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Water discharge and sediment load to Sepetiba Bay from an anthropogenically-altered drainage basin, SE Brazil

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Summary Empirical relationships coupled with the field measurements were used to assess water discharge and sediment load from an anthropogenically-altered drainage basin into Sepetiba Bay in southeastern Brazil. Discharge into Sepetiba Bay is modified by large-scale water diversion from the Paraíba do Sul River, which is one of the more important and impacted rivers in Brazil. The discharge into Sepetiba Bay has increased threefold, from 41 to 129 m^3/s on average, since the water redistribution began. Sediment budget calculations indicate retention of a large fraction of the sediment load by five reservoirs within the drainage system but with highly variable infilling rates. As a consequence the water diversion scheme has lead to a 28% increase in sediment delivery to Sepetiba Bay or 270×10^3 t/yr. The Paraíba do Sul River contributes most of the freshwater input into Sepetiba Bay, whereas the sediment load to the bay is mainly contributed by the local drainage basins.

Introduction

Watershed and water management projects, in general, affect transport of freshwater and sediment to the coastal zone. Reservoirs trap sediment, store and age the continental runoff, increase evaporation rates, and alter groundwater recharge (Vörösmarty et al., 1997; Chen et al., 2001; Smith et al., 2002; Brant, 2000). At the same time, inter-basin water transfers create confrontation between water users and donors due to water gain/loss, which in turn affects water quality, alters river characteristics, and leads to environmental and economic dilemmas (Kjerfve, 1976; Snaddon et al., 1998; Carriquiry and Sanchez, 1999; Sahagian, 2000). Thus, as demand for water grows, it becomes

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a major challenge to understand the dimensions of anthropogenic influence on drainage basins and the delivery of water and sediment to the coastal zone.

To asses the degree of human impact on downstream coastal systems requires understanding of water discharge and sediment load from drainage basins. Such estimates are based on field measurements/data, which are used to calculate/model water and sediment delivery (Syvitski et al., 2000; Carvalho et al., 2002). Unfortunately, continuous stage gauging and suspended sediment sampling are lacking for most rivers globally, and it often becomes necessary to develop models to predict the water discharge and sediment load based on basin properties. Proxy parameters used for modeling typically include robust climate and geomorphic characteristics of drainage basins (Milliman and Syvitski, 1992; Ramireddygari et al., 2000; Picouet et al., 2001).

We applied empirical relationships and field measurements to reconstruct and improve on the current understanding of the water discharge and sediment load to the coastal zone from an anthropogenically-altered drainage basin in southeastern Brazil. Discharge into Sepetiba Bay has been modified by a large-scale water diversion scheme from the Paraíba do Sul River, which has impacted several smaller drainage basins, led to the construction of a series of reservoirs, and was justified by the increasing demand for industrial and potable water for the city of Rio de Janeiro. Limited monitoring has focused on a few sub-basins for short durations, while other sub-basins are totally lacking in measurements. Thus, to understand the complexity of the water diversion scheme and the resulting changes in water discharge and sediment load, we have calculated mass budgets for water and sediment.

Methods

Study site

The Paraíba do Sul drainage basin is subtropical/tropical and measures 56,600 km^2. The river flows 1145 km from west to east and discharges at a current average rate of 670 m^3/s into the South Atlantic Ocean at 22°S latitude (Carvalho et al., 2002). The river has been subjected to a series of hydrological modifications, including the construction of six dams along the middle river and several water diversion schemes in response to increasing demand for water for human consumption, irrigation, and industry.

The major hydrological modification to the Paraíba do Sul River is the diversion of water into the Guandú River to supply potable water for the population in the Rio de Janeiro metropolitan area (Fig. 1), which has grown explosively during the past 60 years from 2.23 to 10.80 million. The demand for water closely follows population growth. In 2001, 703.92 million m^3 of water were required for human use (80%), industrial use (2.4%), and other activities (17.6%) (Governo do Estado do Rio de Janeiro, 2002). Because of the limited availability of water from the watersheds surrounding the Rio de Janeiro metropolitan area, water from the Paraíba do Sul River was diverted into the Guandú River basin, beginning in the 1950s. A portion of this diverted water is treated and distributed to the city of Rio de Janeiro. The remaining water is allowed to discharge into Sepetiba Bay and has become a significant additional source of water and dissolved and particulate materials to this bay.

