1. OVERVIEW OF WORKSHOP AND BUDGETS RESULTS

The key objectives of the Land-Ocean Interactions in the Coastal Zone (LOICZ) core project of the International Biosphere-Geosphere Programme (IGBP) are to:

- gain a better understanding of the global cycles of the key nutrient elements carbon (C), nitrogen (N) and phosphorus (P);
- understand how the coastal zone affects material fluxes through biogeochemical processes; and
- characterise the relationship of these fluxes to environmental change, including human intervention (Pernetta and Milliman 1995).

To achieve these objectives, the LOICZ programme of activities has two major thrusts. The first is the development of horizontal and, to a lesser extent, vertical material flux models and their dynamics from continental basins through regional seas to continental oceanic margins, based on our understanding of biogeochemical processes and data for coastal ecosystems and habitats and the human dimension. The second is the scaling of the material flux models to evaluate coastal changes at spatial scales to global levels and, eventually, across temporal scales.

It is recognised that there is a large amount of existing and recorded data and work in progress around the world on coastal habitats at a variety of scales. LOICZ is developing the scientific networks to integrate the expertise and information at these levels in order to deliver science knowledge that addresses our regional and global goals.

The United Nations Environment Programme (UNEP) and Global Environment Facility (GEF) have similar interests through the sub-programme: "Sustainable Management and Use of Natural Resources". LOICZ and UNEP, with GEF funding support, have established a project: "The Role of the Coastal Ocean in the Disturbed and Undisturbed Nutrient and Carbon Cycles" to address these mutual interests; this Workshop is the second of a series of regional activities within the project.

South America extends across more than 65 degrees of latitude, encompassing the tropics and extending into the cool temperate and subantarctic regions. Physiographically, the western location of the Andean mountain spine provides for extensive river basins and wetlands leading to the Atlantic and Caribbean coast in the east and north, and relatively precipitous landforms abutting the Pacific, with little continental shelf to the west. Climate patterns ensure prevalent wet conditions in the north, east and south-west with arid landscapes to the south-east and west. Demographic patterns are extreme, ranging from several megacities to large tracts of land and shore with near-zero human density. Land use patterns also show great regional variation in areal extent and intensity, for example, extensive and progressive deforestation in Brazil to agricultural use modification in tropical and temperate regions. This array of climate, landforms, land use and demography ensures a heterogeneous coastal zone subject to a variety of pressures and changes and a spectrum of anthropogenic influences. This Workshop is a first step by LOICZ to gain representative descriptions of the biogeochemical performance of the coastal zone ecosystems within the region, in order to address the goals of assessing global changes in material flux processes and the human dimension.

The Workshop was held in Bahia Blanca, Argentina on 10-12 November 1999, with participants subsequently attending the LOICZ 4th Open Science Meeting and reporting on individual and collective results. Ms Monica Gil, a postgraduate student from Argentina and one of the Workshop participants, was awarded the LOICZ OSM Travel Award (full support to an international conference) for the best poster/presentation at the Meeting.

The terms of reference for the Workshop (Appendix VI) and the Activities (Appendices III and V) are contained in this report. The resource persons worked with Workshop participants from five countries (Argentina, Brazil, Chile, Ecuador, Uruguay) to develop and assess biogeochemical budgets for eleven coastal systems in the region, ranging from estuarine lagoonal environments to large bays and fjords. Further site budgets are being developed at home institutions and a national Workshop is foreshadowed for Colombia.

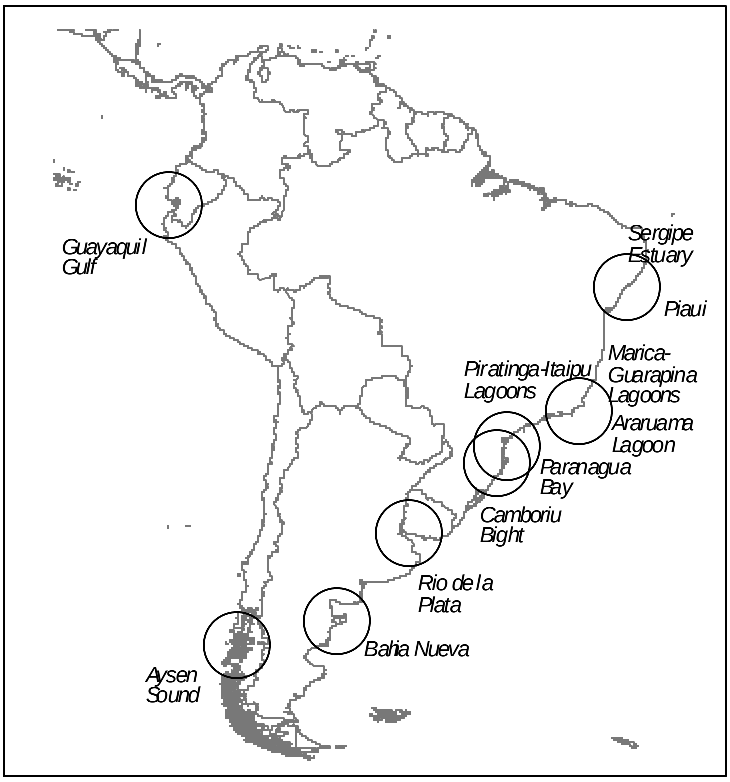

Figure 1.1 Map of budget sites developed by the Workshop.

These continuing activities are a vital part of the project and will be coordinated and supported by the project-funded Regional Mentor, Dr Victor Camacho at the Universidad Autonoma de Baja California in Ensenada, Mexico. The development of typology approaches and the integration of regional data were discussed as a key strand of the Workshop, and the prototype computer programme for calculation of sites budget and model (CABARET, Appendix I) was tested by the Workshop participants. Mr Weber Landim de Souza, a Workshop participant and a student under Prof. B. Knoppers at Universidade Federal Fluminense in Rio de Janeiro, Brazil will take up the LOICZ/UNEP Regional Training Scholarship (South America) in early 2000, for additional training in budget analyses at the Universidad Autonoma de Baja California, Mexico with Dr Camacho.

The initial plenary session of the Workshop outlined the tools and information developed at earlier Workshops, which provide a platform for site assessment and budget derivations. Presentation of the CABARET prototype programme by Dr Laura David, added a further dimension to the tools and training elements, with participants providing vital feedback for the final design of the computer programme. Dr Victor Camacho outlined the role of the Regional Mentor and demonstrated use of the LOICZ modelling approach using the San Quintin model as a training example. The LOICZ Budgets Modelling website was described by Prof. Fred Wulff and Mr Dennis Swaney, and the pivotal role of the electronic site and its use by global scientists in making budget contributions to the LOICZ purpose was emphasised. It was noted that contributing scientists are clearly attributed as authors of their contributed budgets, and that there is provision to updated and provide additional assessment of their budgets.

The group moved from plenary to further develop the site budgets individually and in small working groups, returning to plenary sessions to discuss the budget developments and to debate points of approach and interpretation. Eleven budgets were developed during the Workshop (Figure 1.1, Table 1.1), with two additional sites in Chile and further sites in Brazil and Argentina in progress.

The common element in the budget descriptions is the use of the LOICZ approach to budget development, which allows for global comparisons and application of the typology approach. The differences in the descriptive presentations reflect the variability in richness of site data, the complexity of the sites and processes, and the extent of detailed process understanding for the sites. Support information for the various estuarine locations, describing the physical environmental conditions and related forcing functions including the history and potential anthropogenic pressure, is an important part of the budget information for each site. These budgets, data and their wider availability in electronic form (CD-ROM, LOICZ website) will provide opportunity for further assessment, comparisons and potential use with wider scales of patterns in system response and human pressures.

The budget information for each site is discussed individually and reported in units that are convenient for that system (either as daily or annual rates). To provide for an overview and ease of comparison, the key data are presented in an "annualised" form and nonconservative fluxes are reported per unit area (Tables 1.1 and 1.2).

Key outcomes and findings from the Workshop include:

1. A set of eleven budgets representing a range of coastal settings for the South American region – estuaries, coastal lagoons, large embayments and fjords. These budgets provide insights into seasonality, influence of human activities as drivers of change and sensitivity of system performance to nutrients derived from land and ocean. Further development of a number of these budgets and additional site models are foreshadowed by participants and through the activity of the Regional Mentor. It is expected that additional models will add to "replication" of system types and support further trend analyses of climatic and human forcings on biogeochemical processes across the continent and globally.

2. A variety of site examples and different measurement/data types which show approaches that can be taken under the LOICZ Modelling protocol for first-order evaluation of net metabolism of coastal systems and modelling to meet LOICZ global change goals and UNEP project objectives.

3. The two coastal lagoon systems (Marica-Guarapina, Piratininga-Itaipu) were used for analysis of the net metabolism trends and trophic changes within component parts of the water continuum, from land through the lagoon systems to the sea. Seasonal forcing (wet and dry seasons) were considered along with different stoichiometric ratios in the calculation of net metabolism values.

4. The estuarine systems (Rio Sergipe, Paranagua Bay), modelled as multiple horizontal boxes, indicated seasonal variations in net autotrophy/heterotrophy and nitrogen fixation/denitrification occurring horizontally within the systems. Further refinement of the budgets and additional sites with similar settings will assist in evaluating these variations.

5. The fjord site (Aysen Sound) provided a model of a deep stratified system, with evidence of marked inter-annual variability in surface water net metabolism. Further understanding of the net metabolic patterns of the full system will depend on gaining summer (and a wider seasonal spread of) physico-chemical data.
6. A new tool (CABARET) is nearing final development which will provide user-friendly computer-assisted assessment of material fluxes in estuarine systems following the LOICZ Modelling approach.

The Workshop was hosted by the Instituto Argentino de Oceanografia in Bahia Blanca, Argentina. LOICZ is grateful for this support and indebted to Dr Gerardo Perillo and Institute staff, and to the Workshop resource scientists for their contributions to the success of the Workshop. LOICZ gratefully acknowledges the effort and work of the participants not only for their significant contributions to the Workshop goals, but also for their continued interaction beyond the meeting activities.

The Workshop and this report are contributions to the GEF-funded UNEP project: *The Role of the Coastal Ocean in the Disturbed and Undisturbed Nutrient and Carbon Cycles,* recently established with LOICZ and contributing to the UNEP sub-programme: Sustainable Management and Use of Natural Resources.

Table 1.1 Budgeted South American sites, locations, sizes and water exchange times.

System Name	**Long.** (W)	**Lat.** (S)	**Area** (km^2)	**Depth** (m)	**Exchange Time** (days)
Brazil					
Rio Sergipe estuary[a]	37.10	10.90	33	3	31
Piaui River estuary	37.55	11.00	44	4	6
Marica-Guarapina lagoon system	42.70	22.93	35	1.3	185
Marica Lagoon			29	1.3	314
Guarapina Lagoon			6	1	25
Piratininga-Itaipu lagoon system	43.06	22.95	4	1	23
Piratininga Lagoon			3	1	46
Itaipu Lagoon			1	1	6
Paranagua Bay[b]	48.50	25.50	330	4	12
Camboriu River estuary[c]	48.61	27.10	0.5	2	<1
Araruama Lagoon	42.20	28.80	215	3	985
Uruguay/Argentina					
Rio de la Plata frontal zone	56.98	34.80	6000	8	9
Argentina					
Bahia Nueva, Golfo Nuevo[b]	65.00	42.75	58		50
Ecuador					
Gulf of Guayaquil estuary system	80.25	2.75	3000	10	4
Chile					
Aysen Sound system	73.3	45.40	470	142	>700
- Surface waters					>90
- Deep waters					>470

a marked wet and dry season differences; in the dry season the exchange rate is near zero
b marked wet and dry season differences; values are annual means for the system
c exchange time too short to calculate reliable nonconservative fluxes

Table 1.2 Budgeted South American sites, loads, and estimated *(nfix-denit)* and *(p-r)*.

System Name	DIP load	DIN load	DDIP	DDIN	*(nfix-denit)*	*(p-r)*
	mmol m^{-2} yr^{-1}					
Brazil						
Rio Sergipe estuary[a]	5	1330	-55	-438	36	5860
Piaui River estuary	11	98	15	186	-48	-1570
Marica-Guarapina lagoon system	19	20	-17	<1	280	1850
Marica Lagoon	21	17	-11	8	170	1170
Guarapina Lagoon	27	112	-48	-40	810	5120
Piratininga-Itaipu lagoon system	0	1	2	28	4	-159
Piratininga Lagoon	0	2	2	7	-25	-212
Itaipu Lagoon	5	30	<1	90	90	0
Paranagua Bay estuary[b]	15	187	7	-8	-122	-1500
Camboriu River estuary[c]	1860	19000	o	o	+	+
Araruama Lagoon	10	153	+7	-8	-120	-740
Uruguay/Argentina						
Rio de la Plata frontal zone	220	380	-70	-2300	-1200	7100
Argentina						
Bahia Nueva, Golfo Nuevo[b]	8	176	<-1	-552	-500	1460
Ecuador						
Gulf of Guayaquil estuary system	316	o	-146	o	o	15580
Chile						
Aysen Sound system	<1	14	-6	-165	-110	990
- Surface waters			-34	-440	185	2800
- Deep waters			28	280	-128	-2300

a marked wet and dry season differences; in the dry season exchange rate is near zero
b marked wet and dry season differences; values are annual means for system
c exchange time too short to calculate reliable non-conservative fluxes; (+) system apparently net autotrophic and net nitrogen-fixing
d based on two winter seasons; inter-annual variability in system net metabolism, especially in surface waters

BRAZIL COASTAL SYSTEMS

2.1 Rio Sergipe, Sergipe State

Marcelo F. Landim de Souza

Study area description

Rio Sergipe is a small drowned river valley estuary, located between 10.8°-11.0°S, 37.2°-37.0°W. Based on a 1:50,000 scale map (ADEMA 1984) and available soundings (Alcântara *et al.* 1979), the estuarine area is 33 km^2, with an average depth of about 3 m (Figure 2.1). Runoff is strongly controlled by rain, with an average freshwater discharge range from 560,000 m^3 day^{-1} in the rainy season to 70,000 m^3 day^{-1} in the dry season (Harleman 1979). The maximum tidal height is 3 m. About half of the 3,800 km^2 watershed is in inland regions with annual precipitation of 600-1,000 mm; the rest is in the coastal zone, with 1,000-1,500 mm yr^{-1} (JICA 1998). Most of the higher rainfall zone watershed drains through limestone, sandstone and shale of the Cretaceous Sergipe Basin.

Aracaju, the capital of Sergipe State had about 200,000 inhabitants in 1975 (CONDESE 1973). At that time there were few industrial plants. By the 1996 census the population had increased to about 400,000 (JICA 1998) and an industrial park had been developed. Industries that discharge wastes directly into Rio Sergipe include textile industries, sugar and paper mills, beverage manufacture and coconut processing. The Aracaju industrial district has additional metallurgy, textile and food processing plants, but the effluents are stored in a stabilization tank and discharged into Rio Poxim. In 1980 the effluents from a big fertilizer plant (FAFEN) began to be discharged in the upper Rio Sergipe estuary. Other economic activities in the basin are cattle raising (for which the original forest cover was removed), sugarcane and mining (limestone, potassium, nitrate and crude oil). Formerly mangrove forests covered the estuarine margins, but large areas have been logged to accommodate urban expansion since 1975.

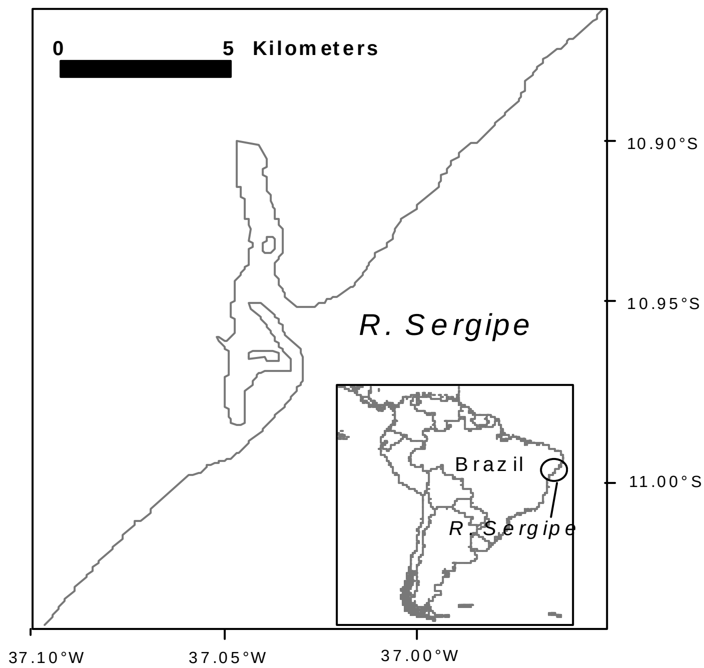

Figure 2.1 Map and location of Rio Sergipe estuary.

For a preliminary salt, water and dissolved nutrients budget, the early data available in Alcântara *et al.* (1979) for June and October 1975 were used. Evaporation and precipitation data were obtained from IESAP (1988) and mean freshwater discharges from Harleman (1979). The anthropogenic input was estimated from a *per capita* index of 9.5 moles inorganic P person yr^{-1} and 140 moles inorganic N person yr^{-1} (S.V. Smith, personal communication). Using a population of about 200,000 persons in 1975 results in approximate waste loads of about 5,000 mol DIP d^{-1} and 80,000 mol DIN d^{-1}.

Water and salt balance

As true oceanic data were not available, the outer part of the estuary was used for the "ocean" and only the inner part was budgeted (Figure 2.1). The present one-dimensional budget should be checked further against two-dimensional procedures, since some stratification was observed, especially in the outer sampling stations.

The difference between hydraulic ($V_{syst}/|V_R|$) residence time and total water exchange time ($V_{syst}/(|V_R|+V_X)$) indicates the efficiency of tidal mixing. Water exchange times were high, due to the low freshwater discharge (Figures 2.2 and 2.3). A slightly positive water balance in the dry season indicates a small residual outflow from the estuary, compared with the balance in the rainy season. In the dry season, the estuary is "plugged", with effectively infinite exchange time. Tidal mixing is the main water flow in both seasons.

DIP and DIN balance

The only dissolved nutrients for which data are available are nitrate (considered as a lower estimate of DIN) and dissolved inorganic phosphorus (DIP). In fact, DIP was below the detection limit in the sampling dates of this budget (Alcântara *et al.* 1979). Although unusual, these results agree with those obtained in a 1999 sampling (unpublished data), in which most samples also had DIP below detection limits, despite the greatly increased anthropogenic loading. To allow further stoichiometric linking, it was assumed that all anthropogenic contribution was removed from water column, resulting in *DDIP* $\cong$ $-5\text{x}10^3$ mol day^{-1}. Given the very long water exchange time, this is not an unreasonable scenario. This leads to the "stoichiometric conclusion" that the estuary is a net autotrophic system.

Dissolved inorganic nitrogen budgets (Figures 2.4 and 2.5) indicate *DDIN* ranging from $-66\text{x}10^3$ mol day^{-1} in the rainy season to $-87\text{x}10^3$ mol day^{-1} in the dry season. In the rainy season (Figure 2.4) more than 50% of DIN inputs were exported to the outer reaches, while in the dry season the export was only about 1% (Figure 2.5).

Thus, this estuary acts as an effective sink of DIP and DIN, especially during the dry season.

It must be emphasized that the extremely low DIP concentrations and high DIN concentrations appear to be very unusual conditions.

Stoichiometric calculations of aspects of net system metabolism

Table 2.1 summarizes the stoichiometric calculations. Assuming that the estimated *DDIP* was assimilated in organic matter with a Redfield N:P ratio, this estuary is a net nitrogen fixing system during the winter and a slight net denitrifying system during the summer. If we assume that the two seasons are of approximately equal length, then the annual average rate of (*nfix-denit*) is +0.1 mmol m^{-2} day^{-1}. That is, the annual average (*nfix-denit*) is near 0.

Net ecosystem metabolism (*p-r*) can be estimated as the negative of the product of *DDIP* and the C:P ratio of produced/consumed organic matter.

Assuming that plankton is the main producer (C:P $\cong$ 106:1):

$(p\text{-}r) = 5.3\text{x}10^5$ mol C day^{-1} = +17 mmol m^{-2} day^{-1} .

If mangrove dominate organic matter metabolism (C:P $\cong$ 1000:1):

$(p\text{-}r) = 5.0\text{x}10^6$ mol C day^{-1} = +160 mmol m^{-2} day^{-1}.

There is, of course, no seasonal signal, since the calculations are based on the assumption that all waste load is taken up. The net uptake of DIP indicates that the system is apparently net autotrophic, with considerable uncertainty in the magnitude of this autotrophy because of the apparent importance of mangroves in the system.

Table 2.1 Summary of stoichiometric calculations for Rio Sergipe.

Season	*DDIP*	$DDIN_{obs}$	$DDIN_{exp}$	(*nfix-denit*)	$(p\text{-}r)_{plank}$[1]	$(p\text{-}r)_{mang}$[2]
Winter (rainy) 10^3 mol day^{-1}	-5	-66	-80	+14	+530	+5,000
mmol m^{-2} day^{-1}	-0.15	-1.9	-2.4	+0.4	+16	+152
Spring (dry) 10^3 mol day^{-1}	-5	-87	-80	-7	+530	+5,000
mmol m^{-2} day^{-1}	-0.15	-0.5	-2.4	-0.2	+16	+152
Annual average 10^3 mol day^{-1}	-5	-77	-80	+3	+530	+5,000
mmol m^{-2} day^{-1}	-0.15	-1.2	-2.4	+0.1	+16	+152

[1]Assuming a C:P ratio of 106:1 for plankton-based particulate material.
[2]Assuming a C:P ratio of 1,000:1 for mangrove-based particulate material.

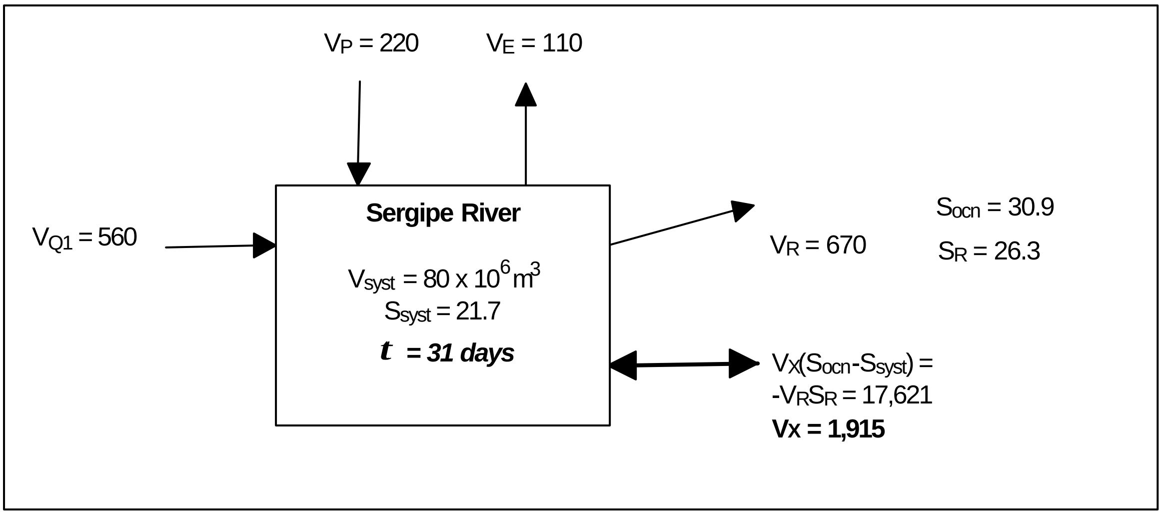

Figure 2.2 Water and salt budgets for Rio Sergipe, June 1975. Water and salt fluxes in 10^3 m^3 day^{-1} and 10^3 psu-m^3 day^{-1}, respectively. Salinity in psu.

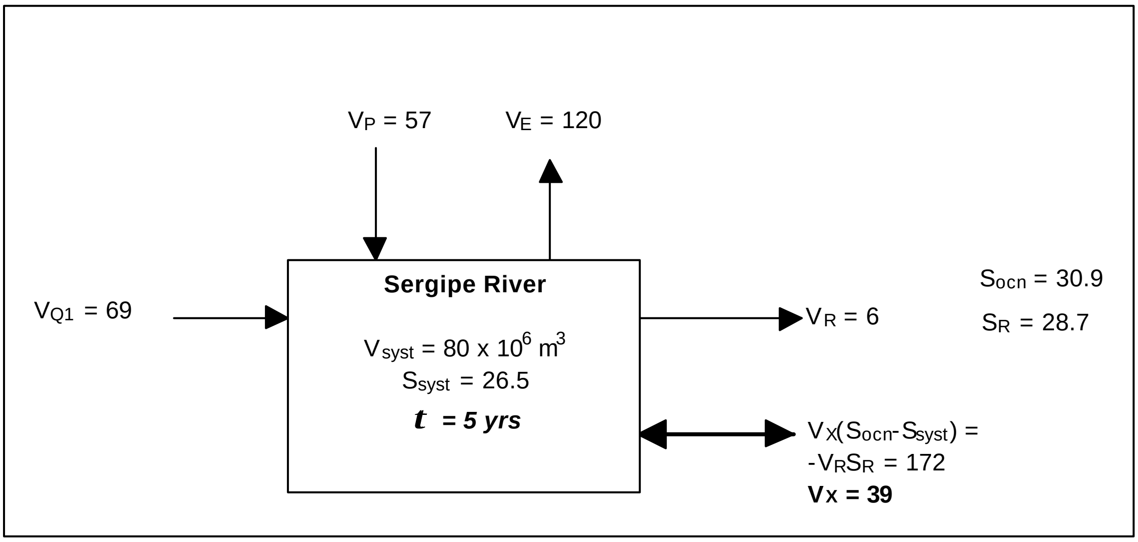

Figure 2.3 Water and salt budgets for Rio Sergipe, October 1975. Water and salt fluxes in 10^3 m^3 day^{-1} and 10^3 psu day^{-1}, respectively. Salinity in psu.

