| Journal of Coastal Research | SI 39 | 702 - 706 | ICS 2004 (Proceedings) | Brazil | ISSN 0749-0208 |
|---|---|---|---|---|---|

# Itajaí-Açu River Estuary (Santa Catarina, Brazil): Preliminary Budget for Dissolved Inorganic Nutrients

**J. Pereira Filho†, L.C. Spillere† and C.A.F. Schettini†**

†CTTMar
Universidade do Vale do Itajaí,
Itajaí-SC, 88302-202, Brazil
jura@univali.br

**ABSTRACT**

PEREIRA FILHO, J.; SPILLERE, L.C. and SCHETTINI, C.A.F., 2006. Itajaí-Açu river estuary (Santa Catarina, Brazil): Preliminary Budget for Dissolved Inorganic Nutrients. Journal of Coastal Research, SI 39 (Proceedings of the 8th International Coastal Symposium), 702 - 706. Itajaí, SC, Brazil, ISSN 0749-0208.

The purpose of this work was to determine a preliminary budget of inorganic dissolved nutrients and to evaluate their variability in the Itajaí-açú River estuary. The estuary is the main estuary of Santa Catarina State, Southern Brazil. The Itajaí-açu River flows through the most economically important region of the state, the Itajaí Valley. Its land use is characterized by intensive agricultural uses, with industrial zones and important cities. The biggest fisheries harbor of Brazil also is located in the lower Itajaí Estuary. The nutrients ($NH_4^+$, $NO_2^-$, $NO_3^-$ and $PO_4^{3-}$) were sampled at 5 stations along the estuary, from Indaial (located 90 km upstream the the river mouth) to Itajaí city, at the estuarine mouth, collected at weekly basis from July 2000 to July 2001. The nutrients concentrations were determined according to classical colorimetric methods and the budgets were calculated according to methodology proposed by LOICZ. The budgets were calculated for two river discharges classes: below 200 $m^3.s^{-1}$ and between 200 and 800 $m^3.s^{-1}$. The results of concentration monitoring suggest the estuary presents a net metabolism heterotrophic. The budgets showed that the estuary behavior as a sink for phosphorus and as a source for amonium. Similar conclusion was found for the Camboriú estuary, situated about 10 km south. The budgets also showed residual transport of DIN and DIP to the coastal zone. Along the estuary The ammonium presented higher concentration at the estuarine head, probably by the anthropogenic influence.

**ADDITIONAL INDEX WORDS:** *Eutrophication, southern Brazilian coastal zone, ecosystem metabolism.*

## INTRODUCTION

Estuaries are transitional environments between the continents and the sea, being the main path of nutrients delivery for the oceans. Through the estuaries flows water and material originated from their drainage basins. The assessment of nutrient fluxes in estuaries and coastal environments has been used to estimate mass balance, aiming to arrive at the net metabolism, or if a given system presents autotrophic or heterotrophic budgets.

The dissolved inorganic nutrients are the prime material for the marine trophic chain and the estuaries are the main path for their delivery to the coastal oceans. This causes the characteristic high primary production of coastal waters, and abundant biological diversity. The nutrient supply is intensified in estuaries situated in highly populated areas, as a function of the domestic and industrial effluents, apart from the agricultural delivery. The increase in concentration of dissolved inorganic nutrients in estuaries and coastal waters causes several modifications in the environment. It can elevate the primary production rates and the fishing resources as well (CEDERWALL and ELMGREN, 1980; NIXON, 1982; NIXON *et al.*, 1986).

However, the anthropogenic inputs frequently lead to excessive water eutrophication, particularly in coastal water bodies with restricted circulations, like bays, bights and coastal lagoons. Several alterations on the chemical characteristics and on the water quality have been reported as consequences of alterations of biogeochemical fluxes, leading to ecological consequences, such as changes on species composition (BEUKEMA, 1991), and frequently increase phytoplankton blooms and decrease oxygen concentration (PARKER and O'REILLY, 1991; PENNOCK *et al.*, 1994).

