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# COMPARISON OF THREE MODELS TO PREDICT ANNUAL SEDIMENT YIELD IN CARONI RIVER BASIN, VENEZUELA

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**Abstract:** Caroní River Basin is located in the south-eastern part of Venezuela; with an area of 92.000 km$^2$, 40% of which belongs to the main affluent, the Paragua River. Caroní basin is the source of 66% of energy of the country. About 85% of the hydro electrical energy is generated in Guri reservoir located in the lower part of the watershed. To take provisions to avoid the reservoir silting it is very important the study of sediment yield of the basin. In this paper result of three empirical sediment yield models: Langbein-Schumm, Universal Soil Loss Equation-USLE and Poesen, are compared with observed data from five sub basins with records of twenty to thirty years. Men values of sediment yield for low, middle and upper Caroní are of 27, 76, 17 t/km$^2$-year, respectively; and 46 and 78 t/km$^2$-year for low and upper Paragua sub basins are. Standard errors of estimates vary between 13 and 29 for Langbein-Schumm model; between 8 and 32 for USLE procedure; and between 9 and 79, for Poesen model. Sediment yield predictions by Langbein-Schumm model seem to the best in Caroní basin.

**Keywords:** sediment yield, soil erosion, soil loss, modeling of sediment yield



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## INTRODUCTION

Sediment delivery to river channels and reservoirs is the most problematic off-site consequence of soil erosion in catchments (Lenhart *et al.*, 2005). The input of sediment by erosion processes into water bodies results in high sediment deposition rates and frequent dredging operations (Verstraeten & Poesen, 1999).

Erosion models are technically capable of calculating the frequency and quantity of runoff and soil loss; nevertheless, arising question is whether the predictions are or not good enough (Jetten, 2003). Variability, and uncertainty associated with input parameter values, are probably the most important reasons why more complex models, in general, do not perform better than easy lumped regression-based models.

More complex models with better process descriptions should, in principle, be capable of better output predictions; however, they also require more input data, increasing often the magnitude of unknown uncertainty and associated error, which will be propagated through the model calculations deteriorating the quality of final results.

Comparison studies of Zhang *et al.* (1996) with those of Rise *et al.* (1993), Bathurst et al (1998), Brochot and Meunier (1995), suggest that additional error resulting from introducing additional parameters often outweighs the potential improvement of prediction due to a better process description.

This investigation aims to compare by means of standard error of the estimates, sediment yield estimated by three empirical lumped models: Langbein-Schumm, Universal Soil Loss Equation (USLE) and Poesen, with sediment yield measured in five sub basins of Caroní River, Venezuela.

Caroní River is located in the South–eastern part of the country. Total area is of about 92,000 km$^2$. Its main affluent, the Paragua River, comprises 40% of this area. Total basin was divided for this study into five sub basins: upper, middle and low Caroni, with 27, 19 and 24% of the area, respectively; and upper and low Paragua, with 24 and 16% of the area, respectively. Sediments yield is estimated at the outlet of each sub basin

## SEDIMENTS YIELD MODELS

### Sediment Rating Curve Method

Sedimentation Curves are used when there are enough sediment concentration data from samples taken at hydrometric gauging stations at the same time that flows are measured. The relationship between sediment yield, $q_s$ and runoff rate, Q is normally represented in a logarithmic paper and adjusted mathematically to **Eq. (1)**:

$$q_s = \frac{aQ^n}{A} \qquad (1)$$

Where $q_s$ is the sediment yield in t/km$^2$-d; Q is the flow rate in m$^3$/s; A is the area of the basin; *a*, *n*, are adjustment parameters of the model.

### Langbein- Schumm Model

Langbein-Schumm (1958) proposed the model given in **Eq. (2)** to estimate suspended sediment yield in basins $q_s$ as a function of effective precipitation P:

$$q_s = \frac{10P^{2.3}}{1+0.0007P^{3.33}} \qquad (2)$$

Where, $q_s$ is the specific annual sediment yield in ton/miles$^2$, P is effective annual precipitation in inches. Factor 10P$^{2,3}$ describes erosive action of rainfall in absence of vegetation. Factor (1/1+0,0007P$^{3,33}$) represents the protective action of vegetation. This model supposes a maximum sediment yield at about 12 inches annual effective precipitation, preceding from a uniform yield from areas with more than 40 inches effective precipitation.

### Universal Soil Loss Equation, USLE Model

The classical form of USLE-Model as presented by Wischmeier and Smith (1978) is given in **Eq. (3)**:

$$E = RK(LS)CP \qquad (3)$$

Where, E is the soil loss due to surface erosion (t/ha-year), R is the rainfall erosivity factor (MJ-mm)/(ha-h-year); K is the soil erodibility factor; L is the slope length factor, S is the slope steepness factor, C is the cover and management factor and P is the support conservation practice factor.

