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Land Use in the Amazon: Soil Erosion, Sedimentation, and the Samuel Dam

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LAND USE IN THE AMAZON: SOIL EROSION, SEDIMENTATION, AND THE SAMUEL DAM

Doug Graham *received a M.A. in Geography in December of 1986. This paper is a summary of his thesis entitled "The Samuel Dam: Land Use, Soil Erosion, and Sedimentation in Amazonia." Graham conducted field research in Brazil during the Summer of 1985, with funding from the Tinker Foundation and the Amazon Research and Training Program. His immediate plans are to continue his training in Geography at the University of Wisconsin—Madison.*

Introduction

This paper examines land use and soil erosion in the Jamarí River basin, located in the Brazilian state of Rondônia (Figure 1). The Jamarí River drains a remote area currently undergoing rapid colonization. In its watershed lies a sizeable portion of Brazil's Northwest Integrated Development Program (Polonoroeste), which every year attracts massive waves of migrant farmers in search of land and employment. A consequence of this settlement activity is an unprecedented, near exponential rate of deforestation (Fearnside 1985a, 1985b). As an ever-increasing area of the Jamarí basin is being exposed to the heavy rainfall of the region, a corresponding increase in soil loss is likely to occur. The prospect of increased rates of soil erosion and sedimentation becomes more critical when brought to bear on the useful life of the Samuel Dam, presently under construction on the Jamarí.

The objective of this study is to quantify the amount of soil loss in the Jamarí basin during the six-year period of colonization between 1978 and 1983. In addition, the relationship between gross erosion in the basin and the sediment load of the river is determined, as well as the impact of land use on this relationship. From this information, an assessment is then made of the impact of land use on the life of the Samuel Dam.