The Paraíba do Sul River was first dammed in 1950, creating the Santa Cecilia reservoir. Four pumps were installed to deliver water 10 m uphill into the Piraí River basin, which originally, before damming, was a tributary of the Paraíba do Sul River (Figs. 1 and 2). Water pumped from the Paraíba do Sul River, currently 160 m^3/s, fills the Santana Reservoir (Fig. 1) until the Piraí River dam. The discharge from the Santana Reservoir and the Piraí River is pumped an additional 33 m uphill into the Vigário Reservoir. From Vigário Reservoir, the subsequent fall to Sepetiba Bay is 390 m. Three hydroelectric power generating stations have been constructed along this fall and have a combined generating capacity of 612 MW (Governo do Estado do Rio de Janeiro, 1997a). The Guandú River is the receiving drainage basin of the water diverted from the Paraíba do Sul River and it is the principal source of natural discharge into Sepetiba Bay (Fig. 1). The distance between Paraíba do Sul River and Sepetiba Bay is 94 km. Sepetiba Bay is a 443 km^2 tidal estuary, supporting extensive mangrove wetlands, high biological productivity, and a rich commercial fishery. Nine additional small rivers drain the Quaternary plain along the northeastern shores of the bay but provide insignificant discharge (Molisani et al., 2004).

Data and methods

Because measurements are not done routinely and continuously, we have chosen to model both water discharge and sediment load to develop mass budgets. We also compiled and used available data on pumped discharges, outflow from dams, and measurements of suspended sediment concentrations (Light, unpublished data, 2003). The modeled water budgets were compared to published discharge data, while sediment loads were compared to limited amounts of measurements made by us.

The water discharge model is based on a steady-state climatic water balance (Schreiber, 1904), assuming that rainfall equals evapotranspiration and runoff. We choose to make the calculations for the wet and dry seasons separately as to minimize violations of the steady-state assumption. Input data consist of monthly precipitation and temperature obtained during 30 years at six locations located within the study area, provided by Light (unpublished data, 2003) and Ministério da Agricultura (unpublished data, 2000). To calculate water budgets, the runoff model was applied separately to the Piraí, Guandú, Vigário Reservoir basins. The overall watershed was divided into six sub-basins, limited by the upstream area of each suspended sediment gauge stations shown in Fig. 1. Each sub-basin was divided into polygons according to five altitude intervals (0—250, 250—500, 500—750, 750—1000, and 1000—1250 m), similar to the procedure adopted by Kjerfve et al. (1997). The polygons were quantified using digital GIS-based maps. We calculated area-weighted estimates of precipitation and temperature for each polygon during the dry (May—October) and rainy seasons (November—April), from which evapotranspiration, runoff ratio, and discharge were calculated separately (Table 1). For polygons