Several studies have been done relating environmental changes as a function of the input of nutrients and organic matter (BEROUNSKY and NIXON, 1985; INNAMORATI and GIOVANARDI, 1990; KIMOR, 1990; CARMOUZE and VASCONCELOS, 1992), although few studies have quantified such inputs (NIXON, 1982; NIXON and PILSON, 1984; SMITH and VEEH, 1989; NIENCHESKI and WINDOM, 1994). The kind of influence these inputs can have on the system depends on the uses and occupation existing on the drainage basin. Highly industrialized areas contribute with heavy metals, hydrocarbons, nutrients and organic matter. Agricultural ares increase soil loss and can deliver loads of pesticides, herbicides and fertilizers (RIBEIRO, 1996).

The main objective of this study was to assess the capability of the Itajaí-Açu River Estuary in transforming organic matter and nutrient cycling. The assessment was based on the establishment of the mass budget of dissolved inorganic nutrients (nitrogen and phosphorus) for the lower estuary.

The Itajaí-Açu River Estuary is situated at about 26.9 ºS and 48.7º W, aproximately 70 km north from Florianópolis, the Santa Catarina State Capital (Figure 1). It receives a contribution of a drainage basin of 15,500 $km^2$, which is about of 25 % of the state area. There are 47 counties in the basin, with more than one million persons living in it. The major cities are Blumenau and Brusque, two of the most important industrial cities of the state. The estuary itself also has great economic importance, as the Port of Itajaí is the main international trade path for the state, and the harbor is one of the most important of Brazil. Along its margins are located dozens of fisheries industries, making it the largest fish land of the country (SCHETTINI, 2002).

The mean river discharge is about 228 $m^3.s^{-1}$, based on 36 years of daily observations at the Indaial fluviometric station. The minimum and maximum observed discharges were 55 and 5390 $m^3.s^{-1}$, respectively (SCHETTINI, 2002). The estuary was classified as salt wedge type (SCHETTINI *et al.*, 1996), where the main driving agent is the river discharge, while the sea level changes caused by tides plays a secondary role. The salt intrusion varies greatly as a function of discharge fluctuations, reaching about 20 km when the discharge is low. At moderate discharges the salt intrusion is pushed seawards, and when it exceed 1000 $m^3.s^{-1}$, all saline waters ware flushed out from the estuarine basin. Despite the major role of the river discharge, it is quite low for long periods of time, increasing the importance of tides and sub-tidal sea-level oscillations caused by meteorological forcing. Local wind acting directly on the water surface can provide additional mixing energy in certain areas of the estuary, where the wind direction coincide with the channel orientation (SCHETTINI, 2002).

## METHODS

The data set used in this study were collected from July 2000 to July 2001 at five stations: #1- Indaial County, #2- Blumenau County, #3- Itajaí County, nearby the Itajaí-Mirim mouth, #4 Itajaí County, about 5 km upstream from the mouth, and #5- at the estuarine mouth (Figura 1). Samples were taken weekly at #1 and #2, and fortnightly at the others. The dissolved inorganic nutrients ($NH_4^+$, $NO_2^-$, $NO_3^-$ and $PO_4^{-3}$) were determined using the classical colorimetric methodology, adapted from STRICKLAND and PARSONS (1972).

Data were grouped in two sets based on the river discharge: low discharge, when it was bellow 200 $m^3.s^{-1}$ and moderate discharge, when it was between 200 and 800 $m^3.s^{-1}$. Higher values of discharge were not considered because there are no saline waters inside the estuarine basin under such conditions. The presence of salinity is necessary to estimate the mixing and the fluxes according the LOICZ methodology.

The first step to reach the nutrients budget was to do the water and salt balance of the estuary from the mean values of salinity and river discharge (VQ), named as system 1, and the adjacent systems, 0 and 2 for each condition class (low and moderate river discharge, Figure 2). The water volume exchanged between the estuary and the ocean (Vx) were estimated from the water and salt balances. From this value it was possible to calculate the nutrient fluxes for both conditions, based on the river discharge VQ and nutrient concentration (Y). An estimation of nutrients input from domestic sewage was also included, considering a *per capita* production of N and P (VON SPERLING, 1996), and multiplying by the population living along the river.