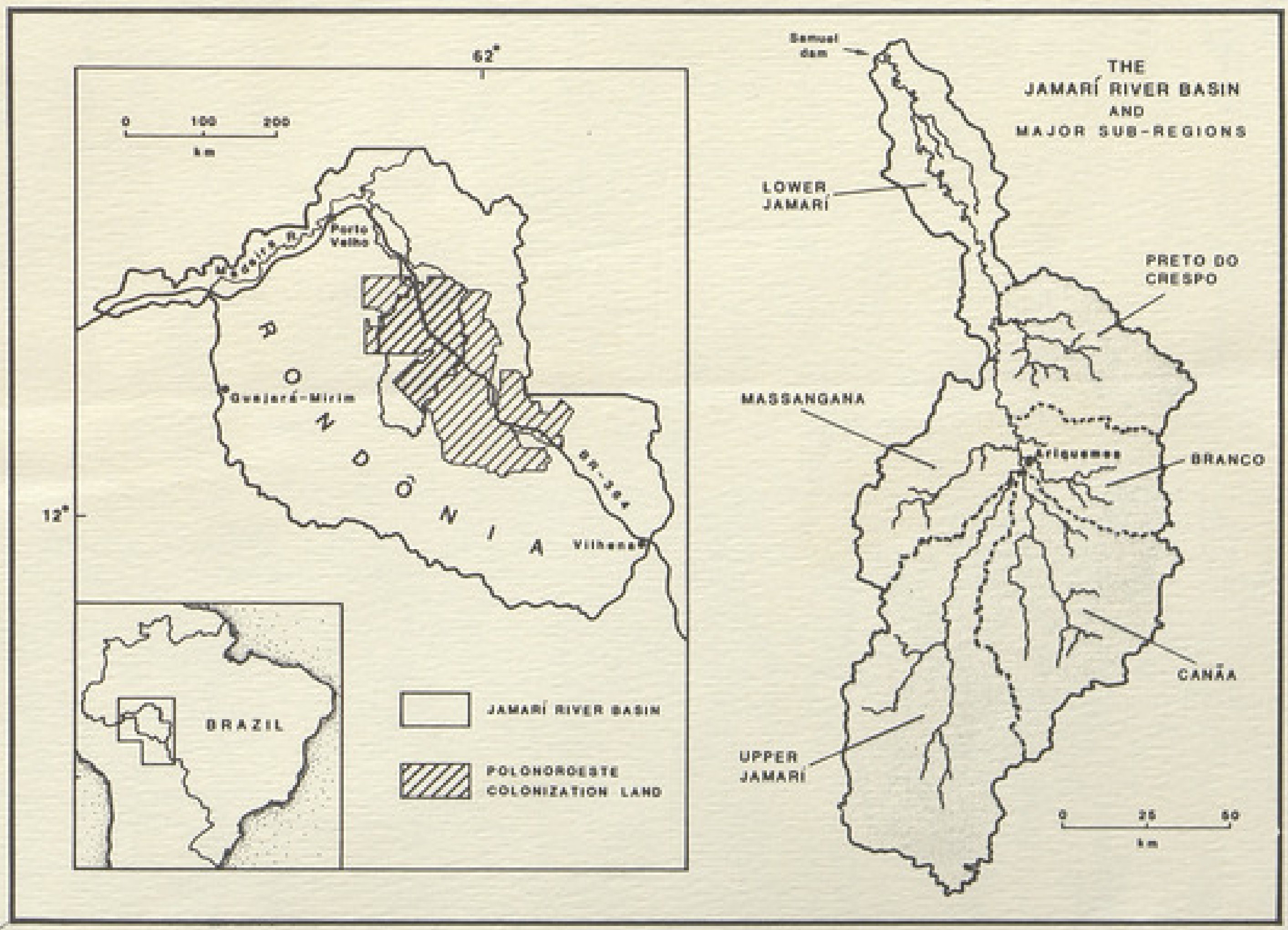


Figure 1. The Jamarí River basin, its major sub-regions, and Polonoroeste colonization land.

Procedure

Soil erosion estimates are obtained through the use of the Universal Soil Loss Equation (USLE). The USLE estimates gross erosion by assigning a numerical coefficient to those landscape variables that influence soil loss, and is presented in the following form

$$A = R \times K \times L \times S \times C \times P$$

where A is the total soil loss in metric tons per hectare; R is rainfall erosivity; K is the soil erodibility factor—a coefficient which reflects the liability of a given soil type to erosion; L and S are ratios comparing soil loss with that from a standard field of specified length (22.6 meters) and slope (9 per cent); C is the crop management factor—a ratio that compares soil loss with that from a bare field devoid of vegetative protection; and P is the conservation practice factor—a ratio which compares soil loss with that from a field with no soil conservation practices (Wischmeier and Smith 1978).

The procedure for estimating sediment production in the Jamarí basin involves a two-sided approach. From one end, the USLE and its component factors are used to estimate gross erosion on land. From the other, the fraction of this figure which makes its way to the Samuel Dam is derived by plotting the river's discharge against sediment load to form a rating curve (Figure 2).