The estimation process of R requires continuous daily pluviographs over periods of various years. However, in the absence of available records, monthly or annual precipitation data can be used to develop regional relationships (Foster *et al.*, 1981; Bolline *et al.*, 1980; Bergsma, 1980; Hrissanthou, 2006). In this research **Eq. (4)** proposed by Agüero (1989) for La Paragua gauging station and adopted by EDELCA (2004) was used to estimate R.

$$R_i = -237.9 + 8.7P_i;\ \mathrm{R}^2 = 0.978 \qquad (4)$$

Where, $P_i$ is the mean precipitation for month i in mm. This expression combines the intensity and duration of rainfall. The resulting value of R is expressed in (MJ-mm)/(ha-h-year) and comes from the total sum of values obtained for every month, as given below:

$$R = \sum_{i=1}^{n=12} R_i;\ \mathrm{i} = 1,...,12 \text{ months} \qquad (5)$$

Factor E is actually not the same as sediment transport of the river, since part of the eroded soil loss is deposited down stream of erosion site in the basin hillslopes. To estimate the real sediment contribution it is frequently used the so called *delivery rate*, f, which represents the proportion between the among of sediment contributed to a specific place in the water course (sediment yield) and gross soil loss estimated as E by means of **Eq. (3).** In that way, sediment yield $q_s$, will be equal to the product of this factor f and E, as in **Eq. (6):**

$$q_s = fE \tag{6}$$

A number of methodologies have been proposed to predict sediment delivery rate. These include simple estimates by an areal relationship and a relief-length ratio. Also, the accounting of many on-site factors such as water available for overland flow; texture of eroded material; ground cover; slope shape, gradient and length; surface roughness; and additional site-specific factors have been recommended by US Forest Service (1980). Roelh (1962) proposed in **Eq. (7)** for delivery rate f as a function of area A:

$$f = 36A^{-0,20} \tag{7}$$

Where f is the delivery rate in percentage, A is the area of the basin in $km^2$. There are several investigations that relate the delivery rate with the area; all of them show a great variability; however the general tendency indicates a strong effect of area on the delivery rate.

### Poesen Model

Poesen (1985) has developed a procedure to estimate soil erosion based on soil characteristics; slope; and rainfall kinetic energy. Poesen model comprises the solution of **Eqs. (8), (9), (10)** and **(11),** as follows:

$$q_{rs} = C(KE)r_s^{-1}\cos S \tag{8}$$

$$q_s = q_{rs}\left[0.301 senS + 0.019 D_{50}^{-0.22}\left(1-e^{2.42 senS}\right)\right] \tag{9}$$

where $q_{rs}$ is the mass of particles detached per unit area (kg./$m^2$); C is a soil cover factor; KE is the rainfall kinetic energy (J/$m^2$); $r_s$ is the soil resistance to drop detachment (J/Kg.); S is the slope gradient, in degrees $q_s$ is down slope splash transport (kg/$m^2$) and $D_{50}$ is median particle diameter (m).

Rainfall kinetic energy, KE (J/$m^2$), is given by Poesen (1985) as in **Eq. (10):**

$$KE = \beta P \tag{10}$$

where β is a factor proportional to the square of mean fall velocity of raindrops in J/$m^2$-mm (β = 12,5 J/$m^2$ mm, given by Poesen), and P is the total rainfall amount in mm.

Resistance of soil material, $r_s$ in J/kg is given by Poesen (1985) as:

$$r_s = 1{,}836.5 + 175.7 \ln D_{50}, \text{ for } 0.0001\text{ m} < D_{50} < 0.0007\text{m} \tag{11}$$

Poesen model for splash detachment is original developed for bare soils. For soil conditions with vegetative cover, is therefore necessary to include an additional factor: C, as USLE, to express the decrease of splash detachment due to vegetation. Rainfall kinetic energy, KE, is the same rainfall erosivity factor, R, of USLE, which is a function of rainfall energy and rainfall intensity. Soil resistance, $r_s$, corresponds to the topographic factor, LS, of USLE, which is a function of slope gradient and slope length.

Compared whit USLE, Poesen model attempts a more detailed consideration of rainfall erosion; e.g., splash detachment; up and down slope splash transport. However, correlations of influencing parameters on erosion remain empirical, as it is the case of USLE. Likewise USLE procedure, Poesen model also uses delivery rate to estimate transported sediment.

