fine particles (clay, loam and small aggregates), nutrients (mainly nitrogen and phosphorous), agrochemical residues and organic pollutants (animal manure), are transported off the field and end up in the drainage network.

The excess of soil mobilization with heavy machinery and the lost of organic matter lead to soil compaction, thus reducing water infiltration and water availability for crops, increasing surface runoff and discharge peaks in the rivers.

### **Methodology for valuation of land use and management impacts on downstream water resources**

Considering that natural resource degradation and water pollution occur everywhere (in rural and urban areas), precise intervention need to be done in a systematic manner.

The geographical area best suited for intervention is the micro-watershed, which, in addition to being a natural hydrological system, is where the farmers live who directly influence natural resources.

The World Bank Land Management II Project in Santa Catarina, in addition to adopting a participatory methodology, implemented a technical strategy based on research results, with the following objectives:

- i) Increase of vegetation cover of soil;
- ii) Increase of water infiltration in soil profile;
- iii) Reduction of soil erosion;
- iv) Reduction of water pollution.

To measure the project results, indicators for the technical objectives were selected together with measuring the degree of farmer organization and income of rural families. The following indicators were analyzed:

#### **a) Rainfall**

Rainfall data was measured using pluviographs and pluviometers in the EPAGRI research center in the micro-watershed.

**b) Vegetation cover and water infiltration in soil profile**

The main cause of erosion in the micro-watershed is rain. Although rain is rather uniformly distributed throughout the year, rainier months coincide with the planting of winter crops (May and June) and summer crops (October and November).

The quantity and intensity of rainfall, the irregular topography and the intense use of land, sometimes for purposes to which it is not suited, make vegetation cover of soil the most practical management practice to control erosion and ensure greater water infiltration in the soil profile.

Vegetation cover was measured by systematically monitoring micro-watershed and farm management plans. Water infiltration was indirectly measured by the increase in the area covered and by the run-off data from the river and hydrographic peaks in the control section at the end of the micro-watershed.

**c) Reduction of soil erosion**

Following the impact of rain on unprotected soil surfaces and the dislodging of particles, the process of transporting the dislodged material begins, most of which ends up in the micro-watershed's water network, causing the sedimentation of rivers, lakes and dams, and influencing water availability and quality.

The amount of sediments transported to rivers is directly related to soil erosion. Thus, by measuring water turbidity and suspended sediment concentration, one obtains a clear indicator of the erosion which takes place in the micro-watershed.

To obtain the rating curves correlating turbidity and suspended sediment concentration, used to estimate daily average of suspended sediment concentration, samples were taken at a measuring station located above the dam (reservoir), and the samples for daily turbidity measurement were taken in the entry point of water at treatment station, before treatment process.

**d) Reduction of water pollution**

Sediment, and its absorbed particles, is an agent that reduces water quality. However, considering the high livestock concentrations (hogs, poultry, and turkeys) in the study area, organic pollution means is correlated efficiency of basic sanitation and of waste management in the animal farms.

The basic indicator used to measure organic pollution was the concentration of fecal coliform bacteria in the river.

**e) Reduction in water treatment costs**

To remove suspended sediment from the water at the treatment station, the Water Supply Company (CASAN) uses Aluminum Sulfate ( $Al_2SO_4$ ). The amount need is related to the

sediment load in the water. Using the average monthly concentration and the total monthly use of  $Al_2SO_4$ , it was possible to monitor the water treatment cost.

The data presented are from the following sources:

1. Monitoring over a ten-year period in the Lajeado São José micro-watershed, Chapecó, SC, with data prior and subsequent to project implementation;
2. Reports received from extensionists and researchers involved in the project.

The manner in which farmers deal with land has direct consequences on the water quantity and quality in the micro-watershed. Natural characteristics of the micro-watershed like soil type, slope and climate influence the dynamics of surface and sub-surface water, including infiltration rate, water storage and availability.

### Valuation results

In the beginning of the 90's, the World Bank Land Management II Project started the process of recovery production capability of land in the micro-watershed through a participatory methodology, evolving farmers and institutions.

