# THE TRANSPORT OF NUTRIENTS AND SUSPENDED SOLIDS BY SOME RIVERS OF THE UPPER PARANAPANEMA DRAINAGE BASIN (SÃO PAULO, BRAZIL)*

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Lotic ecosystems are the main channel of communication between reservoirs and the terrestrial ecosystems of their drainage basins. Nutrients and sediments, as dissolved and particulate material arising from rainfall and surface runoff, are continuously entering these systems. The intensity with which chemical elements and solids are removed obviously varies throughout the basin. A number of interrelated factors are involved in this process. These include annual rainfall patterns and their unequal distribution throughout the basin, land use, and the extent and type of plant cover. When, for example, the drainage basin is extensively forested, export coefficients of nitrogen and phosphorus are very low, but increase progressively when the landscape is dominated by pasture, mixed pasture and crops, and crops, respectively (BEAULAC & RECKHOW, 1982; HILL, 1978). In cropland, nutrient export can be reduced by the use of channels perpendicular to slope gradients, and the maintenance of ground remnants of natural vegetation. Another important factor affecting nutrient removal is the geological origin of the basin (soil types). DILLON & KIRCHNER (1975) compared phosphorus loss from soils in various watersheds in sites of differing geological origin. They found that rivers in sedimentary basins trasnport more P than those in igneous basins. Finally, drainage basin morphology also needs to be considered.

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When land use patterns are similar, phosphorus export increases with an increase in the surface area of drainage basin (PRAIRIE & KALFF, 1986). KIRCHNER (1975), also observed a relation between phosphorus export and drainage density (sum of the lengths of the rivers per unit area of the drainage basin).

Dissolved nutrients and suspended sediments in rivers originate from point sources as well as general areas throughout the basin (non point sources). Point sources involve large-scale nutrient input from specific sites. These include residual water discharges from towns and industrial complexes. Non point sources include the nutrient input from the entire watershed and their contribution is very difficult to evaluate. As mentioned above, the input from these sources depends on the geology, land-use patterns, and morphology of the drainage basin. The relations between runoff and export coefficients of chemical elements allow a comparative evaluation of the importance of non point sources between different drainage basins. GROBLER & SILBERBAUER (1985) found a significant positive correlation between total phosphorus and "reactive" dissolved phosphorus with runoff in seven drainage basins in South Africa, where diffuse sources were predominant, although it should be remembered that both point sources and non-point sources are frequently included in the analysis of river nutrient and sediment loads; human impacts being present to some degree throughout any drainage basin.

There are numerous studies of dissolved and particulate sediment loads in tropical rivers, particularly in Africa (LESAK et al, 1984; GROBLER & SILBERBAUER, 1985). In South America, nutrient and sediment exports were studied in the Rio Bermejo, Argentina, (PEDROSO & BONETTO, 1987), and the Rios Apuré (SAUNDERS & LEWIS, 1988), Orinoco (LEWIS & SAUNDERS, 1989), and Caura (LEWIS et al., 1986) in Venezuela. In Brazil, studies of this sort have been limited mainly to the Amazon basin, including the Rio Solimões—Amazonas (RICHEY et al, 1990), and some tributaries of the Rio Madeira (MARTINELLI et al, 1988), although we have carried out preliminary studies emphasizing dissolved nutrients and seston exports in three rivers feeding the Jurumirim reservoir and in the Rio Paranapanema (HENRY, in press a, b), and the second author has nearly completed similar studies in a further 10 rivers in the same basin, in the south-east of Brazil (GOUVEIA, in preparation). Here we summarize our data from the upper basin of the Rio Paranapanema, state of São Paulo (FIG. 1).