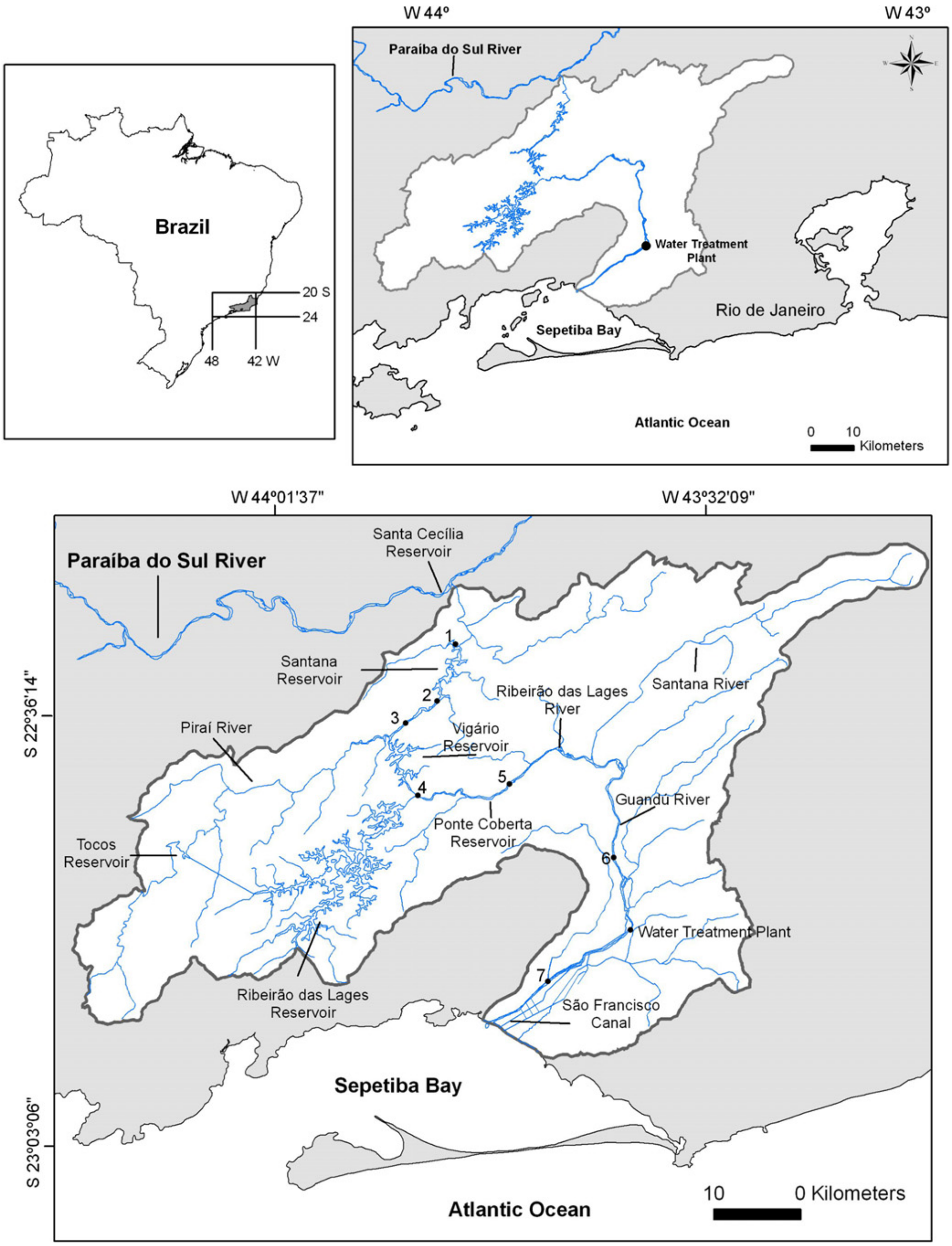

Figure 1 Map of the water diversion scheme and sampling sites.

without temperature measurements, we corrected the temperature from adjacent meteorological stations adiabatically, i.e., by $-0.97\,^{\circ}\mathrm{C}$ per 100 m elevation increase (List, 1966).

The discharge (Q_R, m^3/s) from each sub drainage basin (A, km^2) was computed as

$$Q = \int\int r \times \frac{\Delta f}{r}\,\mathrm{d}A \qquad (1)$$

(Kjerfve, 1990), where Δf is runoff (mm/yr/), r is precipitation (mm/yr), and the non-dimensional quantity $\Delta f/r$ is the runoff ratio, which expresses the fraction of rainfall converted into runoff. The runoff ratio (Schreiber, 1904; Sellers, 1965; Kjerfve, 1990) was calculated from

$$\frac{\Delta f}{r} = \mathrm{e}^{-E_0/r} \qquad (2)$$

Here E_0 is a potential evapotranspiration measure (mm/yr), calculated by using the empirical dependence on air temperature (T, K)

$$E_0 = 1.0 \times 10^9\,\mathrm{e}^{-4620/T} \qquad (3)$$

(Holland, 2001). By summing the contribution from each sub-basin, we estimated the total discharge for the overall drainage basin.

The water balance within the reservoirs was estimated using the difference between the direct rainfall and evaporation. The reservoir evaporation rate was calculated utilizing the mass-transfer theory as proposed by Harbeck (1962)

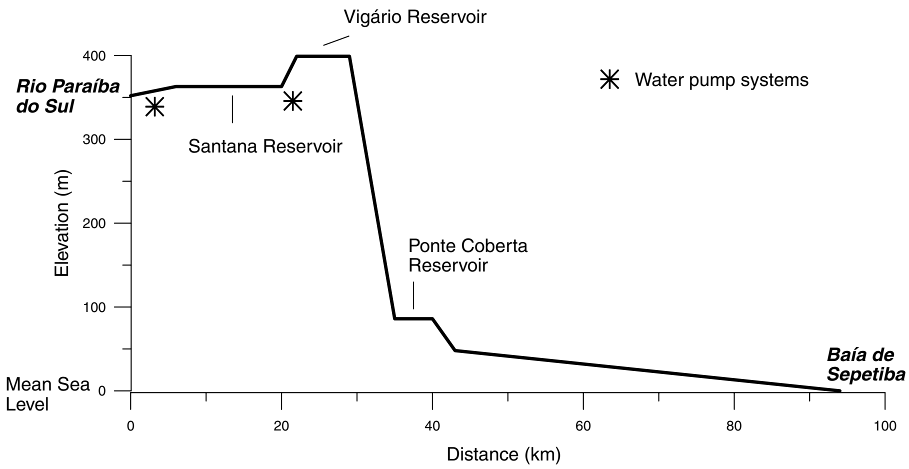

Figure 2 Basin transect from Paraíba do Sul River to Sepetiba Bay, showing location of the main reservoirs relative to a topographic transect.