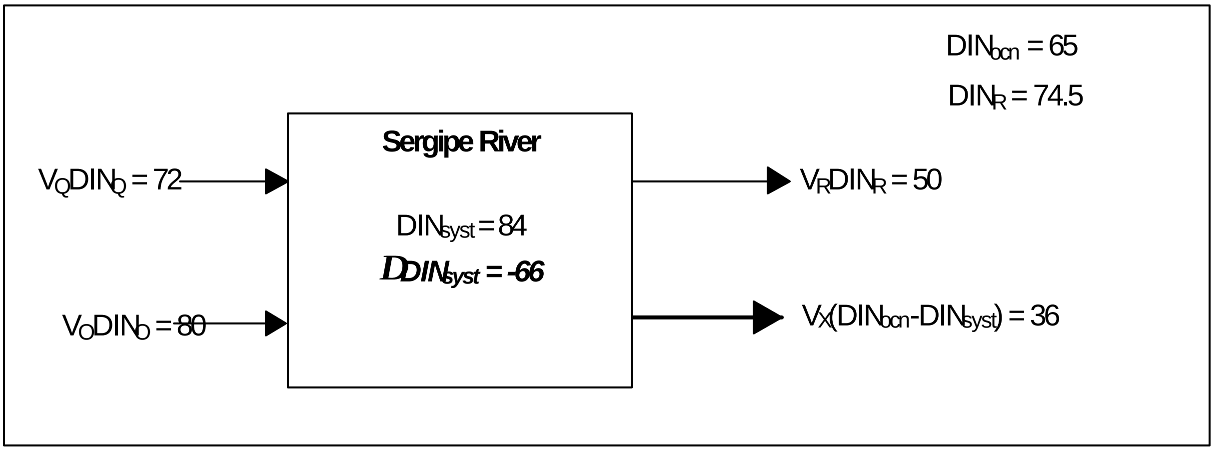

Figure 2.4 Dissolved inorganic nitrogen budgets for Rio Sergipe, June 1975. Fluxes in 10^3 mol day^{-1}.

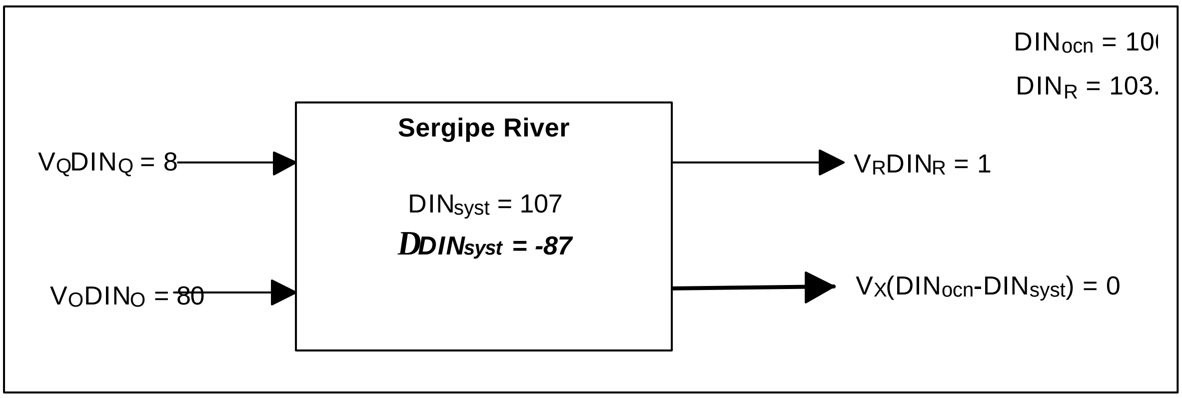

Figure 2.5 Dissolved inorganic nitrogen budgets for Rio Sergipe, October 1975. Fluxes in 10^3 mol day^{-1}.

2.2 Piauí River Estuary, Sergipe State.

***Marcelo F. Landim de Souza*, V.R. Gomes, S.S. de Freitas, R.C.B Andrade, B.A. Knoppers and S.V. Smith**

Study area description

The Piauí River watershed in northern Brazil (10.5°-11.5° S, 37.2°-38.1° W, Figure 2.6) covers 4,220 km^2 of a geologically complex and heterogeneous terrain. An elevation of 100 m occurs between 10-20 km from the coast, and the river originates at an elevation of about 450 m. Coastal areas have a warm humid to sub-humid climate (~1,400 mm yr^{-1}), with 1-3 dry months (“summer-spring”), while the inland areas have Mediterranean to dry climate (<750 mm yr^{-1}), with 4-6 dry months. Annual precipitation varies considerably from this average (UFS 1979). Most of the original vegetation in the basin has been removed to allow extensive cattle raising and crops (citrus fruits, tobacco and cotton). In the coastal zone, mangrove forests are being logged and replaced by coconut plantations.

The Piauí, Piauitinga, Fundo and Guararema rivers are the main tributaries (Figure 2.6). In all of these watersheds there are problems due to deforestation, improper soil use, riparian wood cutting and water pollution (JICA 1998). There is further degradation in the Piauitinga River, near the city of Estância. That river receives effluents from textile industries and high organic loading from citrus juice/food processing and untreated sewage. The resulting changes in water chemistry lead the river toward net heterotrophy, denitrification and also nitrogen loss to the atmosphere as ammonia (Andrade *et al.* 1998).

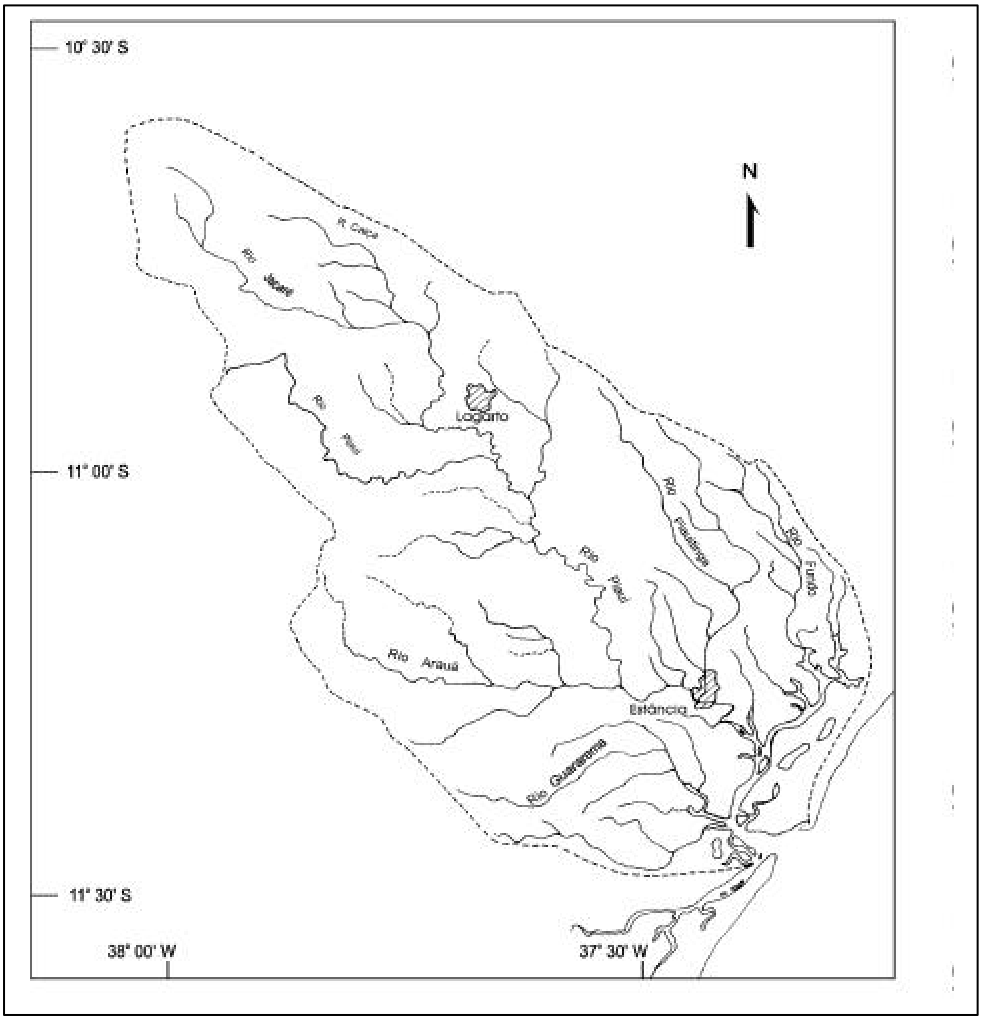

Figure 2.6 Piauí River drainage basin.

The entire estuary is a small drowned river valley, about 35 km long, 44 km^2 in area, and with an average depth of 4 m (Figure 2.7). The estuary has semidiurnal tides, with a maximum spring range of 3 m (Souza 1999). Direct pollution discharge into the estuarine zone is almost absent, but the estuary receives anthropogenic organic loading from the Piauitinga River, as described above. Water flow is regulated through two small reservoirs. Anthropogenic influence on dissolved inorganic nutrient concentrations is restricted to the upper Piauí River estuarine zone (Gomes *et al.* 1998). The Fundo River is essentially unpolluted, although it has a degraded watershed. The estuarine zone of these rivers has extensive mangrove coverage, though subject to increasing deforestation. There is a seaweed bank in the confluence of the Piauí and Real rivers (the prevailing taxon is *Halodule* sp., with some calcareous algae *Acetabularia* sp.). The small phytoplankton population of the turbid waters is dominated by diatoms.

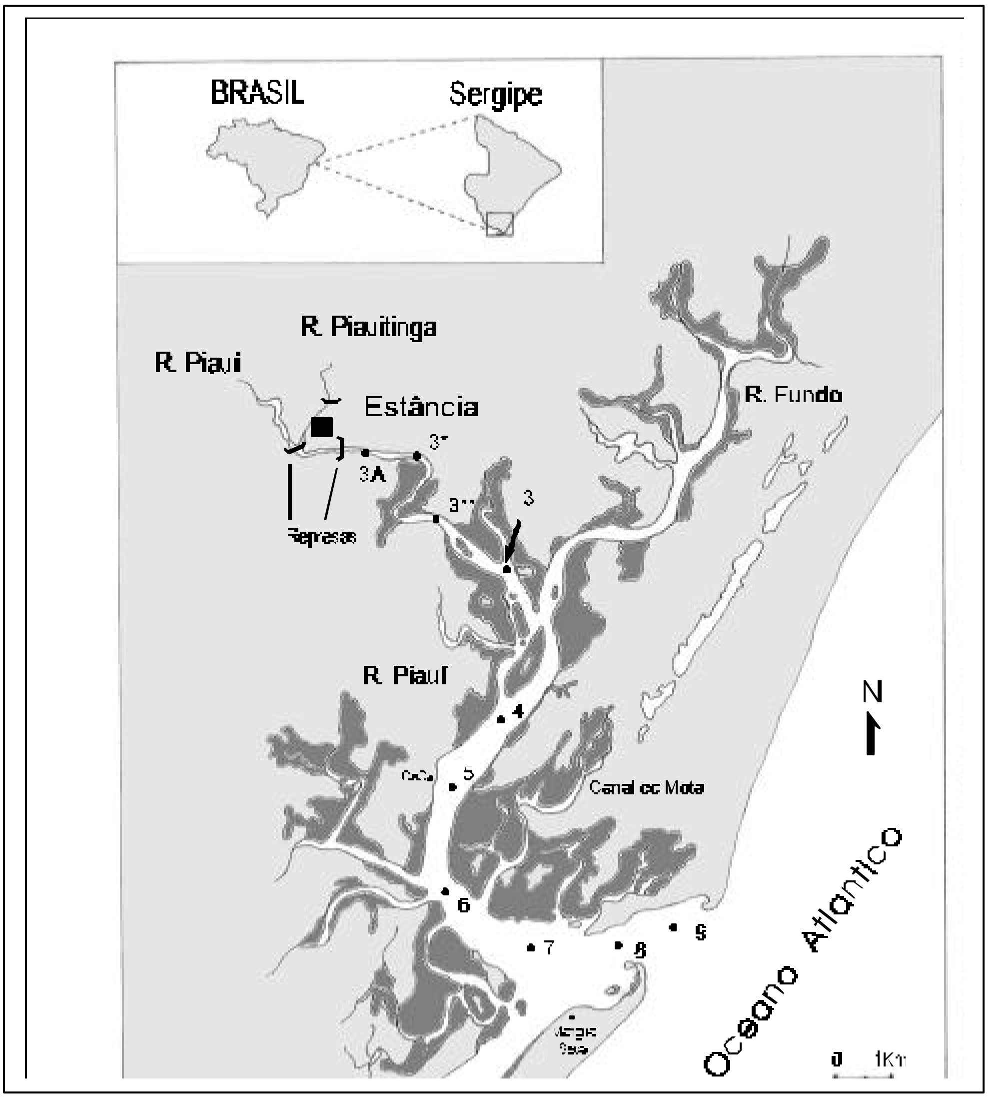

Figure 2.7 Map of Piaui River estuary, with location of sampling points.
Mangrove forests are represented as dark gray areas.

Measurements of community metabolism suggest that the system is heterotrophic on an annual basis, but with occasional episodes of net autotrophy, especially in the lower estuary (Souza 1999). The resulting loss of carbon dioxide to the atmosphere was estimated to be 4.3×10^8 mol yr^{-1}. That study also reported that planktonic net metabolism is approximately neutral, while most of the heterotrophy occurs in benthic and intertidal mangrove areas. However, previous work has revealed that system metabolism is subject to drastic short-term changes (Souza and Couto 1999).

The budgets presented here use data from 1985 for the Fundo River freshwater (Alves 1989), personal unpublished data for 1994-95 samplings for the Fundo River, and 1996-97 data for the rest (Souza 1999). Precipitation and evaporation over the basin were calculated from monthly data of 12 meteorological stations, using Thiessen's polygon method. The same data set was used to obtain freshwater runoff of each sub-basin by a simple rain-runoff model. Total anthropogenic inputs were estimated as the product of average discharge and concentrations at the downstream dam.

Water and salt balance

True oceanic data were not available, so we separated the outer part of the estuary (stations 8 and 9) as an "oceanic" endmember, and prepared the budget for the inner stations (Figure 2.7). The budgeted area of the estuary is 33 km^2 with an average depth of 2.4 m.

The mixing flow needed to maintain the observed salinity gradient is an order of magnitude higher than the residual and freshwater flows (Figure 2.8). Annual precipitation and evaporation are almost balanced, and are of minor importance compared with other water flows. Hydraulic water residence time ($V_{syst}/|V_R|$) is about 34 days, but mixing is sufficient to reduce the total system exchange time ($V_{syst}/(V_X + |V_R|)$ to about 6 days. It should be stressed that this annual average budget is subject to a strong seasonal and interannual variation in flow. The calculations presented here use flow data for 1996-97.

Budgets of nonconservative materials

DIP balance

The polluted Piauitinga River is the main DIP source to the estuary (Figure 2.9, V_{Q1}), with much higher fluxes than the relatively pristine Fundo River and Guararema River (V_{Q2} and V_{Q3}, respectively). *DDIP* for the estuary indicates slight positive flux (+184x10^3 moles yr^{-1}, equivalent to 4.2 mmol m^{-2} yr^{-1}). This positive flux agrees with independent estimates suggesting a somewhat heterotrophic system.

DIN balance

The DIN balance is similar to DIP (Figure 2.10). *DDIN* is +2.2x10^6 mol yr^{-1} (equivalent to 50 mmol m^{-2} yr^{-1}).

DIC balance

Fluvial inputs of DIC are exceeded by export via residual flow (Figure 2.11). There is some positive nonconservative DIC flux, but this is proportionally small (203x10^6 mol yr^{-1}, 4.6 mol m^{-2} yr^{-1}). After the inclusion of estimated CO_2 gas loss to the atmosphere (Figure 2.11), with DIC_g estimated as -430 x10^6 moles $year^{-1}$ (Souza 1999), *DDIC* increases to +633x10^6 mol yr^{-1}, or 14.4 mol m^{-2} yr^{-1}. This value seems very high, both on its own and in comparison with scaling from *DDIP*; however the calculation appears robust. Either *DDIP* underestimates net heterotrophy (perhaps because of DIP adsorption reactions) or the estimated gas flux is too high. In either case, it appears clear that CO_2 is released in excess of consumption by autotrophy.

Stoichiometric calculations based on the 1-box model

Net ecosystem metabolism (*p-r*) was estimated according Gordon *et al.* (1996), but using both the Redfield Ratio and the measured average particulate C:P ratio of the system (Souza 1999). In the former case it resulted in:

$$(p\text{-}r) = -184\text{x}10^3 \text{ x } 106 = -20\text{x}10^6 \text{ mol yr}^{-1} = -450 \text{ mmol m}^{-2} \text{ yr}^{-1}.$$

The utilization of the average C:P of the estuarine suspended matter (449:1) gives a net (*p-r*) of -83 x10^6 mol yr^{-1}, or -1,900 mmol m^{-2} yr^{-1}.

The system appears to exhibit slight net denitrification, with the exact rate dependent upon the N:P ratio used in stoichiometric estimate (Redfield, N:P = 16 or average N:P = 19). Here we use the Redfield Ratio:

$$(nfix\text{-}denit) = (+2{,}199 - (184 \text{ x N:P}) \text{ x } 10^3 = -745 \text{ x } 10^3 \text{ mol yr}^{-1} \cong -17 \text{ mmol m}^{-2} \text{ yr}^{-1}.$$

If the average N:P ratio is used, the estimated rate is -14 mmol m^{-2} yr^{-1}. Either of these is a very slow rate of net denitrification.

<u>Steady-state budgets using sub-basin compartments (3-box model)</u>
The comparison of the one-box balance with a multiple-boxes approach can indicate the importance of partitioning the system for an estuary with sharp gradients and multiple boxes.

<u>Salt and water budgets</u>
The smaller volume and higher freshwater discharge produce a very low water exchange time (about a day) to the inner Piauí River estuary (Figure 2.12). The Piauí River outer estuary exhibits a similar water exchange times (about 2 days). The Fundo River, with less than a half the volume of the former, has a higher exchange time (11 days). Tidal mixing is the main process responsible for water renewal in the three compartments. In the Piauí and Fundo rivers this effect is striking.

<u>Budgets of nonconservative materials</u>
DIP balance
The subdivision of these estuarine sections reveals that net heterotrophy is restricted to the outer Piauí estuary (Figure 2.13; *DDIP* = +713x10^3 mol yr^{-1}; +23 mmol m^{-2} yr^{-1}) and the Fundo River (+28x10^3 mol yr^{-1}; +3 mmol m^{-2} yr^{-1}). The inner Piauí estuary shows negative *DDIP* (-98x10^3 mol yr^{-1}, or -33 mmol m^{-2} yr^{-1}). Adding up these compartments, the 3-compartment model yields *DDIP* for the whole system of +643x10^3 mol yr^{-1} (+15 mmol m^{-2} yr^{-1}), compared to the 1-box model results of +184x10^3 mol yr^{-1}. It is assumed that the 3-box model is the more accurate resolution of *DDIP*.

DIN balance
DDIN balance exhibited the same pattern as *DDIP* (Figure 2.14). *DDIN* in the outer Piauí estuary was +9,999x10^3 mol yr^{-1} (+323 mmol m^{-2} yr^{-1}), and Fundo was +482x10^3 mol yr^{-1} (48 mmol m^{-2} yr^{-1}). Inner Piauí estuary showed a negative *DDIN* flux of -2,312x10^3 mol yr^{-1} (-771 mmol m^{-2} yr^{-1}). The 3-box model thus yields a whole-system *DDIN* of +8.2x10^6 mol yr^{-1} (+187 mmol m^{-2} yr^{-1}). Again, these results are substantially higher than the results from the 1-box model (+2.2x10^6 mol yr^{-1}).

Stoichiometric calculations based on the 3-box model
In the stoichiometric calculations (Table 2.2), we present (*p-r*) estimated using both the Redfield C:P ratio and that of average suspended organic matter in each box. There is about a 4-fold difference in estimated net metabolism for the whole system, depending on the choice of C:P, but in either case the system is net heterotrophic (*p-r* <0). The polluted portion of the estuary (inner Piauí River) is strongly autotrophic but accounts for less than 10% of the estuary area. Rio Fundo is a minor contributor to the system metabolism, and the outer Piauí River dominates the net metabolism. Whichever ratio is used, estimated net metabolic rates for the system are much higher than those obtained by the 1-box approach.

Table 2.2 Net metabolic rates (*p-r*) estimated for each section of the Piauí River and for the whole estuary, based on the 3-box model.

	Whole Estuary		R. Fundo		R.Piauí (inner)		R. Piauí (outer)	
Area (km^2)	44		10		3		31	
C:P	106	Average = 449	106	633	106	359	106	428
10^6 mol C yr^{-1}	-69	-289	-3	-18	+10	+36	-76	-305
mmol C m^{-2} yr^{-1}	-1,568	-6,561	-300	-1,800	+3,333	+12,000	-2,452	-9,839

Table 2.3 summarizes estimates of (*nfix-denit*). The system overall is a very slight net denitrifying system. The calculated rate with the 3-box model is higher than the calculations based on the 1-box model; in both cases the net rate for the whole system is low.

Table 2.3 Net nitrogen fixation - denitrification (*nfix-denit*) estimated for each section of the Piauí River and for the whole estuary, based on the 3-box model.

	Whole Estuary		R. Fundo		R. Piauí (inner)		R. Piauí (outer)	
Area (km^2)	44		10		3		31	
N:P	16	Average = 19	16	19	16	18	16	19
10^3 mol N yr^{-1}	-2,120	-4,048	+34	-50	-744	-548	-1,409	-3,548
mmol N m^{-2} yr^{-1}	-48	-92	+3	-5	-248	-183	-45	-114

Conclusions

Apparently the Rio Piauí estuary is a net heterotrophic system, denitrifying at a very slow rate. The exact results obtained are very sensitive to both the C:P and the N:P ratios of the reacting material, although the qualitative results are the same in either case.

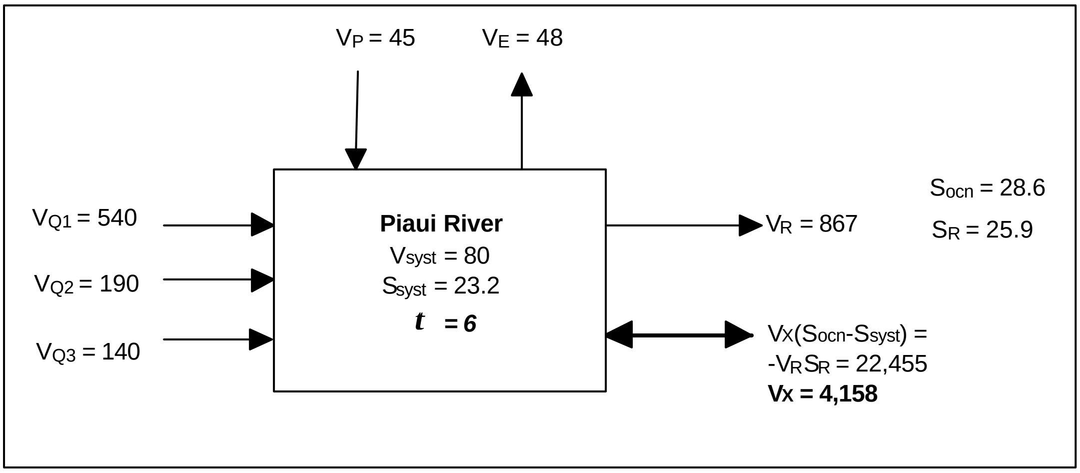

Figure 2.8 Water and salt budgets for Piauí River, 1-box model. System volume in 10^6 m^3. Water and salt fluxes in 10^6 m^3 and 10^6 psu m^3 yr^{-1}, respectively. Heavy (mixing) arrow indicated direction of salt flux. Water exchange time (τ) in days and salinity in psu.

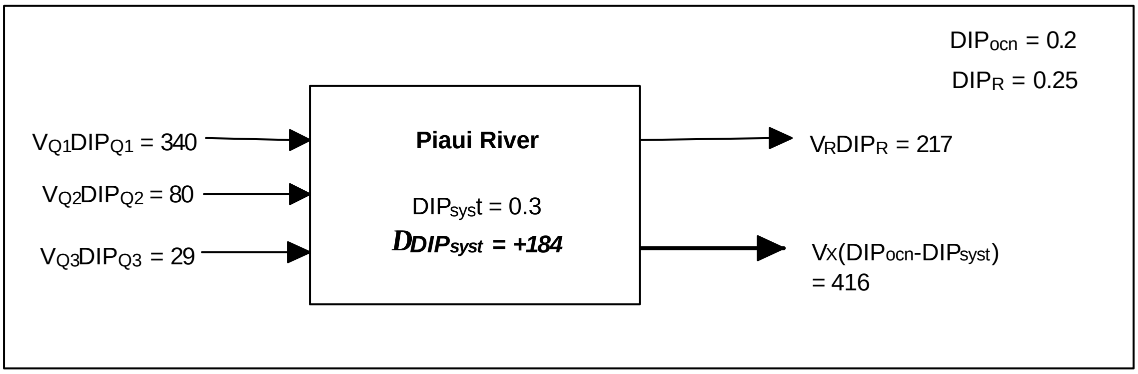

Figure 2.9 DIP budgets for Piauí River, one-box model. Fluxes in 10^3 mol yr^{-1}.

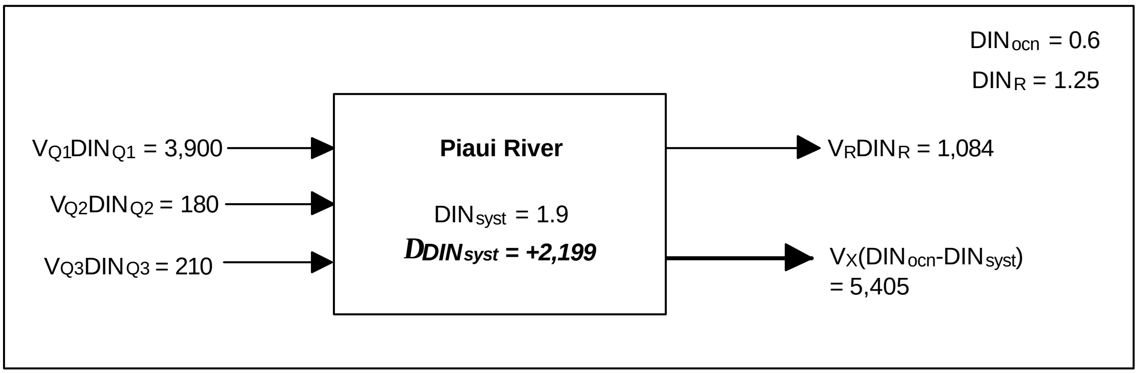

Figure 2.10 DIN budgets Piauí River, one-box model. Fluxes in 10^3 mol yr^{-1}.

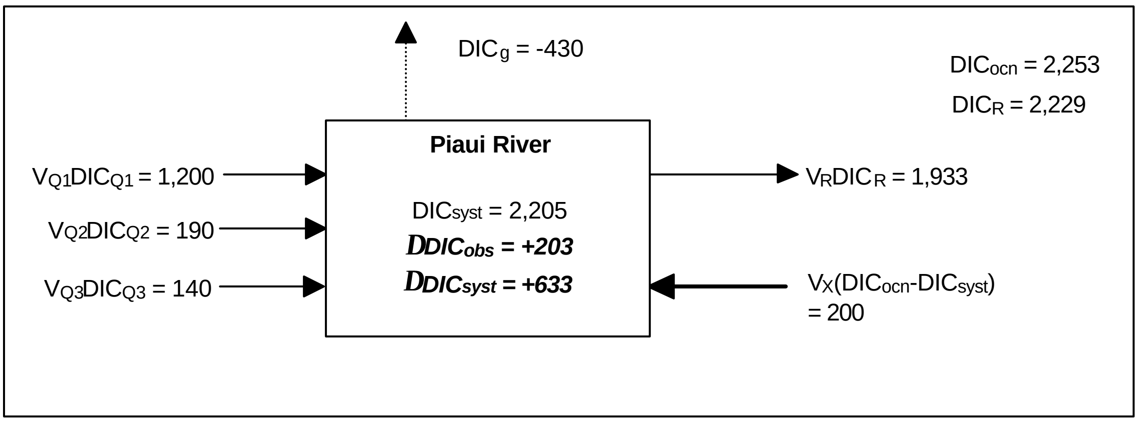

Figure 2.11 DIC budgets for Piauí River, one-box model. Fluxes in 10^6 mol yr^{-1}.

