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URBAN DRAINAGE AND TOTAL SOLIDS: A STUDY OF EROSION IN PALMAS-TOCANTINS (BRAZIL)

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Abstract: The subject of urban drainage and total solids is broached in a case study in which we present an Expected Soil Loss Map of the Água Fria basin in Palmas, Tocantins State, Brazil, as well as data on turbidity and total solids. The methodology has proved useful and the results are easy to interpret.

INTRODUCTION

The subject of "Urban Drainage and Total Solids" provides a wide range of choices for pinpointing problems, defining concepts and proposing solutions. Evidently, actions and concepts include erosion and, depending on the point of view (hydrological, geological, social, etc.), approaches and arguments vary greatly. In this paper, our standpoint is based on concepts more closely related to hydraulics.

A large part of the soil in urban areas is impermeabilized, giving the false impression that this minimizes the creation of sediments. But this process is always intense and erosion in urban environments is high, transporting large amounts of solids. Materials considered "solid" are initially classified into modalities or subgroups, as shown below (Silva et al., 2003; www.ecolnews.com.br):

i)- *Decantable solids*: are solids that can be separated into a decantation device (Imhoff cone) in 60 to 120 minutes.

ii)- *Filterable solids or dissolved solid matter:* are those that pass through a filter that retains the solids with a diameter equal to or greater than 1 micron.

iii)- *Volatile solids*: are solids that volatilize at a temperature of 600°C.

iv)- *Fixed solids*: are non-volatile solids.

v)- *Floating solids or floating matter*: consist of fats, solids, liquids and scum that is removable from the surface of a liquid.

vi)- *Suspended solids or solids in suspension*: are small particles of solid pollutants in waste, which contribute to turbidity and resist separation by conventional means. They are the solids that pass through a filter separating them from filterable solids.

vii)- *Total solids:* constitute the total amount of solids present in an effluent in both solution and suspension. In analytical terms, the total solids contained in effluents are defined as the matter left behind as residue after evaporation at temperatures of 103°C to 105°C. That is the definition used in this paper.

Erosion occurs differently in urban and rural basins. The load of sediment also differs qualitatively and quantitatively in these basins, with values that would surprise the layman. As a quantitative example, Prandini & Nakagawa (1995) demonstrate that the silting of rivers in the São Paulo metropolitan area originates almost exclusively from urban erosion, even though half the basin is occupied by rural properties. A mere 12% of the urban area with intense erosion occasions a large part of the annual contribution of three million cubic meters of sediments in the aforementioned rivers. As a qualitative example, the data in Table 1 for the Oakland region (California, USA) indicate that the runoff from urban areas contains far higher quantities of pollutants than the waters from rural areas.

Table 1 – Average concentrations of pollutants (µg/l) in runoff from urban and rural roads

Type of Pollutant	**Urban**	**Rural**
Total suspended solids	142.000	41.000
Volatile suspended solids	39.000	12.000
Total Organic Carbon	25.000	8.000
Chemical Oxygen Demand (COD)	114.000	49.000
Nitrate + Nitrite	760	570
Total nitrogen (Total Kjeldhal Nitrogen)	1.830	870
Phosphorus as PO_4	400	160
Cu (Total Copper)	54	22
Pb (Total Lead)	400	80

Source: http://lakes.chebucto.org/SWT/swt.html

Back to Brazilian reality, Daniel et al. (2002) investigated the relation between the level of urbanization and water quality parameters for ten sub-basins in the Piracicaba River basin (São Paulo State). The following correlations were found: i) – UA (numerical value of the urban area) *versus* dissolved oxygen: correlation coefficient of 0.82 (inverse correlation between the parameters); ii) – UA *versus* dissolved inorganic carbon: correlation coefficient of 0.91 (direct correlation between the parameters); and iii) – UA *versus* electric conductivity: correlation coefficient of 0.93 (direct correlation between the parameters). This is an interesting finding which attests to the effect of urbanization on water quality.