The nutrient mass balances were estimated from the water and salt budget and nutrient fluxes using the LOICZ proposed methodology (GORDON *et al*, 1996). The non-conservative variation of the nutrients (▲Y) was obtained by the sum of all inputs and outputs, considering the mass conservation principle like $\Sigma$ *inputs* + $\Sigma$ *outputs* + ▲Y = 0.

## RESULTS AND DISCUSSION

Table 1 shows the data set used to calculate the water and salt budgets in both classes of river discharge. Table 2 presents a summary of the data obtained from the balance calculation for dissolved inorganic phosphorus (DIP) and dissolved inorganic nitrogen (DIN), for each class also. Figures 2 and 3 show the schematic drawings for the resulting balances. The non-conservative variation of DIP (▲DIP) during the low discharge class was of -25,9 x $10^6$ mmol.$day^{-1}$ (Figure 2).

The negative signal means that the phosphorus is being removed from the water, not counting the removing by advective transport. Biological assimilation and geochemical processes can lead to such removal, perhaps with higher importance to the adsorption of phosphorus to the particulated suspended matter. The water mixing conditions observed in the

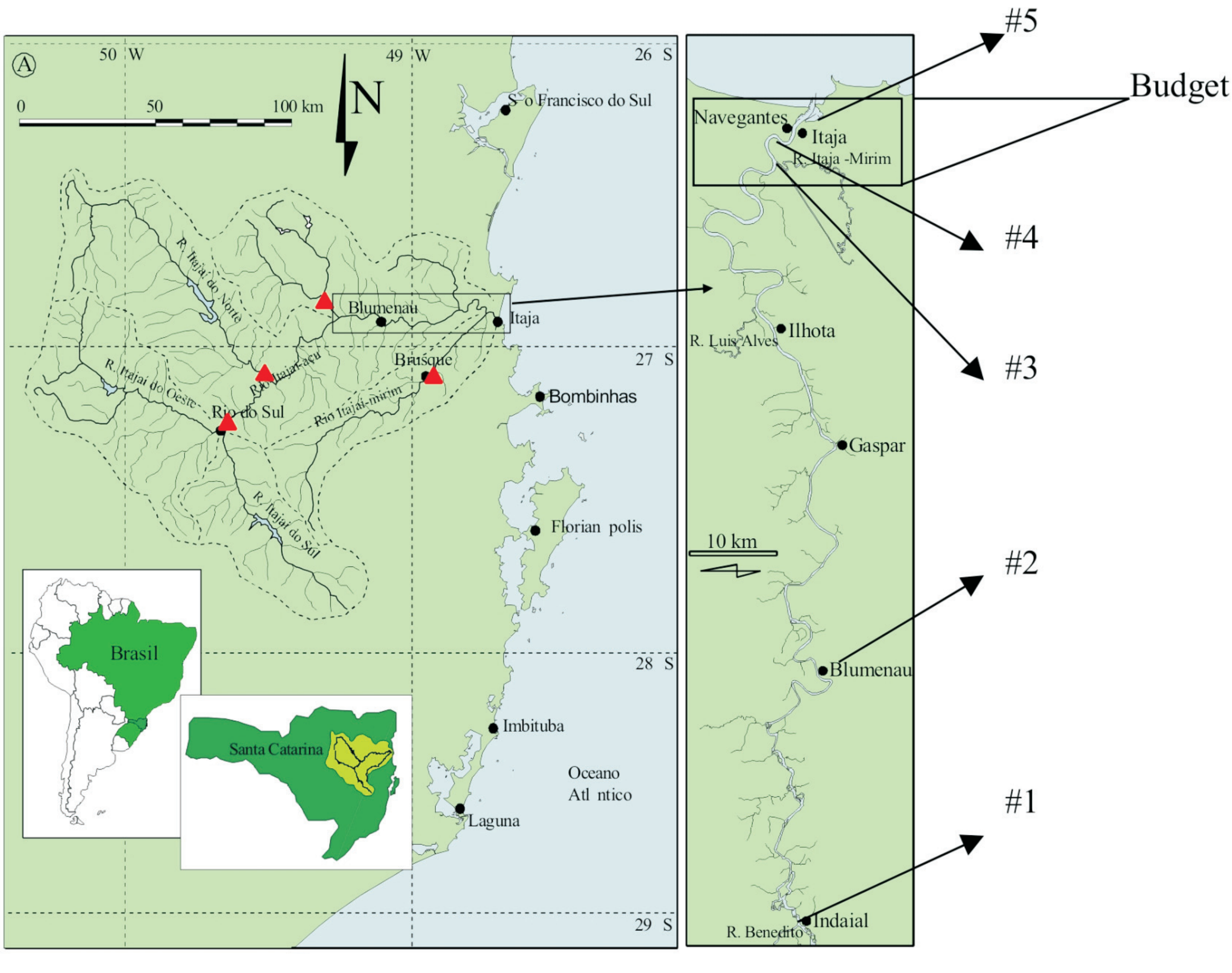


Figure 1. Study Area, includind the sampling points.

Table 1. *Water and Salt budget for the Itajaí-Açú River Estuary. $V_Q$: River discharges, $V_E$: Evaporative flux of water, $V_P$: Precipitation flux of water, $V_R$: Residual flux of water, $S_R$: Residual Salinity ($S_R$= (S1+S2)/2); $V_R S_R$: Salt fluxes, $V_x$: Exchange flux, calculated from the water and salt budget (Vx =$V_R S_R$/ (S2-S1)).*

| | Itajaí River: Indaial | Estuary | Coastal Water (CW) |
|---|---|---|---|
| *River discharge: < 200 $m^3.s^{-1}$* | | | |
| Area ($km^2$) | | 3,17 | |
| Volume (*$10^6 m^3$) | | 20 | |
| Salinity | 0,0 | 11,5 | 23,7 |
| $\Sigma V_Q$ (*$10^6$ $m^3.d^{-1}$) | 14 | | |
| $V_E$ (*$10^6$ $m^3.d^{-1}$) | | -0,06 | |
| $V_P$ (*$10^6$ $m^3.d^{-1}$) | | +0,07 | |
| $V_R$ (*$10^6$ $m^3.d^{-1}$) | | -14 | |