The factors man can influence in order to prevent the erosion and land degradation process are few, but very important. Through vegetative and simple mechanical measures that conserve soil and water, the water absorption rate and storage capacity of the soil can be increased.

As a result of better soil management and greater use of green and organic manure, there was an increase in the productivity of the principal economic crops in the micro-watersheds which received assistance, according to project reports. In the Lajeado São José micro-watershed, comparing 1990 with 1996, increases were as follows: maize 40 percent; soybeans 21 percent; beans 3 percent; tobacco 32 percent. (**Table 3**)

**Table 3 - Productivity (kg/ha) of economic crops in Lajeado São José Watershed**

Crop	Year	
	1990	1996
Maize	3318	4656
Soya bean	2124	2578
Bean	1393	1439
Tobacco	1248	1855
Wheat	1968	1918

In monetary terms, these increases in productivity represent an increase of total farm income from maize: 98 460 US\$/year; soybean: 56 071 US\$/year; bean: 12,272 US\$/year and tobacco: 10 730 US\$/year.

### Vegetation Cover of Soil

The project's strongest technical message for reducing the main cause of erosion, which is the impact of raindrops on bare soil, has been to implement vegetation cover of soil. In 1996, the area under zero and minimum tillage represented 79 percent of the total annual crop area, which was of 15 percent before project intervention.

Other measures for erosion and pollution control, which have been improved by the farmers in the Lajeado São José watershed, include contour-tillage, crop rotation, cover crops, green and organic manure, level terracing and reforestation. Improvement of the area under some of these measures is shown in **Table 4**.

**Table 4 – Improvement of soil conservation through Better Management Practices, equipment and organic pollution control in the Lajeado São José watershed**

Activities	Unit	Year	
		1990	1996
1 - Area under soil conservation(contour terraces)	ha	634	1963
2 – Area under organic manure	ha	1350	2192
3 – Area under zero tillage system	ha	25	1465
4 – Organic manure storage settings	Num.	13	61
5 – Zero tillage sowing machine	Num.	1	23
6 – Sewage disposal	Farmers	10	43
7 – Garbage disposal	Farmers	70	127

### Water Infiltration in Soil

With the increase in soil cover and changes in tillage the system, better conditions of soil profile and soil structure and higher rates of water infiltration are expected, influencing soil water storage and water availability for crops.

Due to improved infiltration, the rain water reaches the drainage network mainly through subsurface flow, reducing rapid rise of the surface water levels and flood hazard.

Infiltration rates, comparing different tillage systems, were measured for different soils in Santa Catarina<sup>3</sup> and results showed that for Ferralsols (which represent 80 percent of the

<sup>3</sup> BALDISSERA, I. T. ; VEIGA, da M. ; TESTA, V.M. ;JUCKSON, I. L. Z. ; BACIC, I. L. Z. Infiltração de águas em solos minerais não hidromórficos de Santa Catarina submetidos a diferentes sistemas de manejo,