Considering urban soil and the source of sediments and total solids, it is worth keeping in mind that the soil in the urban perimeter has various functions, i.e., it is the support and source of material for civil works; it sustains urban and suburban agriculture and green areas; it serves as a medium for the waste disposal and for the storage and filtering of superficial waters (Pedron et al., 2004). The anthropic influence on urban soils causes morphological changes and, in many cases, the superficial horizon is no longer visible, having been removed in bulldozed areas. In landfills, on the other hand, there is a superimposition of surface layers, with distinct and artificial layers resulting from the introduction of removed soil or the disposal of construction debris. Such layers present irregular or discontinued transitions, precisely because of the addition of exogenous materials. The predominating erosion in urban areas is a consequence of the concentration of runoffs, originating mainly from deficiencies in drainage systems (Lloret Ramos, 1995).

Brazil expands its “internal boundaries” with regional development projects, such as the construction of towns in heretofore little impacted environments. That is the case of the capital of the state of Tocantins, the city of Palmas, which is still in the stage of intense construction. The study of Palmas’s urban basins offers a good opportunity to observe the evolution of the anthropic impact on a “natural” area, pinpointing moments when decision-making and specific actions cause positive or negative effects on the quantity of sediments generated and on the quality of local waters. This knowledge allows (ideally, albeit depending on political will) for the adoption of immediate corrections, in the case of deleterious effects, to avoid their propagation. Because of the rapid pace of urbanization, public services are not always timely in meeting demands, thus generating a variety of problems. Problems of a typically demographic nature have already been reported: lack of potable water in the drier periods of years marked by strong droughts, accumulation of solid residues in inappropriate locales, flooding of streets during strong and prolonged rains, and the appearance of large scale erosion (collapse caused by undermining waters). The municipality of Palmas has a Master Plan (which is followed especially in the establishment of neighborhoods and the construction of the city’s streets), but difficulties attending its execution lead to related problems. Additional studies are needed to generate information aimed at improving the quality of local life. In this study, we present a Map of Expected Soil Loss and data on the relation between erosion and the transport of sediments to the microbasin of the Água Fria Creek, inserted in the central area of the municipality of Palmas, state of Tocantins. Additional details are given in Silva & Schulz (2005).

LOCATION AND ENVIRONMENTAL CHARACTERIZATION

The Água Fria Creek microbasin is located in Palmas, the capital of the state of Tocantins, between the meridians of 48° 16' and 48° 23' longitude west and 10° 03' and 10° 20' latitude south (D.S.G., 1979) (Figure 1). Its average altitude is 250 m in the area of the Master Plan, which covers 16,764.10 ha, about 8% of the municipality's total area.

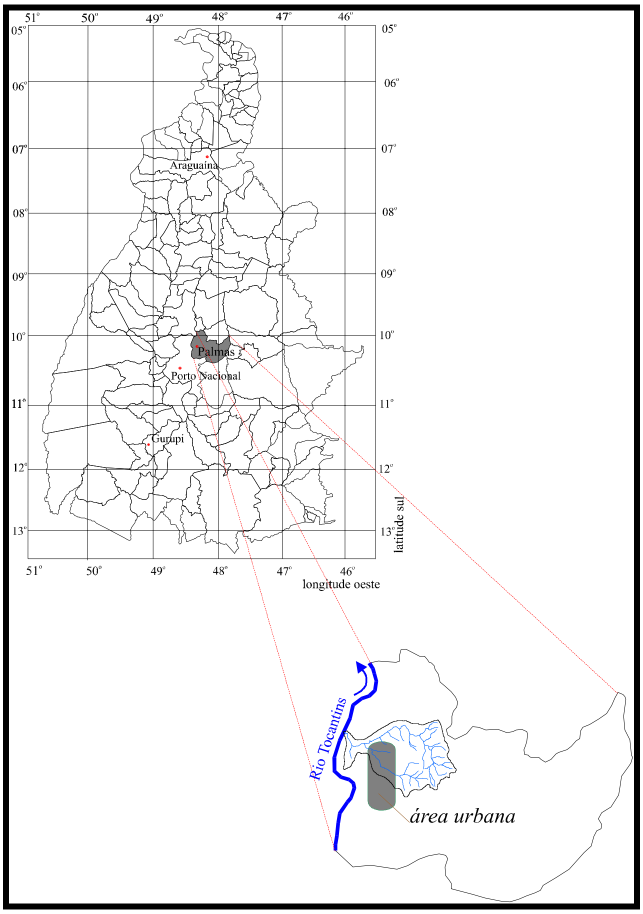

Figure 1 – Location of the Municipality of Palmas and its urban area in the state of Tocantins. Hydrographic profile and perimeter of the Água Fria Creek river basin (no scale)