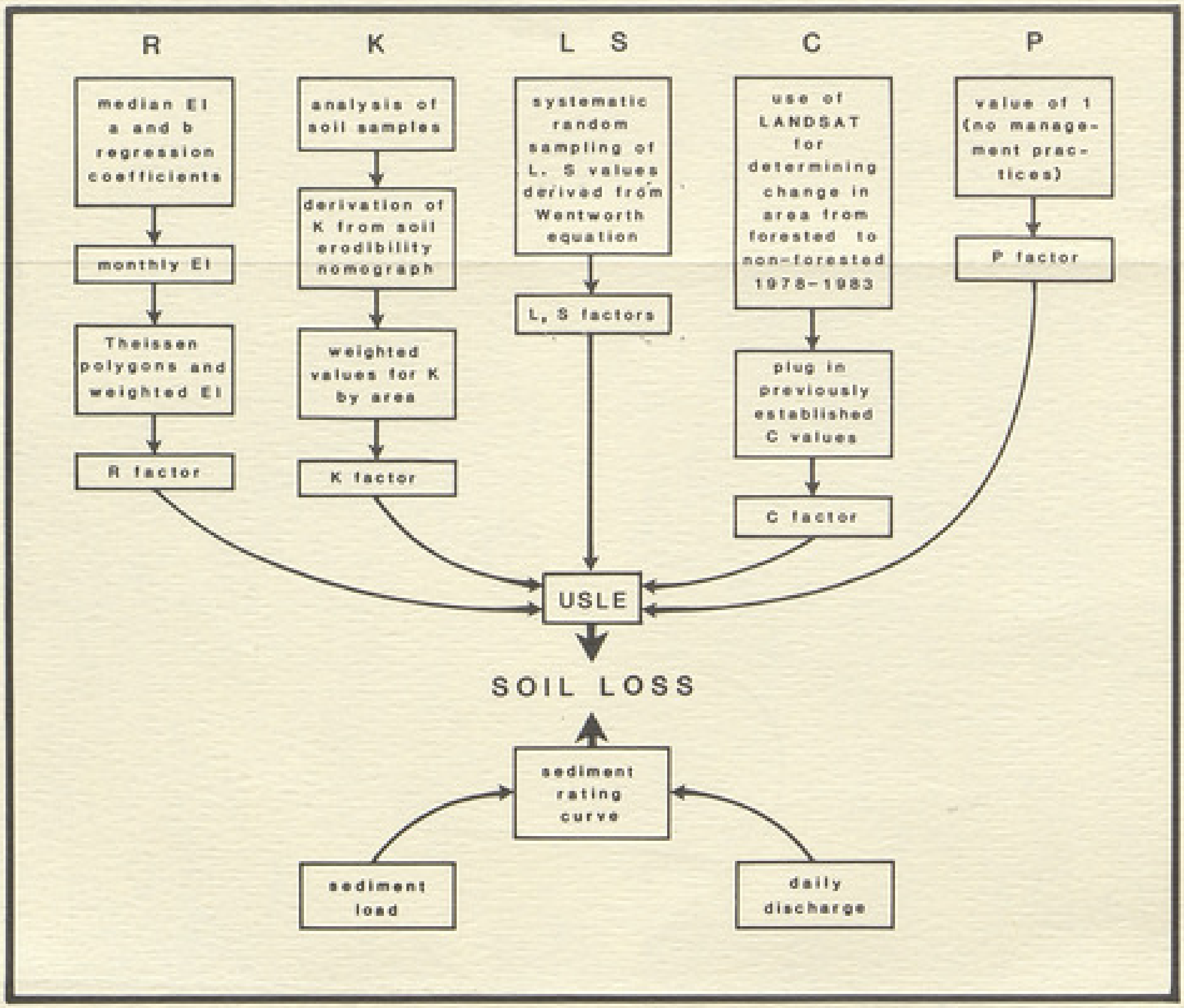


Figure 2. The two-sided approach to estimating soil loss using the USLE and a sediment rating curve.

The R factor in the USLE is directly proportional to a rainstorm parameter termed the erosion index (EI). This index is the product of the total energy of a rainfall event (E) and the maximum 30 minute intensity (I_{30}) occuring during the event.

$$EI = E \times I_{30}$$

where E is in MJ/ha, I_{30} is in mm/hr, and EI is in MJ x mm/ha x hr. (Wischmeier and Smith 1978).

The above equation requires hourly rainfall data. In the Jamarí basin, however, only daily rainfall data are available. For such cases, Richardson et al. (1983) developed a method for calculating EI by treating daily rainfall (P) as an individual storm event

$$EI = aP^b + e$$

where aP^b is the deterministic component, e is the stochastic random component (the difference between the observed EI for a particular event and the EI predicted using aP^b), and a and b are equation parameters. The EI values, calculated from data at six different meteorological stations, are weighted by area using Thiessen polygons.

For the K factor, information on structure, grain size, percent sand, silt, and clay is obtained from soil samples taken from within the basin. The soil erodibility nomograph of Wischmeier and Smith (1978) is then used to derive K values by soil type. These values are then weighed by the total area of each soil type in the basin.

The LS factor is obtained by first randomly generating 100 x,y coordinates within the basin. At each of these locations 4 measurements are taken of slope and one of slope length. The measurements of slope are carried out by employing topographic maps in conjunction with the following equation by Wentworth (1930).