## METODOLOGY

As mentioned above, Caroní river basin is located in the south-east region of Venezuela, with a geographical localization that extends between 3º 37’ northern latitude (the most southern point in the border with Brazil at Sierra of Pacaraima) and 8º 21' (the junction to Orinoco river); and between 60º 35' western longitude (heads of Arabopó river in the upper Caroní) and 64º 37', see **Fig. (1).**

The main affluent of Caroní river is Paragua river, which extends almost parallel to Caroni from south to north until the junction, at “San Pedro de las Bocas” gauging station. About 60% of the area belongs to Caroní River and 40% to Paragua River. For this study, the whole basin is divided into five sub basins: upper Caroní (27% of the area), middle Caroní (19% of the area) and lower Caroní (14% of the area); upper Paragua (24% of the area) and lower Paragua (16% of the area). Available data of sediment yield are recorded at the outlet of each sub basin. Estimations of sediment yield using the proposed models refer to the same points of sub basin.

Regarding basin conditions, about 66% of the area is covered by any kind of forest; 15% of the area is covered by herbaceous vegetation; 12% of the area is covered by shrubby vegetal formations; about 4% of the area is occupied by Guri reservoir; remaining 3% is agriculture, grassland, urban, mining and hydroelectrically infrastructure.

### Sediment Rating Curve Method

Basic information of sub basins needed to apply rating curves is given in Table 1.

**Table 1.** Available stations with records of suspended sediment in sub basin of Caroní river

| Stations | River | Sub-basin | Area km$^2$ | % of area | Elev. (m) | Number of measures | Period | Number of years of measures | Minimum Flow (m$^3$/s) | Maximum Flor (m$^3$/s) |
|---|---|---|---|---|---|---|---|---|---|---|
| Aripichi | Caroní | Upper | 24,506.88 | 27 | 382 | 146 | 1982-1997 | 16 | 140 | 3,886 |
| Arekuna | Caroní | Middle | 17,433.63 | 19 | 345 | 106 | 1988-1998 | 10 | 217 | 8,430 |
| Caruachi | Caroní | Low | 13,159.66 | 14 | 49 | 97 | 1989-1995 | 6 | 2.488 | 9,167 |
| Karun | Paragua | Upper | 22,154.64 | 24 | 295 | 75 | 1987-1997 | 10 | 198 | 3,797 |
| Auraima | Paragua | Low | 14,914.27 | 16 | 270 | 51 | 1982-1995 | 13 | 137 | 5,599 |
| Whole Basin | | | 92,169.08 | 100 | | | | | | |

Results of EDELCA (2004) for sediment curve relations in Caroní basin are given in Table 2. With the exception of Karuachi gauging station, correlation coefficient for those relationships is bigger than 0, 77, high enough for the model to be considered as reliable to predict sediment yield in the basin.

## Langbein-Schumm model

Table 3 gives basic information needed to apply Langbein-Schumm model. Effective rainfall was obtained by conversion of mean monthly flows for each gauging station.

## USLE Model

USLE model was applied under the consideration of its empiric nature and the fact that this procedure was initially developed for agricultural parcels, even though it is widely used in many countries to estimate sediment yield. Hrissanthou, (1990; 2005) applied this model to a basin of 1500 km$^2$ in Central Europe; and to Kompsatos river basin in northwest of Greece with an area of 565 km$^2$. Results of annual values of sediment yield were found satisfactory compared with measured records.

In this research work, USLE factors C, K, and LS, were estimated based on the morpho-dynamic study of the basin made by COPLANARNH (1973) and adopted by EDELCA (2004) for its studies of Caroní basin. Annual average erosive factor R for each sub basin was calculated by means of **Eq. (4)** using monthly rainfall data from EDELCA's hydrometeorological network. Monthly rainfall records are given in Table 3. Morpho-dynamic information and following correspondence between morpho-dynamic classes and extension of sub basin are given in Table 4.

1. Inactive stable;
2. Inactive almost stable, in balance;
3. Inactive almost stable, in precarious balance;
4. Active, with moderate laminar erosion, low potential;
5. Active, with moderate laminar erosion, middle potential;
6. Active, with moderate laminar erosion, high potential;
7. Active, with moderate laminar erosion to strong, low potential;
8. Active, with moderate laminar erosion to strong, middle potential;
9. Active, with moderate laminar erosion to strong, high potential.