The mean annual temperature (Nimer, 1979) is about 24°C and the average annual rainfall is approximately 1,300 mm, varying little from one year to another. The climate, according to Köeppen's classification, is of the Aw type (humid tropical with dry winters). The rainfall is distributed irregularly on a seasonal basis: more than 85% of the total annual rainfall generally occurs between the months of November and March. The geological foundation displays three major lithological groups in the area: i) the Goiano Complex predominates in the more escarped portion of the study area, with rocks of an essentially crystalline nature; ii) the Serra Grande Formation predominates in the softly undulating to undulating part of the topography; and iii) the Pimenteiras Formation predominates in the flat or gently undulating part of the topography. The rocks of the two latter formations are of a sedimentary nature (RadamBrasil, 1981). The urbanized area of the municipality of Palmas, situated along the banks of the Tocantins River, comprises plains and fluvial terraces subject to periodic flooding, and areas with flat-topped relief and drainage depths separated by flat-bottomed valleys. The Serra do Lajeado and its surroundings are characterized by surfaces of tabular, flat structures, their tops coinciding with the geological structure, limited by escarpments and reworked by pediplane processes (RadamBrasil, 1981). The topography of the microbasin under study (see 3D digital format in Silva & Schulz, 2000) shows a relief of topographical movement concentrated in the high parts of the basin and the rest undulating gently.

The microbasin is drained by three main canals: the Suçuapara creek (sub-basins S1 and S2 in Figure 2), the Brejo Comprido creek (sub-basins BC1, BC2 and BC3), and the Água Fria creek (sub-basins AF1, AF2 and AF3), which is larger and gives the basin its name. The main springs feeding the Água Fria stream are located in the escarped regions of the Serra do Lajeado, in the high part of the microbasin. The Brejo Comprido creek also springs from a steeply sloping region, but of a lower altitude. In contrast, the only spring feeding the Suçuapara creek is situated in a flat region inside the area of the Palmas Master Plan. The Suçuapara creek is a tributary of the Brejo Comprido creek, which, in turn, flows into the Água Fria stream, which empties into the Tocantins River. The classes of soil occurring here are (Ranzini, 1998): indiscriminate gleysoil occupying 7.6% of the area; indiscriminate concretionary – 27.8%; clayey dark red latosol – 21.8%; medium textured dark red latosol – 8.4%, cambisoil – 8.0%, litholic neosoil – 10.3%; and lastly, an area of exposed rock – 1.0%.

According to RadamBrasil (1981), the predominant vegetation is Cerrado (savannah-like vegetation), and there are also areas with sparse arboreal vegetation (savannah or bare country) and dense arboreal vegetation (Cerradão) with gallery forests. Then there are the slope forests, which are more concentrated at the foot of the Serra do Lajeado, formed mostly by dense arboreal vegetation that suffers the influence of drought in the autumn and winter months. The soil coverage map produced by Silva (1999) showed the occurrence of eleven classes of coverage: forest on 21.6% of the area; water bodies – 0.2%; urban grass – 0.7%; buildings – 0.3%; paving – 0.4%; exposed soil – 1.2%; stunted arboreal vegetation – 23.5%; sparse grassland – 26.2%; exposed rock – 1.0%; burned area – 6.7%; and low grassy groundcover – 18.2%. Today, the creation of the "Luis Eduardo Magalhães" reservoir has left part of the municipality flooded and these percentages must be updated on new soil usage maps.