| $V_R.S_R$ | | -246 | |
| $V_X$ (*$10^6$ $m^3.d^{-1}$) | | +20,1 | |
| *River discharge: 200 - 800 $m^3.s^{-1}$* | | | |
| Area ($km^2$) | | 3,17 | |
| System Volume (*$10^6 m^3$) | | 20 | |
| Salinity | 0,7 | 7,2 | 23 |
| $\Sigma V_Q$ (*$10^6$ $m^3.d^{-1}$) | 31 | | |
| $V_E$ (*$10^6$ $m^3.d^{-1}$) | | -0,009 | |
| $V_P$ (*$10^6$ $m^3.d^{-1}$) | | +0,01 | |
| $V_R$ (*$10^6$ $m^3.d^{-1}$) | | -31 | |
| $V_R.S_R$ | | -468 | |
| $V_X$ (*$10^6$ $m^3.d^{-1}$) | | +29,6 | |

estuary and the high concentrations of particulated suspended matter is favorable for adsorption. On the other hand, the system´s high turbidity decrease the light penetration in the water column and the photosynthetic activity as well. Thus, is more plausible that the geochemical removing processes of DIP are the dominant in this estuary. The DIP removing is more evident at low discharge conditions, as more salt water is present inside the estuarine basin, more mixing can take place, and higher is the water flushing time. This is particularly true during spring tides, and some distinction of the phosphorus budgets may be observed following the tidal phase. The ▲ DIP decrease at moderate river discharge class, to -18.6 x $10^6$ mmol.day$^{-1}$, or 28 % compared with the low discharge class (Figure 3), showing minor adsorption rate. This can be explained by the increase in the river discharge inducing higher levels of water column stratification, and consequently less mixing taking place, and flushing time being reduced as well. The non-conservative variation (▲ DIN) of the dissolved inorganic nitrogen (DIN = $NO_3^-$ + $NO_2^-$ + $NH_4^+$) for the low discharge class was +272 x $10^6$ mmol.day$^{-1}$ (Figure 3).

The positive signal means that DIN is being produced in the estuary, which is not explained by the advective transport and/or sewage inputs. This behavior can be explained by the fact the estuary receives a large load of organic matter originated from smaller creeks, tributaries and the fishery industry, beside the sewage inputs.