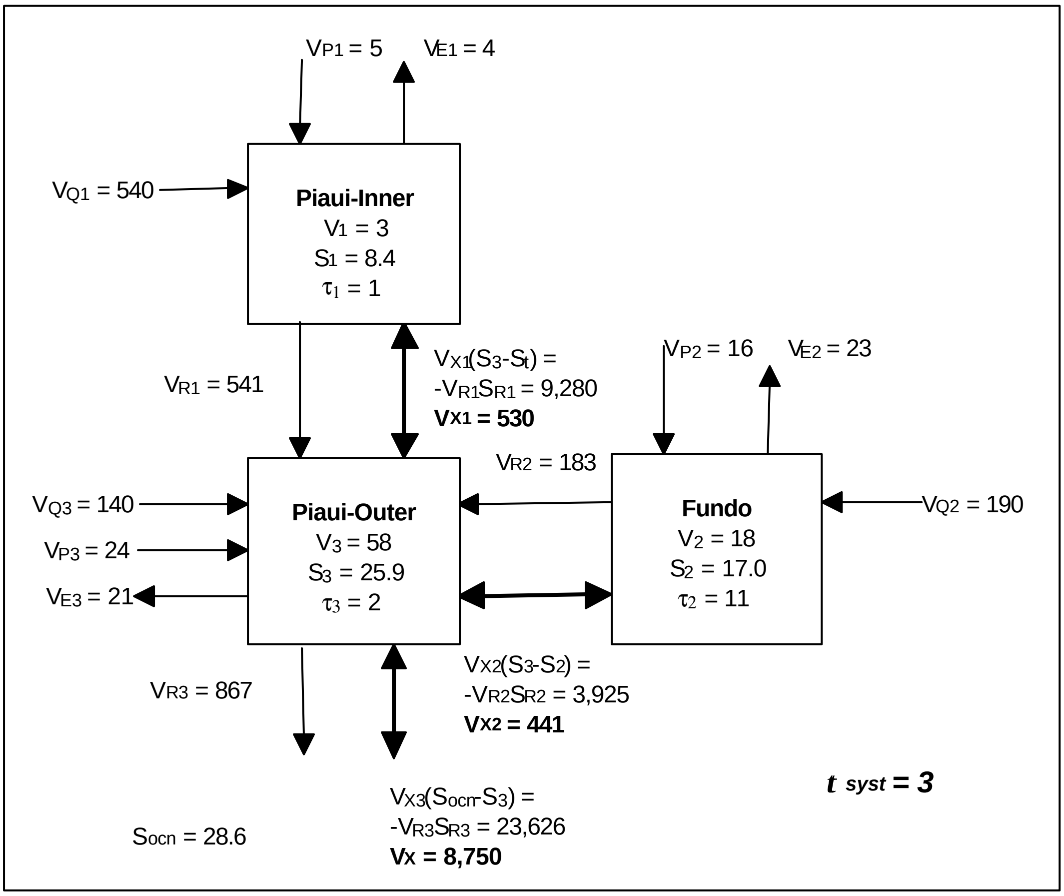

Figure 2.12 Three-compartment water and salt budgets for Piauí River estuary. Water volume in 10^6 m^3. Water and salt fluxes in 10^6 m^3 and 10^6 psu m^3 yr^{-1}, respectively. Mixing arrows (bold) indicate the direction of salt flux. Water exchange time (τ) in days and salinity in psu.

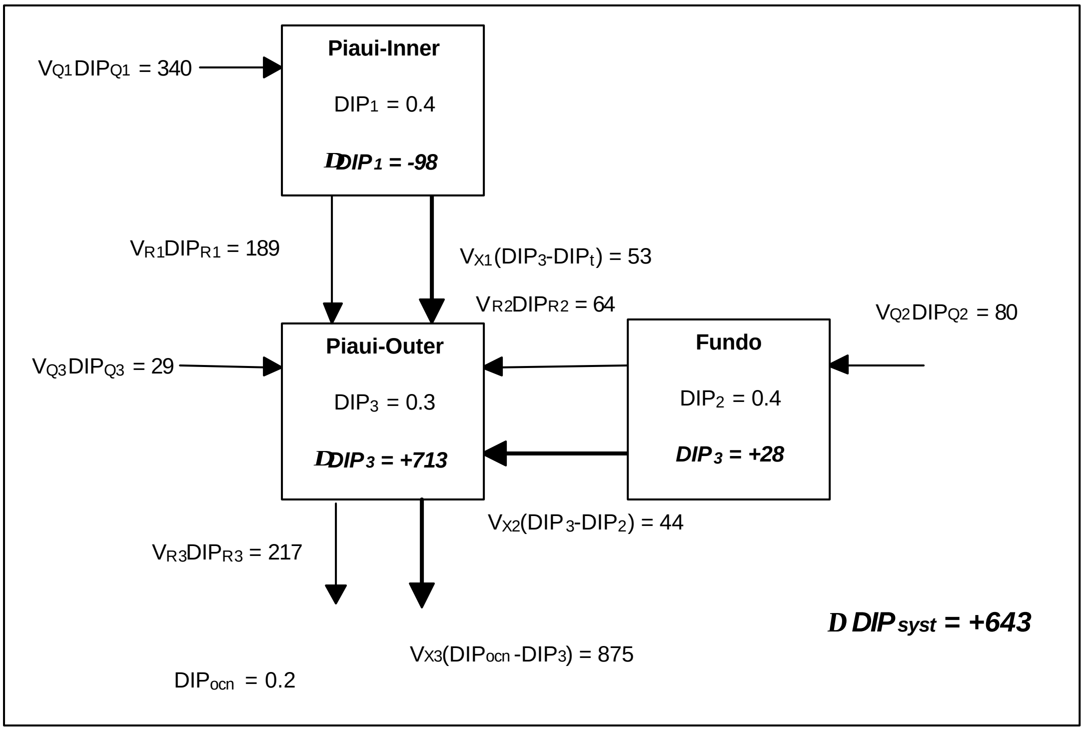

Figure 2.13 Three-compartment budget of DIP in Piauí River estuary. Fluxes in 10^3 mol yr^{-1}.

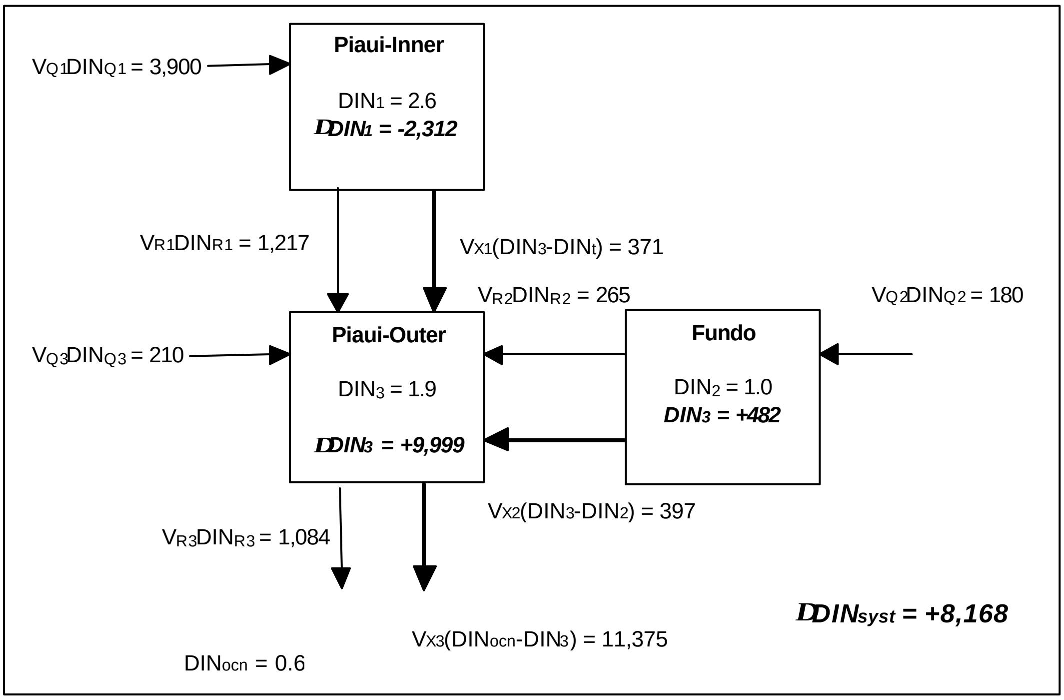

Figure 2.14 Three-compartment budget of DIN in Piauí River estuary. Fluxes in 10^3 mol yr^{-1}.

2.3 Maricá-Guarapina coastal lagoons, Rio de Janeiro State

***Erminda da C.G. Couto**, Nicole A.C. Zyngier, Viviane R. Gomes , Bastiaan A. Knoppers and Marcelo F. Landim de Souza*

Study area description

The Maricá-Guarapina system comprises three small choked coastal lagoons and a wetland connected by narrow channels, on the east coast of Rio de Janeiro state (22.93°S, 42.70°W, Figure 2.15). Present anthropogenic influence is mainly sewage inputs, but in the 1950's the system suffered several hydrological impacts, such as the artificial change of oceanic opening from the middle to the eastern extreme, and since then landfill in the link channels has restricted water circulation.

Maricá Lagoon (area 29 km^2, mean depth 1.3 m) is a shallow lagoon which receives untreated organic waste with no direct input of seawater. It is linked to Guarapina Lagoon (area 6 km^2, mean depth 1.0 m), a shallow lagoon permanently connected to the sea via an artificial channel - Ponta Negra Channel (Figure 2.15) (Couto 1989). In choked coastal lagoons, the entrance channel serves as a dynamic filter that effectively reduces or eliminates tidal water fluctuations and tidal currents. In Guarapina Lagoon, which is characterized by a 1.5 km long and 40 m wide tidal channel, water level oscillations are usually reduced to 1 % or less as compared to the adjacent coastal tide (Kjerfve and Knoppers 1991). Tidal exchange between Maricá Lagoon and Guarapina Lagoon is dampened by intermediate lagoons, wetlands and channels (Knoppers *et al.* 1991). The marginal vegetation consists predominantly of the macrophyte *Typha dominguensis* Pers (Typhaceae), which seems to serve as a physical and biological filter for biogenic matter transferred from the drainage basin to the lagoon. However, some export of material from the vegetation belt may occur during sporadic inundation and washout events during the passage of metereological fronts (Couto 1989).

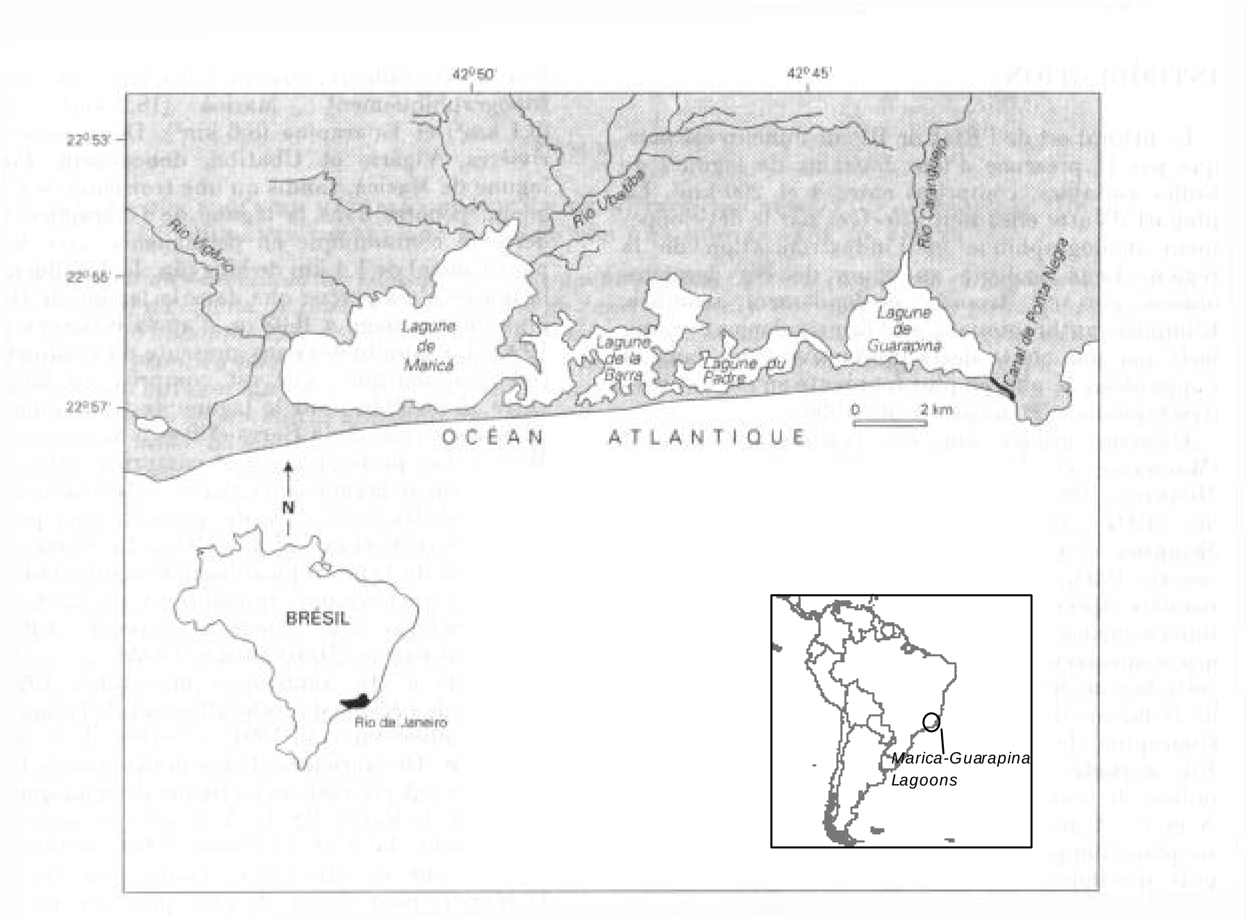

Figure 2.15 Map and location of Marica-Guarapina Lagoons.

This system exhibits pronounced annual cycles of salinity (Moreira 1988; Couto 1989; Machado 1989). Salinity changes are always smallest in the internal cells of lagoon systems. However, intense rain events may induce drastic salinity changes. These events result in marked biogeochemical and ecological responses (Knoppers and Moreira 1988).

Primary production is dominated by phytoplankton production. In the summer Guarapina Lagoon is dominated by planktonic cyanobacteria (Moreira 1988). Mean annual primary production range is ~300-400 g C m^{-2} yr^{-1} in Guarapina lagoon (Machado and Knoppers 1988; Moreira 1989). The highest fraction of suspended detrital organic matter is encountered during the less productive period during late autumn and winter. Most of the suspended detritus originates from autotrophic production, as indicated by the relatively low particulate organic carbon to nitrogen ratios, with C:N by weight less than 9:1, and seems to be an important source of nutrients for primary production in the spring (Moreira 1988; Knoppers and Moreira, 1990; Moreira and Knoppers 1990). The presence of large suspended detrital pools has been confirmed for Barra Lagoon (Carmouze *et al.* 1993) and Guarapina Lagoon (Moreira 1988).

Measurements of nutrient release rates from the sediment-water interface have been made in Maricá (Fernex *et al.* 1992), Barra (Kuroshima 1995) and Guarapina (Machado 1989) lagoons. The results reflect seasonal variability of benthic nutrient fluxes, with the highest flux usually occurring during the summer when primary production is highest.

The system presented marked seasonal shifts between autotrophy and heterotrophy, with autotrophy dominating during the summer and heterotrophy during the winter. Net autotrophy and heterotrophy are equal on an annual basis (Knoppers and Kjerfve, *in press*.). In Maricá and Barra Lagoons sporadic dystrophic crises and fish kills induce nutrient pulses (Esteves 1992; Carmouze *et al.* 1993).

A consistent data set for Maricá Lagoon does not exist. Knoppers *et al.* (1991) presented concentration ranges from sporadic sampling effort conducted by FEEMA. Nutrient and chlorophyll *a* concentrations and the ratio of total inorganic nitrogen to total inorganic phosphorus (TIN/TIP) are far less in Guarapina Lagoon than in the other lagoons along the Rio de Janeiro coast (Knoppers *et al.* 1991). The major fraction of organic matter is stored in phytoplankton. Ammonia was the major component (>50%) of TIN with major sources being the bottom in Guarapina (Machado 1989) and human effluents in Maricá. An estimate based on the *per capita* load of phosphorus from the population in Maricá City (38,500) suggests that this lagoon receives large amounts of effluent discharges (FEEMA 1987). The N/P ratio indicated a trend towards nitrogen limitation. Loading from the Guarapina drainage basin is minimal and conditions closely resemble a natural state (Figueiredo *et al*. 1996). However, Guarapina Lagoon receives a considerable load from its adjacent interior lagoons (Padre, Barra and Maricá lagoons). The source of the high TIN load (ammonia) in Guarapina is primarily due to decomposition of benthic macroalgae (*Cladophora vagabunda*) in Padre Lagoon. The intermediate lagoons change their role in the transfer of matter and nutrients seasonally between Maricá and Guarapina lagoons, alternately functioning as a filter and as an internal recycling source of releasing nutrients (Knoppers *et al.* 1991). Using both total phosphorus and chlorophyll *a* concentrations as trophic state (TP) indices demonstrates that Maricá, Barra, Padre and Guarapina lagoons presented an eutrophic state.

Available early data was compiled to construct a preliminary nutrient budget and apply the LOICZ biogeochemical approach (Gordon *et al.* 1996) on an annual basis.

Water and salt balance
Total water residence time was about 314 days in Maricá, 25 days in Guarapina, and only 185 days considering the whole system. The annual average salinity was higher in Guarapina (17 psu) than Maricá (5 psu). In Guarapina Lagoon mixing with the adjacent sea is continuous. Tidal exchange between Maricá and Guarapina lagoons is dampened by the narrow channel. In this lagoon a small residual flow is produced by hydraulic gradient. This results in a high residence time.

Nonconservative materials balance

Dissolved inorganic phosphorus and nitrogen concentrations were higher in Maricá (3.4 µM DIP and 9.6 µM DIN) than Guarapina (0.5 µM DIP and 5.2 µM DIN). Most of the hydraulic flux DIP exported from Maricá (90.4%) is retained in Guarapina. This resulted in net seaward fluxes of 3×10^3 moles DIP yr^{-1}.

The negative net nonconservative fluxes of DIP and DIN show that autotrophic processes prevail in the system. A small fraction of DIN (3.7 %) exported from Maricá is retained in Guarapina. This resulted in net seaward fluxes of 694×10^3 moles DIN yr^{-1}.

Stoichiometry and net system metabolism

The net N-fixation was estimated as $+4.9 \times 10^6$ moles N yr^{-1} (+0.17 mole N m^{-2} yr^{-1}) in Maricá and $+4.9 \times 10^6$ moles N yr^{-1}(+0.81 mole N m^{-2} yr^{-1}) in Guarapina. The results are summarised in Table 2.4.

Table 2.4 Nonconservative dissolved inorganic P and N fluxes in the Maricá - Guarapina system.

	*ΔDIP***	*ΔDIN$_{obs}$***	*ΔDIN$_{exp}$***	*(nfix-denit)$^{(1*)}$*	*(p-r)**
Maricá	-320	+230	-5,120	+0.17	+1.2
Guarapina	-290	-236	-4,640	+0.81	+5.2
Whole system	-610	-6	-9,760	+0.28	+1.8

[1]Redfield N:P ratio
* mol m^{-2} yr^{-1}
** x 10^3 mol yr^{-1}

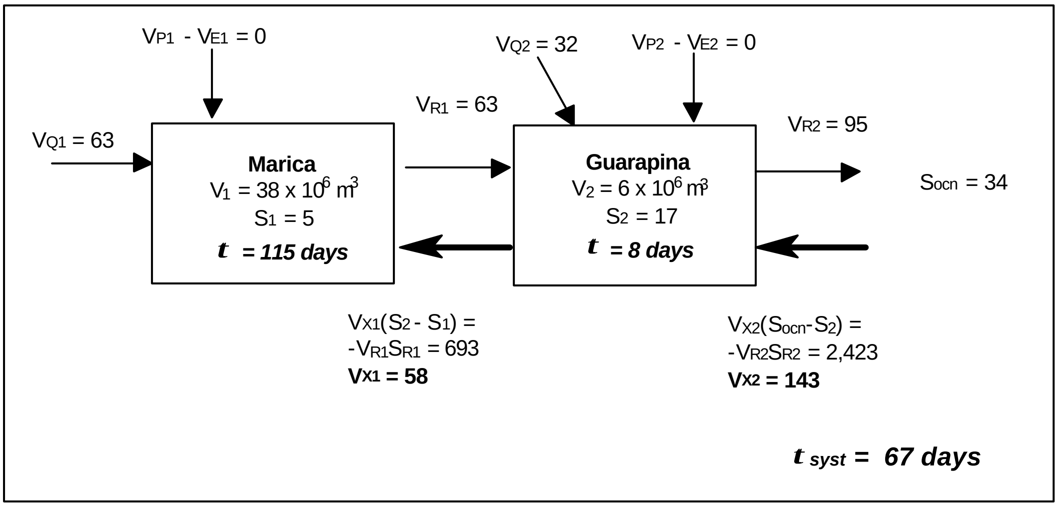

Figure 2. 16 Water and salt budgets for Marica-Guarapina coastal lagoons. Water flux in 10^6 m^3 yr^{-1}, salt flux in 10^6 psu-m^3 yr^{-1} and salinity in psu.

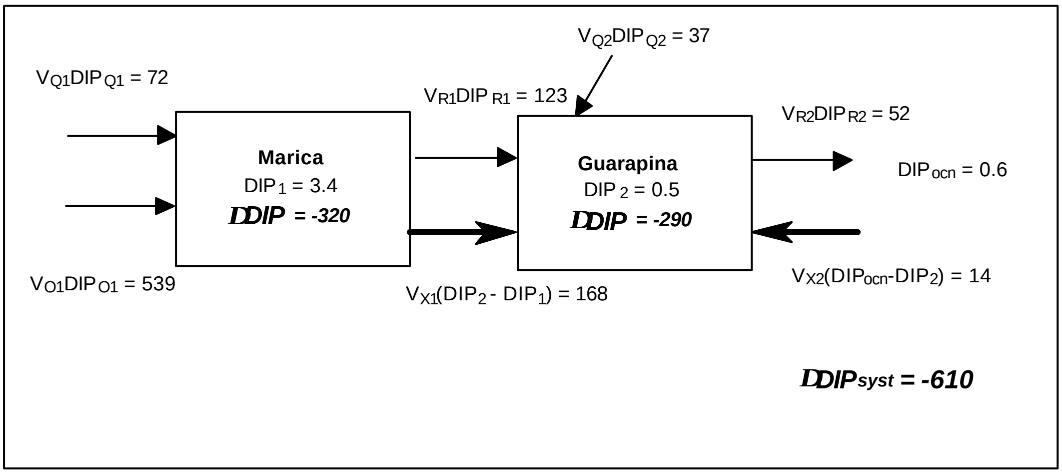

Figure 2.17 DIP fluxes in the Marica-Guarapina Lagoons. Fluxes in 10^3 mol yr^{-1}.

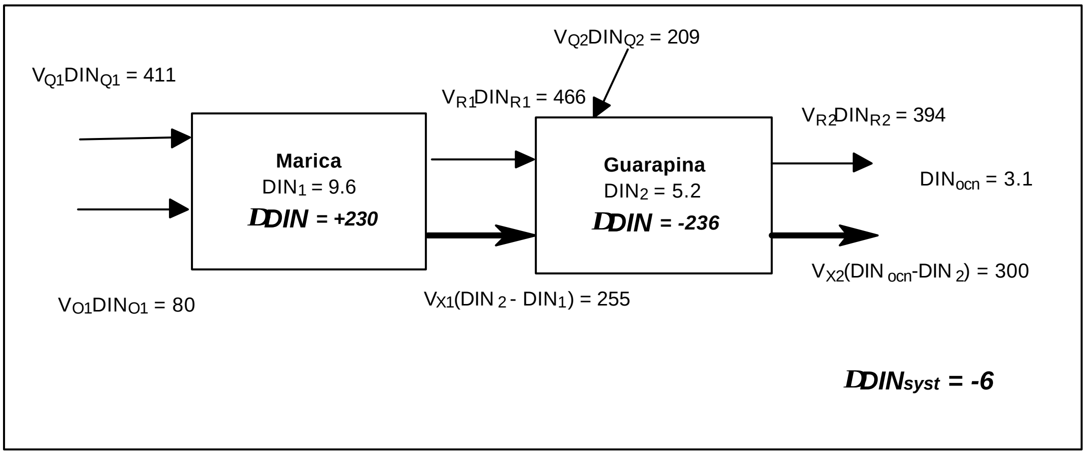

Figure 2.18 DIN fluxes in the Marica-Guarapina Lagoons. Fluxes in 10^3 mol yr^{-1}.

2.4 Piratininga-Itaipú Coastal Lagoons, Rio de Janeiro State

Erminda C.G. Couto, Nicole A.C. Zyngier and M.F.Landim de Souza

Study area description

The Piratininga ("putrid water" in the Tupi native language)-Itaipú Lagoons system is one of the smaller of the choked coastal lagoons of Rio de Janeiro east coast (22.97°-22.93°S, 43.10°-43.03°W). The natural eutrophication stage of this system has been greatly accelerated by strong sewage pollution and uncontrolled land usage (Carneiro 1992).

Piratininga Lagoon (3 km^2) receives large amounts of untreated organic waste with no direct input of seawater. It is linked by Camboatá Channel to Itaipú Lagoon (1 km^2), which is permanently connected to the sea via the artificial Itaipú Channel (Figure 2.19) (Lacerda *et al.* 1992). The oceanic opening of Piratininga was permanently closed, and in 1991 a lock was constructed in the narrow channel that links the two lagoons, to manage water level and flow, in the attempt to control cultural eutrophication. Itaipú opening was also artificially dredged and enlarged. A lock was constructed in Camboatá Channel to manage and improve the water quality through the dilution of nutrient concentrations by freshwater (low tide) and seawater (high tide) and to raise the water level of the lagoon. Observations suggest that this goal was not fully achieved (Cunha 1996).

Available early data (1989-90, before lock construction) was compiled to construct a preliminary nutrient budget on an annual basis.