MATERIAL AND METHODS

Silva (1999) gives a detailed description of the methodology employed in this study to draw up the map of expected soil loss, which was based on the use of geoprocessing and on water samplings conducted in the field, followed by laboratory analyses. The activities are summarized below. We followed the method proposed by Wischmeyer & Smith (1978), which defines the Universal Soil Loss Equation (USLE), presented in its simplest form as:

$$A = R.K.L.S.C.P \qquad (1)$$

In this equation, A is the soil loss calculated per area unit (in $t.ha^{-1}.year^{-1}$), R is the rainfall erosion factor (in $MegaJoule.mm.ha^{-1}.h^{-1}.year^{-1}$), K is the soil's erodibility (in $t.ha.h.ha^{-1}.MJ^{-1}.mm^{-1}$), L is the slope length factor, S is the declivity factor, C is the soil coverage factor, and P is the conservationist practice factor. The last four factors are undimensional. Each of these factors was assessed separately, as described below.

i) R factor: At the time this work was done Palmas had no erosion data. So R was calculated by the arithmetical average method (Garcez, 1967), using annual average erosiveness data from the municipalities of Porto Nacional, Miracema do Tocantins and Fátima. Because the study area is small (16,764.10 ha), the single value of R = 6.049,33 $MJ.mm.ha^{-1}.h^{-1}.year^{-1}$ was adopted.

ii) Relief, topography and L and S factors: A numerical model was made of the terrain in the study area. The steps are described in detail, with the respective maps, in Silva & Schulz (2000). The distribution of the L and S factors clearly affects the soil loss distribution.

iii) Soil map and K factor: We used the soil map of the municipality of Palmas, drawn up by Ranzani (1998) on a scale of 1:100,000, which was digitalized and georeferenced. The erodibility of each soil was estimated by Mitchell & Bubenzer's method (1980), which considers the soil's texture and content of organic matter (%). Using the resources of the IDRISI version 2.0 for Windows software (Eastman, 1995), we attributed the value of the K factor to each type of soil, generating a "K factor" file later used to calculate the soil loss values.

iv) C factor: A soil coverage map of the basin was first drawn up on a scale of 1:100,000 using an image from INPE – National Space Research Institute, which is a multispectral image taken by the Landsat 5 satellite (TM3, TM4 and TM5 bands) on July 27, 1998. This image was enhanced, geometrically corrected and later classified, following the recommendations of Novo (1992) and Valério Filho (1994). The type of coverage was considered in the parameterization of the C factor. The values of each cover were obtained from the studies cited in the References section of this paper.

v) P factor: The P=1.0 factor was adopted for the entire basin, since none of the rural properties engage in any kind of conservation practice, according to technicians of the Tocantins State Agriculture Federation (FAET), who researched the region between 1997 and 1998. The urban area also lacks any activity and/or civil works to deter soil losses (*in loco* visits).

Two factors (R and P) are constant (influencing the overall expected soil loss, but not its distribution). The other four factors vary spatially, generating distribution maps as well. Generically, equation 1 generates punctual values and can be expressed as:

$$\text{Map(A)} = \text{R Constant.map (K Factor).map (LS Factor).map (C Factor). P Constant} \qquad (2)$$

This phase of the work was also done with the IDRISI software (“Image Calculator” command), after which the map was reclassified to facilitate its interpretation. This procedure concluded the drawing of the Expected Soil Loss map.

Within the context of the transportation of sediments and evaluation of total transported solids, study sections had to be established, outflows calculated, field collections made, and collected material analyzed. The steps involved are described below.

i) Determination of sub-basins: Eight sections were selected to make up the sedimentometric network and to take field readings and samplings, three in the Água Fria stream, three in the Brejo Comprido creek, and two in the Suçuapara creek. This selection required visits, conversations with residents/frequenters, and aerial photographs. The selection criteria were: accessibility, shape and appearance of the drainage canal (for the collection, measurement and calculation of outflow), and representativeness of the spot in relation to its drainage area (sub-basin). The sections were plotted on the topographical chart and the sub-basins were digitalized based on the hydrographic profile and the level curves. Figure 2 illustrates this work. The collections and calculation of outflows were done monthly, from February 1998 to February 1999, on the same day of each month.