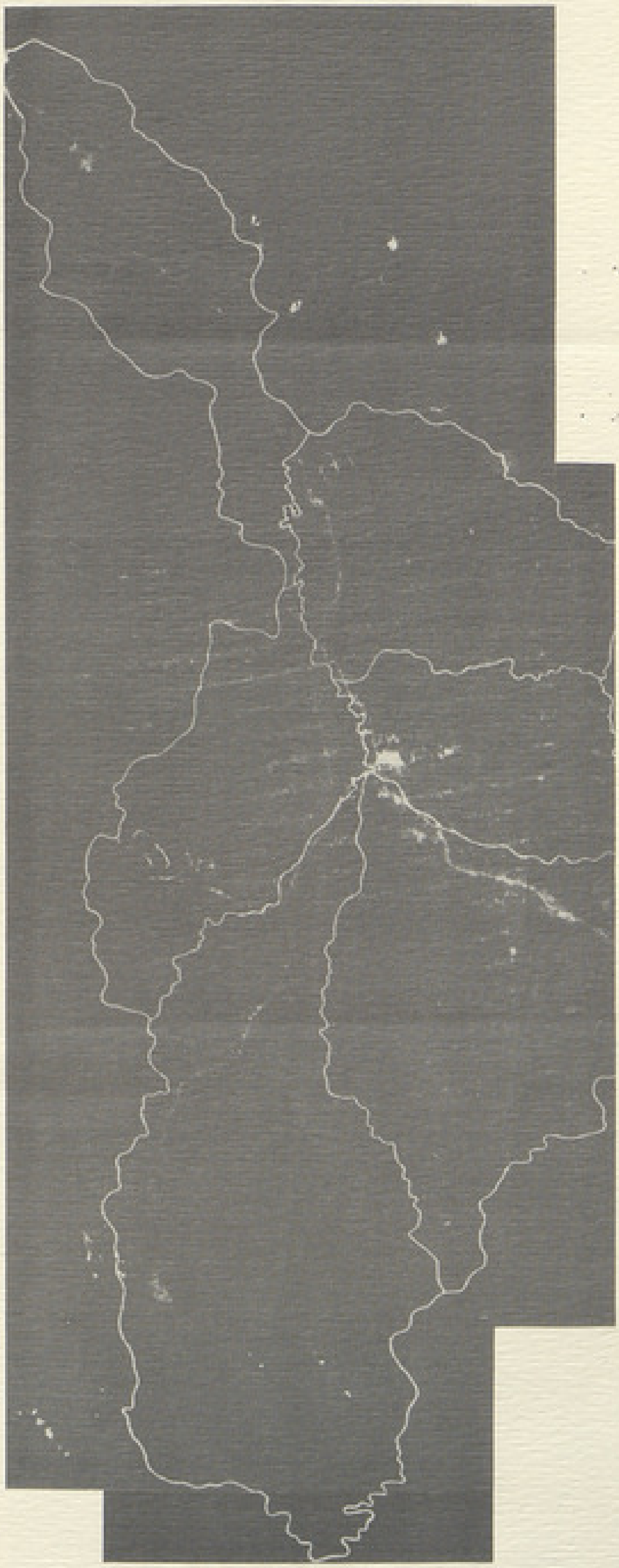
$$\text{slope (per cent)} = (F \times I) / 636.6 \times 100$$

where F equals the contour frequency (the number of contour lines per kilometer), I equals the contour interval in meters, and

636.6 is a constant. For slope length, each of the 100 coordinates includes a measurement from the coordinate to the nearest indicated peak elevation on the map. The values of average slope and slope gradient are then entered into the LS formula of Wischmeier and Smith (1978).

The C factor values for canopy cover are also obtained from Wischmeier and Smith (1978). The base C value, that which describes the majority of the basin's canopy cover under natural conditions, is .001—that of a mature rainforest. Where this condition has been altered in a given area and replaced with roads, pastures, crops, or mining, the C factor is changed accordingly.

The change in area of each of these canopy conditions is documented by satellite imagery. Three scenes from LANDSAT 4 in 1978 and three scenes in 1983 are used to bracket the 6 year period under study (Figure 3). The increase in cleared area during this period is shown in TABLE 1.