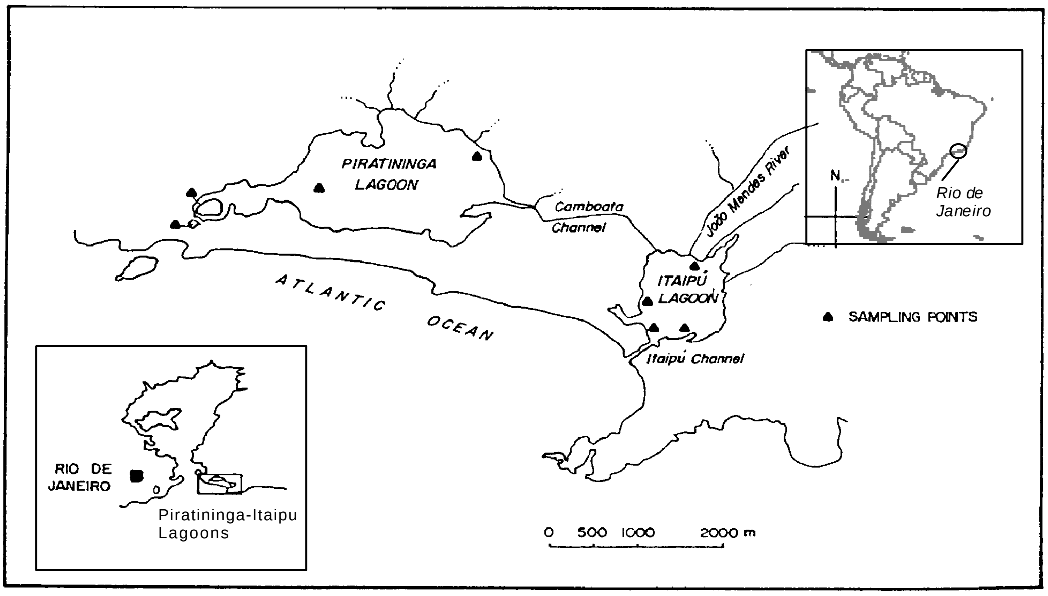

Figure 2.19 Map and location of Piratininga-Itaipu Lagoons, Brazil.

Early studies in the system

Carneiro *et al.* (1990) estimated the water retention time for the two lagoons. These authors estimated that in Piratininga water exchange ranged from 46 days in summer to 995 days (i.e., effectively no exchange) in winter. Itaipú was estimated to vary from 14 days in summer to 289 days in winter. Although Itaipú Lagoon is tidally dominated, tidal influence on Piratininga Lagoon is dampened by the 2.4 km long narrow channel connecting the two lagoons. The great differences between the two systems are reflected by the salinity and redox potential. Itaipú Lagoon is polyhaline (14-30 psu) while Piratininga salinity ranges from 5 to 20 psu. Both systems presented a certain degree of anoxia. In

Piratininga anoxia extends throughout the water column and attains very low Eh values (-302 to +130 mV), whereas in Itaipú, anoxia is restricted to bottom waters (-66 to +20 mV), as surface waters are well oxidized (+210 to +236 mV). In general, bottom waters in both systems were relatively more acid and warm (Lacerda *et al.* 1992). Sporadic dystrophic crises and fish kills induce nutrients pulses (Carmouze *et al.* 1993).

Piratininga Lagoon is dominated by the benthic macroalga *Chara hornemanii* Wallm. *Cladophora vagabunda* is also present. In 1990 *C. hornemanii* occupied aproximately 60% of the lagoon area and represented a considerable standing stock of organic matter (53g C m^{-2}, 10g N m^{-2}, and 0.6g P m^{-2}). During their growth period (winter through summer), the macroalgae assimilate nutrients from the water column. During the autumn decay period, nutrients are released to the water. Phytoplankton standing crop appears to be negligible. High chlorophyll *a* concentrations were only measured near decaying populations of *C. hornemanii*.

Nutrient and chlorophyll *a* concentrations and the ratio of total inorganic nitrogen to total inorganic phosphorus (DIN/DIP) are far greater in Piratininga Lagoon than in the other lagoons along the Rio de Janeiro coast (Knoppers *et al.* 1991). The major fraction of organic matter in Piratininga is stored in seaweed. In Itaipú organic matter is present in phytoplankton. Ammonium was the major component (>50%) of DIN, with major sources in Piratininga being human effluents and algal banks. The use of trophic state indices as total phosphorus (TP) and chlorophyll *a* concentrations demonstrate that Itaipú Lagoon is in the upper limit of mesotrophic state, with the TP level indicating an eutrophic state, whereas chlorophyll *a* indicates a mesotrophic state. This may be attributed to the high TP load from Piratininga Lagoon and the high DIP remineralized in sediments, released by frequent resuspension of bottom materials by strong tidal currents. Piratininga Lagoon is permanently hypertrophic. In shallow waters, continuous effluent loading, and long water exchange time allow the growth of extensive algal banks. Although nutrient loading into Itaipú Lagoon is higher than for Piratininga Lagoon, fast tidal dilution mitigates the effects of the high effluent loading (Knoppers *et al.* 1991).

<u>*Salt and water balance*</u>

Total water exchange times calculated from the water and salt budgets (Figure 2.20) ranged from 46 days in Piratininga to about 6 days in Itaipú. These values compare with the much longer estimates in the literature (Knoppers *et al.* 1991). Mixing exchange seems to be the main water renewal process to both lagoons, despite the long and narrow channel linking them.

<u>*Nonconservative materials balance*</u>

DIP balance

The average concentrations of DIP are almost equal in both lagoons (Figure 2.21). The resulting flux calculations demonstrate that the lagoons are sources of nutrients and are interpreted to indicate that heterotrophic processes prevail. It should be kept in mind that the episodic anoxia in the water column of some areas favour the release of DIP, and to an uncertain degree overestimate the heterotrophy. Both lagoons are DIP sources to coastal waters.

DIN balance

The difference of DIN concentrations between the lagoons was small, as for DIP (Figure 2.22). Nonconservative fluxes were positive, being higher in the smaller Itaipú Lagoon. The whole system is a source of DIN delivery to coastal waters.

Stoichiometric calculations

The net N fixation-denitrification rates (*nfix-denit)* were low in both systems, using Redfield or the macrophyte (*C. hornemanii*) C:N:P ratio of about 228:36:1 (Tables 2.5, 2.6). Piratininga exhibited slight net denitrification, while Itaipu apparently fixed a small amount of N. The whole system apparently ranged from very slight net N-fixation to net denitrification, depending on the choice of Redfield or *C. hornemanii* N:P ratios.

There is higher net heterotrophy in Piratininga Lagoon, with the estimated rate being dependent on the C:P ratio used. The utilization of these different ratios for organic matter can produce a factor of two variations in the estimated net heterotrophy for the whole system. The higher values probably better express the metabolism of Piratininga Lagoon. For Itaipú, there are no data on primary production that can define whether phytoplankton or macrophyte dominate the system metabolism.

Table 2.5 Stoichiometric calculations for Piratininga-Itaipu Lagoons, based on the Redfield ratio.

	DDIP	*$DDIN_{obs}$*	*$DDIN_{exp}$*	*(nfix-denit)*	*(nfix-denit)*	*(p-r)*	*(p-r)*
	10^3 mol yr^{-1}	10^3 mol yr^{-1}	10^3 mol yr^{-1}	10^3 mol yr^{-1}	mmol m^{-2} yr^{-1}	10^3 mol yr^{-1}	mmol m^{-2} yr^{-1}
Piratininga	+6	+22	+96	-74	-25	-636	-212
Itaipú	0	+90	0	+90	+90	0	0
System	+6	+112	+96	+16	+4	-636	-159

Table 2.6 Stoichiometric calculations Piratininga-Itaipu Lagoons, based on the macrophyte (*Chara sp.*) C:N:P ratio of 228:36:1.

	DDIP	*$DDIN_{obs}$*	*$DDIN_{exp}$*	*(nfix-denit)*	*(nfix-denit)*	*(p-r)*	*(p-r)*
	10^3 mol yr^{-1}	10^3 mol yr^{-1}	10^3 mol yr^{-1}	10^3 mol yr^{-1}	mmol m^{-2} yr^{-1}	10^3 mol yr^{-1}	mmol m^{-2} yr^{-1}
Piratininga	+6	+22	+216	-194	-65	-1,368	-456
Itaipú	0	+90	+0	+90	+90	0	0
System	+6	+112	+216	-104	-26	-1,368	-342

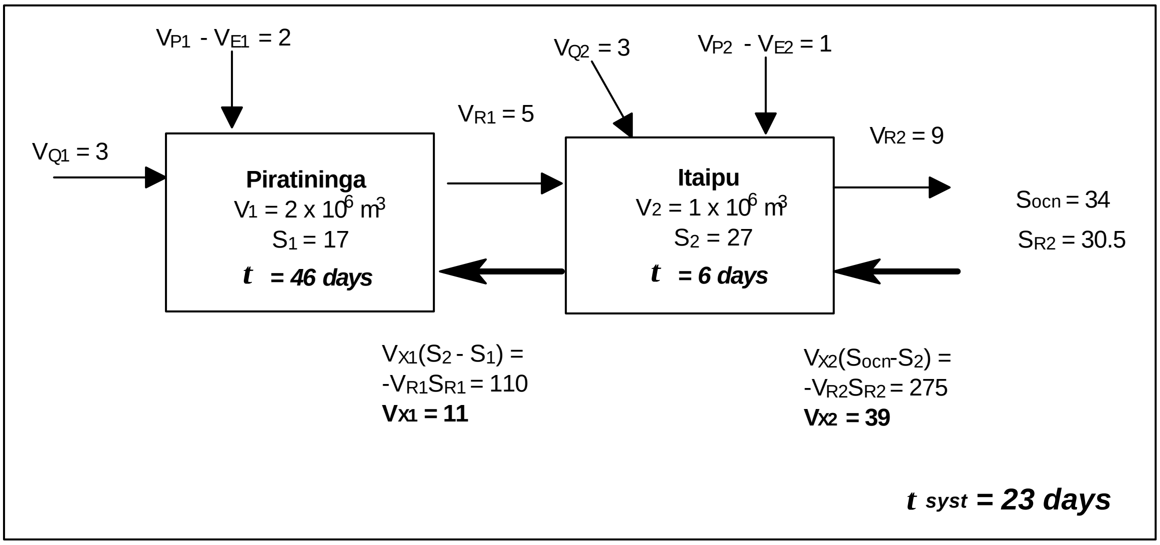

Figure 2.20 Water and salt budgets for Piratininga-Itaipú coastal lagoons. Water flux in 10^6 m^3 yr^{-1}, salt flux in 10^6 psu-m^3 yr^{-1} and salinity in psu.

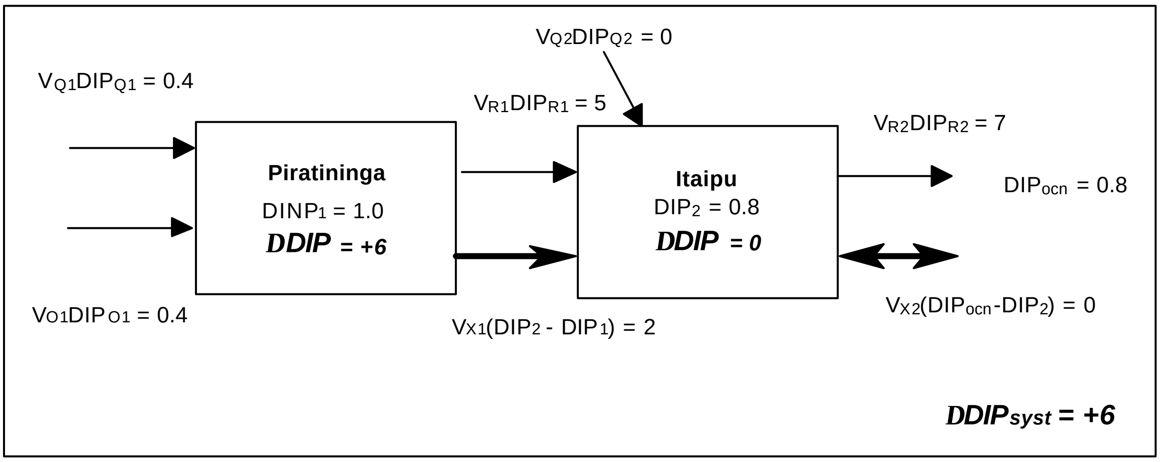

Figure 2.21 Dissolved inorganic phosphorus fluxes in the Piratininga system. Fluxes in 10^3 mol yr^{-1}.

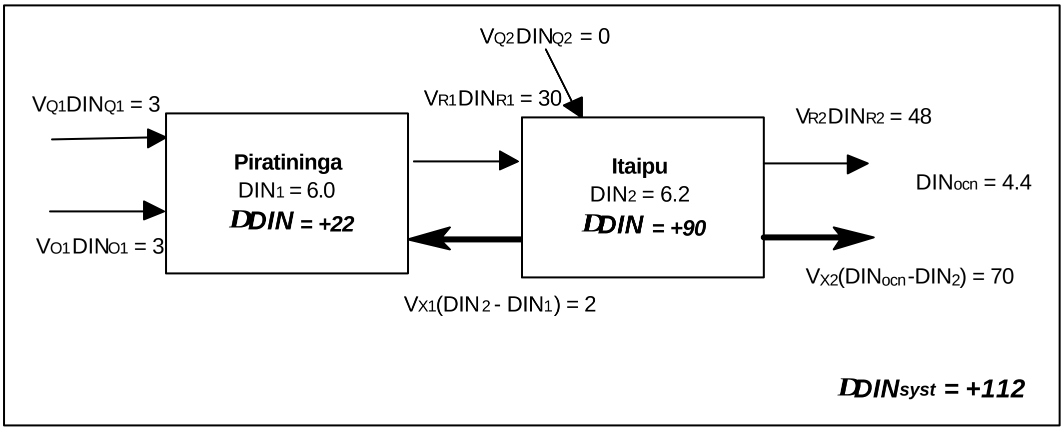

Figure 2.22 Dissolved inorganic nitrogen fluxes in the Piratininga system. Fluxes in 10^3 mol yr^{-1}.

2.5 Paranaguá Bay estuarine complex, Paraná State

E. Marone, Eunice C. Machado, R.M. Lopes and E.T. Silva

Study area description

Paranaguá Bay (25.5°S, 48.5°W) is one of the most important estuarine ecosystems of the south-west Atlantic, covering an area of about 600 km^2 of water surface, including the north-south branch, Laranjeiras Bay, and Paranaguá Bay itself in the east-west direction. The budgeted area of this system is approximately 330 km^2 (Table 2.7). The bay is located in Paraná State (southern Brazil). Conservation units established through federal and state regulations protect a large proportion of the area. Around 19% of the Atlantic rainforest remnants of Brazil are situated here. The Paranaguá Bay coastal zone is divided into five environmental units: mangrove plain, coastal plain with forest, coastal plain with agriculture and living facilities, fluvial plain with forests and fluvial plain with agriculture (MMA 1996). The bay is bordered by the Atlantic mountain range.

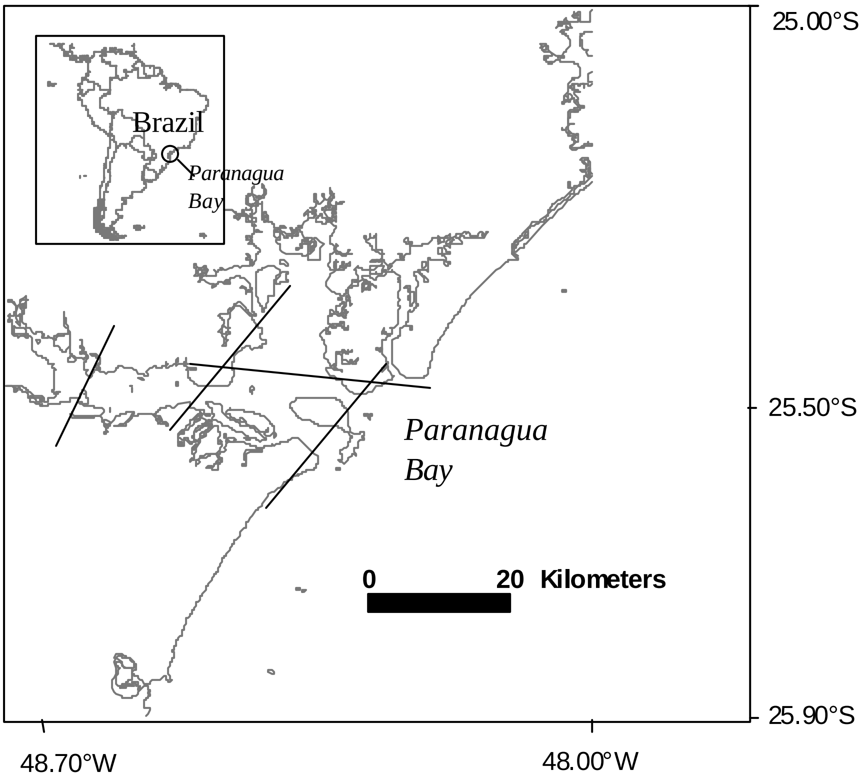

Figure 2.23 Map of Paranaguá Bay, Brazil. Bars show the budgeted segmentations of the bay.

Paraná is one of most developed and densely populated Brazilian states. Its coastal zone is an important centre for economic activities, which are concentrated in services, fisheries and – to a smaller extent – agriculture, with less industrial development. The port of Paranaguá is the most important in southern Brazil and the biggest in grain export in South America. Major environmental impacts are associated with the port activities (dredging, ship movement and litter disposal) and agriculture, which is responsible for 800 kg per year of pesticide use (IPARDES 1989). The present work is the first attempt of modelling the land-ocean fluxes of Paranaguá Bay, under the LOICZ definitions.

Due to the marked spatial differences of the system, Paranaguá Bay is divided into three separate regions (see Figure 2.24). Since seasonal variation is also important, fluxes for the three sectors will be considered separately for rainy and dry periods (with equal duration):

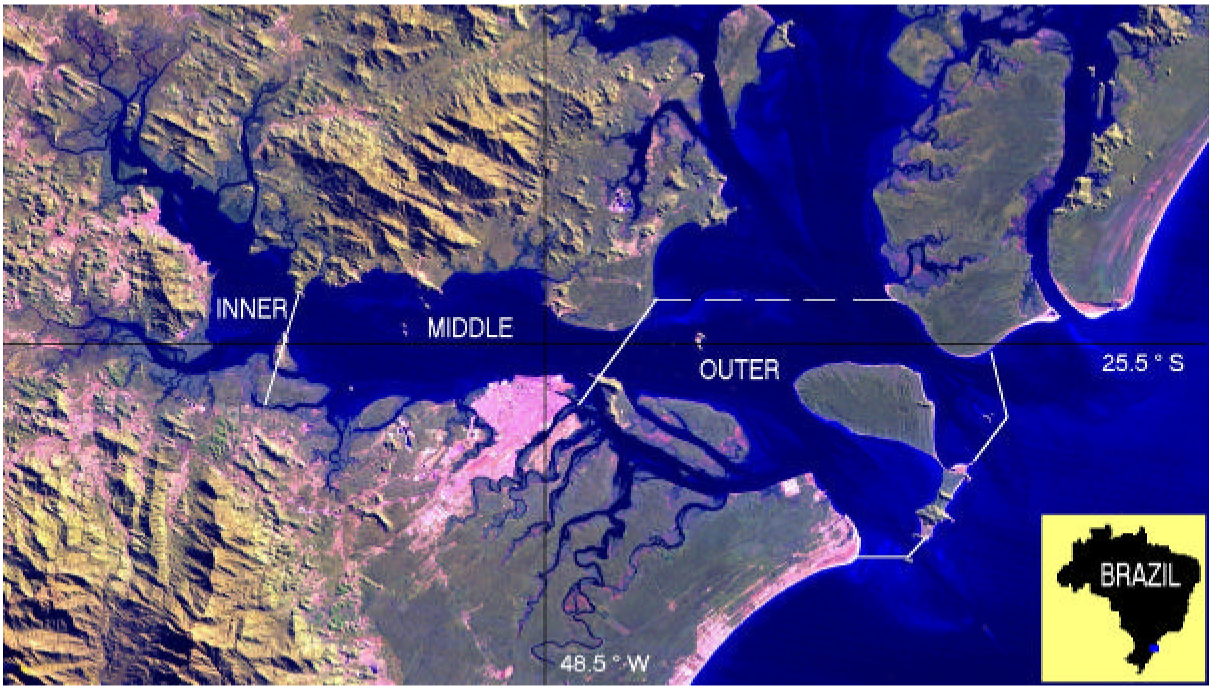

Figure 2.24 Aerial photograph of Paranaguá Bay and the surrounding region.

i inner part: meso-tidal, oligo-mesohaline, average depth 1.9 m;
ii middle part: micro-meso tidal, oligo-polyhaline, average depth 4.3 m;
iii outer part: micro-meso tidal, poly-euhaline, average depth 7.0 m.

The main features of these three sectors and seasons are showed in Table 2.7.

Figures 2.25 – 2.30 show the different box models for water, salt and nonconservative materials.

Salt and water balance

There is a remarkable difference between rainy (summer) and dry (winter) seasons in the water balance, when fluxes are reduced around 2-4 times (Figure 2.25). Evaporation exceeds precipitation during the dry period and precipitation exceeds evaporation during the rainy season. In both seasons they are very similar, and not very important for the total water balance. The water fluxes depend mainly on river runoff, but recent estimates of groundwater contribution have shown values that can be of the same order of magnitude as the precipitation contribution. These values must be considered carefully because they arose from very preliminary measurements. The possible contribution of dissolved chemical components, normally high in groundwater lenses, is another point to deal with in the future.

Residual fluxes increase from the inner to the outer part of the bay, primarily because of inflows from tributaries along the bay. The outer part was modelled considering no net exchange with the northward branch of the system (Laranjeiras Bay). Laranjeiras Bay has an independent connection to the coastal area and sea through the Superagüí Channel in the middle-north section. As this point could be a source for discrepancies and inaccuracies, the Outer-Laranjeiras boundary fluxes were not considered, following preliminary results that showed no significant net flux at this boundary, where budgets were calculated using V=0. This problem is related to time scales: our measurements in Laranjeiras boundary were done for up to two different spring tidal cycles for each season (12.42 h). On the other sections we deployed seasonal moorings (up to four months of half-hourly data). The cross-section fluxes at the Outer-Laranjeiras boundary showed null values in all cases (near zero or less than the measurement mean error). When net fluxes are near zero and close to the confidence limits in some fixed small time scale, it is very difficult to integrate those values for a long period.

The estuarine complex is discharging water to the coastal zone with residual flux values that run from $6x10^6$ m^3 day^{-1} in dry seasons, to more than $23x10^6$ m^3 day^{-1} during rainy seasons. The system shows a net import of salt during dry periods and an equivalent export during rainy seasons. These values came from the balance calculation that consider a non-stationary process between summer and winter conditions.

It seems clear that the seasonal time scale must be considered as the main time scale for the system due to the differences in river runoff between rainy and dry seasons. On the other hand, as the circulation is driven also by tidal forcing, the differences must be filtered out. In other words, long-term (seasonal) time series are required to accurately calculate residual and mixing fluxes in that area.

Water exchange times (τ), as depicted in Figure 2.25, are 2 or 3 times lower during rainy seasons compared with dry season residence times. Values run from approximately 11 to 22 days in the dry season, and from 5 to 8 days during the rainy season, for the inner, middle and outer regions.

Nonconservative materials balance

Preliminary versions of DIN (NH_4^++NO_3^-+NO_2^-) and DIP budgets, presented in Tables 2.8 and 2.9 and Figures 2.25 and 2.26, are based on data obtained between June 1994 and July 1995 (Machado *et al.* in press). Samples of surface and bottom water were collected monthly at nine stations, three in each sector of the system. Data of DIN and DIP concentrations in rivers were obtained by periodic sampling conducted in winter 1997 and summer 1998. There are no data available for dissolved organic nutrients. Moreover, budgets include estimates on anthropogenic loading of DIP and DIN, that is, sewage discharge from the cities of Antonina (17,070 inhabitants) and Paranaguá (107,675 inhabitants) to the inner and middle sectors respectively. For this estimate, we assume that the production *per capita* is about 80 mmol inorganic P and 930 mmol inorganic N $person^{-1}$ day^{-1} (B. Knoppers, personal communication), and that 70% of the population contributes effectively to the sewage.

DIP balance

Nonconservative fluxes of DIP are positive in the three sectors of Paranaguá Bay during the rainy season, suggesting that there is a net production of DIP within the system in this season. During the dry season DIP fluxes are positive only in the outer sector, whereas the inner and middle sectors seem to be a net sink. On an annual basis and over the whole system, *DDIP* amounts to $+2.3x10^6$ mol P yr^{-1} or +7.0 mmol P m^{-2} yr^{-1}. Assuming that phosphate desorption from sediments does not contribute substantially to *DDIP*, then this DIP production is probably the result of net organic matter oxidation. Sewage discharge amounts to approximately $0.9x10^6$ mol P yr^{-1}. This accounts for 31% of the observed non-conservative flux of DIP (*DDIP*). The Paranaguá Port constitutes an additional anthropogenic, non-quantified, source of P-fertilizers residues from charge and discharge operations.

DIN balance

The picture is somewhat more complicated for DIN: the inner sector appears to be a net sink of DIN in both periods, especially in the rainy season. On the other hand, nonconservative fluxes of DIN are positive in the outer sector of the bay, both seasons, mainly in the rainy period. On an annual basis over the entire estuary, *DDIN* is $-2.7x10^6$ mol N yr^{-1} or -8 mmol m^{-2} yr^{-1}, suggesting that net consumption of DIN predominates.

Stoichiometric calculations of aspects of net system metabolism

Although the DIP and DIN concentrations in the sections do not show significant differences between the rainy to dry seasons, hydrographic fluxes are much higher during the rainy season. This is reflected in the export of DIN and DIP to the adjacent coastal area. Nonconservative flux for DIP indicates low uptake during the dry season, and high release during the wet season. *DDIN* switches from moderate uptake during the dry season to moderate release during the wet season.

Independent estimates suggest that organic metabolism in this system is dominated by plankton and mangrove detritus (Brandini 1985; Machado *et al.* in press). Stoichiometric calculations of nitrogen fixation - denitrification (*nfix-denit*) shown in Tables 2.8 and 2.9 are made from the differences between observed and expected *DDIN*. The expected values of organic particle decomposition are based on a range for $N:P_{part}$ between mangrove detritus ($N:P_{part} \approx 11:1$) and plankton ($N:P_{part} \approx 16:1$). Net denitrification predominates, with values between -24.3 to $-10.6x10^6$ mol N yr^{-1} or -0.07 to -0.03 mol N m^{-2} yr^{-1}. The exception is the middle sector of the bay during the rainy season, where nitrogen fixation surpasses denitrification. Although these rates are only rough estimates, they seem reasonable.

Moreover, these results are in agreement with early studies, which reported predominantly low N:P ratios, lower than the classical Redfield ratio, attributed to denitrification (Knoppers *et al.* 1987; Machado *et al.* in press). However, direct denitrification rate estimates are not available for Paranaguá Bay.