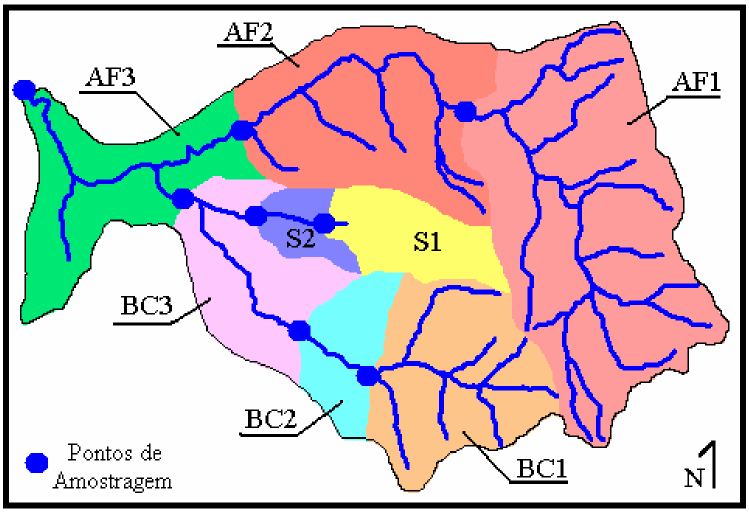

Figure 2 – Division of the Água Fria stream microbasin into its eight sub-basins and their respective sampling points

ii) Outflow estimate: Two cross-sections per stretch of river were used, and the distance between them was measured. In each section, the surface water depth was measured at 0.50 m intervals, starting from one of the banks. These measurements were used to calculate the areas between the measured verticals and the areas of both the cross-sections (FAO, 1993). The average area for the stretch is the arithmetic average of the area of the two sections. The water velocity was measured by the floater method (made possible by the small dimensions and geometry of the stretches). The floater was always launched upstream of the stretch, so that acceleration and oscillation effects were suppressed before it passed through the first section. The travel time between the sections was recorded, as described in Pião (1995). Dividing the distance between the sections by the travel time yields the experimental velocity. More than ten velocity experiments were conducted in each stretch, and their arithmetical average used. The average velocity and average area of the sections indicate the net outflow of the canal in that stretch.

iii) Physical parameters for sediment concentration and water quality: The water samples were taken to the laboratories of the University of Tocantins (Unitins), where their turbidity and total solids were quantified. The turbidity was identified in NTU (Nephelometric Turbidity Units), using a turbidimeter. The total solids were estimated from three 500-ml water samples, using the vertical integration method described by Carvalho (1994). The samples were homogenized and 100 ml from each sample poured into pre-weighed containers, which were placed in an oven at 103°C to evaporate until their weight stabilized. They were then weighed again and the weight of the empty container subtracted, yielding the total solids content of the water sample, according to the methodology cited in Pião (1995) and described in greater detail by Eaton et al. (1995). The term “total solids” used here refers to the dissolved and particulate fractions in suspension.

iv) Solid discharge and liquid production of sediments for sub-basins and for the total area: Based on the outflows from the stretches, the concentrations of sediment and complementary information obtained monthly for the collection sections, the total solids discharge was calculated by Colby’s simplified method, as cited by Carvalho (1994) and Tavares (1986), in tons of sediments per day (t/day). The monthly total solids flow for each sub-basin was then estimated using the arithmetical average of the data of that month and the following one, multiplied by the number of days between the two collections. The product of the subtraction of what exited from the sub-basin from what entered it was considered. The net annual solid outflow was determined by adding up the positive values of the twelve collection months. The negative values, which indicate deposition of sediment in the sub-basin, were also added up separately to identify the total deposition in the sub-basin throughout the year. A measurement taken in a transversal section quantifies the sediment carried away in the drainage area upstream of that section. To find the quantity of sediment removed and carried away from a stretch of the basin or sub-basin, we followed the description given by Lajczack & Jansson (1993). A sub-basin's net annual production of sediments is computed by area unit.