**Table 2.** Sediment relation curves for four stations of Caroní basin to estimate sediment yield

| Stations | River | Model | Correlation (R) |
|---|---|---|---|
| Arekuna | Caroní | $Q_s = 0.5289Q^{0.7227}$ | 0.88 |
| Aripichi | Caroní | $Q_s = 0.2064Q^{1.3026}$ | 0.77 |
| Auraima | Paragua | $Q_s = 0.3065Q^{1.2019}$ | 0.86 |
| Caruachi | Caroní | $Q_s = 135.93Q^{0.3875}$ | 0.01 |
| Karen | Paragua | $Q_s = 0.18Q^{1.2968}$ | 0.82 |

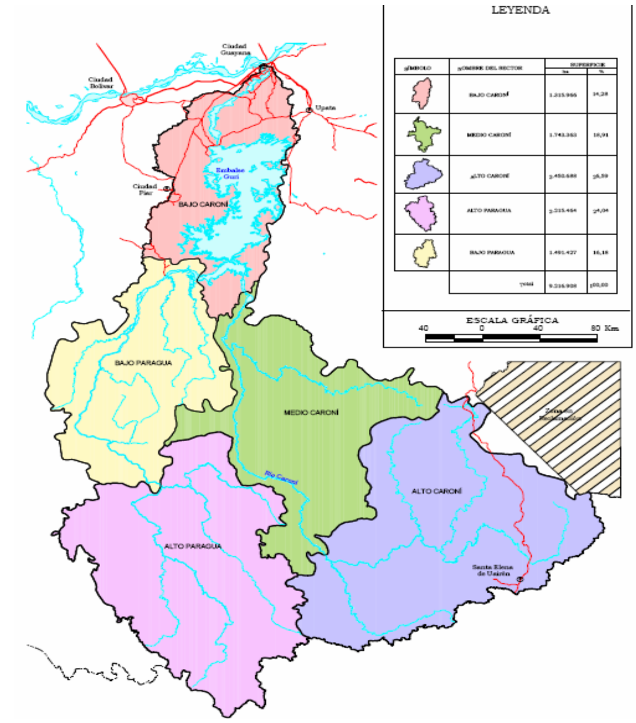


**Fig. 1** Location of sub basins of Caroní River

**Table 4.** Dominant classes of morpho-dymamic balance in sub basins of the Caroní River

| Morpho-dynamics class | Low Caroni area (%) | Middle Caroni area (%) | Upper Caroni area (%) | Low Paragua area (%) | Upper Paragua area (%) | CP* | Slope (S) % | L** | K Factor |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 4.1 | 23.6 | 13.3 | 4.0 | 26.9 | 0.001-0.006 | <4 | 1.1 | <0.005 |
| 2 | 6.2 | 21.8 | 18.5 | 54.2 | 26.2 | 0.1-1 | <4 | 1.4 | (0.045-0.06) |
| 3 | 0.2 | 1.0 | 0.8 | 0.4 | 1.3 | 0.1-1 | 4-8 | 1.15 | >0.6 |
| 4 | 6.4 | 0.7 | 1.5 | 0 | 0 | 0.02-0.08 | 4-8 | 1.6 | (0.005-0.015) |
| 5 | 35.2 | 29.7 | 21.0 | 28.2 | 36.4 | 0.02-0.08 | 8-30 | 1.2 | 0.015-0.045 |
| 6 | 14.3 | 3.7 | 8.4 | 2.4 | 4.8 | 0.1-1 | 8-30 | 1.8 | >0.6 |
| 7 | 0 | 0.1 | 2.0 | 0.2 | 0 | 0.001-0.006 | 30-60 | 2.2 | <0.005 |
| 8 | 2.9 | 16.0 | 27.8 | 9.5 | 2.7 | 0.02-0.08 | >60 | 1.9 | (0.005-0.015) |
| 9 | 0 | 2.4 | 6.4 | 0.8 | 0 | 0.1-0.3 | >60 | 2.4 | (0.045-0.06) |
| Guri Reservoir | 28.4 | 0 | 0 | 0 | 0 | | | | |
| Total Area ha) | 1,315,966 | 1,743,363 | 2,450,688 | 2,215,464 | 1,491,427 | | | | |

* Covering and protection factor (CP)
** Slope longitude factor (L)

## Poesen Model

Poesen model was developed for small experimental parcels; however Hrissanthou, (2006) applied the model to a basin of 122, 5 km$^2$ in Cyprus, Greece finding satisfactory results. In this in this research study kinetic energy was calculated using rainfall data given in Table 3; results of these calculations are given in Table 5.

## RESULTS

Estimated results of sediment yield for Caroní River sub basins applying Langbein-Schumm, USLE, and Poesen models are given in Tables 6 to 9. For comparison proposes recorded values are also presented in the same tables.