Net ecosystem metabolism (NEM = [*p-r*]) can also be estimated from *DDIP* and C:P ratio of the reacting organic matter. For this calculation, we assume that the reacting organic matter is dominated by plankton and mangrove detritus, with C:P ratios about 106:1 and 1000:1, respectively. On an annual sacale, this amounts to -2,300 to $-244x10^6$ mol C yr^{-1} or -7 to -0.7 mmol C m^{-2} yr^{-1}), over the whole system. With mangroves dominating the net metabolism, the rates of (*p-r*) seem to be excessively high. This suggests that the net reacting matter is plankton, contradicting the earlier studies cited above. In either case, if the stoichiometric assumptions are valid, Paranaguá Bay appears to be net heterotrophic throughout the annual cycle, with higher net metabolic rates during the warmer, rainy season.

Table 2.7 Physical characteristics of inner, middle and outer sections of Paranaguá Bay.

Sector	Section Area (10^3m^2)	Area (10^6m^2)	Mean Depth (m)	Water Volume (10^6m^3)	Runoff (10^6 m^3day^{-1}) Rainy	Runoff (10^6 m^3day^{-1}) Dry	Tidal Discharge (m^3 sec^{-1})	Tidal Prism (10^6m^3)
Inner	9	50	2	95	10*	3*	5,331	119
Middle	50	93	4	400	7	2	7,885	176
Outer	130	187	7	1,309	4	1	12,724	284

* Data calculated from Mantovanelli *et al*. 1999.

Table 2.8 Nonconservative dissolved inorganic P and N fluxes and stoichiometric calculations for Paranaguá Bay during the dry period.

SECTOR	PROCESS	RATE (mmol·m^{-2}·d^{-1})	RATE (10^3 mol·d^{-1})
Inner	*DDIP*	0.00	0.0
	DDIN	-0.1	-3
	(*nfix-denit*)$^{(1)}$	-0.1 to -0.1	-3 to -3
	(*p-r*)$^{(2)}$	0	0
Middle	*DDIP*	-0.04	-3.7
	DDIN	-1.0	-91
	(*nfix-denit*)$^{(1)}$	-0.3 to -0.5	-32 to -50
	(*p-r*)$^{(2)}$	+4 to +40	+392 to +3,700
Outer	*DDIP*	+0.02	+3.2
	DDIN	+0.2	+40
	(*nfix-denit*)$^{(1)}$	-0.1 to 0	-11 to +5
	(*p-r*)$^{(2)}$	-2 to –17	-339 to -3,200
Whole Bay	*DDIP*	-0.00	-0.5
	DDIN	-0.2	-54
	(*nfix-denit*)$^{(1)}$	-0.1 to -0.1	-46 to -49
	(*p-r*)$^{(2)}$	0 to +2	+53 to +500

$^{(1)}$ $(N:P)_{part}$ assumed to be between 16 (plankton) and 11 (mangrove detritus).
$^{(2)}$ $(C:P)_{part}$ assumed to be between 106 (plankton) and 1000 (mangrove detritus).

Table 2.9 Nonconservative dissolved inorganic P and N fluxes and stoichiometric calculations for Paranaguá Bay during the rainy period.

SECTOR	PROCESS	RATE (mmol·m^{-2}·d^{-1})	RATE (10^3 mol·d^{-1})
Inner	*DDIP*	+0.06	+3.0
	DDIN	-0.6	-28
	(*nfix-denit*)$^{(1)}$	-1.5 to –1.2	-76 to -61
	(*p-r*)$^{(2)}$	-6 to –60	-318 to -3,000
Middle	*DDIP*	+0.02	+1.8
	DDIN	+0.1	+11
	(*nfix-denit*)$^{(1)}$	-0.2 to –0.1	-18 to -9
	(*p-r*)$^{(2)}$	-2 to –18	-191 to -1,800
Outer	*DDIP*	+0.05	+8.5
	DDIN	+0.3	+56
	(*nfix-denit*)$^{(1)}$	-1.2 to –0.3	-80 to -38
	(*p-r*)$^{(2)}$	-5 to –45	-901 to 8,500
Whole Bay	*DDIP*	+0.04	+13.3
	DDIN	+0.1	+39
	(*nfix-denit*)$^{(1)}$	-0.5 to –0.3	-174 to -107
	(*p-r*)$^{(2)}$	-4 to –40	-1,410 to -13,300

$^{(1)}$ $(N:P)_{part}$ assumed to be between 16 (plankton) and 11 (mangrove detritus).
$^{(2)}$ $(C:P)_{part}$ assumed to be between 106 (plankton) and 1000 (mangrove detritus).

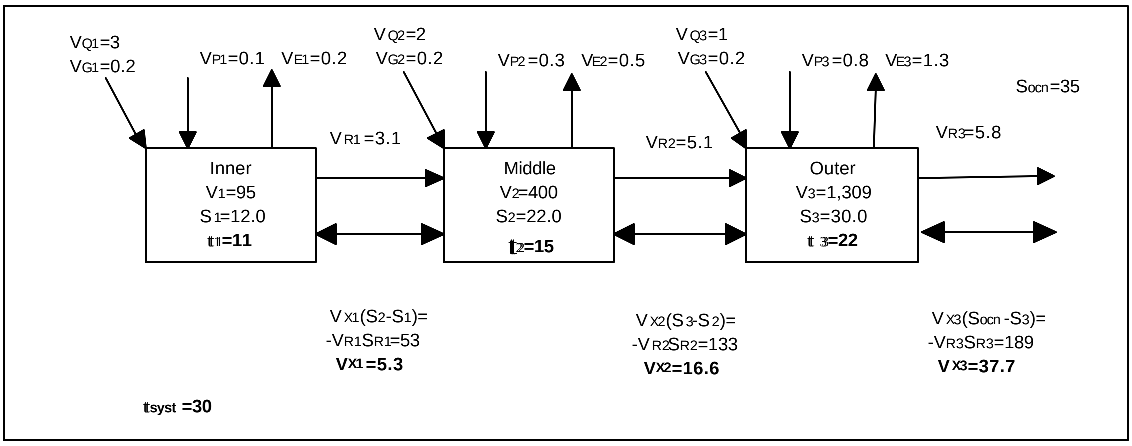

Figure 2.25 Water and salt budgets for Paranaguá Bay in the dry season. Volume in 10^6 m^3, water fluxes in 10^6 m^3 day^{-1}, salt fluxes in 10^9 psu-m^3 day^{-1}, salinity in psu and water exchange time (ι) in days.

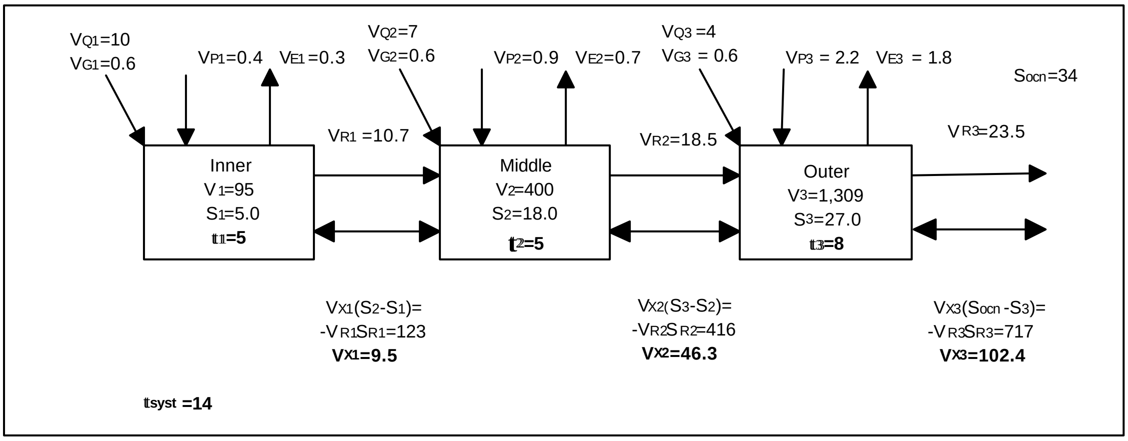

Figure 2.26 Water and salt budgets for Paranaguá Bay in the rainy season. Volume in 10^6 m^3, water fluxes in 10^6 m^3 day^{-1}, salt fluxes in 10^9 psu-m^3 day^{-1}, salinity in psu and water exchange time (ι) in days.

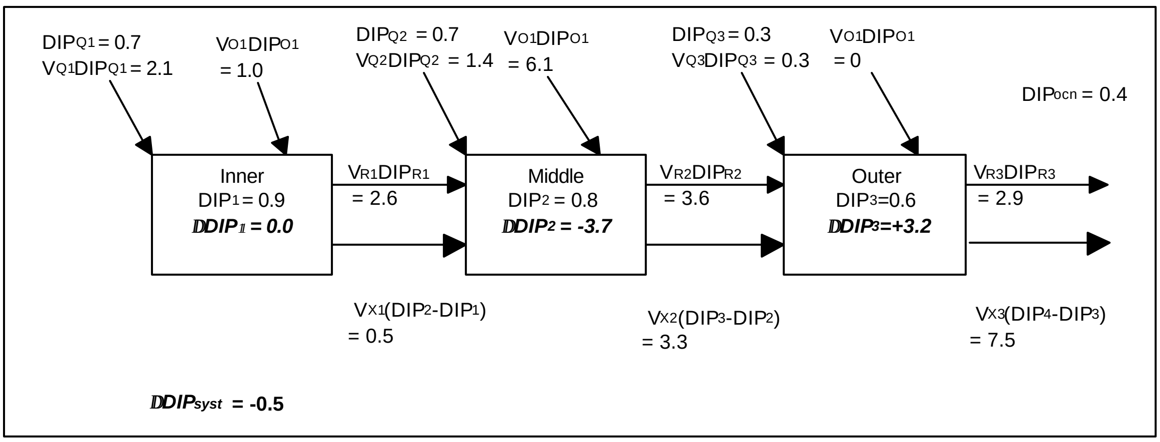

Figure 2.27 DIP budget for Paranaguá Bay in the dry season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

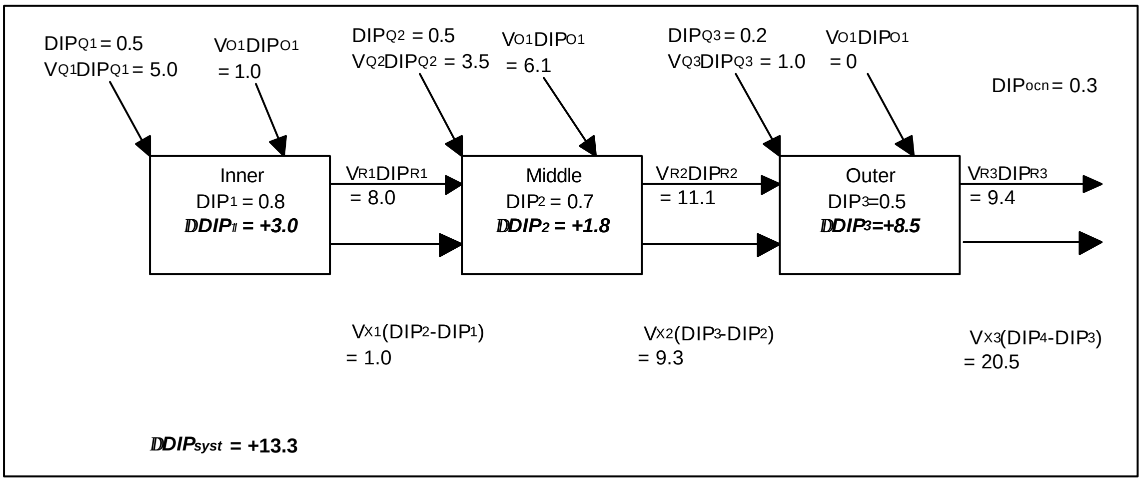

Figure 2.28 DIP budget for Paranaguá Bay in the rainy season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

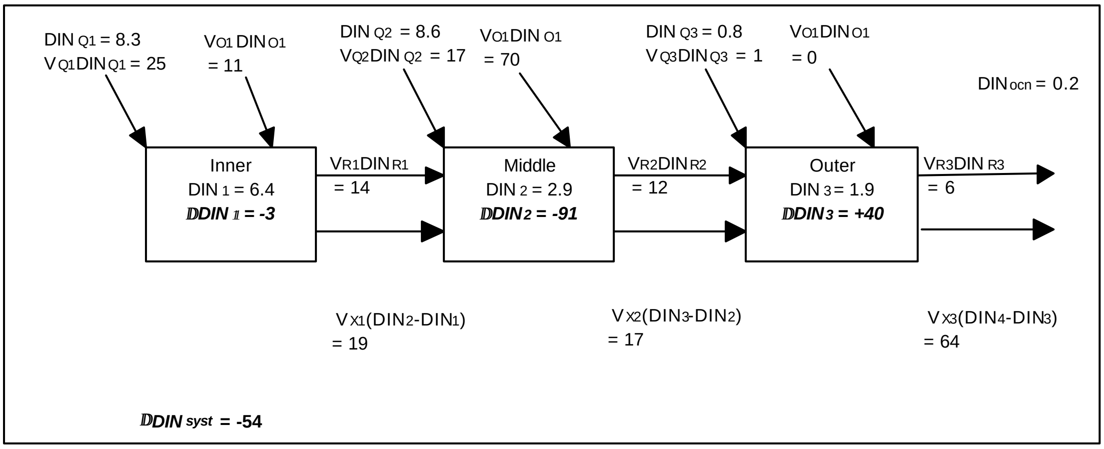

Figure 2.29 DIN budget for Paranaguá Bay in the dry season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

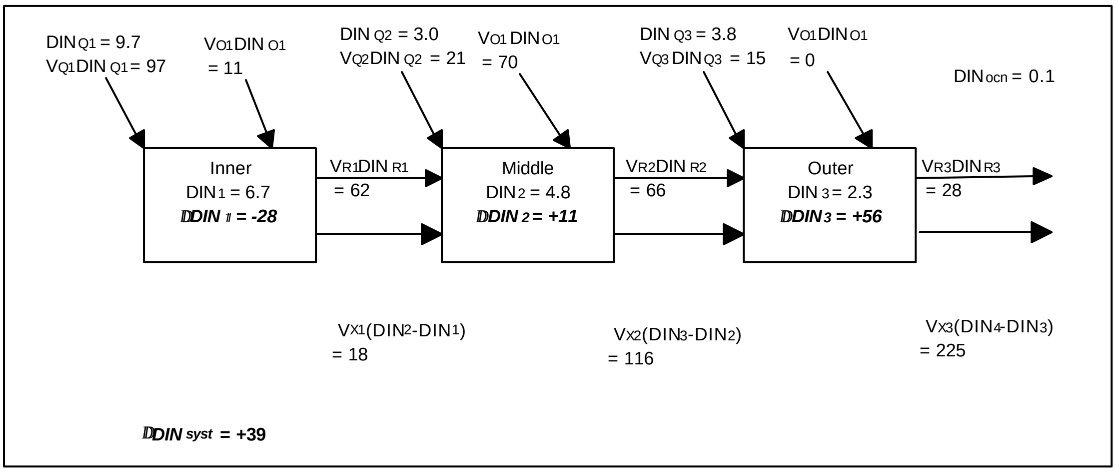

Figure 2.30 DIN budget for Paranaguá Bay in the rainy season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

2.6 Camboriu River Estuary, Santa Catarina State

Jurandir Pereira Filho and C.A. Schettini

<u>Study area description</u>

The estuary of the Camboriú River is a small system in Santa Catarina state, southern Brazil, which flows to the Camboriú Bight, and on to the inner shelf (Figure 2.31). The area of its drainage basin is about 200 km^2 and it is used mainly for agricultural activity. The regional climate is subtropical, with mean precipitation of about 1,600 mm yr^{-1} and evaporation of about 1,000 mm yr^{-1}. The mean annual temperature is about 19°C. Although the system is very small, the combined estuary and bight are economically very important. Balneário Camboriú City is the major tourist resort in southern Brazil. The resident population is nearly 50,000, but the population can increase up to 800,000 during the summer season and holidays.

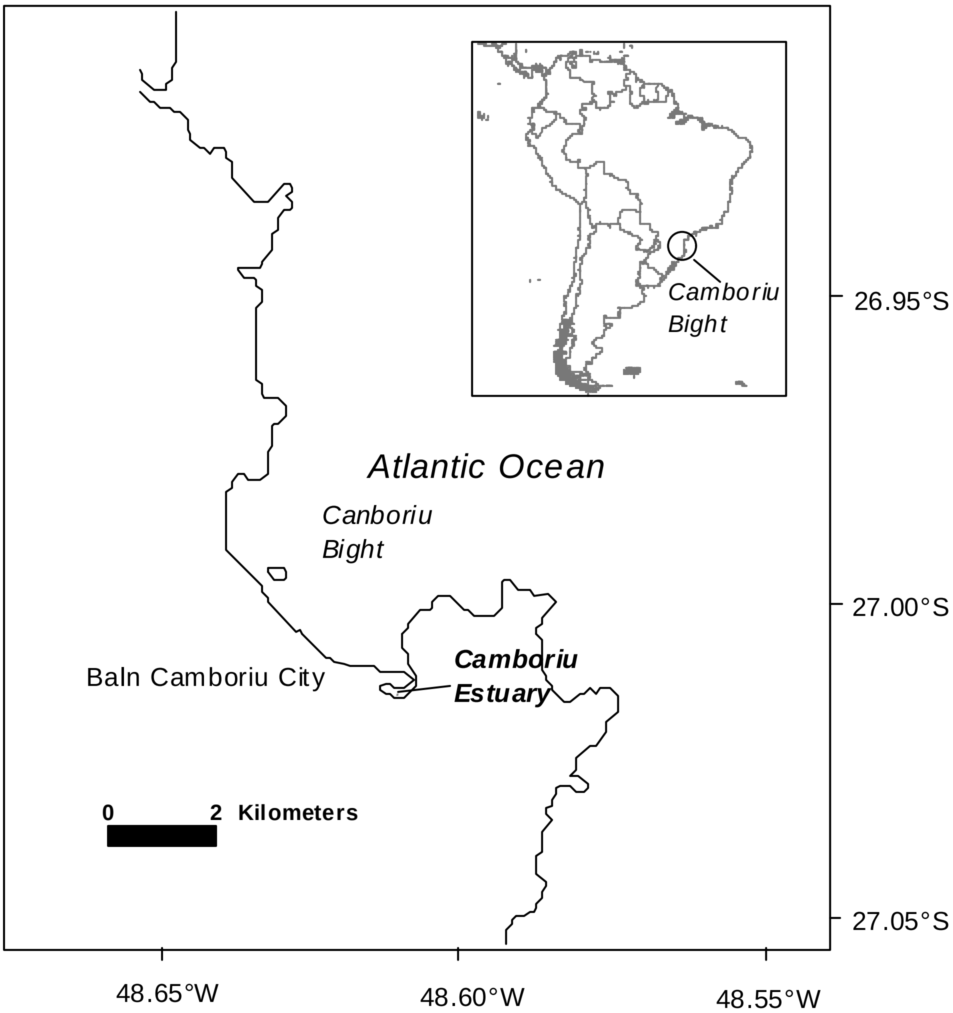

Figure 2.31 Map and location of the Camboriú River Estuary.

The sewage system is precarious, and the sewage treatment plant is not enough during the population peaks. The sewage treatment plant effluent flows to the estuary and there are many other small effluents along the beach. This scenario results in poor water quality both in the estuary and in the bight (Kuroshima *et al.* 1996).

Schettini *et al.* (1996) and Siegle *et al.* (1999) described the hydrological and morphological characteristics of the system. The local tide is semi-diurnal, with a mean range of 0.8 m and a maximum of 1.2 m. The meteorological influence over tide height is important and can raise tides up to 1 m above the astronomical tide (Schettini *et al.* 1996; Carvalho *et al.* 1996). The estimated freshwater inflow to the system is about 500,000 m^3 day^{-1}, on average. Siegle *et al.* (1996, 1998) classified the Camboriú River estuary as a shallow and partially mixed estuary. The water column stratification is greater during neap tide conditions, whereas during spring tide condition the water column is vertically almost homogeneous. The estuary is the main source of materials to the bight. Its channel is about 120 m wide near the mouth and has a mean depth of 2 m. There are a few mangrove patches around the inlet, but they are severely degraded.

Most of the bight has an homogeneous water column, but close to the estuarine mouth there is a buoyant plume that indicates local stratification. The Itajaí-açu River mouth is just 15 km to north, but its plume goes north and does not play an important role to the bight water quality, although it does influence the inner shelf salinity (~ 33 psu).

A major project was carried out to evaluate the bight water quality, with 16 sampling stations distributed over the bight, surveyed monthly over a year in 1994 and 1995. This characterization was summarized by Morelli (1997). Some minor projects were carried out in the estuary, and there is an ongoing project with fortnightly sampling along the estuary (Kuroshima, unpublished data). Information from experiments over tidal cycles is also available after 1998 and was used in this work to characterize the estuary (Pereira Filho *et al.*, unpublished data). The Camboriú River estuary budget was calculated using some of these data (Tables 2.10 and 2.11).

Table 2.10 Characteristics of the Camboriú Riversystem.

Length	9,500 m
Mean Depth	2 m
Area	0.5 km^2
Volume	1 x 10^6 m^3
System + Flood Plain	0.7 km^2
Mean Discharge	500,000 m^3 day^{-1}

Table 2.11 Average salinity and nutrient concentrations of the Camboriú Riversystem.

	Camboriú River	Camboriú Inner Estuary	Camboriú Outer Estuary	Camboriú Bight
Salinity (psu)	0.0	9.5	25	28.7
DIP (mmol m^{-3})	0.5		0.7	0.4
NO_3^- (mmol m^{-3})	7.5		2.8	1.5
NO_2^- (mmol m^{-3})	0.3		1.0	0.2
NH_4^+ (mmol m^{-3})	10.4		29.7	10.0
DIN (mmol m^{-3})	18.1		33.5	11.7

Source: Camboriú River-Kuroshima (unpublished data); Schettini *et al.* (1996)
Camboriú Estuary- Pereira Filho *et al.* (in preparation)
Camboriú Bight- Morelli (1997)

Water and salt balance

Figure 2.32 illustrates the water and salt budget for Camboriú River estuary. The budget was calculated using LOICZ Biogeochemical Modelling Guidelines (Gordon *et al.* 1996). The river discharge (V_Q) is based on Schettini *et al.* (1996). There are no data on groundwater discharge (V_G) and we assume it to be zero. Direct rainfall and evaporation over the estuary are close to zero. The residual water flux to the Camboriú Bight (V_R) is 500 x 10^3 m^3 day^{-1}. The average salinity in the inner estuary and in the Camboriú Bight is based on Schettini *et al.* (1996) and on Morelli (1997) respectively. The mixing flux (V_X) calculated the Camboriú estuary and bight is 3,628x10^3 m^3 day^{-1}. Water exchange time ($V_{syst}/(V_X + |V_R|)$) is about 0.24 day.

Budgets of nonconservative materials

The nutrient budgets have been calculated, although experience in other systems (e.g., Mamberamo Estuary, Indonesia; MaeKlong River, Thailand) indicates that estimates of nonconservative fluxes for systems with such short exchange times are unreliable because of insufficient time to develop a reliable nonconservative signal in the water composition and extreme sensitivity of the results to estimates of loading and exchange.

DIP balance

Figure 2.33 shows the DIP budget. The Camboriú River delivers about 250 mol day^{-1} of DIP to the estuary. There are no data from atmospheric DIP input by precipitation, but it is probably small. We do not have data on sewage loading, so it was estimated using a mean *per capita* waste production. Considering a *per capita* daily discharge of DIN and DIP as 0.3 mol and 0.04 mol respectively (from Von Sperling 1996), the sewage loading was obtained using the resident population: 58,000 (Censo IBGE in Morelli 1997). The estimated DIP input from sewage loading is about 2,300 mol day^{-1}. Residual DIP flux is 275 mol day^{-1} and exchange flux is 1,088 mol day^{-1}, resulting in an estimated ΔDIP of about -1,200 mol day^{-1} (-2.4 mmol m^{-2} day^{-1}).

This very rapid rate of DIP flux is unreasonably rapid for biotic uptake and might indicate either abiotic uptake or an erroneous estimate of *DDIP*. Let us consider the possibilities for uncertainty in this estimate. Besides uncertainty in the actual *per capita* production of waste, there is uncertainty in how much of the actual waste production reaches the system. Halving the sewage delivery of DIP (through some combination of a lower estimate of *per capita* waste production and only partial delivery of wastes to the estuary) would decrease *DDIP* to zero. This seems extreme, but it demonstrates sensitivity of the actual uptake to waste load estimates. The population can increase considerably in some periods of the summer, resulting in a large increase of sewage loading. With a population of 800,000 (e.g., approximating the peak of tourist season), the DIP loading from sewage would be 32,000 mol day^{-1} and the new *DDIP* estimate would be about -31,000 mol day^{-1}. This extreme apparently does not describe the budget, because the nutrient data set used to construct this budget was obtained in the beginning of the autumn, at the end of the holiday season.

The prudent conclusion from these results is that rapid water exchange and uncertainties in nutrient loading preclude quantification of *DDIP* for this system. It does seem likely that the system is taking up DIP.

DIN balance

The DIN budget is shown in Figure 2.34. The riverine DIN load is about 9,000 mol day^{-1}, and the estimated sewage load is about 17,000 mol day^{-1} (see discussion of waste production, above). The main N form is ammonium, which represents almost 90% of DIN in the system. This probably results from the high sewage loading, for which ammonium is the main N form. The residual DIN flux from the estuary is 11,500 mol day^{-1} and the exchange flux results in a DIN transport from the estuary of about 79,800 mol day^{-1}. The estimated nonconservative DIN flux is thus about +65,000 mol day^{-1} (+130 mmol m^{-2} day^{-1}), and the estuary apparently represents a source of DIN.

As discussed above for DIP, there is too much uncertainty in the loading to be confident of the actual *DDIN* for this system. Considering the magnitudes of uncertainty, it seems likely that the system is, indeed, a DIN source. The magnitude of the source remains unresolved.

Stoichiometric estimates of aspects of net system metabolism

It has been observed that neither the *DDIP* nor the *DDIN* estimate can be considered quantitatively reliable. Nevertheless, it appears possible to derive some qualitative understanding of net metabolism in this system. The system appears to be a net sink for DIP, qualitatively indicating the likelihood that (*p-r*) is positive; that is the system appears to be a net autotrophic system. Net autotrophy would indicate that DIN should be taken up by net production, yet this system appears to be a DIN source. It therefore seems likely that nitrogen fixation exceeds denitrification; that is, (*nfix-denit*) appears to be positive.