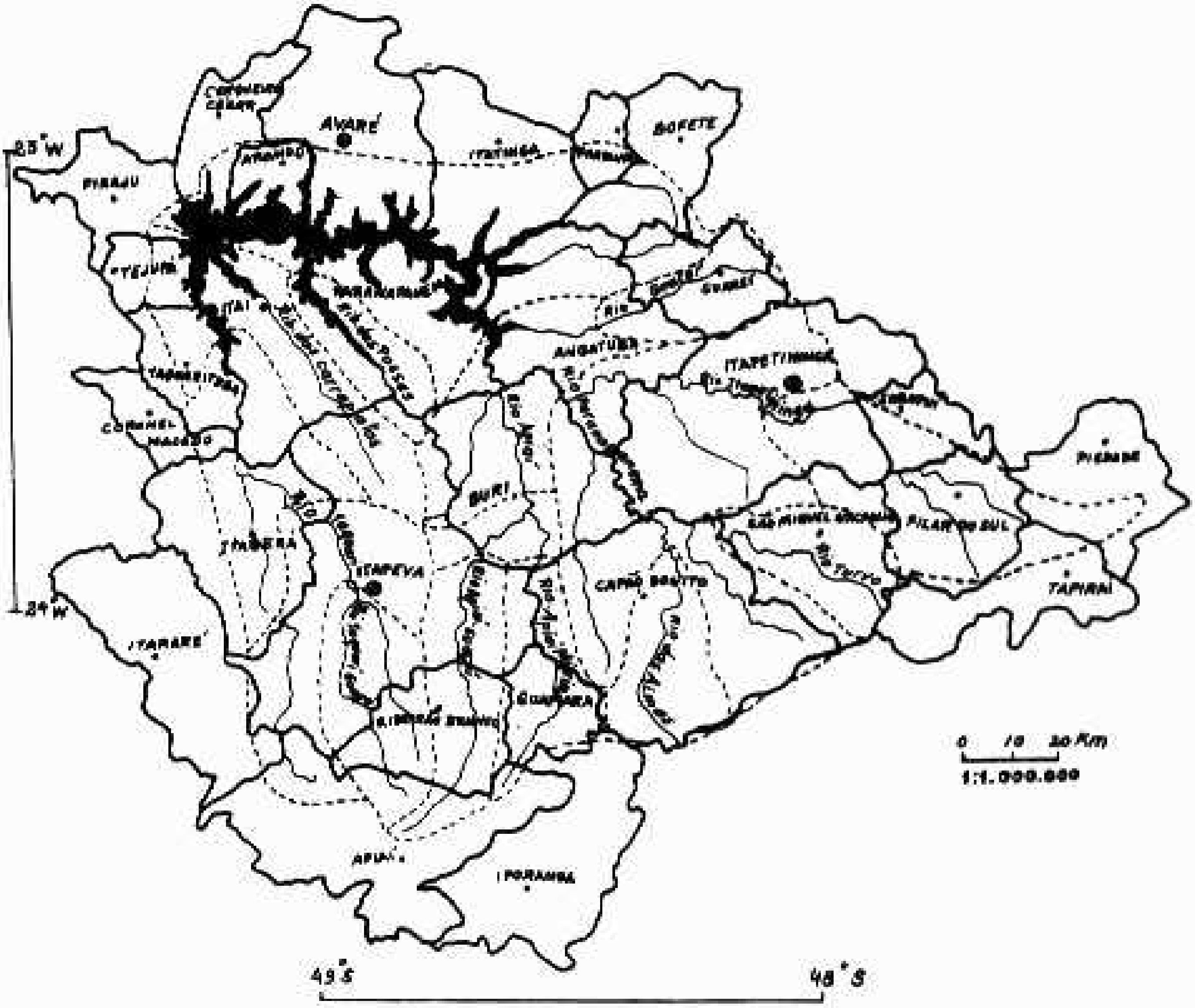

Fig. 1. The upper Rio Paranapanema and the drainage basins studied.