Table 1 Summary of meteorological data (average for the years 1971—2002) and calculated runoff for the rainy/dry seasons, for the three basins of the modified watersheds

Basins	Area (km^2)	Polygon	T (°C)	Rainfall (mm)	E_0 (mm)	$\Delta f/r$	Q (m^3/s)
Piraí River	680	6	22/17[a]	1110/373[a]	78/59[a]	0.49/0.21[a]	24/3
Vigário	41	1	25/18	978/349	95/64	0.38/0.16	1/0
Guandú River	1509	12	23/19[a]	954/371[a]	86/68[a]	0.40/0.17[a]	40/7

[a] The values are expressed as area-weighted averages for each elevation polygon.

$$E = Nu(e_0 - e_a) \tag{4}$$

where E is the evaporation (mm/year), N is a coefficient of proportionality based on apparent relation between N and surface area of the reservoir, u is the wind speed (m/s), e_0 is the saturation vapor pressure (hPa), which is a function of the air temperature (List, 1966), and e_a is the measured vapor pressure (hPa) (Table 2).

The predicted long-term sediment load for the overall modified drainage basin was evaluated based on an empirical model that takes into account climatic and morphologic characteristics of the watershed (Morehead et al., 2003). The long-term mean sediment load Q_s (kg s^{-1}) was calculated as

$$Q_s = 2 * 10^{-5} * R^{3/2} * A^{1/2} * 0.2 * 10^{0.0578*T} \tag{5}$$

where R is the basin relief (m), A is the basin area (km^2), and T is the mean annual temperature (°C). The same procedure adopted for the water discharge model was used for the sediment load calculations. Each sub-basin was chosen based on the location of the sediment gauging stations along the course of the rivers and then sub-divided into polygons with similar topographic characteristics. Total sediment load for each sub-basin was calculated by summing the polygons.

The data on the sediment load pumped from the Paraíba do Sul River and transferred between reservoirs were provided by Light (unpublished data, 2003) and by Governo do Estado do Rio de Janeiro (1997b). The simulated sediment load into Sepetiba Bay was compared to a limited set of field measurements ($n = 7$) at the seaward site 7 (Fig. 1) during the dry and rainy seasons. Measured sediment load was calculated by multiplying suspended sediment concentration and water discharge.

Results

Water mass-balance

The geographic location, extent, and relief of the modified drainage system are shown in Fig. 1, and meteorological and hydrological characteristics the rivers, reservoirs, and basin

Table 2 Morphology and seasonal (rainy/dry) meteorological (average for the years 1971—2002) characteristics of the reservoirs and their drainage basins in the modified watersheds

Reservoir	Area (km^2)	Volume (10^6 m^3)	Rainfall (R) (10^6 m^3)	Wind speed (m^3/s)	Relative humidity (%)	Evaporation (E) (10^6 m^3)	R—E (10^6 m^3)
Santana	6	20	6.5/1.9	1.2/1.9	82/83	0.9/0.8	5.6/1.0
Tocos	1	5	1.0/0.3	1.2/1.9	82/83	0.2/0.1	0.9/0.2
Vigário	4	38	3.8/1.4	1.2/1.9	82/83	0.6/0.6	3.2/0.8
Lages	31	601	33/11	1.2/1.9	82/83	4.6/4.3	29/6.3
Ponte Coberta	1	17	1.0/0.4	1.2/1.9	82/83	0.2/0.1	0.9/0.2

polygons are shown in Tables 1 and 2. The discharges were calculated for the dry and rainy seasons based on Eq. (1) and data in Table 1. For the Piraí River basin, the runoff ratio varied from 0.08 in dry season to 0.66 in the rainy season, while the runoff ratio for Guandú River basin was 0.04 and 0.61, respectively. The corresponding discharge rates for the Piraí River, obtained by summing sub-basin runoffs, were 3 and 24 m^3/s in dry and rainy seasons, respectively. For the Guandú River, the simulated water discharges were 7 and 40 m^3/s during the dry and rainy seasons, respectively.