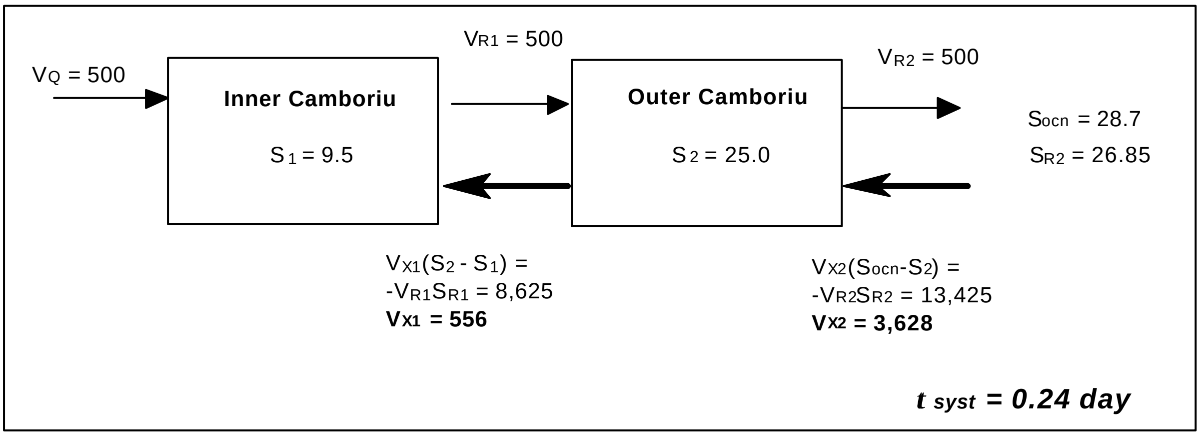

Figure 2.32 Steady-state water and salt budget for Camboriú River estuary, based on a 2-box model. Water fluxes in thousand m^3 day^{-1}; salt fluxes in thousand psu m^3 day^{-1}.

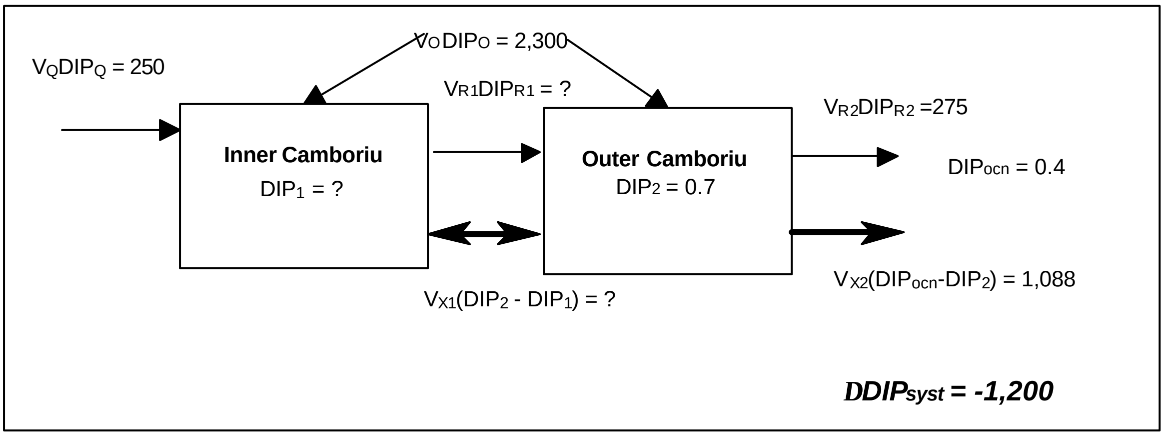

Figure 2.33 Steady-state DIP budget for Camboriú River estuary; two-box model. Arrows indicate directions of hydrographic fluxes. Fluxes in mol day^{-1}.

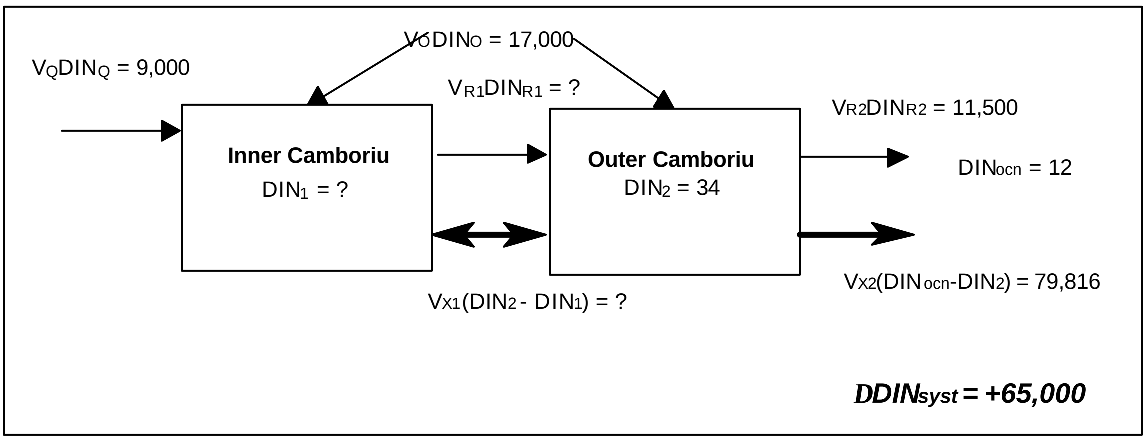

Figure 2.34 Steady-state DIN budget for Camboriú River estuary; two-box model. Arrows indicate directions of hydrographic fluxes. Fluxes in mol day^{-1}.

2.7 Araruama Lagoon, Rio de Janeiro State – a hypersaline lagoonal system

Weber F. Landim de Souza and B.A. Knoppers

Study area description

Araruama Lagoon (22.7°-23.0°S, 42.0°-42.4°W, Figure 2.35) lies parallel to the coast of Rio de Janeiro state, and is connected to the sea by a long, straight, narrow channel that strongly dampens water exchange (Campos *et al.* 1979; Kjerfve *et al.* 1996). Araruama has an area of 215 km^2, a volume of $640x10^6$ m^3 , a mean depth of 3 m. The climate is semiarid (P ≈800 mm yr^{-1}; E ≈1,000 mm yr^{-1}). There is negligible river runoff relative to the large volume, making the lagoon permanently hypersaline (S ≈54 psu) (Barbieri 1985; Kjerfve *et al.* 1996; Landim de Souza *et al.* 1995). Carbonate-rich sediments are covered with 1-3 mm thick microalgal mats, dominated by the cyanobacteria *Phormidium* sp., *Oscillatoria* sp., and *Lyngbya* sp. in shallow areas.

Nutrients were measured over an annual cycle in 1994 at 15 stations at a fortnightly frequency. Sampling design and results (salinity and nutrient data) are found in Souza (1997). Oceanic data are from André (1990) and Weber *et al.* (1994). Temperature and salinity were measured with a thermometer and hand refractometer (Shibuya Model S-1). The nutrients ammonium, nitrite, nitrate and orthophosphate were analyzed according to Grasshoff *et al.* (1983). Low algal biomass and DIP concentrations occur throughout the year (Chlorophyll *a* = 1.9 μg l l^{-1} and DIP = 0.18 μmol l^1, mean values). Observed concentrations for DIN reveal a seasonal pattern, negatively correlated with temperature. This seasonal trend is reflected by the mean DIN:DIP ratio, which indicates shifts from phosphorus to nitrogen limitation of primary production.

A first Araruama budget with the LOICZ approach, as described by Gordon *et al.* (1996), was made by Souza *et al.* (submitted) and Souza and Smith (1998). Using average data, it was postulated that Araruama represents an autotrophic system. In contrast to these results, Knoppers *et al.* (1997) postulated the system to be heterotrophic, although the number of measurements in that study was small. The different results for the measured and modelled ecosystem metabolism may indicate that the LOICZ budget is better adjusted to the system. On the other hand a seasonal shift between heterotrophy and autotrophy might exist, and might be averaged out over a year. To answer these questions the present budget was conducted with monthly concentrations, to verify shifts in the type of ecosystem metabolism throughout the year.

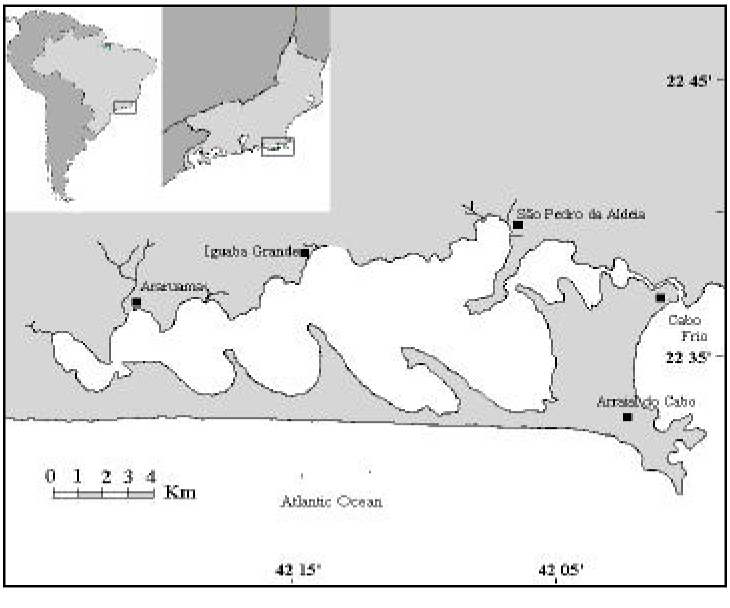

Figure 2.35 Location of Araruama Lagoon, Brazil.

Water and salt balance
Table 2.12 summarizes the water and salt balance for Araruama lagoon with seasonal and average annual values. The low inputs of river water (V_Q – calculated as in Holland 1978 and Kjerfve 1990) and sewage (V_O – calculated to a population of 109,000 inhabitants with a *per capita* water consumption rate of 0.22 m^3 day^{-1}; IBGE 1991; Tchobanoglous and Schroeder 1987) do not affect the budget. Other input and output terms of lagoon water, such as water usage for salt production, input of seawater by an artificial channel for sodium carbonate production, inputs of groundwater and potable water carried by trucks are not well established, but also appear to be not significant. Salt extraction may have been an important component to the budget in the previous decade, but in this decade it has undergone a great decline and is not significant. The major input and ouput terms show that Araruama lagoon represents, on average, a net evaporative system with a net inflow of seawater. Seasonal results reveal an oscillation in this pattern in response to changes in the hydrological regime through the year, but confirm the negative water balance.

Table 2.12 Monthly salt and water budgets for Araruama Lagoon. Water fluxes in 10^3 m^3 day^{-1}, salinity in psu and salt fluxes in 10^6 psu m^3 day^{-1}. V_O is assumed to be constant, at 24,000 m^3 day^{-1}.

Period	V_Q	V_P	V_E	V_O	V_R	V_X	*t* *(days)*	S_{ocn}	S_{syst}	V_RS_R
Annual	140	503	-867	24	200	450	985	36.2	56.9	9,310
Spring/ Summer	207	571	-1,011	24	209	467	947	36.2	57.1	9,750
Autumn/ Winter	72	435	-723	24	192	435	1,021	36.2	56.7	8,918

Budgets of nonconservative materials
DIP balance
The average and seasonal DIP budgets are given in Table 2.13. The principal component of DIP delivery to the system is anthropogenic waste (V_oDIP_o). Other DIP delivery and exchange are insignificant. An important consequence is that seasonal variations in *DDIP* will not be revealed in the budget because of the assumed constant generation of waste. The system is a net sink for DIP. In general, residual flow and mixing flow of DIP tends to be from the ocean to the lagoon, except for low outflux V_RDIP_R during spring/summer, maybe as a response to a higher river flux, V_Q, when compared with the other periods.

DIN balance
The average and seasonal DIN budgets are shown in Table 2.13. The system is a net sink for DIN; as with DIP, the principal DIN load is the anthropogenic flux (V_oDIN_o). The results of residual flow of DIN tend to be from the ocean to the lagoon. Mixing flow of DIN corresponds to the outflow of DIN, which may be a response to balance the higher DIN concentrations in the autumn/winter period, about two times higher than in the spring/summer period.

Stoichiometric calculations of aspects of net system metabolism
Assuming that the production and decomposition of organic matter follow the phytoplanktonic ratio, we adopted the Redfield ratio (C:N:P = 106:16:1) for the estimation of nitrogen fixation minus denitrification and net ecosystem metabolism. Nitrogen fixation minus denitrification (*nfix-denit*) is calculated as the difference between observed and expected *DDIN*. Expected *DDIN* is *DDIP* multiplied by N:P Redfield ratio (16:1). Net ecosystem metabolism, production - respiration (*p-r*), is estimated as negative of *DDIP* multiplied by the Redfield C:P ratio (106:1). Results (Table 2.14) show net nitrogen fixation of about 9,000 mol day^{-1}, and net ecosystem metabolism is autotrophic ([*p-r*] = +700,000 mol day^{-1}). Both results are almost constant, suggesting that the system has a capacity to buffer the flux changes through the year or as a result of the anthropogenic fluxes. Although both results seem significant, they are very small when normalized to the large lagoon area ([*nfix-denit*] = 0.04 mmol m^{-2}

day^{-1}; [p-r] = 3.3 mol m^{-2} day^{-1}). If a higher C:N:P ratio is assumed (550:30:1) due to dominance of microphytobenthic communities in the system metabolism, results are about ten times higher for nitrogen fixation and about 5 times higher for autotrophic metabolism. Although the results are divergent in comparison to measured metabolism, they confirm the previous budget (Souza and Smith 1998). If it is assumed that the variations of the measured system metabolism are high (25-50 %), then Araruama lagoon may be slightly autotrophic.

Table 2.13 Monthly DIP and DIN results for Araruama Lagoon. Tabulated fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}. Sewage DIP and DIN loads are assumed to be constant, at 6,000 and 90,000 mol day^{-1}, respectively.

Period	Y_{ocn}		Y_{syst}		$V_O Y_O$		$V_R Y_R$		$V_X(Y_{ocn} - Y_{syst})$		DY	
	DIP	DIN	DIP	DIN	DIP	DIN	DIP	DIN	DIP	DIN	DIP	DIN
Jan	0.3	1.2	0.1	1.9	6	90	- 0.08	- 0.7	- 0.2	1	- 6	- 95
Feb	0.2	1.1	0.1	3.0	6	90	0.16	2.8	0.2	- 6	- 6	- 87
Mar	0.2	1.2	0.4	5.3	6	90	- 0.60	- 6.8	1.0	20	- 8	- 129
Apr	0.3	1.6	0.0	4.2	6	90	- 0.06	- 1.2	- 0.2	2	- 6.	- 96
May	0.3	1.7	0.1	5.1	6	90	0.01	0.2	0.0	- 1	- 6.	- 90
Jun	0.3	1.6	0.2	8.8	6	90	- 0.04	- 1.0	0.0	3	- 6.	- 96
Jul	0.3	2.2	0.4	5.1	6	90	0.04	0.4	0.0	- 1	- 6.	- 92
Aug	0.4	2.0	0.2	10.4	6	90	0.16	4.0	0.3	- 13	- 7	- 81
Sep	0.3	1.8	0.2	4.0	6	90	0.22	2.7	0.3	- 5	- 7	- 88
Oct	0.3	1.8	0.1	4.5	6	90	0.20	3.1	0.4	- 6	- 7	- 88
Nov	0.2	1.2	0.1	3.5	6	90	0.11	1.5	0.2	- 3	- 6	- 89
Dec	0.3	1.4	0.0	2.0	6	90	0.10	1.3	0.3	- 1	- 7	- 91
Annual	0.3	1.6	0.2	4.8	6	90	0.02	0.6	0.2	- 1	- 7	- 94
Spring/ Summer	0.2	1.3	0.1	3.4	6	90	- 0.02	0.2	0.3	1	- 7	- 97
Autumn/ Winter	0.3	1.8	0.2	6.3	6	90	0.06	0.9	0.1	- 3	- 6	- 90

Table 2.14 Monthly nitrogen fixation minus denitrification (*nfix - denit*) and net ecosystem metabolism (*p-r*) results for Araruama Lagoon. Fluxes in 10^3 mol day^{-1}**.**

	(*nfix-denit*)		(*p-r*)	
	10^3 mol day^{-1}	mmol m^{-2} day^{-1}	10^3 mol day^{-1}	mmol m^{-2} day^{-1}
Annual	8.8	4.0	678	308
Spring/Summer	8.7	4.0	697	317
Autumn/Winter	9.0	4.1	658	299

3. URUGUAY ESTUARINE SYSTEMS

3.1 The Frontal Zone of the Río de la Plata System, Uruguay/Argentina

Gustavo J. Nagy

<u>*Study area description*</u>

The estuarine frontal zone of the Río de la Plata system (34.75°-34.90°S, 56.73°-57.25°W) is approximately 6,000 km^2 (Figure 3.1), with an average depth of 8 m (6-10 m), and a volume of about $50x10^9$ m^3. Nutrient sources are river discharge (75%) and sewage (25%) (Pizarro and Orlando 1985), mostly from Buenos Aires City (population ≈10,000,000), at the tidal river zone. Atmospheric load of nitrogen from Buenos Aires (World Bank 1995) is only about 1% of the total N load. Sewage and atmospheric loads from Montevideo (population=1,500,000) at the studied area can be ignored in this large budgeted box. The system is fed by two tributaries, the Paraná River and the Uruguay River. Both rivers are highly sensitive to ENSO-induced regional variability in flow, and show increasing flows in the last decades, reinforced due to stronger El Niño activity since the late seventies, with a total water inflow greater than 25,000 m^3 s^{-1} ($2.2x10^9$ m^3 day^{-1}) since 1980. Long term (1940-1990) yearly average salinity at Montevideo has decreased 3 psu (Nagy *et al.* 1996a,b). There is a moderate seasonal discharge of freshwater with three peaks runoff: April (Paraná River flood), June (mostly Paraná River) and October (Uruguay River flood).

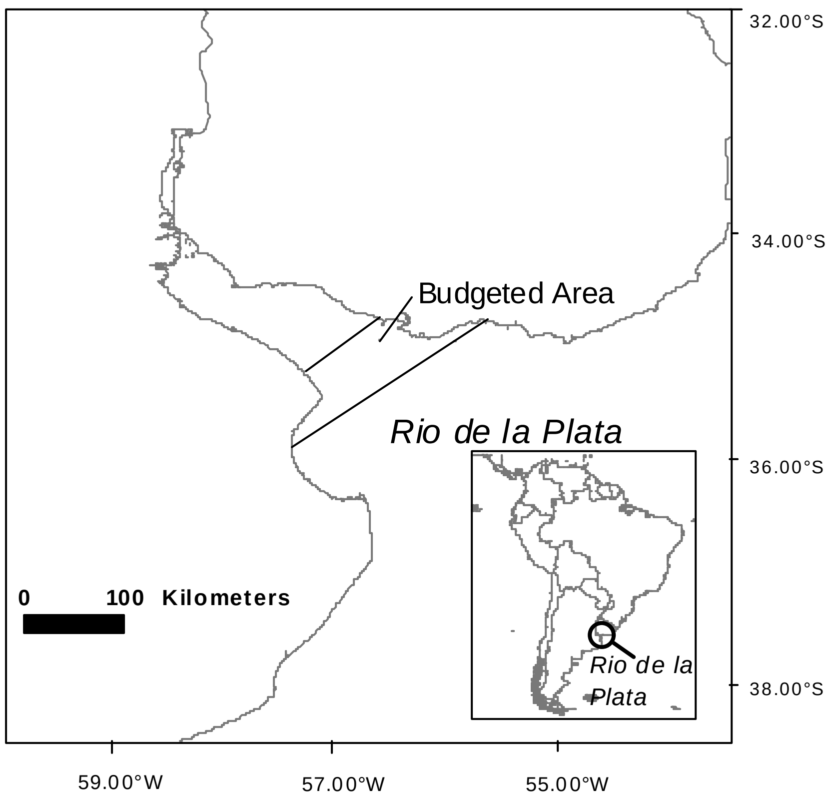

Figure 3.1 The Frontal Zone of the Rio de la Plata system. The budgeted box covers the minimum surface area during low/average freshwater inflow.

The location of the frontal zone moves upstream or seaward with axial winds, and the vertical structure undergoes a cycle of mixing-stratification controlled by both river flow and wind. Wind speeds greater than 10 m s^{-1} (occurrence = <5%) mix a water column up to 10 m depth, while winds greater than 7 m s^{-1} (occurrence = 25%) mix shallow waters (< 7 m depth). Yearly average wind speed at Montevideo is

7 m s^{-1}. Therefore, the zone is often (weekly time-scale) well-mixed or partly-mixed (vertical difference in salinity <3 psu, without a marked halocline), preventing the development of anoxic conditions. Geomorphology (wide cross-section, banks and channels) and Coriolis force induce a laterally hetererogeneous tidal level (<40 cm at the northern coast and >60 cm at the southern one), salinity distribution and stratification. Tidal excursion, mixing, and resuspension are less important than wind forcing. When stratification develops, the dominant pattern is the "type 2b," of Hansen and Rattray (Nagy and Blanco 1987; López Laborde and Nagy 1999).

The water is highly turbid for salinities <3 psu, where the turbidity maximum is a site for inorganic reactivity and sedimentation. Estuarine plankton communities are dominated mostly by diatoms and dinoflagellates, and by cyanobacteria during the summer. Chlorophyll *a* concentrations vary from 1 to 12 mg m^{-3} (Gómez-Erache *et al.* 2000), equivalent to a phytoplankton standing stock of about 100-1200 mg C m^{-3} or a primary production of about 50-600 g C m^{-2} day^{-1}.

Calculations were made for a steady-state single-box mixed-layer budgets of water, salt, inorganic nitrogen and inorganic phosphorus (oxygen saturation >90%). Budgets were estimated on the basis of mean data and selected cruises from Pizarro and Orlando (1985) (as used by Smith 1997 for the NP budget of the whole Rio de la Plata), frontal zone measurements (Blanco 1989), outer region mean values for 1981-1987 (Nagy and Blanco 1987; Blanco 1989; Nagy *et al.* 1997), coastal ocean waters (Hubold 1980; Dohms 1983; Fillmann 1990), plus recent unpublished nutrient and primary production data.

The concentration data for nutrients and water fluxes are used to calculate the hydrographic fluxes for these dissolved nutrients following the LOICZ Modelling Guidelines (Gordon *et al.* 1996). Data used are summarized in Table 3.1. Two anchored 36-hour (hourly) sampling experiments performed in November 1989 at the frontal zone were used to improve the estimations of freshwater input (Table 3.2). The results are within the mean range of freshwater and nutrient inputs.

Table 3.1 Water composition data used for the budget calculations under mixed conditions for Rio de la Plata estuary. (Q_V = 26,000 m^3/s [2.2x10^9 m^3/d] at the time of the data collection).

Property	River	System	Ocean
Salinity (psu)	0.3	15.0	29.0
DIP (mmol/m^3)	1.6	0.8	0.5
DIN (mmol/m^3)	29	7	3

Water and salt balance

At steady state, a simple box model describes the salt flux under well-mixed conditions (Figure 3.2), based on the salinity data in Table 3.3. V_X represents mixing between the frontal zone water and coastal ocean. Flow was about 2.2x10^9 m^3 day^{-1}, 24% from the Uruguay River. V_R is the residual flow to maintain a constant volume (= $-V_Q$; rainfall, evaporation, and other freshwater terms can clearly be ignored in this very large river-dominated system). We solve for V_X as the unknown: 3.4x10^9 m^3 day^{-1}. Water exchange time in the budgeted box is 9 days.

Budgets of nonconservative materials

DIP balance

The water flux data in Figure 3.2 and Table 3.1, and the concentration data for DIP in Table 3.1, are used to construct the DIP budget under well-mixed conditions (Figure 3.3). Nonconservative flux (*DDIP*) is about -1.1x10^6 mol day^{-1} (-0.2 mmol m^{-2} day^{-1}) and accounts for about one third of the river input. Pizarro and Orlando (1984) found phosphate adsorption in freshwaters. Therefore, DIP balance is quantified with some difficulty, due to inorganic reactivity involving both sinks (mostly in fresh waters) and sources (mostly in estuarine waters).

Table 3.2 River composition data at the entrance of the Frontal Zone, Rio de la Plata estuary (November 1989; $V_Q = 26,000\ m^3/s$).

Property	River
Salinity (psu)	0.3
DIP ($mmol/m^3$)	1.4
NO_3 ($mmol/m^3$)	29
NH_4 ($mmol/m^3$)	2
DIN ($mmol/m^3$)	31
N/P	22
Si ($mmol/m^3$)*	176

*Silicate shows less input variability (mostly in the range 140-200 $mmol/m^3$) and behaves more conservatively than DIP and DIN, and may be used as a reference for nutrient behavior.

DIN balance

The water flux data in Figure 3.2 and the concentration data for DIN ($N0_3^- + NH_4^+$) in Table 3.1 are also used to construct the DIN budget under well-mixed conditions (Figure 3.4). *DDIN* is -38×10^6 mol day^{-1} (-6.3 mmol m^{-2} day^{-1}), accounting for about 60% of the river input. The sink for DIN may reach >75% during strong biological uptake periods (Blanco 1989).

Most of the results presented in Tables 3.2 and 3.3 and in Figure 3.4 are in the same range than those calculated by Smith (1997), when corrected for the real V_Q for the whole system. DIN influxes are somewhat smaller, especially with regard to ammonium.

Table 3.3 Hydrographic fluxes of dissolved inorganic nutrients (Y's) in the Frontal Zone, Rio de la Plata estuary, (mean V_Q), and calculated nonconservative fluxes (*DY*) to balance the budgets.

Material	V_QY_Q	V_RY_R	$V_X(Y_{ocn}-Y_{syst})$	*DY*	*DY*
(Y)	10^6 mol day^{-1}	10^6 mol day^{-1}	10^6 mol day^{-1}	10^6 mol day^{-1}	% terrig in.
DIP	+3.6	-1.4	-1.1	-1.1	30
DIN	+63	-11	-14	-38	60

Stoichiometric calculations of aspects of net system metabolism

Net ecosystem metabolism (*p-r*) estimated from Redfield stoichiometry (C:N:P = 106:16:1) and *DDIP* is $+117\times10^6$ mol day^{-1} (or 20 mmol m^{-2} day^{-1} or 7 mol m^{-2} yr^{-1}). Probably some DIP uptake by sorption processes also occur, so this estimate is likely to overestimate (*p-r*).

Indirect measurements of productivity for the whole system (nutrient behavior, chlorophyll, pH, oxygen saturation) show that activity is greatest at intermediate salinities (2-18 psu), and in the budgeted box during the summer time. Therefore the estimated values cannot be extrapolated for the whole system.

On the assumption that all DIP uptake is biotic, the expected amount of N in the nonconservative flux according to Redfield ratio is -18×10^6 mol N day^{-1}, about half of the observed DIN sink of -38×10^6 mol day^{-1}. The remainder of the DIN sink is nitrogen fixation minus denitrification ([*nfix-denit*] = $DDIN_{obs} - DDIN_{exp}$), which is thus estimated to be -20×10^6 mol N day^{-1} (-7.3×10^9 mol yr^{-1}, or about -1.2 mol m^{-2} yr^{-1}), mostly due to denitrification. Cyanobacterial nitrogen fixation may be considered as a minor process on yearly basis, but it probably should be taken into account at low salinities when summer time budgets are developed.