In Table 6 annual observed and calculated values of sediment yield for upper Caroní basin are compared. Estimated mean values using Langbein-Schumm, USLE, and Poesen models are 97, 132 and 16 t/km$^2$-year, respectively, while observed mean is only 27 t/km$^2$-year; corresponding standard errors of estimates are 77, 109 and 13 t/km$^2$-year. Results obtaines by Langbein-Schumm model are highly influenced by lower effective rainfall of the sub basin (see Table 3). USLE model results are influenced by six morpho-dynamic classes associated with the estimation of critical values of involved factors of the model.

Results obtained by Poesen model may be affected by soil detached particles mass without consideration of particles mass transported by runoff; nevertheless the results of this model adjust best to observation values. High erosion values are due to easy conditions of soil erodability in the upper Caroni basin, which belongs to category eight of morpho-dynamic balance classification.

In Table 7 annual observed and calculated values of sediment yield for middle Caroní sub basin are compared. Estimated mean values by Langbein-Schumm, USLE, and Poesen models are 79, 64 and 38 t/km$^2$-year, respectively; while observed mean is 76 t/km$^2$-year. Standard errors of estimates are 15, 17 and 40 t/km$^2$-year. For this sub- basin, Langbein- Schumm model results in the best prediction. Erosion rate in this sub-basin is smaller than for upper Caroni, which could be due to the resistance of soils as they belong to type five (5) of the morpho-dynamic balance classification.

In Table 8 annual observed and calculated values of sediment yield in the upper Paragua basin are presented. Estimated mean values by Langbein-Schumm; USLE and Poesen models are; 54, 42 and 9 t/km$^2$-year, respectively; while observed mean is of 46 t/km$^2$-year. Standard errors of estimates are; 13, 8 and 38 t/km$^2$-year. In this basin, Langbein-Schumm and USLE models result in the best prediction. Erosion rates in the upper Paragua basin are higher than in Caroní basin.

In Table 9 annual observed and calculated values of sediment yield for low Caroní basin are compared. Estimated mean values by Langbein-Schumm; USLE and Poesen models are: 7, 54 and 3 t/km$^2$-year, respectively, while observed mean is only 17 t/km$^2$-year. Standard errors of estimates are; 21, 45 and 23 t/km$^2$-year. In this basin, results of Langbein- Schumm model fit the best to observed data. Erosion rates in this sub-basin are also low due the characteristics of the soil.

In Table 10 annual observed and calculated values of sediment yield in the lower Paragua basin are compared. Estimated mean values by Langbein-Schumm; USLE and Poesen models are; 54, 49 and 2 t/km$^2$-year, respectively; observed mean is 78 t/km$^2$-year. Standard errors of estimates are; 29, 32 and 79 t/km$^2$-year. In this basin, Langbein-Schumm and USLE results fit the best to observed values. The variability of results in this sub-basin is due to variety soil type as they belong to three different morpho-dynamic balanced classifications (1, 2

**Table 5.** Rainfall Kinetic Energy (KE) in J/m$^2$ for each sub basin of Caroni River to be used by Poesen model

| Subbasin | Upper Caroni | Middle Caroni | Low Caroni | Upper Paragua | Low Paragua |
|---|---|---|---|---|---|
| Mean value | 38,293.56 | 33,391.81 | 16,576.25 | 49,387.50 | 34,350.00 |
| Deviation | 5,817.53 | 3,612.61 | 1,729.75 | 5,220.67 | 4,718.61 |

and 5). The very low values resulting from the application of Poesen model are probably due to structure characteristic of the model which considers an erosion term and a term that reduces the erosion as vegetation cover increases.

Even if Langbein-Schumm model does not involve topographic and geologic factors, it is worth to mention that effective precipitation as input variable of this model agrees with the characteristics of vegetable covering existing in Caroní River basin: 66% forests, with herbaceous formations; 15% shrubby vegetable formations; and 12% mixed cover.

Estimated annual values of the sediment yield in all sub basins were relatively satisfactory, fitting Langbein-Schumm results better to observed values. Analyzing the structure of Langbein-Schumm model it is easy to realize that sediment yield increases with effective precipitation until a maximum amount of rainfall of 0 to 12 inchs; it diminishes for values between 12 and 45 inches; and remains almost constant for effective rainfall values over 45 inches.

Further more; there is a direct relationship between effective precipitation and vegetation cover, as follows: for 0 to 12 inches effective rainfall, shrubby vegetation cover in deserts areas; for 12 to 45 inches effective rainfall, grassland; and for effective rainfall values over 45 inches, forests cover (Langbein et al (1957). Values of effective rainfall are higher than 45 inches in every one of the sub basins used for the study. This is the reason why the results obtained by this model tend to the mean or to lower value (in Tables 6 to 10), assuming forest vegetative cover.