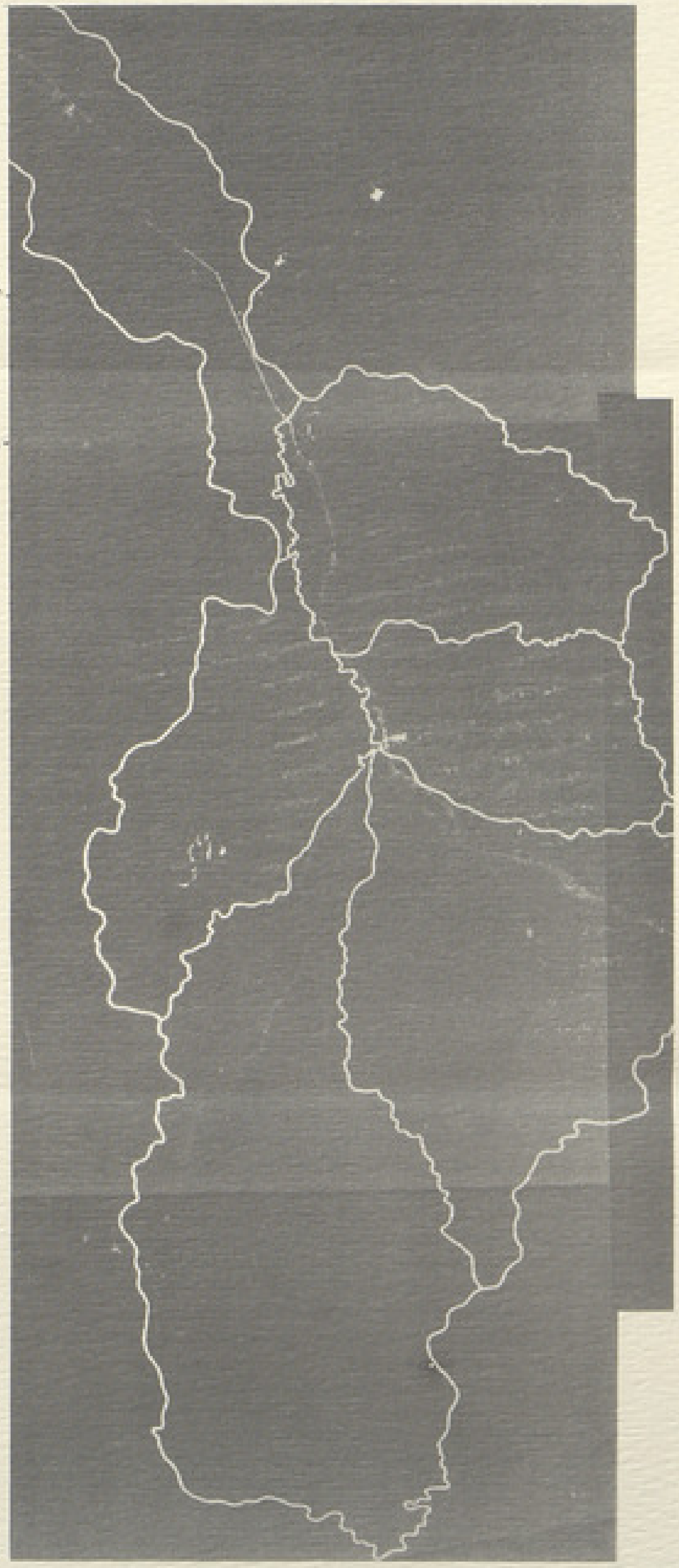


Figure 3. LANDSAT MSS band 5 images showing deforested areas (lighter-colored hatchmarks) in the Jamari basin and its subregions in 1978 (left) and 1983 (right). Scale = *(approx.)* 1:1,040,000

TABLE 1
DEFORESTATION FIGURES FOR THE JAMARÍ BASIN
BETWEEN 1978 AND 1983

Sub Region	Total Area (km^2)	Cleared Area (km^2) 1978	Cleared Area (km^2) 1983	Increase in Cleared Area (km^2) '78 to '83	Per cent Increase From '78 to '83
Lower Jamarí	2,010	.29	73.69	73.40	25,310
Preto do Crespo	2,192	1.13	306.02	304.89	26,981
Branco	1,408	1.49	337.91	338.22	22,699
Massangana	1,905	.93	270.13	269.20	28,946
Canãa	3,140	1.17	452.85	451.68	38,605
Upper Jamarí	4,624	.40	211.73	211.33	52,832
Entire Basin	15,280	5.41	1,654.09	1,648.68	30,474

Since there are no soil conservation practices being used by the farmers in the basin, the P factor is given a value of 1, thus nullifying its effect on the USLE.