The formers were not computed in the balance. This indicates that a big amount of organic matter is being decomposed in the region. The ▲ DIN at moderate discharge class was +336 x $10^6$ mmol.day$^{-1}$ (Figure 3), representing an increase of about 23% compared with the low discharge class. This behavior corroborates the hypothesis of extra inputs, because as the discharge increases, the same happens with the organic matter inputs, leading to the increase of decomposition and the values of ▲NID.

Table 2. *DIP and DIN Budget calculated during the different River discharges.*

| | Itajaí River | Estuary | Coastal Water |
|---|---|---|---|
| *DIP Budget River Discharge: < 200 $m^3.s^{-1}$* | | | |
| DIP (mmol.$m^{-3}$) | 0,8 | 0,73 | 0,6 |
| $\Sigma(V_Q.DIP)_{Ind+sew}$ (*$10^6$ mmol.$d^{-1}$) | 27,8 | | |
| $\Sigma(V_Q.DIP)_{Itajaí-Naveg.}$ (*$10^6$ mmol.$d^{-1}$) | | 10 | |
| $V_R$ . $DIP_R$ (*$10^6$ mmol.$d^{-1}$) | | -9,3 | |
| Vx.($DIP_{CW}$-$DIP_{est}$) (*$10^6$ mmol.$d^{-1}$) | | -2,63 | |
| **Δ DIP** (*$10^6$ mmol.$d^{-1}$) | | **-25,9** | |
| *DIN Budget River Discharge: < 200 $m^3.s^{-1}$* | | | |
| DIN (mmol.$m^{-3}$) | 28 | 47,3 | 21,2 |
| $\Sigma(V_Q.DIN)_{Ind+sew}$ (*$10^6$ mmol.$d^{-1}$) | 675 | | |
| $\Sigma(V_Q.DIN)_{Itajaí-Naveg}$ (*$10^6$ mmol.$d^{-1}$) | | 59 | |
| $V_R$ . $DIN_R$ (*$10^6$ mmol.$d^{-1}$) | | | -479 |
| Vx.($DIN_{CW}$-$DIN_{est}$) (*$10^6$ mmol.$d^{-1}$) | | -527 | |
| **Δ DIN** (*$10^6$ mmol.$d^{-1}$) | | | **+272** |
| *DIP Budget River Discharge 200 - 800 $m^3.s^{-1}$* | | | |
| DIP (mmol.$m^{-3}$) | 0,7 | 0,82 | 0,5 |
| $\Sigma(V_Q.DIP)_{Ind+sew}$ (*$10^6$ mmol.$d^{-1}$) | 38,5 | | |
| $\Sigma(V_Q.DIP)_{Itajaí-Naveg.}$ (*$10^6$ mmol.$d^{-1}$) | | 10 | |
| $V_R$ . $DIP_R$ (*$10^6$ mmol.$d^{-1}$) | | | -20,5 |
| Vx.($DIP_{CW}$-$DIP_{est}$) (*$10^6$ mmol.$d^{-1}$) | | -9,47 | |
| **ΔDIP** (*$10^6$ mmol.$d^{-1}$) | | | **-18,6** |
| *DIN Budget River Discharge 200 - 800 $m^3.s^{-1}$* | | | |
| DIN (mmol.$m^{-3}$) | 34,6 | 45,9 | 21,1 |
| $\Sigma(V_Q.DIN)_{Ind+sew}$ (*$10^6$ mmol.$d^{-1}$) | 1335 | | |
| $\Sigma(V_Q.DIN)_{Itajaí-Naveg}$ (*$10^6$ mmol.$d^{-1}$) | | 59 | |
| $V_R$ . $DIN_R$ (*$10^6$ mmol.$d^{-1}$) | | | -1085 |
| Vx.($DIN_{CW}$-$DIN_{est}$) (*$10^6$ mmol.$d^{-1}$) | | -645 | |
| **Δ DIN** (*$10^6$ mmol.$d^{-1}$) | | **+336** | |