## CONCLUSIONS

The research was carried out in the space unit conformed by sub basins Upper, Middle and Low Caroní River, as well as Upper and Low Paragua River. Historical records of monthly rainfall and runoff coming from EDELCA's hidrometeorological network were used.

Even if Langbein-Schumm model does not involve topographic and geologic factors, it is worth to mention that effective precipitation as input variable of this model agrees with the characteristics of vegetable covering existing in Caroní River basin: 66 forests, with herbaceous formations; 15% shrubby vegetable formations; and 12% mixed cover. This model fit to observed data in 80% of the cases.

Estimated annual values of the sediment yield in all sub basins were relatively satisfactory. Regarding the application of Langbein-Schumm model, values of effective precipitation in each sub basin of the Caroní are higher than 45 inches supposing that the model will predict sediment yield tending to the mean or smaller values as should correspond to an area with forest vegetative covering.

In spite of the empiric nature of the USLE and the fact that this equation was developed for small agricultural parcels, calculated annual values of sediment yield in three of five sub basins (60% of the cases): Middle Caroní, Upper and Low Paragua, were relatively satisfactory; however, standard deviation was higher than that of Langbein-Schumm method.

Results of Poesen model are the worst. This model was developed for small experimental parcels, and dos not fit well to Caroní basin conditions. Predictions by this model are consistently smaller compared to observed records. This anomaly could be explained by the fact that this method only considers transport of the particles removed by impact of the rain drop without taking into account transported particles by runoff.

According to the results of this research, it seems to be convenient for further applications to adapt Langbein-Schumm and Poesen models to local conditions of the sub basin involved in this study.

**Table 6.** Comparison between annual observed and calculated values of sediment yield in the upper Caroní basin

| Year | Observed | Langbein-Schumm | USLE | Poesen |
|---|---|---|---|---|
| | $q_s$ (t/km$^2$-year) | | | |
| 1980 | 26.02 | 88.95 | 140.27 | 13,76 |
| 1981 | 40.10 | 95.63 | 147.40 | 18,34 |
| 1982 | 23.63 | 67.69 | 135.31 | 16,99 |
| 1983 | 14.83 | 102.13 | 103.67 | 13,43 |
| 1984 | 31.25 | 148.22 | 161.77 | 19,96 |
| 1985 | 26.69 | 83.34 | 113.51 | 14,54 |
| 1986 | 23.01 | 93.90 | 108.23 | 13,94 |
| 1987 | 19.75 | 105.00 | 104.62 | 13,54 |
| 1988 | 32.88 | 118.97 | 96.81 | 12,64 |
| 1989 | 33.92 | 82.96 | 100.02 | 13,02 |
| 1990 | 29.40 | 75.36 | 162.74 | 20,07 |
| 1991 | 25.01 | 97.85 | 140.85 | 17,61 |
| 1992 | 13.28 | 159.43 | 106.04 | 13,69 |
| 1993 | 26.14 | 93.33 | 158.38 | 19,58 |
| 1994 | 25.94 | 95.05 | 139.80 | 17,49 |
| 1995 | 25.63 | 99.94 | 138.03 | 17,29 |
| 1996 | 31.06 | 82.81 | 154.62 | 19,16 |
| 1997 | 19.86 | 115.76 | 132.45 | 16,66 |
| 1998 | 34.16 | 78.45 | 153.89 | 19,07 |
| 1999 | 43.42 | 63.03 | 145.96 | 18,19 |
| Mean | 27.30 | 97.39 | 132.22 | 16,45 |
| Standard error of estimates | | 77.26 | 109.57 | 13.09 |