RESULTS AND DISCUSSION

The Expected Soil Loss map (Figure 3) shows current erosion as a function of current usage, occupation, coverage pattern and management. The classes and their interpretation were taken from Carvalho (1994). Note that class 1 (< 10 $t.ha^{-1}.year^{-1}$) occupies 76.7% of the total area. Class 6, showing high indices of soil loss (> 200 $t.ha^{-1}.year^{-1}$), occurred in 1.8% of the entire basin. Two classes coexist in the urban region (see Figures 1 and 3), but classes 2 and 3 occur principally in the regions of denser occupation with flat relief. Class 4 occurs where the occupation rate is high and the relief gently undulating.

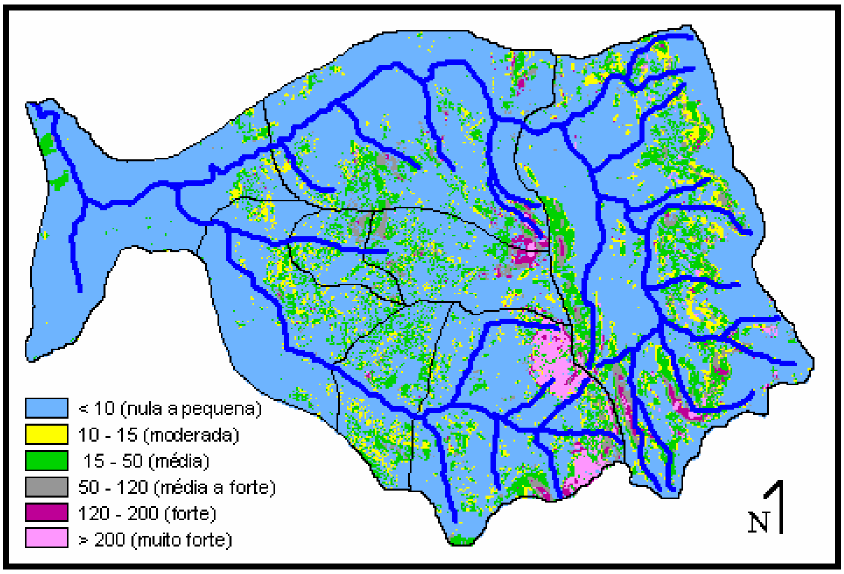

Figure 3 – Expected Soil Loss Map for the Água Fria river basin (Palmas, TO).

Values in $t.ha^{-1}.year^{-1}$

The "null and small" class indicates an annual erosion rate within the limits of sustainability. It should be pointed out that this classification indicates impacts of laminary erosion. The "moderate" class indicates soil use and management and/or soil cover that lead to a slightly higher soil loss rate than the soil formation rate, but do not severely compromise this natural resource. Although this erosion is moderate, something should be done to reduce the loss to sustainable limits (the reference value is 10 $t.ha^{-1}.year^{-1}$). The other classes indicate loss rates far above tolerable limits, requiring rapid action and investments in soil conservation practices. The "very strong" class is mainly associated with the strongly moving relief, as was also observed by Silva (1997) in the Serra dos Parecis (state of Rondônia). This class is concentrated in the region of the headwaters of Brejo Comprido creek and some of its tributaries (southern portion of the basin, on the eastern side of the urban area – see Figure 1), and also occurs in stretches of the high regions of the slopes of the springs of some of the tributaries of Água Fria creek (eastern and northeastern portions of the study area).

The urban perimeter (mid-southern portion of the basin) shows blotches of “medium” and “strong” classes associated mainly with variations in the ***C*** factor of the USLE, i.e., the use of space and the soil cover in the period under study. This area consisted mainly of low grassy groundcover and, to a lesser extent, stunted arboreal vegetation, possibly resulting from burning. After “cleaning”, the land was often left unprotected and subject to the erosive action of rain. It was found that, during droughts, the vegetation suffers from lack of water and part of it succumbs, especially the smaller vegetation (grasses, for instance). The reduction in soil cover exposes it naturally to erosion by rain. The arrival of the first rains cause the vegetation to spring up again, gradually recovering the ground and forming a new protective cover for the soil’s surface. Landscape analyses made by flying over the municipality of Palmas revealed that the land use is more disordered in the peripheral regions, which partly explains the occurrence of blotches of severe soil loss in the urban area.