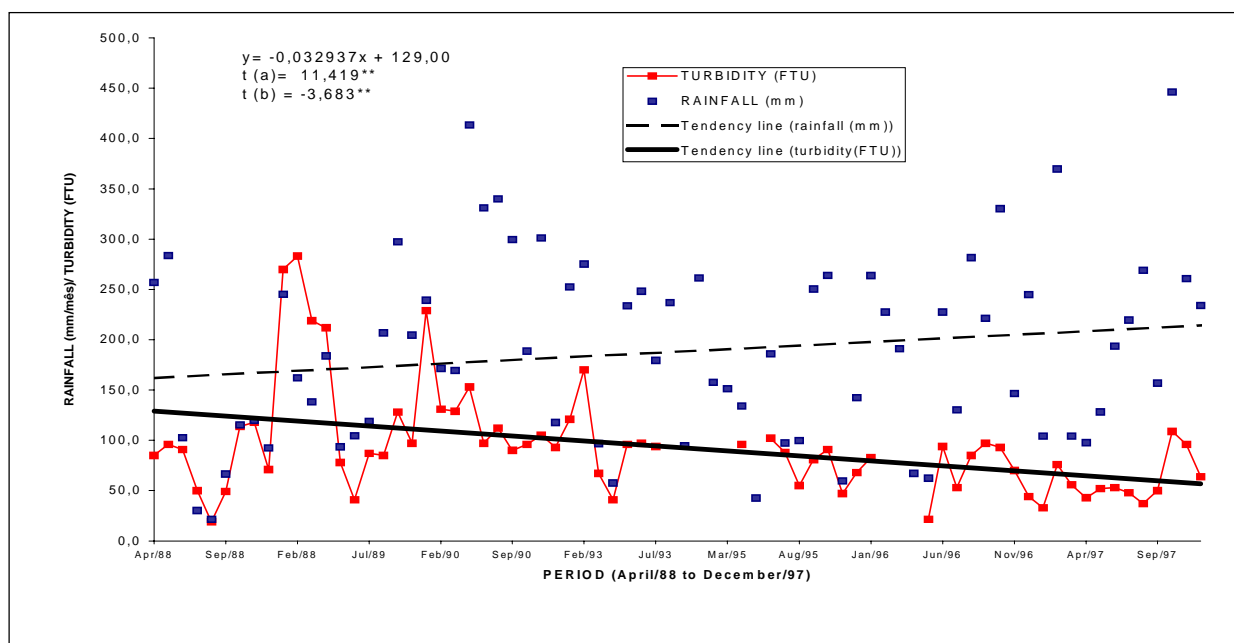
soils in the Lajeado São José micro-watershed) the infiltration rate (in mm/h), was 93 percent higher under zero tillage system when compared to conventional tillage.

### Soil erosion, turbidity and suspended sediment

The change in land use and management, particularly for direct and minimum tillage, associated with conservation-oriented support practices, has led to a significant reduction in the erosion process, as seen in the performance of the following indicators:

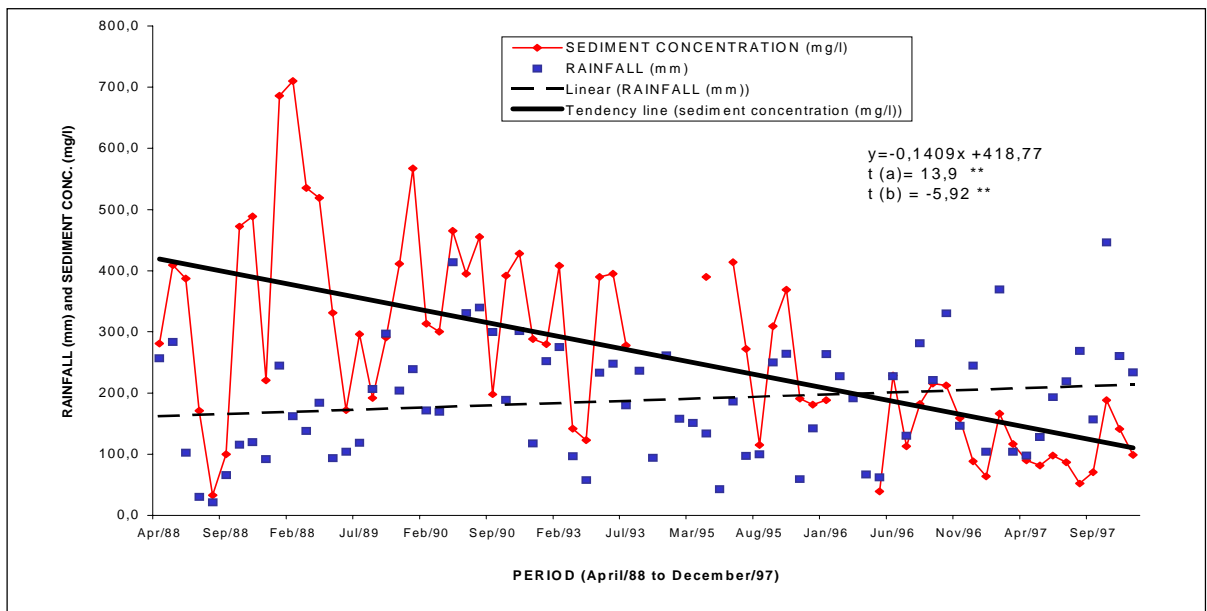
#### *Water turbidity and suspended sediment concentration*