The long-term mean water budget is summarized in Fig. 3. The budget incorporates water inflow from the Paraíba do Sul River, water transfers among the reservoirs, and the runoff from the basins as calculated from runoff ratios (Eq. (1)). The water balance within the reservoirs was estimated by using the calculated difference between direct rainfall (R) and evaporation (E) (Eq. (4)) for each reservoir (Table 2). We assumed quasi steady-state conditions during each of the two seasons. For all reservoirs, R—E was slightly positive but, on average, yielded less than 0.5 m^3/s discharge, and thus do not show up in the diagrammatic presentation of the average water fluxes (Fig. 3).

The major source of discharge in both the dry and rainy seasons is the Paraíba do Sul River, contributing a constant 160 m^3/s as a consequence of the water diversion scheme. In addition to water pumped from the Paraíba do Sul River, we calculated the runoff from the Piraí River (Fig. 3) to be, on average, only 13 m^3/s, emphasizing the importance of Paraíba do Sul River as the major source of discharge into Sepetiba Bay.

The water volume, retained in the Piraí River basin both from basin runoff and the Paraíba do Sul River, is subsequently transferred into the Guandú River basin. The upper

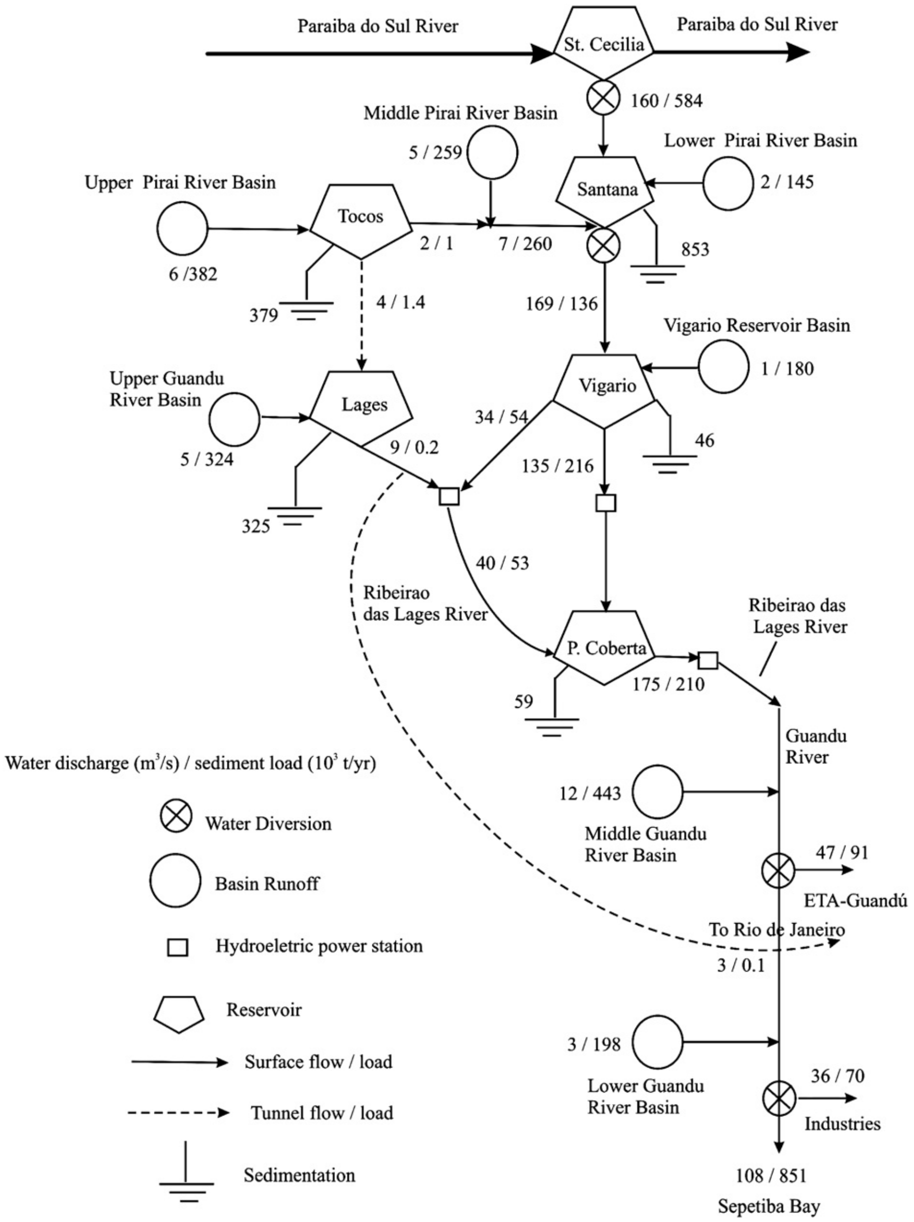

Figure 3 Calculated steady-state annual water fluxes (m^3/s) and sediment loads ($\times 10^3$ t/yr).

Piraí River flow is retained by the Tócos reservoir and redirected to Lages Reservoir in the upper Guandú River basin. The water transport between these reservoirs is characterized as an inter-basin water transfer. In addition, discharge from the Santana Reservoir is transferred to the Vigário Reservoir at a rate of 178 m^3/s, yet another an inter-basin water transfer.

The water diverted from the Paraíba do Sul and the runoff from the Piraí River basin discharge into Guandú River basin at a rate of 178 m^3/s, regulated according to hydroelectric power requirements. The upper Guandú River basin runoff is retained by the Lages dam, which in turn discharges a regulated flow into the Ribeirão das Lages River. From the Lages reservoirs, 3 m^3/s flow through a subterranean tunnel to a water treatment plant, located in Rio de Janeiro. Both discharge from the upper Guandú River and input from the Vigário Reservoir, enter the Ponte Coberta Reservoir, along the middle course of the Guandú River.

The mean water discharge into the middle basin of the Guandú River from the Ponte Coberta Reservoir measures 175 m^3/s and thus is far greater than the runoff from the Guandú River, which was calculated to be 20 m^3/s on average (Fig. 3). Along the middle river basin, 47 m^3/s are transferred from Guandú River to the water treatment plant that supplies water to the city of the Rio de Janeiro, while 36 m^3/s of the downstream discharge is used for