The data on turbidity and total solids indicate that, in general, the surface waters of the drainage canals of Água Fria creek were not much altered during the period under study. As indicated in Figure 4, the highest annual average value was 38.9 NTU in basin AF3, which is low, according to Mota (1995). There were a few punctual cases with turbidity values considered high (e.g., above 100 NTU). The total solids revealed a different situation (Figure 5), with high values in some sub-basins in the rainy season (especially in the initial phase of the study period), but decreasing considerably in the dry season. The values presented here vary greatly, a fact that was also observed by Gomes & Chaudhry in urban creeks in the municipality of São Carlos (SP) (Mota, 1995). This parameter suggests that the microbasin’s surface waters are already beginning to feel the effects of the urbanization of Palmas. For the present study, Silva (1999) located factors that inhibit more deleterious effects. Such is the case of the important participation of riverbank forests within the context of the protection of water resources, especially in the stretches of canals cutting through Palmas’ urban perimeter. This is illustrated by the fact that the months of August, September and October (for the AF1 sub-basin) and September and October (AF2 sub-basin) do not generate data, because the two sub-basins are not perennial, i.e., they dry up during strong droughts.

These numbers allow us to estimate that, during the study period, approximately 138,000 tons of sediment were exported to the waters of Tocantins River. The specific production of sediment was about 827 $t.km^{-2}.year^{-1}$. Enger & Smith (in Silva, 1999) indicate a lower value (612 $t.km^{-2}.year^{-1}$) for the Amazon region. M.M.A. (1997) cites much lower values for the

Paraguay River basins studied there (from 66 to 205 t.km^{-2}.year^{-1}). By comparison with the Amazon region, one can infer that, during the study period, the surroundings of the Água Fria microbasin were already undergoing greater than average erosion, due not only to urban expansion, although that is a major cause. The data also allow one to infer that erosion was still not affecting, to any substantial degree, the quality of the waters of the microbasin's drainage system. Possibly, since most of the riverbank forests along the drainage canals were still relatively well preserved and doing their job of filtering into these drainage canals, that may have been a positive factor to mitigate the effects of erosion on the water quality.

As additional information, the literature contains information about problems and preventive and/or corrective measures for urban erosion, such as can be found in Nelson & Booth (2002), Esteves (1988), http://www7.caret.cam.ac.uk/guide_suds.htm or Richter (http://www.4sos.org/wssupport/ws_rest/Urban-Runoff.doc).