In order to estimate the percentage of the gross erosion in the basin that is delivered to the Samuel Dam, the discharge of the Jamarí River is plotted against its sediment load. The resultant point distribution is described by an equation in the following form: aQ^b, where Q is the discharge. This "best fit" regression line (the rating curve) is then used to generate annual values of sediment delivery.

Where gaps exist in the daily sediment record of the Jamarí River, a rating curve allows the estimation of sediment load based on the magnitude of the river's discharge. The values of daily and annual sediment employed in this analysis are derived from a rating curve constructed from paired observations of sediment and discharge provided by Eletronorte, the Brazilian power company's northern subsidiary.

For the year 1983, sediment data are as yet unavailable. Therefore the values of sediment delivery for that year are generated with discharge data from 1983, but with a and b parameters from the 1982 rating curve.

Results and Conclusions

By applying the USLE variables to the conditions in the Jamarí basin, annual gross erosion estimates are derived which, from 1978 to 1983, show a steady increase (TABLE II). This is commensurate with the decrease in forest cover during the same period.

TABLE II
VALUES OF SEDIMENT PRODUCTION IN THE JAMARÍ BASIN
BETWEEN 1978 AND 1983

Year	Gross Erosion (tons)	Sediment Delivered (tons)	Delivery Ratio
1978	614,063	25,417	.04
1979	704,697	50,566	.07
1980	739,183	9,696	.01
1981	823,555	97,438	.12
1982	1,279,808	32,543	.03
1983	906,285	54,643	.06

An independent measure of delivered sediment, estimated from the rating curve, also shows an increase, although less pronounced than that of gross erosion. This disparity may be due to the fact that the overall rating curve is based upon observations through the period 1978-1982. Estimation of similar rating curves based upon annual data (Figure 4) indicate that, for a given discharge, values of sediment for the early years of the study are overestimated by the overall curve while those toward the end tend to be underestimated, thus compressing the range of values and disguising the effects of land use change upon the sediment regime.

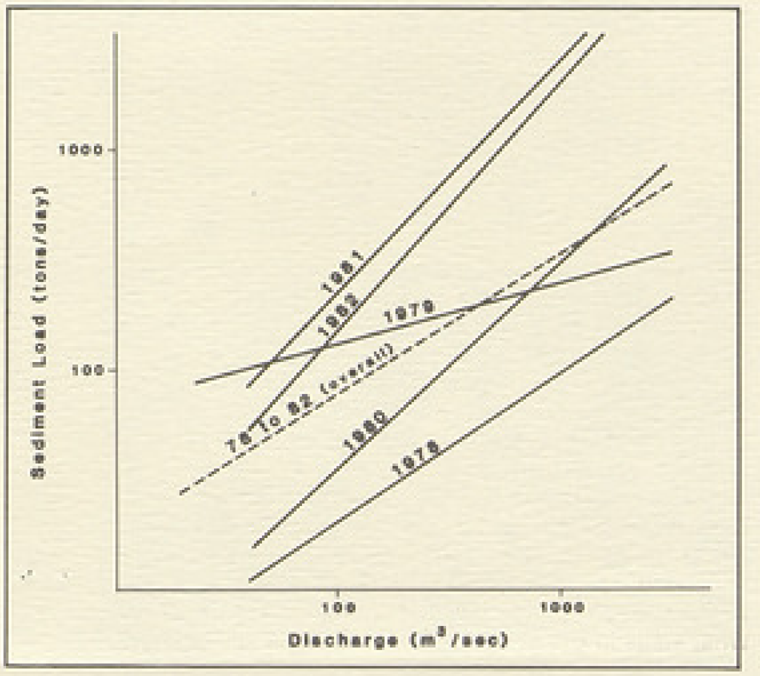


Figure 4. Individual annual rating curves for the Jamarí River. At the expense of losing seasonal information, breaking down the overall rating curve by year provides a temporal picture of the sediment regime.