industrial purposes. Although, no details are available for the fate of water withdrawn by the industrial plants, we assume that all water used industrially is eventually returned to the river channel. The drainage system discharges into Sepetiba Bay through the São Francisco Canal. Our calculations indicate that the discharge into Sepetiba Bay on average measures 108 m^3/s with average seasonal variations from 84 to 132 m^3/s during dry and rainy seasons, respectively.

Sediment budget estimation

In the case of sediment load, we did not attempt to estimate differences between dry and wet seasons. The calculated annual sediment load along the altered watershed is summarized in Fig. 3. The pumped water from the Paraíba do Sul River transfers 584×10^3 tons of sediment per year (t/yr) into the Piraí River basin. This sediment load was calculated based on a transfer of 160 m^3/s of water from the Paraíba do Sul River and mean measured suspended sediment concentration upstream of St. Cecilia dam (118 mg/L) (Governo do Estado do Rio de Janeiro, 1997b). This sediment concentration is the best value available, but could differ substantially from concentrations within the St. Cecília reservoir, where water is collected for diversion. Thus, estimated sediment loads are probably somewhat overestimated, as the river most likely has higher suspended sediment concentration than the reservoir. The calculated trapping efficiency of the dams within the Sepetiba drainage system varies substantially from 14% to almost 100%. However, since the suspended sediment concentration measurements were collected within the upper reaches of the St. Cecilia reservoir, we assume that the measured sediment concentration already reflects sediment trapping and have made no adjustments to the calculated sediment input from Paraíba do Sul River reaching the Santana reservoir.

Aside from sediment transfer from the Paraíba do Sul River, the predicted sediment load from the Piraí River basin (upper, middle, and lower river basins) was estimated and shown in Fig. 3. In view of sediment load transfers between the Santana and Vigário reservoirs, measured to be 136×10^3 t/yr, most of the sediment load from the Piraí and Paraíba do Sul rivers (about 90%) is trapped within the Piraí River basin.

When the Vigário Reservoir sediment balance is estimated from inflow, outflow, and from the adjacent basin, the calculations suggests that the Vigário dam traps sediment at a rate of 46×10^3 t/yr (Fig. 3), which represents 14% of the total sediment inflow into Vigário Reservoir. Before discharge into the Guandú River, sediment load from Vigário Reservoir is, in part, trapped by Ponte Coberta Reservoir. The balance between sediment inflow and outflow indicates that Ponte Coberta Reservoir retains 59×10^3 t/yr. The outflow from this reservoir discharges towards to the coast and Sepetiba Bay.