The exchanges of N and P between the estuary and inner shelf were estimated based on the mass balances, with net seaward transport for both nutrients. The net DIP transport was 11.9 x $10^6$ and 30,0 x $10^6$ mmol.day$^{-1}$ for low and moderate river discharge classes, respectively. The net DIN transport was 1,0 x $10^9$ and 1,7 x $10^9$ mmol.day$^{-1}$ for low and moderate river discharge classes, respectively. These values give us an idea about the nutrient contribution for the adjacent shelf close to the estuarine mouth, where a prominent estuarine plume is

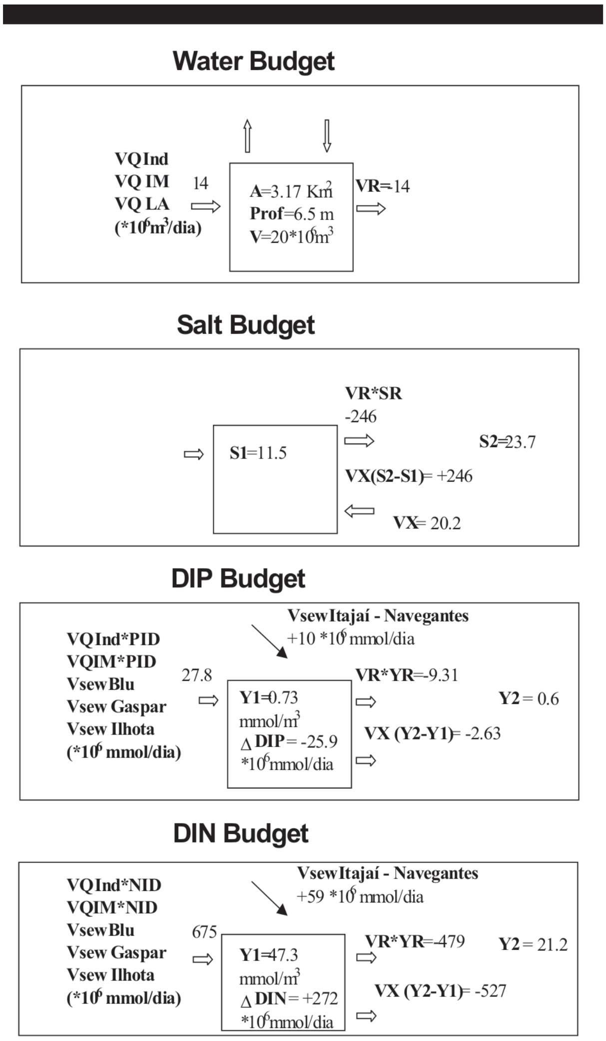


Figure 2. Water, salt, DIN and DIP Budgets during periods of River Discharge<200m$^3$.s$^{-1}$. Nutrient concentrations (Y, in mmol.m$^{-3}$), River Discharges (VQ, in 10$^6$ m3/d), nutrient entries due the river discharge (VQ*Y) and due the sewage (Vsew): *10$^6$ mmol.d$^{-1}$. Ind= Indaial City, Blu=Blumenau City, IM= Itajaí Mirim River, LA= Luís Alves River, sew= sewage, Y1 and Y2= nutrient concentration in the system and in the adjacent system (coastal water), VR= Residual Flow, SR= Residual Salinity (SR=(S1+S2)/2), S1= system salinity, S2 = adjacent system salinity, Vx= Mixing flux. According GORDON *et al* (1996).