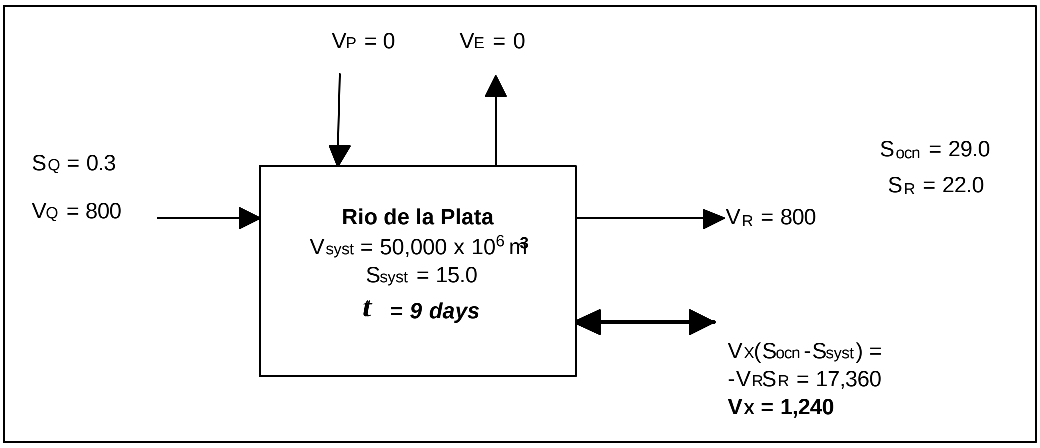

Figure 3.2 Steady-state water and salt budgets for the Frontal Zone, Rio de la Plata estuary. Water fluxes in 10^9 m^3 yr^{-1} and salt fluxes in 10^9 psu-m^3 yr^{-1}.

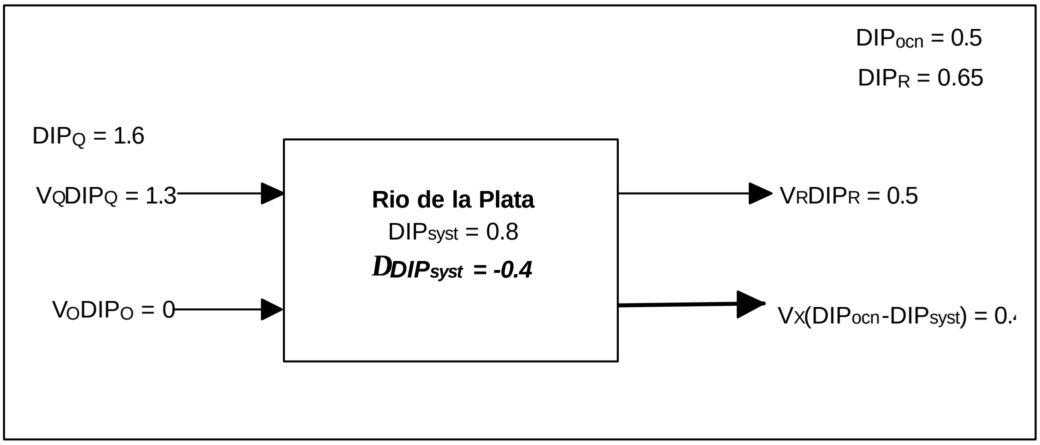

Figure 3.3 Steady-state state DIP budget for the Frontal Zone, Rio de la Plata estuary. Fluxes in 10^9 mol yr^{-1} and concentrations in mmol m^{-3}.

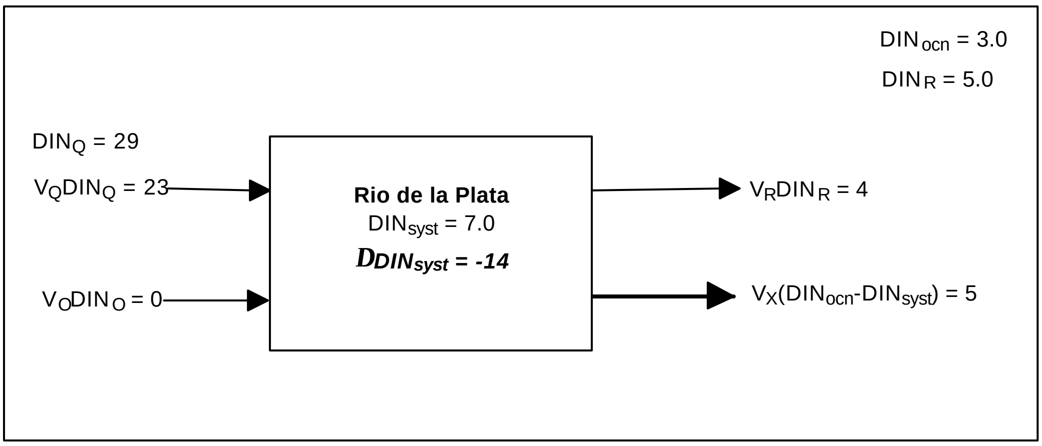

Figure 3.4 Steady-state DIN budget for the Frontal Zone, Rio de la Plata estuary. Fluxes in 10^9 mol yr^{-1} and concentrations in mmol m^{-3}.

4. ARGENTINA ESTUARINE SYSTEMS

4.1 Bahia Nueva, Golfo Nuevo, Patagonia

***<u>Monica N. Gil</u>* and J. L. Esteves**

<u>Study area description</u>

Bahía Nueva (42.75°S, 65.00°W) is located in the western extreme of Golfo Nuevo, Patagonia, Argentina (Figure 4.1). It has a semicircular shape with the mouth oriented in a NW (Punta Arco) - SE (Punta Este) direction. The volume of the bay is nearly 1.1×10^9 m^3 and the surface area is 58×10^6 m^2. The climate is semiarid and in general evaporation exceeds precipitation. Average annual rainfall is about 170 mm and average annual evaporation is nearly 800 mm (Rivas 1985). The bay water temperature varies from 10°C in winter to 17.5°C in summer. Nitrogen has been proved to be the limiting nutrient for primary production in this system (Charpy *et al.* 1982).

Puerto Madryn City is the only human settlement on this coast and it has about 50,000 inhabitants. Tourism, fisheries and aluminum production are the most important economic activities. The main wastewater discharges into the bay are a secondary-treated sewage (plant efficiency ~50%) and industrial effluents (principally fishery plants). Since not all the community is connected to the municipal sewage, polluted groundwater is also expected to reach the coast.

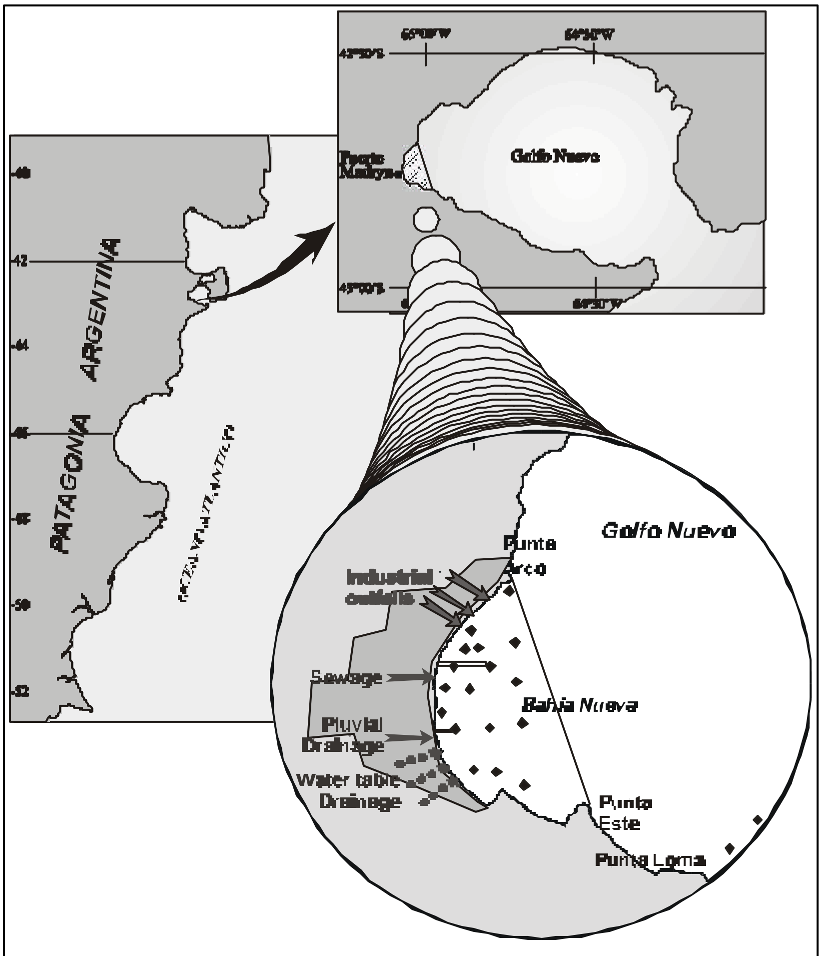

Figure 1. Bahía Nueva, sampling station locations.

Figure 4.1 Bahia Nueva, showing sampling station locations.

According to literature information (Lanfredi 1974; Krepper and Rivas 1979; Rivas 1983), there is a weak water circulation inside the bay (< 2.5 cm sec^{-1}), mainly depending on the wind. Temperature, salinity and chemical analysis of seawater have suggested that Golfo Nuevo water flows into the bay from the south and exits towards the north (Esteves *et al.* 1997). The same authors have observed a clear anthropogenic impact from urban and industrial activities in Puerto Madryn City and from the harbour itself.

The main objective of this work is to develop inorganic nutrient budgets (N and P) in the bay, following LOICZ methods (Gordon *et al.* 1996). Though this system is relatively open, it may behave like a semi-enclosed water body depending on prevailing wind conditions. Thus, each budgeted period would only reflect the situation during the sampling for that period. Furthermore, since salinity differences between the bay and the inflowing water from Golfo Nuevo is low (0.05-0.20 psu), the calculated fluxes have relatively high uncertainties. In any case, this study must be considered as a preliminary one, with at least a qualitative description of the system.

Seawater data
Surface and near-bottom water samples were collected at 9 to 19 stations (Figure 4.1) during 6 campaigns: December 1993 (summer), November 1994 (spring), June 1995 (fall), May 1998 (fall), July 1998 (winter) and September 1998 (winter). Month-season correspondence was determined according to De Vido and Esteves (1978). Samples from stations 1 and 2 (Punta Loma, at the southern extreme of the study area) were considered to represent inflowing water from the gulf.

Seawater salinity, NO_3^-, NO_2^-, NH_4^+ (DIN = NO_3^- + NO_2^- + NH_4^+) and PO_4^- (DIP) were measured by our research group. Salinity was determined with a Plessey environmental salinometer, Model 6230N (standard seawater: IAPSO, Dinamarca, chlorinity: 19.380%). Inorganic nutrients were analyzed according to Strickland and Parsons (1972), employing a Technicon Autoanalyzer. Results for each campaign are shown in Table 4.1. Each value represents an average of the composition of all surface and nearbottom samples.

Table 4.1 Salinities and inorganic nutrient concentrations in Bahía Nueva and in the inflowing water from the gulf (mean values and standard deviations).

	S_{gulf}	S_{bay}	DIP_{gulf}	DIP_{bay}	DIN_{gulf}	DIN_{bay}
	(psu)			(mmol m^{-3})		
Dec 93	33.58	33.62	0.91	1.09	0.00	0.87
	0.02	0.05	0.12	0.11	0.00	0.77
Nov 94	33.82	33.92	1.64	1.07	2.09	0.95
	0.05	0.14	0.97	0.15	0.37	0.38
Jun 95	34.52	34.71	1.16	1.21	4.08	4.61
	0.03	0.15	0.12	0.17	0.47	2.56
May 98	33.79	33.64	1.23	1.22	4.28	3.23
	0.02	0.19	0.01	0.26	0.33	1.66
Jul 98	33.97	34.03	1.20	1.13	5.84	2.93
	0.01	0.03	0.09	0.14	2.84	0.70
Sep 98	34.00	34.09	0.87	1.03	1.11	0.68
	0.01	0.07	0.05	0.09	0.46	0.37

Freshwater data
Freshwater information is shown in Tables 4.2a and 4.2b. Daily outputs due to evaporation (V_E) and inputs due to direct precipitation (V_E), were calculated by multiplying the area of the bay and the daily evaporation and precipitation respectively. Daily rainfall data for each campaign were assumed to be the daily average calculated over fifteen days before the last day of sampling.

Table 4.2a Freshwater inputs to Bahia Nueva.

	Precipitation	Evaporation	Runoff#	Groundwater	Outfalls	Total
	V_P	V_E	V_Q	V_G	V_O	V_Q#
	10^3 m^3 day^{-1}					
Dec 93	0	-33	0	8	9	-16
Nov 94	13	-44	0	8	9	-14
Jun 95	6	-216	0	5	11	-194
May 98	1,009	-228	357	6	11	1155
Jul 98	35	-196	1	5	11	-144
Sep 98	12	-67	0	5	10	-40

Estimated values.

Because the local climate is dry, contributions from runoff (V_Q) are not in general very important. The only significant runoff flow into the bay occurred during April 1998. This one high-runoff period was estimated to have influenced the May 1998 budget.

Table 4.2b Inorganic nutrient concentrations in freshwater inputs, Bahia Nueva.
(Concentrations in *Vp, Ve* and *Vq* are assumed to be 0).

		Groundwater			Outfalls		
		Y_G	Y_{O1}	Y_{O2}	Y_{O3}	Y_{O4}	Y_{O5}
		(mmol m^{-3})					
Dec 93	DIP	5	103	606	670	7	0
	DIN	50	2,561	8,295	3,844	572	0
Nov 94	DIP	5	112	666	537	4	0
	DIN	50	2,094	2,169	5,316	443	0
Jun 95	DIP	5	127	215	82	6	0
	DIN	50	2,618	1,644	1,600	314	0
May 98#	DIP	5	148	411	98	0	26
	DIN	50	3,511	2,571	2,128	0	1,034
Jul 98#	DIP	5	148	411	98	0	26
	DIN	50	3,511	2,571	2,128	0	1,034
Sep 98	DIP	5	148	411	98	0	26
	DIN	50	3,511	2,571	2,128	0	1,034

Outfalls concentrations were not measured. They were assumed to be equal to September values.

There are five principal outfalls discharging into the bay: sewage (O1), two effluent discharges from fisheries processing (O2, O3), a discharge from a defective pluvial pipe (O4) and the effluent from an aluminum plant (O5). Sewage and groundwater volume fluxes (V_{O1} and V_G) and groundwater composition were derived from Grimm and Esteves (1997). Groundwater nutrient concentrations represent the average of the water composition of three wells located near the shoreline and sampled in March 1997. Outfall volume fluxes V_{O2} to V_{O5} were estimated. Chemical characterization of all outfalls was done by our research group, according to APHA (1980). Salinities of all freshwater inputs, as well as nutrient concentration of rainfall, evaporation and runoff fluxes, were assumed to be 0.

Water and salt budgets

Because we assumed that Golfo Nuevo water enters the bay from the south (inflowing water, V_{in}) and exits via the north area (outflowing water, V_{out}), we went to the Gomez-Reyes modification of LOICZ methods (Gómez-Reyes *et al.* 1997) for budget development. Water and salt balances (Table 4.3) were carried out assuming steady state and according to the following equations:

$$V_Q^* = V_P + V_E + V_Q + V_G + V_O$$

where

V_Q^*: total freshwater fluxes;

V_P: direct precipitation flux;

V_E: evaporation flux;

V_Q: runoff flux;

V_G: groundwater flux;

V_O: outfalls fluxes.

$$V_{in} = (V_Q^* S_{bay})/(S_{gulf} - S_{bay})$$

$$V_{out} = -V_Q^* - V_{in}$$

$$t = V_{bay} / V_{out}$$

where

V_{in}: inflowing water from the gulf;

V_{out}: outflowing water to the gulf;

S_{bay}: mean bay water salinity;

S_{gulf}: mean salinity of inflowing water from the gulf;

t: water exchange time;

V_{bay}: bay volume.

Variability in estimated water exchange times is partly attributed to errors due to the low salinity differences between the bay and the gulf. Nevertheless, the budgets suggest that there is much longer water exchange time in summer-spring periods (mean = 157 days) than in winter-fall months (mean = 30 days).

Table 4.3 Water and salt budgets results for Bahia Nueva.

		V_{in}	V_{out}	t
		(10^3 m^3 day^{-1})		(days)
Dec 93	(summer)	13,448	-13,432	82
Nov 94	(spring)	4,749	-4,735	232
Jun 95	(fall)	35,441	-35,247	31
May 98	(fall)	259,028	-260,183	4
Jul 98	(winter)	81,672	-81,528	13
Sep 98	(winter)	15,151	-15,111	73

Nonconservative materials budgets

Nutrient budgets were carried out in accordance with the following equation:

$$DY = -V_{out}Y_{bay} - V_{in}Y_{gulf} - V_{Q*}Y_{Q*}$$

where

- Y: mean inorganic nutrient (DIP or DIN) concentrations for each sampling time;
- $V_{Q*}Y_{Q*} = V_PY_P + V_EY_E + V_Q Y_Q + V_GY_G + V_OY_O$, that is, the nutrient loading of all freshwater fluxes;
- ($V_{out}Y_{bay}$) and ($V_{in}Y_{gulf}$) are the nutrient loadings of outflowing and inflowing seawater, respectively;
- *DY*: biogeochemical flux of Y *(DDIP or DDIN).*

DIP balance

Tables 4.4a to 4.4c summarize results for the DIP balance. The bay behaves as a very slight net DIP sink in November 1994, May 1998 and July 1998 and as a slight net source in the other sampling periods. In any case, the nonconservative behavior is near 0. A further important observation is that the influx of DIP from the open gulf to the bay far exceeds the terrigenous inputs.

Table 4.4a DIP loadings in freshwater inputs, Bahia Nueva. (V_P, V_E and V_Q loadings are assumed to be 0).

		Groundwater		Outfalls		Total	
	$V_G\ DIP_G$	$V_{O1}DIP_{O1}$	$V_{O2}DIP_{O2}$	$V_{O3}DIP_{O3}$	$V_{O4}DIP_{O4}$	$V_{O5}DIP_{O5}$	$V_{Q*}\ DIP_{Q*}$
(10^3 mol day^{-1})				(10^3 mol day^{-1})			
Dec 93	0.00	0.87	0.09	0.10	0.00	0.00	1.1
Nov 94	0.04	1.0	0.10	0.08	0.00	0.00	1.2
Jun 95	0.02	1.3	0.03	0.01	0.00	0.00	1.4
May 98	0.02	1.5	0.06	0.01	0.00	0.00	1.6
Jul 98	0.02	1.5	0.06	0.01	0.00	0.00	1.6
Sep 98	0.02	1.4	0.06	0.01	0.00	0.00	1.5

Table 4.4b DIP loadings in outflowing (V_{out}) and inflowing (V_{in}) water, Bahia Nueva.

	$V_{out}DIP_{bay}$	$V_{in}DIP_{gulf}$
	(10^3 mol day^{-1})	
Dec 93	-14.6	12.2
Nov 94	-5.1	7.8
Jun 95	-42.6	41.1
May 98	-317.4	318.6
Jul 98	-92.1	98.0
Sep 98	-15.6	13.2

Table 4.4c Results for nonconservative DIP flux calculations, Bahia Nueva.

		DDIP	
		(10^3 mol day^{-1})	(mmol m^{-2}day^{-1})
Dec 93	(summer)	1.3	0.02
Nov 94	(spring)	-3.9	-0.07
Jun 95	(fall)	0.1	0.00
May 98	(fall)	-2.8	-0.05
Jul 98	(winter)	-7.5	-0.13
Sep 98	(winter)	0.9	0.02

DIN balance

Budgets of inorganic forms of N are shown in Tables 4.5a to 4.5c. The bay appears to be a net DIN sink during all sampling periods. Apparent high consumption in May and July may be real or could result from underestimates of nutrient loading from runoff.

Table 4.5a DIN loadings in freshwater inputs, Bahia Nueva. (V_P, V_E and V_Q are assumed to be 0).

		Groundwater		Outfalls		Total	
	$V_G\ DIN_G$	$V_{O1}DIN_{O1}$	$V_{O2}DIN_{O2}$	$V_{O3}DIN_{O3}$	$V_{O4}DIN_{O4}$	$V_{O5}DIN_{O5}$	$V_{Q*}\ DIN_{Q*}$
(10^3 mol day^{-1})				(10^3 mol day^{-1})			
Dec 93	0.42	22	1.20	0.58	0.09	0.00	24
Nov 94	0.42	18	0.33	0.80	0.07	0.00	20
Jun 95	0.23	27	0.25	0.24	0.05	0.00	28
May 98	0.23	36	0.39	0.32	0.00	0.16	37
Jul 98	0.23	36	0.39	0.32	0.00	0.16	37
Sep 98	0 .23	33	0.39	0.32	0.00	0.16	34

Table 4.5b DIN loadings in outflowing (V_{out}) and inflowing (V_{in}) water, Bahia Nueva.

	$V_{out}DIN_{bay}$	$V_{in}DIN_{gulf}$
	(10^3 mol day^{-1})	
Dec 93	-12	0
Nov 94	-4	10
Jun 95	-162	145
May 98	-840	1,109
Jul 98	-239	477
Sep 98	-10	17

Table 4.5c Results for nonconservative DIN flux calculations, Bahia Nueva.

		ΔDIN	
		(10^3 mol day^{-1})	mmol m^{-2} day^{-1}
Dec 93	(summer)	-12	-0.2
Nov 94	(spring)	-26	-0.4
Jun 95	(fall)	-11	-0.2
May 98	(fall)	-306	-5.3
Jul 98	(winter)	-275	-4.7
Sep 98	(winter)	-41	-0.7

Stoichiometric calculations of aspects of net system metabolism

According to Gordon *et al.* (1996), if we accept that *DDIP* fluxes are principally derived from organic matter production or degradation, then net nitrogen fixation minus denitrification (*nfix-denit*) and net ecosystem metabolism (NEM, [*p-r*]), may be estimated.

The difference between observed *DDIN* in the budget ($DDIN_{obs}$) and expected *DDIN* ($DDIN_{exp} = DDIP \times (N{:}P)_{part}$, where $(N{:}P)_{part}$ is the N to P ratio in organic matter being produced or degraded in the system) would represent (*nfix-denit*). We do not have data on the P and N composition of particulate material in Bahía Nueva. However, if we assume various N:P ratios ≤ 16, (*nfix-denit*) calculations indicate net denitrification (Table 4.6). While the mean rate estimates all suggest net denitrification, the standard deviations are large relative to the means. The rates are not greatly influenced by the choice of N:P, because *DDIP* (hence, $DDIN_{exp}$) is usually near 0. Denitrification requires anaerobic conditions, and the most likely place for this to occur is in the sediments.

Net ecosystem metabolism (NEM), the difference between primary production and respiration (*p-r*), may be estimated as the negative of the nonconservative DIP flux multiplied by the C:P ratio of the organic matter being produced. Again, we do not have information about this. But if we use the Redfield C:P ratio of 106, the system would seem to be slightly net autotrophic ($p>r$) during three sampling periods (November ′94, May ′98, July ′98), and net heterotrophic ($p<r$) three times (December ′93, June ′95, September ′98) (Table 4.6). The average of the results would indicate net autotrophic behavior, but near 0. The magnitude, but not the sign, of net ecosystem metabolism would be altered by the use of some other C:P ratio.

Table 4.6 Stoichiometric derivations, Bahia Nueva.

		(nfix-denit)			***(p-r)***
		(mmol m^{-2} day^{-1})			
Organic matter nutrient ratios		(N:P=16)	(N:P=8)	(N:P=4)	(C:P=106)
Dec 93	(summer)	-0.5	-0.4	-0.3	-2
Nov 94	(spring)	0.7	0.2	-0.1	7
Jun 95	(fall)	-0.2	-0.2	-0.2	0
May 98	(fall)	-4.5	-4.9	-5.1	5
July 98	(winter)	-2.6	-3.7	-4.2	14
Sep 98	(winter)	-1.0	-0.9	-0.8	-2
Average		-1.4	-1.7	-1.8	4
Std. Dev.		1.9	2.1	2.3	6

Conclusions

This preliminary nutrient budget for Bahía Nueva lets us evaluate human impacts related to nutrient inputs from Puerto Madryn City. While DIP loading is undoubtedly having a local effect on the bay, input from the open gulf is far greater than terrigenous loading. By contrast, terrigenous DIN loading is often as large as or larger than the input from the gulf. Clearly human influence on the DIN loading to the bay is important.

No correlation was observed between water exchange times and nutrient biogeochemical fluxes. A better approach of seawater inflowing and outflowing fluxes will be needed, in order to improve the results. A net consumption of N inorganic forms was observed, while nonconservative net phosphate fluxes remain near 0.

Although the system appears to denitrify in excess of fixing nitrogen and to be net autotrophic, the mean estimates of net system performance are near 0.

Acknowledgements*:* We wish to thank Lic. Marta Commendatore and Ing. Miriam Solís for sample collection and analysis. We are also indebted to Mr. Horacio Ocariz for bay volume and area calculations and to Lic. Andrés Rivas for his helpful suggestions. Financial assistance was provided by funds of ARG/92/63 "Patagonian Coastal Zone Management Plan" GEF/UNDP project and funds of Agencia Nacional de Promoción Científica y Tecnológica (PIC 0111) and CONICET (PIP4271/96).

5. ECUADOR ESTUARINE SYSTEMS

5.1 Gulf of Guayaquil

Isabel Tutivén U.

<u>Study area</u>
Guayaquil Gulf, located between 2.0°-3.5° S, 79.5°-81.0°W, is the largest estuary of the Pacific coast of South America (Figure 5.1). Its waters are very productive and are fished by Ecuador and by other nations (Stevenson 1981). Plankton biomass is dominated by coccolithophores and diatoms with high plankton biomass. During the period studied by PMRC (1989), the net productivity in surface waters was from 800 to 1000 mg C m^{-3} day^{-1} during the wet season, measured at one station.

The gulf has a surface area of 5,000 km^2 and a drainage area of 51,000 km^2 (Epler and Olsen 1993). The system can be divided into an outer estuary from Puna Island (located inside of the estuary at 80.25°-81.0° W), and an inner estuary that extends upstream 75 km from Puna Island. It narrows to the Guayas River channel (Stevenson 1981). The maximum depth of the gulf decreases from 180 to 18 m (Figure 5.1).