In the waters of Lajeado São José, turbidity in the period from 1988 to 1997 was significantly reduced (61 percent) as observed in **Figure 5**. In 1988 the average monthly value was 130 units of turbidity, reduced to 50 units in 1997.



**Figure 5 – Turbidity in waters of Lajeado São José, Chapecó SC, and rainfall from April/88 to April/97.**

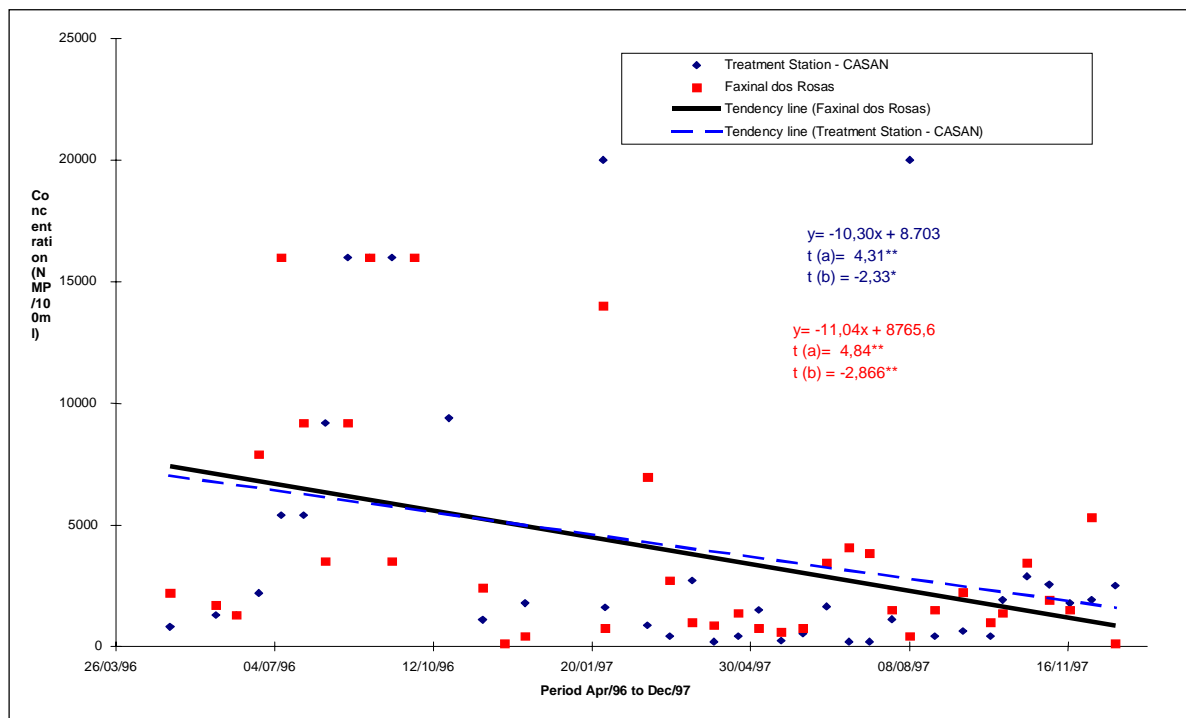
With regard to the suspended sediment concentration, there was also a significant reduction (69.5 percent), when comparing 1988 average monthly values (400 mg/L) to 1997 values (112 mg/L) as shown in **Figure 6**.