Even so, considerably more sediment appears to be generated than is observed leaving the basin. This is to be expected since only a fraction of the gross erosion in a watershed is delivered downstream. The delivery ratio for the Jamarí basin varies within bounds frequently observed in basins of its size (USDA-SCS 1971). The annual fluctuation in these ratios is largely a function of the basin's topography, which is relatively flat over most of its area, thus allowing for numerous storage areas. During years of particularly heavy rainfall, these stored reserves of sediment are met by runoff of sufficient energy to transport them to the river system.

Given the constraints of limited resources and available data in the region, the present study represents the optimum scale at which such an analysis can be carried out. Indeed, the USLE, when applied on a broad scale, has the advantage of being more easily transferable from one region to another. In addition, for those areas in Amazonia where land use is characterized by large scale development projects (e.g., Carajás, Tucuruí, Polonoroeste), a concomitant large scale analysis is often more appropriate when examining natural processes on a more systemic level. Moreover, given the present rate and probable future course of deforestation in this region, it is important to have an easily operationalized tool which gives reliable results that can be acted upon before erosion damage becomes irreversible.

The obvious trade-off to the general scale approach is that the more detailed information is lost as it becomes lumped in aggregate form. One loses the more precise data, but total detail is not the objective here. As stated earlier, the objective of this study is to quantify the soil loss in the Jamarí basin and to determine its impact on the useful life of the Samuel Dam. A more deep-seated objective is to determine whether or not the USLE is an applicable and effective tool in such settings at the given scale. The answer lies in the values of sediment delivery, derived totally independently from the USLE. As stated earlier, the ratios of the two measurements, gross erosion and delivered sediment, are commensurate with a basin of the Jamarí's size. This indicates that, under the above conditions, the USLE meets the requirements of reliability while being applied on a large scale. Therefore the sediment figures in this study are quite valid provided they remain in their intended context: as a means of gaining insight into natural processes at the drainage basin level.

Although the forest clearing in some areas of the Jamarí basin is taking place at an alarming rate, from the standpoint of sediment delivery, the impact of land use on the useful life of the Samuel Dam remains to be felt. Even though the increase in cleared area from 1978 to 1983 is an incredible 30,474 per cent (TABLE I), in terms of area this increase amounts to only 10 per cent of the basin. Thus, in 1983, 90 per cent of the basin was still under forest cover. However, this ratio of cleared to forested area is likely to grow in coming years. For example, the completion in 1984 of paving operations on the BR-364 highway saw a marked influx of migrants and an unprecedented amount of deforestation. Although this lies beyond the time frame of the present analysis, it is reasonable to assume that in 1984 the increase in cleared area would be commensurate with (if not greater than) the rates found in this study.

The useful life of the Samuel Dam is projected to be 100 years (Eletronorte 1979). However, the various streamflow and sediment studies which form the basis for this projection do not take into account changes in watershed land use and soil erosion. Under present conditions this useful life appears safe, but if the ratio of cleared to forested land in the basin increases to the point where the forested area can no longer buffer the sediment being generated from the cleared area, an increase in sediment delivery to the dam will ensue. When this change will take place, and at what stage in the deforestation process, is still unknown.