The sediment load for the middle and lower Guandú River basin was estimated to be 641×10^3 t/yr. Due to demands for water along this river segment, 91×10^3 t/yr of sediments are removed by a water treatment plant and 70×10^3 t/yr by industries. We assumed that the sediment load transferred by water demand would be filtered and remain in the river channel. The resultant sediment load to Sepetiba Bay was estimated, taking into account the discharge from the Ponte Coberta reservoir and the long-term predicted sediment load from the Guandú River basin. According to the sediment mass budget, the long-term sediment load from the anthropogenically-altered drainage basin into Sepetiba Bay is 851×10^3 t/yr.

Discussion

Existing field data, including our own measurements, are limited and cannot be used to make definitive water and sediment budgets for the Sepetiba Bay drainage system. However, by application of the empirical models, it is still possible to make a set of first order estimates of the components of the water and suspended sediment budgets. The results of our calculations can at this point not be verified by gauged measurements. However, the simulations of the water and sediment budgets for the Sepetiba Bay drainage system show that the resultant water discharge and sediment load are dominated by water pumped from the Paraíba do Sul River, but also dependent on the aging and storage of water behind dams, the operating rules of reservoir discharges, and yields from basins along the modified watercourse.

The hydrological model was calibrated by comparing the simulated discharges with limited available measurements. The simulated natural discharges for Guandú and Piraí rivers basin, 3.6 and 2.3 m^3/s, respectively, in the dry season were in good agreement to gauged values (3.2 and 2.6 m^3/s for Guandú and Piraí river basins, respectively) for the same period (Governo do Estado do Rio de Janeiro, 1997c). According to data available at http://www.cedae.rj.gov.br, the mean annual water flow contribution from Guandú River basin is 20 m^3/s, which compares excellently to our simulations of 20 m^3/s. The empirical relationships based on climatic and morphological data appear to be robust enough to reproduce well hydrological characteristics of the watershed. This methodology offers a viable means for estimating runoff from drainage basins.

Water diversion from the Paraíba do Sul River significantly augments the water discharge into Sepetiba Bay. The freshwater input into the bay used to be 41 m^3/s, based on data from Rodrigues (1990) and our simulations for the Guandú River basin before the diversion (Fig. 3). After the water diversion from the Paraíba do Sul River, the continental runoff to the bay has increased threefold and actual flow into the coastal system now measures 129 m^3/s. Before the water diversion, the Guandú River discharge into Sepetiba Bay was 20 m^3/s. At this time, the Guandú River receives water from the Paraíba do Sul River and currently discharges into the coastal system at a rate of 108 m^3/s, on average, which represents 86% of the total freshwater input into Sepetiba Bay. The fivefold increase of discharge through the Guandú River, coupled with the operating rules for reservoir discharges, has significantly decreased the impact of runoff from the original Guandú basin into Sepetiba Bay.

The turnover time of the water in the reservoirs, calculated as the reservoir volume divided by water input (or discharge) is overall relatively short (Table 3). In the case of four of the five reservoirs, the turnover time varies from 1 day (Coberta reservoir) to 10 days (Tocos reservoir). The outlier, however, is the Lages reservoir with a 580 day turnover time on account of a very small discharge on average, which in turn has water quality implications. The storage and aging of the water in the reservoirs can lead evaporation being an important component of the water balance. For some basins, water losses by evaporation represent 7—26% of the total freshwater input (Vörösmarty and Moore, 1991; Oyebande, 1995). The balance between rainfall and evaporation for the reservoirs in the Sepetiba watersheds indicates higher gain due to rainfall than loss due to evaporation. Even if the reservoirs were well mixed on a timescale shorter than the turnover time, the rainfall onto the reservoir surfaces exceeds evaporative losses in spite of a 12% evaporative loss of the water input from the Paraíba do Sul River.