**Figure 6 –Suspended sediment concentration in waters of Lajeado São José, Chapecó SC, and rainfall from April/88 to December/97.**

### **Reduction in water contamination and treatment costs**

As a consequence of reduced erosion, improvements in basic sanitation and more adequate management of animal waste, waters of Lajeado São José show a decreasing concentration of fecal coliform bacteria at two sampling points (one in the middle of the watershed and the other at the treatment station), as indicated in **Figure 7**; regression equations show that this reduction is significant over time.



**Figure 7 – Concentration of fecal coliform bacteria at different collection points, in waters of Lajeado São José, Chapecó, SC**

***Reduction in water treatment cost***

Besides impoverishing the soil and the farmer, erosion makes it more expensive to treat the water offered to consumers in the city of Chapecó downstream.

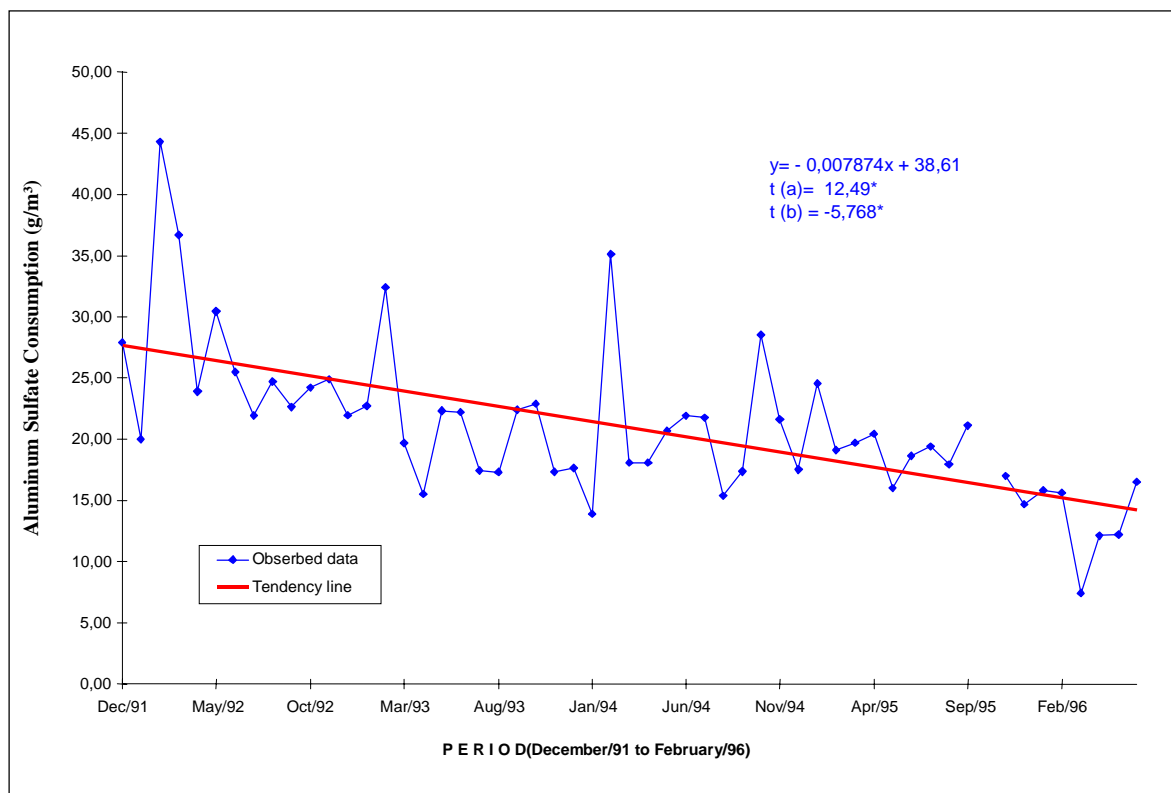
From data obtained at the treatment station, it was noted that the quantity of aluminum sulfate used to remove the suspended sediment from the water of Lajeado São José fell from 28 g/m<sup>3</sup> in 1991/92 to an average of 15 g/m<sup>3</sup> in 1996 (**Figure 8**). Considering the amount of treated water of 750 000 cubic meters per month, for Chapecó city, the monthly cost reduction was of 50 percent (from US\$ 3 000 to US\$ 1 500).