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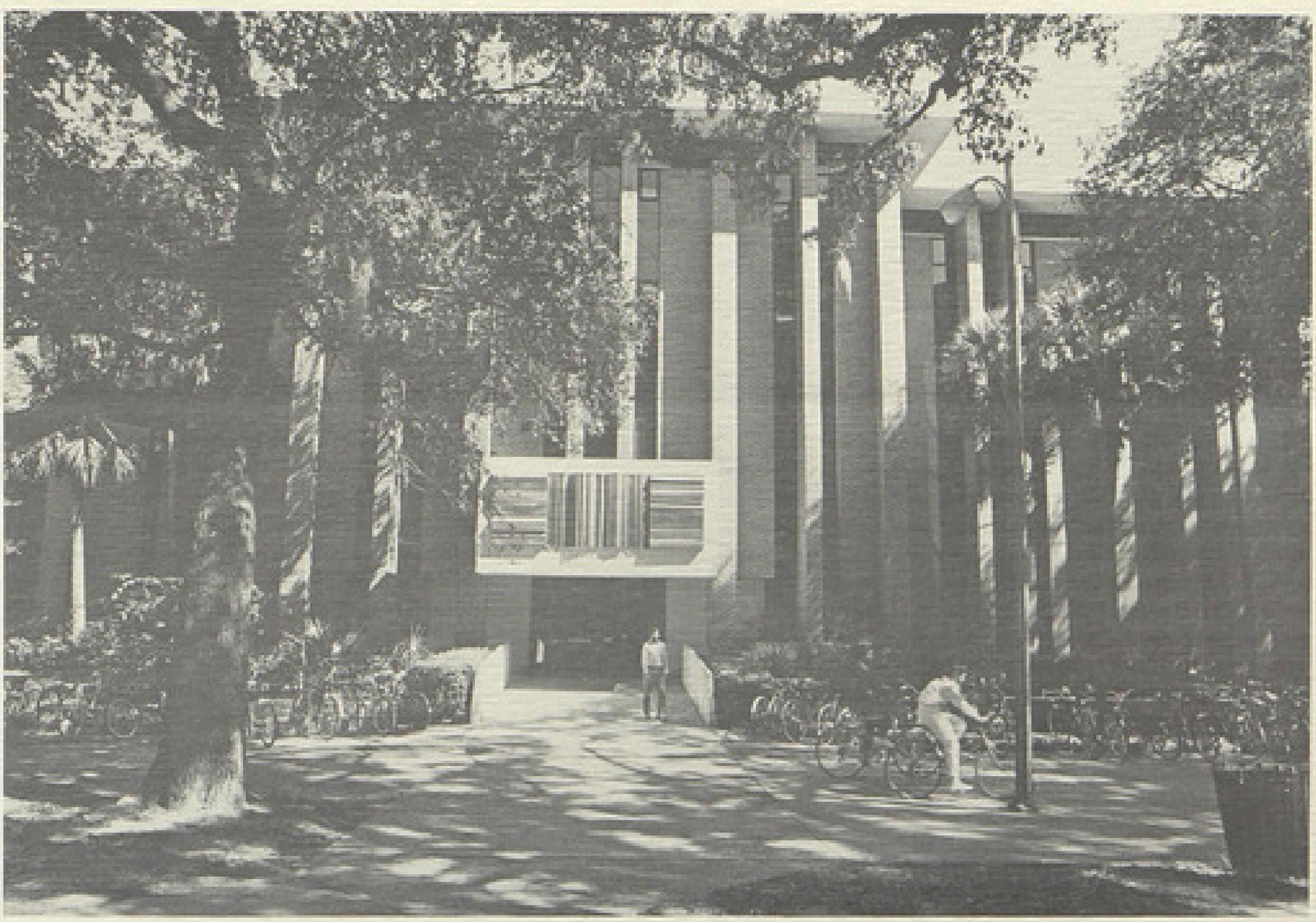
CLAS CONFERENCE

The Center for Latin American Studies announces its 36th annual conference on "The Jewish Presence in Latin America" to be held from February 22-25, 1987. This year's conference will be a collaborative effort with UF's Center for Jewish Studies and the Latin American Jewish Studies Association (LAJSA).

The Center for Jewish Studies was established at the University of Florida in 1973. It has grown considerably in scope and prestige since its founding. The Latin American Jewish Studies Association was formed in 1982 on the occasion of the tenth national LASA meeting in Washington, D.C. The February event will be LAJSA's Fourth Research Conference. It will continue the organization's tradition of alternating conferences between Jewish and Latin American auspices.

The conference will feature a variety of activities. "Latin American Jewish Literature" will be the first day's subject, focus-



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