Surface water samples were collected approximately every two months (7th-8th May 1988, 3rd-4th July 1988, 5th and 7th September 1988, 9th–10th November 1988, 9th–10th January 1989, and 6th–7th March 1989). Analyses were carried out for: suspended solids; "reactive" silicate (GOLTERMAN & CLYMO, 1969); nitrate; nitrite and ammonium–nitrogen (MACKERETH et al, 1978); and total and dissolved inorganic phosphate (STRICKLAND & PARSONS, 1960). The load values were computed by multiplying the concentrations by flow, using the daily flow measurements from flowmetric stations maintained by the São Paulo Electricity Company (CESP) and the Department of Waters and Electric Energy (DAEE). Export coefficients were calculated by the formula:

$$E = \frac{\sum_{i=1}^{n} \bar{Q} \times \bar{C}}{A}$$

where $E$ = annual export
$\bar{Q}$ = mean flow for each two month period
$\bar{C}$ = mean concentration, for the period between two consecutive sampling periods,
$n$ = frequency of annual sampling (6),
$A$ = area of drainage basin.

TABLE 1 presents some information on the morphology of each basin. Six of the ten rivers are classified as 4th order, following the scheme of CHRISTOFOLETTI (1969). The drainage basin of the Jurumirim reservoir is approximately 18,000 $km^2$, while the drainage areas of some of the tributaries feeding the reservoir range from 540 to 5,780 $km^2$. The perimeters and diameters of the various watersheds were, therefore, highly variable. The total lenght of the rivers in the drainage basin of the reservoir was 8,500 km (measured from maps, scale 1:250,000 and probably underestimated). For the remaining basins, lengths varied from 260 to 3,000 km. The hydrographic and drainage densities showed no significant variation, however, when comparing all of the rivers.

The lowest load value (annual mean) for suspended matter was recorded downstream of the reservoir, while the highest was in the Rio Paranapanema at Campina do Monte Alegre (TABLE 2). Since the downstream load corresponds to only about 10% of the introduced load, we conclude that approximately 90% of the suspended solids were being retained in the reservoir. With regard to nutrient export, the coefficient downstream was the lowest for the 10 drainage systems. Although "reactive" silicate load was highly variable between rivers, this was not so for the export/runoff coefficients (c.v. = 11%). Similar values were not obtained for total and dissolved organic phosphate. Coefficients of variation in this case were 41% and 38%, respectively. Despite the fact that the export coefficients obtained for dissolved inorganic nitrogen (DIN) were higher than for nitrate, the coefficients of variation were similar (c.v. = 31% for $NO_3^-$ and c.v. = 29% for DIN).

In order to quantify the transfer of phosphate from the soil to the rivers, we calculated the export coefficients per unit runoff ($mg.m^{-2}.mm^{-1}$) for each basin: a measure of the degree of erosion, especially of phosphorus. The runoff values for each basin (annual flow/drainage basin area) are shown in TABLE 3. Differences between basins are attributed to rainfall patterns, hydrological retention, and percentage and type of plant cover for each basin. The total dissolved phosphate per unit runoff ranged from 0.012 to 0.046 $mg.m^{-2}.mm^{-1}$. These values are very low when compared to those of GROBLER & SILBERBAUER (1985) for South Africa (1.31 $mg.m^{-2}.mm^{-1}$), as well as those of PINTER & JOLANKAI (1982) for northern temperate zones (0.31 $mg.m^{-2}.mm^{-1}$). Although these values referred to total phosphorus, whereas our data for upper Paranapanema basin refer only to dissolved phosphate, we conclude that the differences result from the reduced phosphate removal due to more widespread plant cover. This is being studied by GOUVEIA (in preparation), who is examining the vegetation cover of each basin and its relationship to the export/runoff coefficients presented here.