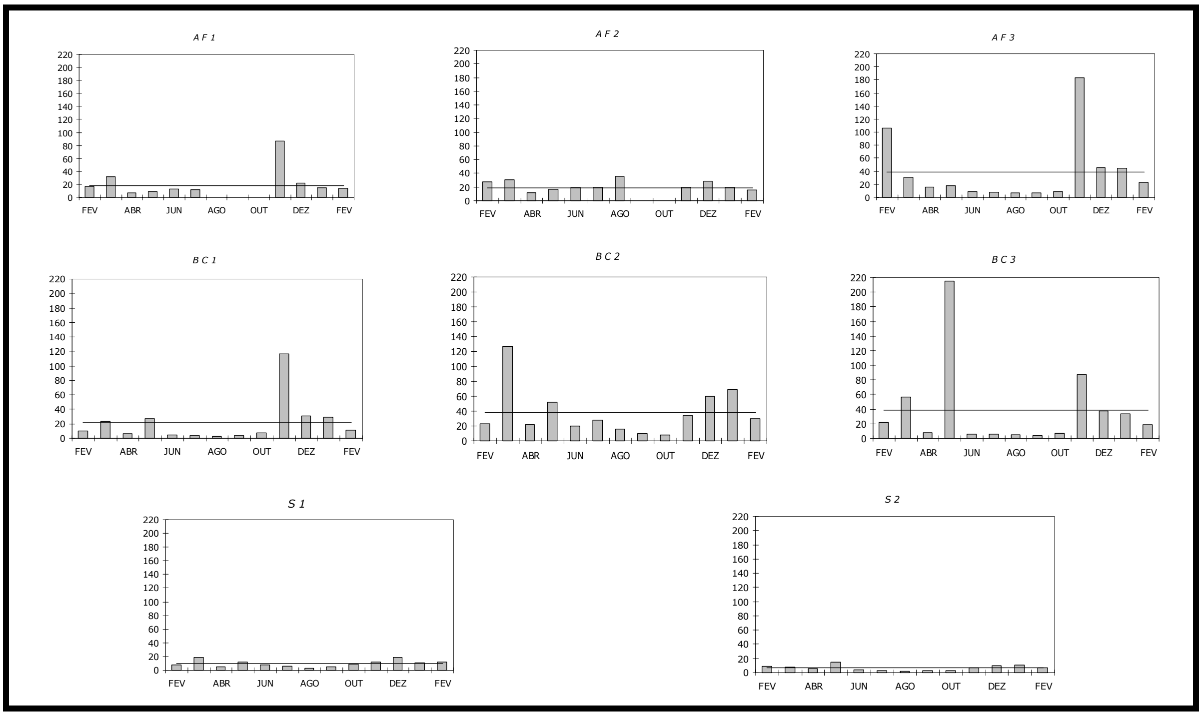

Figure 4 – Turbidity values (in NTU) for the eight sub-basins during the period under study. Horizontal bars indicate mean values (year).

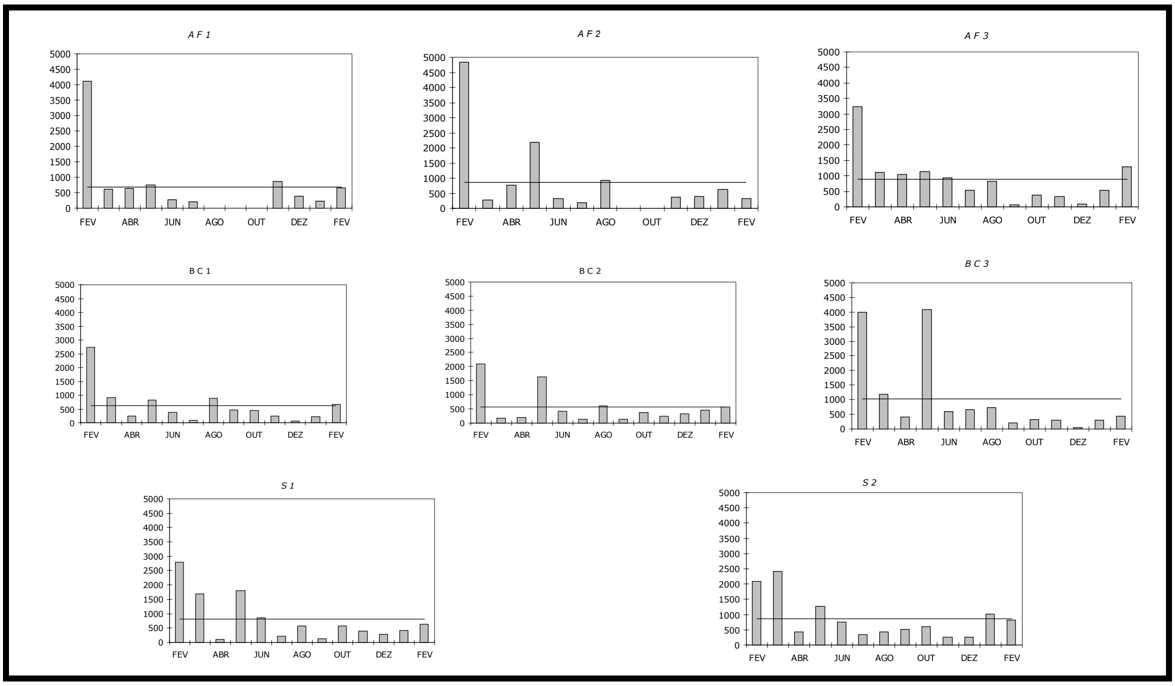

Figure 5 – Total solids values (in mg/l) for the eight sub-basins during the period under study

Horizontal bars indicate mean values (year).

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