To assess the anthropogenic impact of water diversion on the sediment delivery to Sepetiba Bay, an empirical relationship was used to estimate basin sediment loads. A model was used to assess the continental sediment delivery to the inner Gulf of Honduras (Thattai et al., 2003), with the results comparing quite well to the simulations for the same watersheds using the Revised Universal Soil Loss Equation (RUSLE) approach. In this study, the calibration of model prediction was performed by comparing it with a limited set of field measurements from most seaward gauging station (site 7, Fig. 1) but with very poor agreement. The difference between measured (346×10^3 t/yr) and calculated (851×10^3 t/yr) sediment load to Sepetiba Bay is attributed to the few measurements. The sediment load was measured only seven times during two years during both rainy and dry seasons. The load estimates were highly variable as a result of suspended sediment concentrations varying from 5 to 288 mg/L. This variability and the limited number of measurements explain the differences between modeled and measured sediment loads into Sepetiba Bay. Our sediment budget model does not include the erosion/deposition responses of the riverbed, which may explain differences between observed and model loads.

Sediments are retained by the succession of dam reservoirs, which modulate the impact of sediment transfer from Paraíba do Sul River to Sepetiba Bay. We calculated the bulk sedimentation rate for each of the five reservoirs based on the difference between sediment input and output, distributing the sediment over the reservoir area (Table 3). The calculations indicate that for four of the reservoirs, the sedimentation rate varies from 0.9 cm/yr for Vigário reservoir to 5.1 cm/yr for Coberta reservoir, which corresponds to sediment infilling rates anywhere from 15 to 2126 years if no compaction takes place, and considerably longer with sediment compaction. However, Tocos reservoir is an outlier, with the calculation of an unreasonably fast sedimentation rate of more than 33 cm/yr and an infilling time of only 15.2 years. This is obviously not reasonable and suggests the need for more and better field measurements to calibrate/adjust/verify the calculated water and sediment budgets.

Based on our calculations, the water diversion from the Paraíba do Sul River yields an additional 270×10^3 t/yr of sediment as compared to the pre-diversion load of the Guandú River into Sepetiba Bay. This additional sediment load accounts for the measured increase of sedimentation rates in the Sepetiba Bay, assessed by Pb^{210} (Forte, 1996; Molisani et al., 2004). Although the water balance shows that the water transfers from the Paraíba do Sul River is responsible for the almost all (86%) water discharge into Sepetiba Bay, this is not true for the sediment load. The sediment retention behind successive dams, the load transfers among reservoirs and the estimated sediment contribution from the

Table 3 Reservoir sediment infilling and water residence time

	Area (km^2)	Volume (10^6 m^3/s)	Water flux (m^3/s)	Water turnover (days)	Sedimentation accumulation (10^3 t/yr)	Sedimentation rate (cm/yr)	Sediment infill (years)
Santana	26	46	169	3.2	593	2.0	89.2
Tocos	1	5	6	9.6	379	33.0	15.2
Vigário	4	38	135	3.3	46	1.0	950
Lages	31	601	12	579.7	325	0.9	2126
P. Coberta	1	17	175	1.1	59	5.1	331

Assumption. Sediment density (kg/m^3) is 1150 kg/m^3; sedimentation accumulation equals reservoir load inputs—reservoir load export and annual steady state is assumed.

basins suggest a progressive retention of the sediment load from the Paraíba do Sul River. Nevertheless, the water diversion scheme has increased the sediment load which now reaches Sepetiba Bay by 28%. Thus, the majority of the sediment load still originates within the local Sepetiba watersheds. Of the total 28% (=270×10^3 t/yr) increased sediment yield to Sepetiba Bay, 14% is attributed to the watershed and 14% to water diversion from the Paraíba do Sul River.

Conclusion

The water diversion from the Paraíba do Sul River has significantly altered the amount of water and sediment input to Sepetiba Bay during the past several decades. According to calculated budgets, the water discharge into Sepetiba Bay has increased threefold from 41 to 129 m^3/s, on average, after water diversion began. The Guandú River, as a receiving environment of the water from the Paraíba do Sul, has a fivefold increase in water flow, which decreases the importance of runoff from the Guandú River basin to Sepetiba Bay. The evaporation caused by aging and storage of water flow behind dams is not a critical issue for this water diversion scheme because the higher direct precipitation which compensates for evaporative water loss. The sediment budget indicates that the water diversion from Paraíba do Sul River augments the sediment load to the Guandú River basin by 28% (or 270×10^3 t/yr), less important as compared to increase in water discharge due to progressive retention of the sediment load by reservoir trapping. This increased sediment load is consistent with measured increases in sedimentation rates in the inner portions of Sepetiba Bay (Forte, 1996) and more annual dredging of sediments in the shipping channel leading to the Sepetiba Port (Garga and Medeiros, 1995; Barbosa and Almeida, 2001).

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