The use of aluminum sulfate increases the water acidity which must be corrected through the use of a base. In case of Lajeado São José, calcium hydroxide is used for that purpose, at a rate of 0.45 mg of calcium hydroxide per mg of aluminum sulfate.

With the reduction of aluminum sulfate from 28 g/m<sup>3</sup> of water to 14 g/m<sup>3</sup>, the use of calcium hydroxide is reduced from 12.6 g/m<sup>3</sup> to 6.3 g/m<sup>3</sup>.

The monthly savings from a reduction in use of calcium hydroxide is **945 US\$** (from 1 890 to 945 US\$).

The total savings for water treatment is **2 445 US\$ per month**.



**Figure 8 – Aluminum sulfate consumption to treat water from Lajeado São José river, for domestic use - Chapecó - SC . Data Source: CASAN – Water Treatment Station (Chapecó City – SC).**

The project invested **25 000 US\$** in subsidies to farmers for making improvements in erosion control and **30 000 US\$** in road improvements which also helped reduce erosion significantly. Farmers investment over the project period in equipment and soil conservation practices totaled **48 000 US\$**. Thus, total investment in the whole micro-watershed **103 000 US\$**. Considering the reduction in water treatment costs, this investment will be **recovered in about 4 years**.

## Conclusions and lessons learned

The results of the study clearly demonstrate that the objectives of the World Bank Land Management II Project's technical strategy were achieved, resulting in a significant improvement in water quality, reduced soil degradation, evolution of crop productivity and increased income for rural families.

The results also show clearly that investment in watershed management projects have a secure economic return by yielding important downstream benefits, like reduction in water pollution and reduction in water treatment costs, in addition to better quality of life.

The erosion control in the micro-watershed led to a monthly reduction in **water treatment cost of 2 445 US\$**.

Important conclusions of the project are:

- Zero tillage (or minimum tillage) is an ideal system to be implemented from the start of intervention in micro-watershed since it achieves the basic objectives of the technical strategy of increasing coverage, increasing water infiltration and reducing surface runoff, as well as achieving the objectives (from the direct standpoint of the farmer) of reducing costs and increasing production with less risk;
- Increasing incomes and production is an excellent entry point for reducing environmental degradation;

The major acceptance of soil cover by micro-watershed farmers is due to the fact that, under this cover, economically important crops are implemented using the zero tillage system which, besides reducing soil erosion, offers on-farm benefits from the first year of implementation through savings in labor time, and reduction in the number of agricultural operation, thus reducing production costs. An increase in productivity from the first harvest has also been observed. A similar situation occurs with minimum tillage.

- The active participation and organization of land users have been two essential factors for project success;
- To induce technology changes with farmers, formal education or extension is needed. However, equally important are: strengthening farmers organisation; promoting participatory methodologies for planning and execution of activities at the micro-watershed level; and environmental education. All these activities should be based and centred on production activities that is what farmers are most interested;
- Decentralization of research and extension is necessary to achieve the projects' objectives;

- Monitoring costs are relatively small but not insignificantly. Even a simple monitoring system needs a complete structure of technicians and collaborators, with laboratory support. However, without such monitoring, it would not be possible to consistently evaluate the results of efforts carried out in the micro-watershed;
- All subsystems within the micro-watershed should be taken into account in the management plans, including urban areas that are important water pollution-sites;
- Watershed management projects, if well conducted, make efficient the public and private investment, generating on and off site benefits and presenting important returns in monetary terms and in water quality for population.

#### **Conclusions regarding externalities:**

- Sedimentation, reduction of water storage capacity and water quality problems as a consequence of erosion processes can be minimized by implementing Better Management Practices in the watershed;
- All watersheds for public water supply, should implement a natural resources management plan and part of the downstream economic benefits should be invested in the watershed and used by farmers for further improvements in water quality.

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