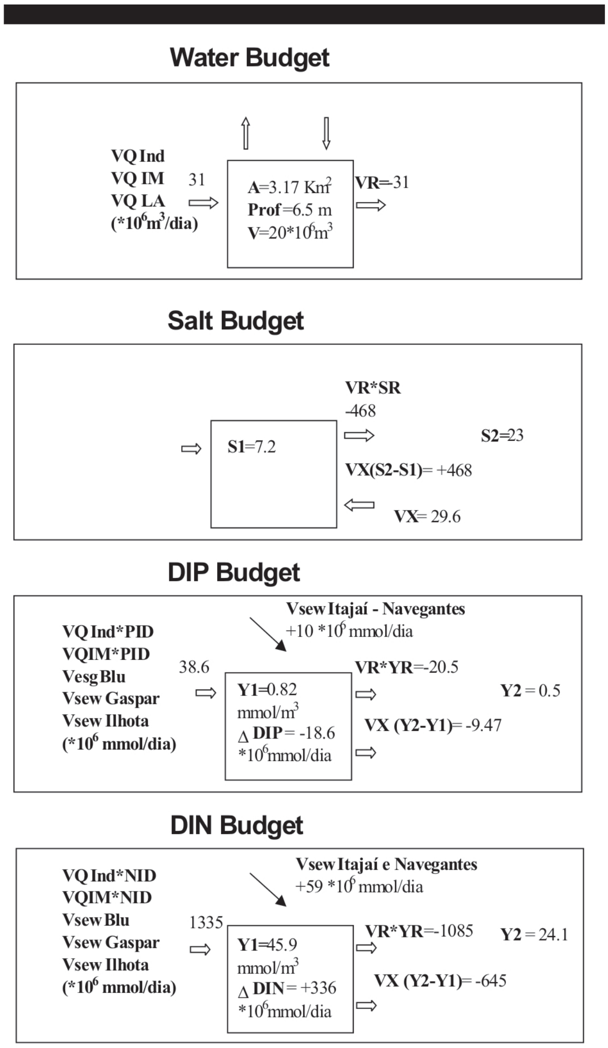


Figure 3. Water, salt, DIN and DIP Budgets during periods of River Discharge between 200 and 800m$^3$.s$^{-1}$. Nutrient concentrations (Y, in mmol.m$^{-3}$), River Discharges (VQ, in 10$^6$ m3/d), nutrient entries due the river discharge (VQ*Y) and due the sewage (Vsew): *10$^6$ mmol.d$^{-1}$. Ind= Indaial City, Blu=Blumenau City, IM= Itajaí Mirim River, LA= Luís Alves River, sew= sewage, Y1 and Y2= nutrient concentration in the system and in the adjacent system (coastal water), VR= Residual Flow, SR= Residual Salinity (SR=(S1+S2)/2), S1= system salinity, S2 = adjacent system salinity, Vx= Mixing flux. According GORDON *et al* (1996).

observed, which exhibits an increase of biology productivity and diversity (SCHETTINI *et al.*, 1998).

## CONCLUSIONS

From one year of weekly monitoring the concentration of inorganic dissolved nutrients (phosphorus and nitrogen) in the lower estuary of Itajaí-Açu River, it was possible to establish their mass balance using the LOICZ methodology. The main achievements are:

- The DIP is removed from water and the main processes responsible for that is the adsorption to the particulated suspended matter;
- The DIN is produced, mainly in the ammonium form, due the organic matter decomposition originated from mineralization processes. The organic matter can be originated from domestic sewages, small tributaries and the fishery industry.
- The estuary presented behavior predominately heterotrophic, independent of the river discharge class: low ( < 200 m$^3$.s$^{-1}$) or moderate (> 200 and < 800 m$^3$.s$^{-1}$).

## ACKNOWLEDGEMENTS

The authors thank the PROPPeC/UNIVALI for the grant give through the FAP and the scolarship of Luciana Spillere; to Leandro Franklin da Silva, Valdenir Ines and Marcos Berribilli for their support in the field surveys.

## LITERATURE CITED

BEROUNSKY, V. M. and NIXON, S. W., 1985. Eutrophication and the Rate of Net Nitrification in a Coastal Marine Ecosystem. *Estuarine, Coastal and Shelf Science*, 20:

BEUKEMA, J.J., 1991. Changes in composition of bottom fauna of a tidal-flat area during a period of eutrophication. *Marine Biology*, 111: 293-301.

CARMOUZE, J.-P and VASCONCELOS, P., 1992. The Eutrophication of the Lagoon of Saquarema, Brazil. *Science of the Total Environment*, Suppl., pp. 851-859.

CEDERWALL, H. and ELMGREN, R., 1980. Biomass increase of benthic macrofauna demonstrates eutrophication of the Baltic Sea. *Ophelia*, Suppl.1: 287-304.

GORDON, D. C.; BOUDREAU, P. R.; MANN, K. H.; ONG, J-E.;

SILVERT, W.; SMITH, S. V.; WATTAYAKORN, G.; WULFF, F. and YANAGI, T., 1996. *LOICZ Biogeochemical Modelling Guidelines. LOICZ Reports and Studi*es 5. LOICZ IPO, Texel, The Netherlands.