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TABLE 1 – Morphometric parameters of some drainage basins in the upper section of the Paranapanema River (state of São Paulo, Brazil): area (A), perimeter (P), total length of the rivers (L), diameter (D), hydrographic density (Dh), drainage density (Dd) and order (following the scheme of CHRISTOFOLETTI, 1969).

| Nº | Basin | A ($km^2$) | P (km) | L (km) | D (km) | Dh(N/A) ($km^{-2}$) | Dd(L/A) ($km^{-1}$) | Order |
|---|---|---|---|---|---|---|---|---|
| 1. | Paranapanema | 17,978 | 738 | 8,505 | 203 | 0.066 | 0.0473 | 6 |
| 2. | Taquari (Faz. Agrolim) | 2,152 | 225 | 1,084 | 75 | 0.068 | 0.504 | 4 |
| 3. | Taquari (Itapeva) | 836 | 137 | 441 | 53 | 0.077 | 0.527 | 4 |
| 4. | Apiaí–Guaçu (Taquari–Vaí) | 946 | 178 | 488 | 67 | 0.068 | 0.515 | 4 |
| 5. | Apiaí–Guaçu (Buri) | 2,039 | 251 | 1,022 | 82 | 0.063 | 0.501 | 4 |
| 6. | Apiaí-Mirim (Itapeva) | 727 | 156 | 356 | 53 | 0.059 | 0.489 | 3 |
| 7. | Turvo (Itapetininga) | 710 | 136 | 431 | 41 | 0.097 | 0.607 | 4 |
| 8. | Itapetininga (Porto Velho) | 1,501 | 219 | 848 | 78 | 0.080 | 0.565 | 5 |
| 9. | Guareí (Angatuba) | 539 | 112 | 260 | 36 | 0.070 | 0.482 | 4 |
| 10. | Paranapanema (C. Monte Alegre) | 5,779 | 405 | 2,977 | 117 | 0.071 | 0.515 | 6 |

TABLE 2 — Means ($\overline{x}$) and amplitude of variation (A.V.) of loads and export coefficients of 10 drainage basins of the upper section of the Paranapanema River (São Paulo state, Brazil).

| Parameter | Load* | | Export coefficients** | |
|---|---|---|---|---|
| | $\overline{x}$ | A.V. | $\overline{x}$ | A.V. |
| Suspended solids | 151 | 46– 556 | 22.5 | 1.0–42.1 |
| "Reactive" silicate | 21 | 5– 90 | 2.6 | 2.1– 2.9 |
| $NO_3^-$ | 374 | 53–1,607 | 35.2 | 18.6–58.6 |
| D.I.N. ($NO_3^- + NO_2^- + NH_4^+$) | 459 | 88–1,500 | 44.5 | 29.6–75.9 |
| Total $PO_4^{---}$ | 112 | 29– 416 | 13.3 | 5.6–22.8 |
| Inorganic $PO_4^{---}$ | 51 | 9– 200 | 5.8 | 4.0– 9.8 |

* in kg. day$^{-1}$ (except for suspended solids and "reactive" silicate expressed in ton. day$^{-1}$)

** in mg.m$^{-2}$.year$^{-1}$ (except for suspended solids and "reactive" silicate expressed in g.m$^{-2}$.year$^{-1}$).

TABLE 3 – Runoff and export coefficients/runoff of the total $PO_4^{---}$ in some drainage basins of the upper section of the Paranapanema River (São Paulo state, Brazil).

| Nº | Basins | Runoff (mm.year$^{-1}$) | Export/Runoff (mg.m$^{-2}$.mm$^{-1}$) |
|---|---|---|---|
| 1. | Paranapanema | 481 | 0.012 |
| 2. | Taquari (Faz. Agrolim) | 355 | 0.023 |
| 3. | Taquari (Itapeva) | 404 | 0.042 |
| 4. | Apiaí–Guaçu (Taquari–Vaí) | 503 | 0.019 |
| 5. | Apiaí–Guaçu (Buri) | 493 | 0.027 |
| 6. | Apiaí–Mirim (Itapeva) | 483 | 0.026 |
| 7. | Turvo (Itapetininga) | 650 | 0.017 |
| 8. | Itapetininga (Porto Velho) | 658 | 0.019 |
| 9. | Guareí (Angatuba) | 501 | 0.046 |
| 10. | Paranapanema (C. Monte Alegre) | 609 | 0.033 |