**Table 7.** Comparison between annual observed and calculated values of sediment yield in the middle Caroní basin

| Year | Observed $q_s$ (t/km$^2$-year) | Langbein-Schumm $q_s$ (t/km$^2$-year) | USLE $q_s$ (t/km$^2$-year) | POESEN $q_s$ (t/km$^2$-year) |
|---|---|---|---|---|
| 1966 | 72.49 | 71.75 | 84.48 | 13.33 |
| 1967 | 87.31 | 80.38 | 71.25 | 43.09 |
| 1968 | 79.60 | 67.89 | 53.03 | 33.49 |
| 1969 | 65.61 | 73.84 | 72.63 | 43.85 |
| 1970 | 83.09 | 87.98 | 63.73 | 39.34 |
| 1971 | 84.16 | 71.02 | 61.92 | 38.14 |
| 1972 | 79.77 | 70.20 | 47.96 | 30.50 |
| 1973 | 70.32 | 73.69 | 49.54 | 30.53 |
| 1974 | 66.03 | 82.63 | 51.05 | 32.53 |
| 1975 | 76.09 | 87.48 | 62.25 | 37.79 |
| 1976 | 84.19 | 76.93 | 54.54 | 34.35 |
| 1977 | 61.73 | 70.17 | 38.57 | 24.47 |
| 1978 | 58.71 | 92.97 | 57.25 | 34.95 |
| 1979 | 76.65 | 97.28 | 70.06 | 42.37 |
| 1980 | 75.77 | 76.41 | 77.42 | 45.82 |
| 1981 | 99.07 | 77.22 | 78.48 | 47.06 |
| 1982 | 70.91 | 60.52 | 63.17 | 39.01 |
| 1983 | 60.46 | 82.00 | 63.97 | 38.87 |
| 1984 | 80.80 | 94.74 | 62.76 | 37.90 |
| 1985 | 69.34 | 72.84 | 58.08 | 36.23 |
| 1986 | 68.54 | 83.69 | 66.85 | 40.23 |
| 1987 | 62.91 | 84.58 | 65.10 | 39.49 |
| 1988 | 79.70 | 91.40 | 77.51 | 45.93 |
| 1989 | 81.05 | 73.75 | 57.58 | 35.81 |
| 1990 | 87.28 | 72.64 | 74.12 | 44.95 |
| 1991 | 74.99 | 67.92 | 55.76 | 34.83 |
| 1992 | 52.17 | 77.95 | 77.83 | 46.71 |
| 1993 | 83.91 | 108.20 | 65.73 | 39.99 |
| 1994 | 81.52 | 70.39 | 60.47 | 36.93 |
| 1995 | 74.36 | 72.26 | 66.80 | 40.26 |
| 1996 | 87.13 | 78.55 | 75.13 | 45.46 |
| 1997 | 61.53 | 68.02 | 51.06 | 32.39 |
| 1998 | 81.77 | 93.25 | 74.07 | 44.21 |
| 1999 | 97.72 | 72.06 | 71.79 | 43.67 |
| Mean | 75.78 | 78.90 | 64.17 | 38.07 |
| Standard error of estimates | | 14.96 | 17.30 | 39.81 |

**Table 8.** Comparison between annual observed and calculated values of sediment yield in upper Paragua basin

| Year | Observed $q_s$ (t/km$^2$-year) | Langbein-Schumm $q_s$ (t/km$^2$-year) | USLE $q_s$ (t/km$^2$-year) | POESEN $q_s$ (t/km$^2$-year) |
|---|---|---|---|---|
| 1980 | 41.84 | 52.48 | 43.95 | 9.62 |
| 1981 | 52.99 | 55.65 | 42.30 | 9.35 |
| 1982 | 46.34 | 45.40 | 46.79 | 10.26 |
| 1983 | 41.11 | 50.51 | 43.89 | 9.68 |
| 1984 | 50.01 | 55.87 | 42.53 | 9.40 |
| 1985 | 40.46 | 47.93 | 37.58 | 8.36 |
| 1986 | 44.18 | 57.35 | 44.11 | 9.68 |
| 1987 | 34.06 | 52.41 | 33.20 | 7.51 |
| 1988 | 38.46 | 65.56 | 38.90 | 8.67 |
| 1989 | 54.30 | 60.34 | 40.47 | 8.98 |
| 1990 | 51.75 | 43.86 | 47.42 | 10.39 |
| 1991 | 45.81 | 45.63 | 35.58 | 7.99 |
| 1992 | 27.60 | 52.18 | 40.95 | 9.05 |
| 1993 | 55.43 | 77.29 | 53.65 | 11.65 |
| 1994 | 55.74 | 43.56 | 47.11 | 10.27 |
| 1995 | 36.34 | 44.44 | 36.10 | 8.02 |
| 1996 | 52.97 | 63.06 | 40.49 | 8.99 |
| 1997 | 35.56 | 45.53 | 39.83 | 8.85 |
| 1998 | 49.22 | 62.16 | 45.89 | 10.08 |
| 1999 | 57.38 | 49.56 | 46.05 | 10.12 |
| Mean | 45.58 | 53.54 | 42.34 | 9.35 |
| Standard error of estimates | | 13.32 | 7.53 | 38.00 |