INNAMORATI, M. and GIOVANARDI, F., 1990. Interrelationships between Phytoplankton Biomass and Nutrients in the Eutrophicated Areas of the North-Western Adriatic Sea. *In*: Vollenweider, R.A.; Marchetti, R. and Viviani, R. (eds.) *Marine Coastal Eutrophication Proceedings*. Elsevier, pp: 235-250.

KIMOR, B., 1990. The Impact of Eutrophication on Phytoplankton Composition in Coastal Marine Ecosystems. *In*: Vollenweider, R.A.; Marchetti, R. and Viviani, R. (eds.) *Marine Coastal Eutrophication Proceedings*. Elsevier, pp. 871-878.

NIENCHESKI, L.F. and WINDOM, H.L., 1994. Nutrient flux and budget in Patos Lagoon Estuary. *The Science of Total Environment*, 149, pp. 53-60.

NIXON, S.W., 1982. Nutrient Dynamics, Primary Production and Fisheries Yields of Lagoons. *Oceanologica Acta*, Suppl.:, pp.357-371.

NIXON, S.W.; OVIATT, C.A.; FRITHSEN, J. and SULLIVAN, B. 1986. Nutrients and the producitivity of estuarine and coastal marine ecosystems. *Journal of Limnology Society of South Africa*, 12, pp. 43-71.

NIXON, S. W. and PILSON, M. E.Q., 1984. Estuarine Total System Metabolism and Organic Exchange Calculated from Nutrient Ratios: An Example from Narragansett Bay. *In*: Kennedy, V.S. (ed.). *The Estuary As a Filter - Seventh Biennial International Estuarine Research Conference.* Academic Press, pp.261-290.

PARKER, C.A. and O'REILLY, J.E., 1991. Oxygen depletion in Long Island Sound: a historical perspective. Estuaries, 14: 248-265.

PENNOCK, J.R.; SHARP, J.H. And SCHROEDER, W.W., 1994. What controls the expression of estuarine eutrophication? Case studies of nutrient enrichment in the Delaware Bay and Mobile Bay Estuaries, USA. *In:* DYER, K.R. and ORTH, R.J. (eds.). *Changes in fluxes in estuaries: Implications from science to management.* Olsen and Olsen, pp.139-146.

RIBEIRO, C.H.A., 1996. Uma Análise da Qualidade de Água da Baía de Guanabara entre 1980 e 1993. Niterói, RJ: Universidade Federal Fluminense, Dissertação de Mestrado, 137 p.

SCHETTINI, C. A. F. 2002. Caracterização física do estuário do rio Itajaí-Açu, SC, *Revista Brasileira de Recursos Hídricos*, 7 (1), pp.123-142.

SCHETTINI, C.A.F.; KUROSHIMA, K.N.; PEREIRA FILHO, J.; RÖRIG, L.R. and RESGALLA, JR., C., 1998. Oceanographic and ecological aspects of the Itajaí-açu river plume during a high discharge period. *Anais da Academia Brasileira de Ciências*, 70 (2), pp.335-351.

SCHETTINI, C. A. F.; CARVALHO, J. L. B. and JABOR, P., 1996. Comparative hydrology and suspended matter distribution of four estuaries in Santa Catarina State Southern Brazil. *Proceedings of the Workshop on Comparative Studies of Temperate Coast Estuaries* (Bahía Blanca, Argentina). UNS/IADO/NSF/IAI, pp.29-32.

SMITH, S.V. and VEEH, H.H., 1989. Mass Balance of Biogeochemically Active Materials (C,N,P) in a Hypersaline Gulf. *Estuarine, Coastal and Shelf Science*, 29. pp. 195-215.

STRICKLAND, J.D. and PARSONS, T.R., 1972. *A Practical Handbook of Seawater Analysis*. Ottawa: Fish. Res. Board. Can. Bull., 310p.

VON SPERLING, M. 1996. *Introdução à qualidade das águas e ao tratamento de esgotos*. Belo Horizonte: Departamento de engenharia Sanitária e Ambiental; Universidade Federal de Minas Gerais. 2. ed., 243p.