**Table 9.** Comparison between annual observed and calculated values of sediment yield in low Caroní basin

| Year | Observed $q_s$ (t/km$^2$-year) | Langbein-Schumm $q_s$ (t/km$^2$-year) | USLE $q_s$ (t/km$^2$-year) | POESEN $q_s$ (t/km$^2$-year) |
|---|---|---|---|---|
| 1958 | 12.57 | 8.64 | 63.69 | 2.51 |
| 1959 | 12.05 | 8.18 | 42.25 | 2.91 |
| 1960 | 12.34 | 6.71 | 39.72 | 2.23 |
| 1961 | 13.77 | 8.54 | 49.05 | 2.78 |
| 1962 | 12.07 | 7.10 | 35.98 | 2.23 |
| 1963 | 13.10 | 6.65 | 43.11 | 2.78 |
| 1964 | 13.76 | 9.15 | 31.71 | 2.13 |
| 1965 | 11.61 | 8.46 | 35.83 | 2.44 |
| 1966 | 12.65 | 6.90 | 46.78 | 2.82 |
| 1967 | 12.91 | 5.67 | 45.77 | 2.83 |
| 1968 | 14.78 | 6.90 | 53.66 | 3.22 |
| 1969 | 13.74 | 7.34 | 46.48 | 2.89 |
| 1970 | 13.53 | 6.15 | 54.94 | 3.28 |
| 1971 | 14.37 | 6.12 | 40.57 | 2.60 |
| 1972 | 14.53 | 6.05 | 66.12 | 3.86 |
| 1973 | 14.72 | 7.15 | 39.19 | 2.48 |
| 1974 | 13.07 | 7.57 | 32.74 | 2.32 |
| 1975 | 13.48 | 6.87 | 66.73 | 3.77 |
| 1976 | 13.58 | 5.58 | 62.08 | 3.66 |
| 1977 | 14.92 | 7.59 | 42.80 | 2.53 |
| 1978 | 12.99 | 8.35 | 57.72 | 3.32 |
| 1979 | 12.57 | 6.70 | 59.53 | 3.61 |
| 1980 | 13.75 | 6.46 | 79.50 | 4.28 |
| 1981 | 14.05 | 5.10 | 80.46 | 4.45 |
| 1982 | 15.33 | 6.60 | 60.81 | 3.58 |
| 1983 | 14.11 | 8.59 | 56.92 | 3.33 |
| 1984 | 12.71 | 6.66 | 59.80 | 3.45 |
| 1985 | 13.80 | 12.17 | 68.81 | 3.91 |
| 1986 | 11.45 | 8.46 | 68.87 | 3.86 |
| 1987 | 12.96 | 7.75 | 59.05 | 3.34 |
| 1988 | 13.49 | 6.48 | 69.19 | 3.81 |
| 1989 | 14.42 | 6.37 | 57.74 | 3.43 |
| Mean | 16.85 | 7.28 | 53.68 | 3.14 |
| Standard error of estimates | | 21.44 | 44.97 | 23.77 |

**Table 10.** Comparison between annual observed and calculated values of sediment yield in low Paragua basin

| Year | Observed $q_s$ (t/km$^2$-year) | Langbein-Schumm $q_s$ (t/km$^2$-year) | USLE $q_s$ (t/km$^2$-year) | POESEN $q_s$ (t/km$^2$-year) |
|---|---|---|---|---|
| 1980 | 75.47 | 54.37 | 62.49 | 2.06 |
| 1981 | 89.20 | 46.51 | 51.38 | 1.74 |
| 1982 | 79.76 | 51.23 | 42.15 | 1.47 |
| 1983 | 80.16 | 51.30 | 52.74 | 1.78 |
| 1984 | 78.81 | 52.09 | 40.75 | 1.40 |
| 1985 | 67.53 | 59.84 | 51.69 | 1.75 |
| 1986 | 73.93 | 54.62 | 41.85 | 1.45 |
| 1987 | 64.42 | 62.35 | 53.35 | 1.79 |
| 1988 | 65.77 | 61.89 | 46.06 | 1.55 |
| 1989 | 84.23 | 54.62 | 42.34 | 1.46 |
| 1990 | 86.91 | 62.35 | 51.73 | 1.75 |
| 1991 | 76.04 | 61.89 | 31.09 | 1.13 |
| 1992 | 58.81 | 48.29 | 54.06 | 1.80 |
| 1993 | 97.00 | 47.08 | 57.09 | 1.91 |
| 1994 | 92.28 | 54.07 | 44.90 | 1.53 |
| 1995 | 64.65 | 67.36 | 52.31 | 1.76 |
| 1996 | 85.34 | 43.15 | 54.40 | 1.82 |
| 1997 | 66.38 | 45.76 | 41.41 | 1.43 |
| 1998 | 82.40 | 62.67 | 57.54 | 1.91 |
| 1999 | 95.34 | 43.43 | 56.27 | 1.90 |
| Mean | 78.22 | 54.24 | 49.28 | 1.67 |
| Standard error of estimates | | 29.13 | 32.24 | 79.32 |

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