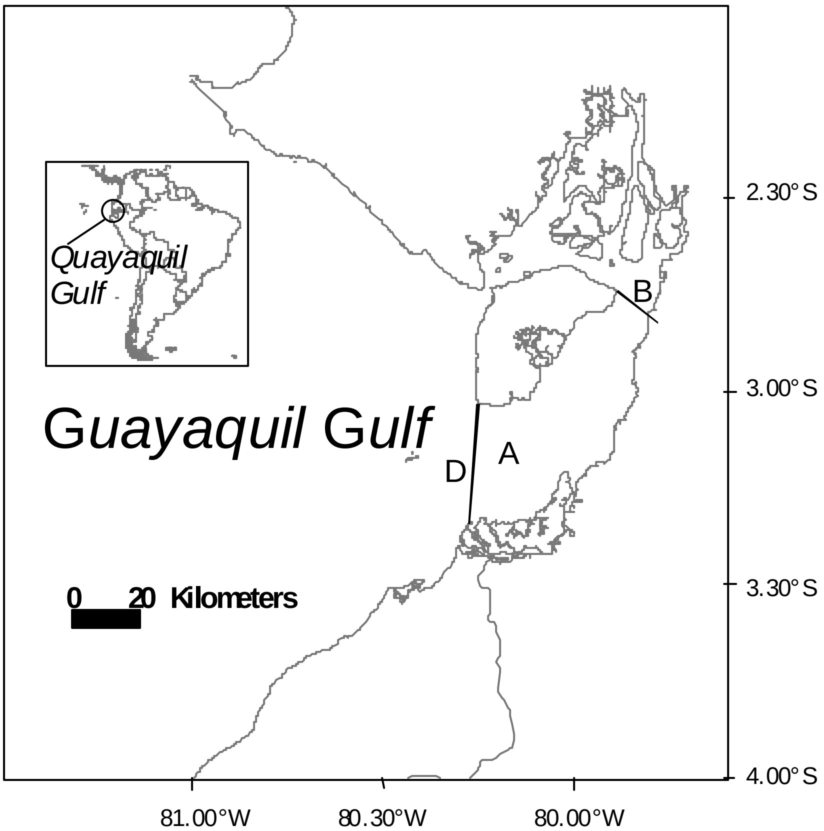

Figure 5.1 Location and map of Guayaquil Gulf, Ecuador.

The tidal regime is semi-diurnal and can range up to 5 m (Stevenson 1981); it decreases in the outer estuary. Tidal influence extends upstream to about 2.3°S. Salinity is >0 psu at the interior estuary in dry season between August and November and 0 psu in the wet season (Tutivén 1993).

The Ecuadorian coast is in a transitional zone where two climatic systems meet, one from the North Pacific and the other from the South Pacific. The boundary is the Inter-tropical Convergence Zone (ICZ). This boundary fluctuates, establishing the seasonal variations found in Ecuador. Because of seasonal variability, waters from the north enter the Gulf during the wet season, and waters from the south enter during the dry season.

In the wet season (December-April), the northerly trade winds are strong and move a high pressure centre towards the south. The ICZ is located about 2°N. During this period, convection activity increases and precipitation may total 900 mm (Stevenson 1981). Saline, warm water from Panama is displaced south, producing a temperature increase to 25°C in the waters along the Ecuadorian coast.

Industrial activity has changed water quality in the estuary over the past 20 years. The main industrial activity is aquaculture, which began in 1980 and is now distributed throughout most of the estuary. Between 1969 and 1987 the area covered by shrimp farms rose from 0 to 740 km^2 (Clirsen 1986, 1987). In 1995 there were 1,700 km^2 of shrimp ponds throughout Ecuador, of which 1,400 km^2 were located in the Gulf of Guayaquil (PMRC 1989).

Industrial activity is based around Guayaquil City, the largest city in Ecuador, with direct influence on the estuary. DIGMER (Direccion General de la Marine Mercante) reports indicate significant liquid discharges from 35 industries, with 25 generating organic effluent. These discharges total about 4,100 kg of BOD day^{-1} (~250 m^3 day^{-1}).

Sewage discharges total about 15,000 kg of BOD per day from the two main treatment plants, Progreso and El Guasmo (EMAG 1985). For budget calculations, this study must account not only these two, but also 12 other treatment plants in Guayaquil.

Water and salt balance

Guayaquil Gulf is homogeneous during the dry season and stratified in the wet season. Calculations are made for each season. The volume of the budgeted part of the gulf is approximately 30×10^9 m^3, and the area is about 3×10^3 km^2 with an average depth of 10 m (Figure 5.1). The data are averages for each season during the 1962-1964 period. Because of the great length of the gulf and the lack of composition data for the riverine portion of the estuary, we have inserted an inner gulf box upstream of the budgeted portion of the system. Direct evaporation and precipitation are not accounted for in this budget because of lack of information; however, it can be assumed that the freshwater budget is dominated by river flow. The system volume (Box A, Figure 5.1) is approximately 30×10^9 m^3 , and the area is about 3,000 km^2, with an average depth of 10 m.

During the dry season, the outer estuary is treated as a single, vertically-mixed box (Figure 5.2). V_X for the exchange between the ocean and the outer estuary is about $4{,}400 \times 10^6$ m^3 day^{-1}, compared with river flow (V_Q) of 130×10^6 m^3 day^{-1}. Thus, mixing is the dominant water exchange term. Water exchange time for the whole system is about 7 days during the dry season.

During the wet season, the system is treated as a stratified, two-box system (Figure 5.3). Again, the budgeted portion is the outer estuary with an upstream box representing composition of water upstream of the budgeted region. Deep inflow and surface outflow between the ocean and outer estuary ($V_{ocn-syst}$, $V_{syst-ocn}$) are about $5{,}000 \times 10^6$ m^3 day^{-1}, about the same magnitude as V_X during the dry season, but the river flow term (V_Q) is much larger (~600×10^6 m^3 day^{-1}) and reflects the stronger wet-season effect of river flow on water exchange. Water exchange time decreases slightly, to 6 days.

Nonconservative materials balance

DIP balance

Figures 5.4 and 5.5 summarize the dissolved inorganic phosphorus (DIP) budgets for the system during the dry and wet seasons respectively. It should be noted that these budgets do not include either aquaculture-associated loads or the various waste loads indicated in the description of the study area. This is appropriate, because the nutrient data used here were collected in 1962-1964 – before the development of aquaculture and the growth of the city of Guayaquil.

A similar *DDIP* of about -1.1×10^6 mol day^{-1}, or -0.4 mmol m^{-2} day^{-1} was found under very different regimes of river load and stratification.

DIN balance

Nitrogen data available for this system only included nitrite. The data were checked closely, to ascertain that this designation was definitely not a typographical error. Nitrite data alone are not useful in determining an inorganic nitrogen budget, because nitrite typically accounts for less than 1% of the DIN and is not correlated with the more abundant forms of DIN. Therefore a nitrogen budget cannot be calculated at this time.

Stoichiometric calculations of aspects of net system metabolism

The difference between organic carbon production (p) and respiration (r) is calculated using the relationship $(p-r) = -DDIP \times (C:P)_{part}$, where $(C:P)_{part}$ is the C:P ratio of reacting organic matter and is assumed to equal the Redfield Ratio of 106:1. The calculated *DDIP* of -0.4 mmol m^{-2} day^{-1} is therefore equivalent to a calculated (p-r) of about +42 mmol m^{-2} day^{-1}. Compared to the primary production for one station of about 75 mmol m^{-2} day^{-1}, this suggests that this system is strongly net autotrophic. The calculated *p/r* ratio of 2.3 seems excessive and may indicate either inorganic P uptake or errors in the budget.

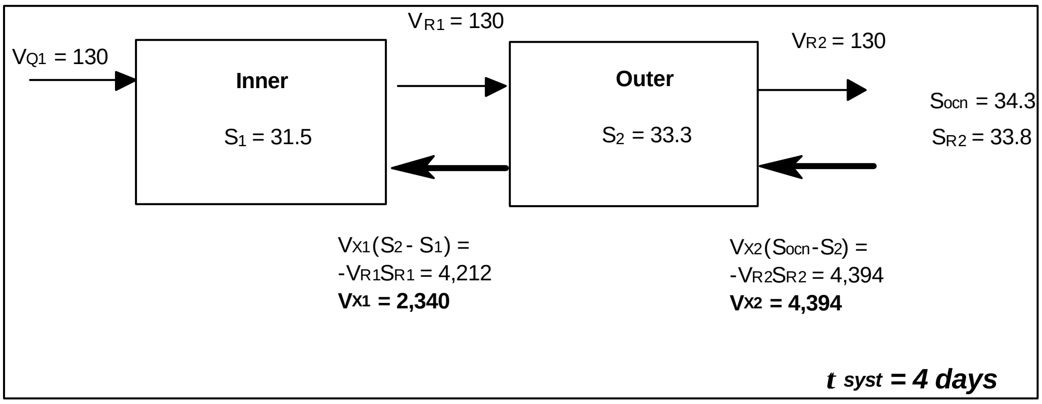

Figure 5.2 Salt and water budgets for Guayaquil Gulf during the dry season. Water fluxes are in 10^6 m^3 day^{-1}; salt fluxes are in psu m^3 day^{-1}. Directions of flux for salt are indicated by the arrows.

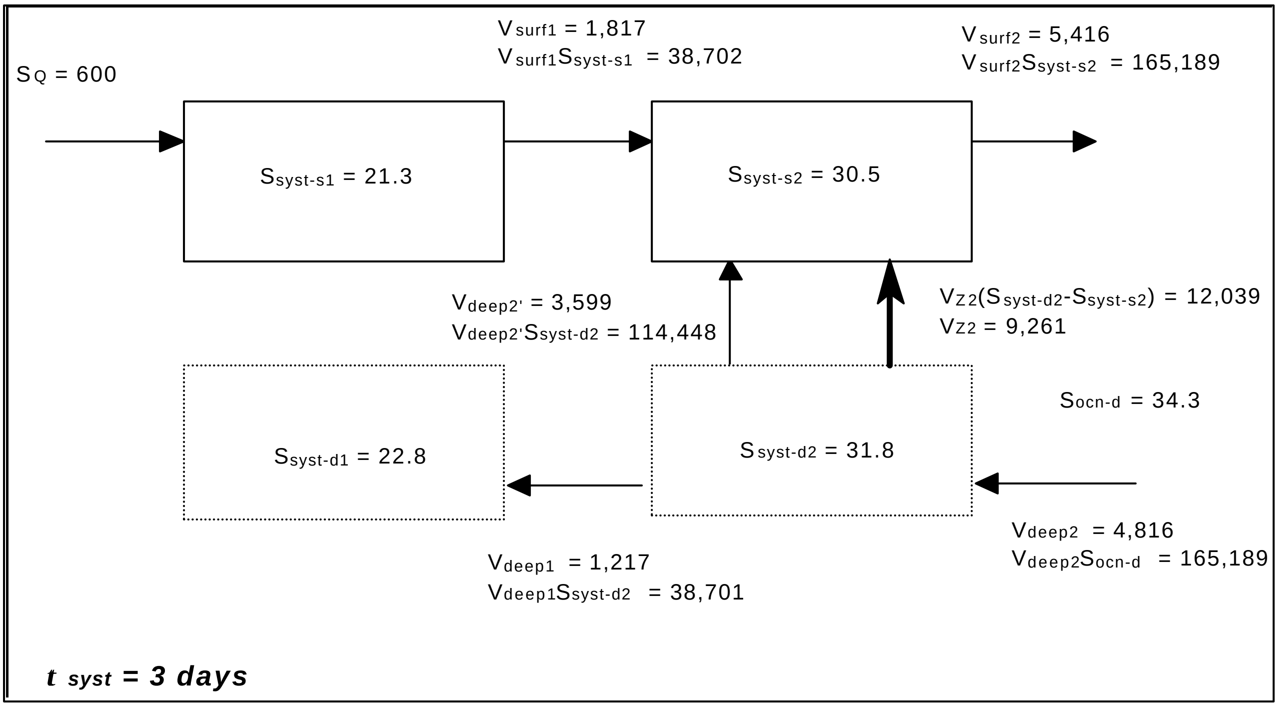

Figure 5.3 Salt and water budgets for Guayaquil Gulf during the wet season. Water fluxes are in 10^6 m^3 day^{-1}; salt fluxes are in psu-m^3 day^{-1}. Directions of flux for salt are indicated by the arrows.

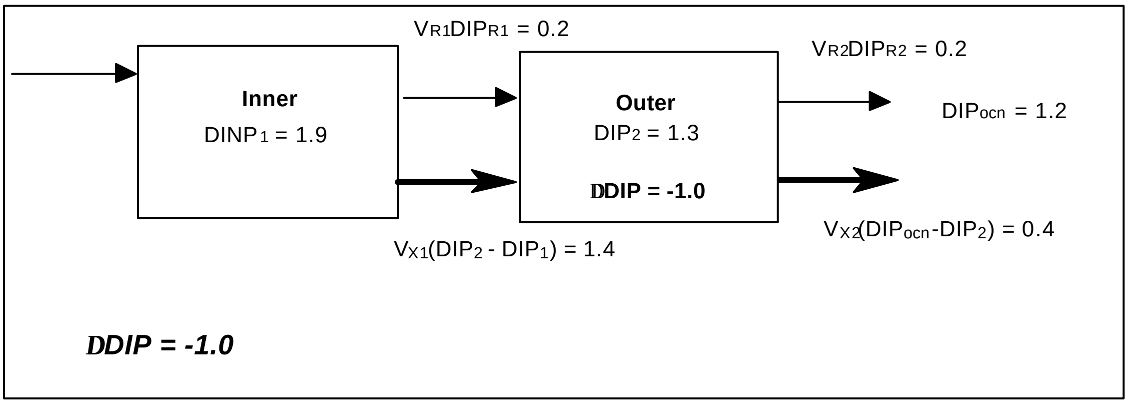

Figure 5.4 DIP budget for Guayaquil Gulf during the dry season. Fluxes in 10^6 mol day^{-1}. Directions of flux are indicated by the arrows.

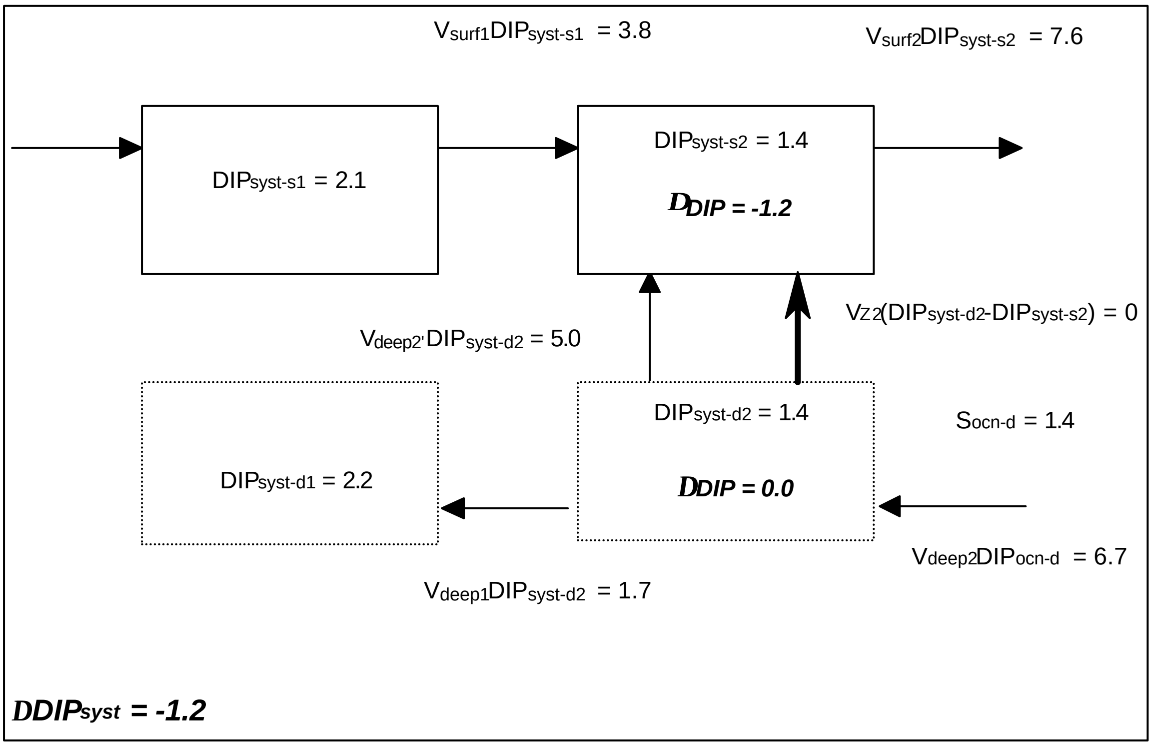

Figure 5.5 DIP budget for Guayaquil Gulf during the wet season. Fluxes in 10^6 mol day^{-1}. Directions of flux are indicated by the arrows.

6. CHILE ESTUARINE SYSTEMS

6.1 Aysén Sound, Chile

***Nelson Silva S.*, Dafne Guzmán Z. and Alexander Valdenegro M.**

Study area description

Chile has a large estuarine system in its southern extreme, which spreads between Puerto Montt (42.5ºS) and Cape Horn (55.5ºS), a distance of about 1,400 km, and includes a great quantity of islands surrounded by innumerable channels. The basins of this estuarine system were formed as a result of erosive glacier action and by the tectonic sinking of the longitudinal valley south from Puerto Montt (Borgel 1970-1971). After the last glacial age, the sea level rose and those basins were flooded by the sea, forming a mixed system of drowned river valleys, fjords and inner seas.

Due to the heavy rains in the area (e.g., 1,040 mm in Guafo; 3,170 mm in Melinka; 3,870 mm in Puyuhuapi: Pickard 1971), an estuarine system was generated. This system has a high economic value, due to the great quantity and diversity of natural resources and also because of its convenience for the culture of marine species. These characteristics have brought about a quick growth of urban areas, an increase of the riverine population and the establishment of more than 360 businesses using marine culture. Among these businesses, 125 are salmon and trout growth and nursery centers (Fundación Chile 1996).

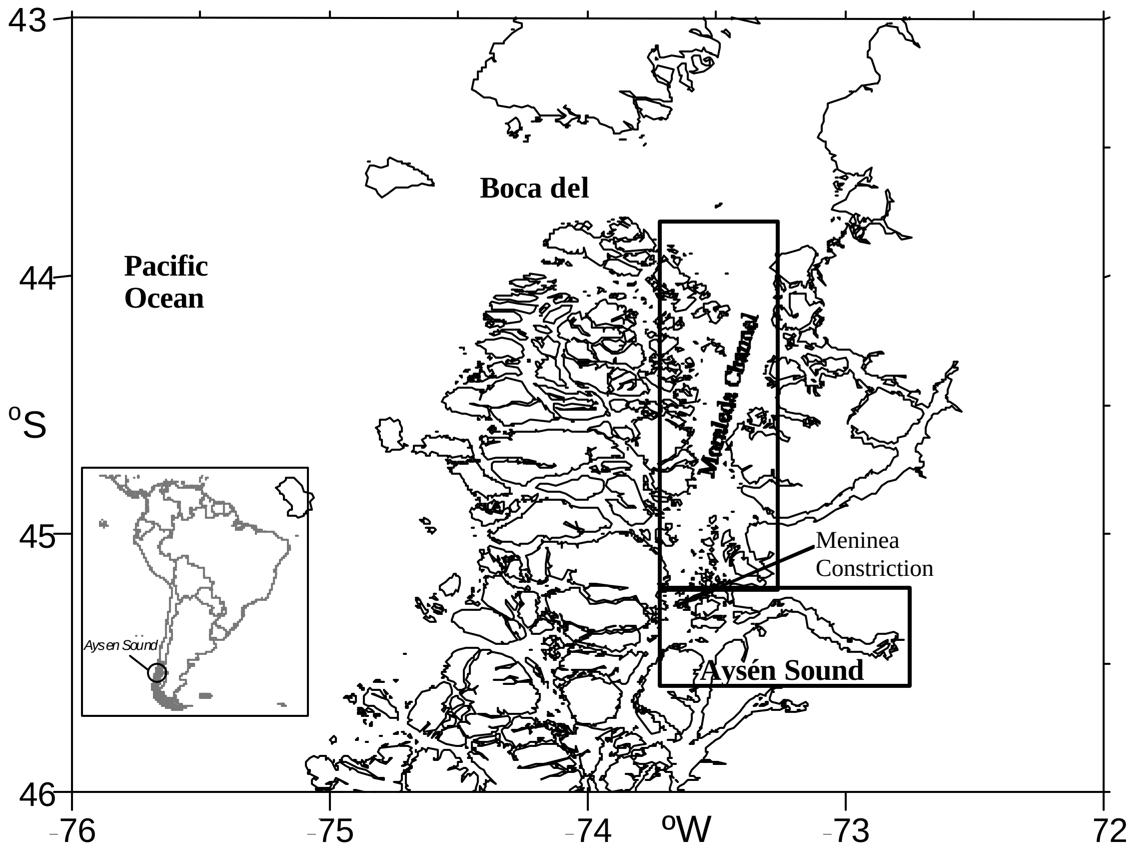

Figure 6.1 Location of Aysen Sound, Chile.

Hydrographic Aspects

Aysén Sound is a fjord which is located between 45.3°-45.5°S, 72.8º-73.8ºW, with a length of about 73 km, an average depth of 142 m and an area of about 470 km^2. Its mouth is connected to the southern extreme of the Moraleda Channel which is in turn connected to the sea at its northern extreme through the "Boca del Guafo" (Figure 6.1).

The Aysén River flows into the head of this fjord, and it has as principal discharges the Mañiguales (15 million m^3 day^{-1}), the Simpson (9 million m^3 day^{-1}) and the Claro (500 thousand m^3 day^{-1}) rivers. In addition, the Cuervo (9 million m^3 day^{-1}) and Lagunillas (4 million m^3 day^{-1}) rivers flow directly into the fjord (Ministerio de Obras Públicas 1997). There are other rivers for which there are no flow records; but which seem to be relatively unimportant.

Due to the large freshwater contribution from rivers and rain, Aysén Sound is characterized by a two-layer structure, separated by a strong halocline. The upper layer, which is about 25 m thick, has salinities between 0 psu at the head and 29 psu at the mouth. The lower layer is more homogeneous, with salinities between 30 and 31 psu (Figure 6.2) (Sievers and Prado 1994; Silva *et al.* 1995, 1997). The upper layers are well-oxygenated throughout the sound and have concentrations from 5 to 7 ml l^1. However, the lower layers have concentrations about 5 ml l^1 in the first third of the sound, but then it rapidly decreases towards the head to values lower than 2.5 ml l^1 near the bottom (Silva *et al.* 1995, 1997). This situation is also seen in the pH measurements in the area, which are 7.75 at the mouth and 7.35 at the head (Silva *et al.* 1997).

Nitrate (DIN) and phosphate (DIP) also show a two-layer structure, with lower values at the surface, due to the contribution of low-nutrient rivers (Silva *et al*. 1990a, 1990b) and biological uptake. The upper layer has concentrations of 0-1.2 µM of phosphate and 0-12 µM of nitrate. The lower layer is more homogeneous, with concentrations of 1.4-1.8 µM of phosphate and 1.2-12 µM nitrate, increasing from the mouth to the head (Silva *et al*. 1997). The average N:P Redfield ratios for the sound waters, obtained by linear regression, were 10.6:1 with a correlation coefficient of 0.971 (Calvete 1997).

The decrease of dissolved oxygen and pH and the increase of dissolved nutrients towards the head of the fjord indicate a strong remineralization of organic material at the head of the fjord. The above would be due principally to the nutrient regeneration from marine organic matter produced in the sound and terrestrial organic matter brought by the rivers. A probable sluggish circulation in this upper part of the sound will contribute to the permanence of high values of DIN and DIP. Chemical measurements in sound sediments show high concentrations of organic matter (8-10%), organic carbon (1.5-4%) and Kjeldahl nitrogen (0.1-0.3%) (Silva *et al.* 1998), which are characteristic of the highly productive areas.

General circulation

Near the southern extreme of the Moraleda channel, off Meninea island (45.27º S; 73.63º W), there is a shallow sill (60 m deep), which makes the southern part of the Moraleda channel and Aysén Sound form a deep basin partially isolated from the open ocean. This "Meninea constriction" constrains the circulation in the levels below the sill (60-300 m) and results in different oceanographic characteristics in the two basins. The southern basin is warmer, less saline and more oxygenated than the northern one, which is connected to the open ocean through the Guafo mouth.

The former situation, where the isolated basin is more oxygenated than the basin with free exchange to the open ocean, could be explained on the basis of an estuarine circulation mechanism and the presence in the channels of low oxygen deep water from Equatorial Subsurface origin (Silva *et al.* 1995). The water from the 25 to 60 m depths has a small net flow towards the south that allows the northern basin water to pass into the southern basin, where it sinks into deeper levels because of its higher density than the interior water. Thus 25 to 60 m water fills most of the deep part of the southern basin, carrying its characteristics and producing the situation described above. In order to maintain the volume balance, the less saline upper layer water of the southern basin has a net flow to the north, flowing out towards the adjacent oceanic area.

A net current of 16 cm sec^{-1} towards the ocean for the surface layer, and a net current of 2 cm sec^{-1} for the subsurface layer, have been shown as a result of two-month current meter measurements in the Meninea area (Salinas and Hormazábal 1996).

Water and salt budgets

By means of the employment of a two-layer box model and based on the methodology proposed by LOICZ, a water and salt budget for Aysén Sound was prepared. To do that, the following assumptions were made:

- $V_G = 0$ and $S_G = 0$ (groundwater), since it was not possible to estimate them. In any case, the terms seem likely to be small compared with river flow and rainfall.

- $V_0 = 0$ and $S_0 = 0$ (riverine fresh water). These terms were considered irrelevant, since the greater sources of freshwater are the rivers and the rain.

- $V_E = 0$ (evaporation), since it was considered as minor term in the estuarine system compared with high precipitation volumes (≈2 m $year^{-1}$) and relatively low mean annual air temperature (≈10°C) of the area.

- V_Q (River flow) was obtained based on historical records of the Mañiguales, Simpson, Claro, Lagunillas and Cuervo rivers, which provide the estuarine system with fresh water. Since monthly records were available, the records were divided into two seasonal periods (summer and winter). These values were increased by 30%, to correct them for freshwater input provided by rivers and coastal runoff for which there are no records.

- S_Q (river salinity) was assumed to be 0.1 psu, as has been reported in other studies.

- V_P (precipitation) was obtained based on historical records from Puerto Aysén (Dirección Meteorológica de Chile 1983-1996). Monthly records were compiled into two seasonal periods (summer and winter).

- Due to the presence of a halocline centered around 25 m depth, the box model was considered as a two-layer one, with the first layer in the upper 25 m and the second below 25 m.

- Due to the presence of the Meninea constriction (which behaves as a physical barrier to water movement), the 25-80 m stratum was considered as the deep layer of the oceanic box. Meanwhile in the estuarine system, the deep layer was considered to cover the strata from 25 m to the bottom.

- The Meninea constriction was considered as the limit of the estuarine system, since it represents a physical barrier between the oceanic and the estuarine system.

Based on the previously stated considerations, and data taken by Cimar Fiordo 1 (winter 1995), Cimar Fiordo 4-1, (winter 1998) and Cimar Fiordo 4-2, (summer 1999) cruises, a water and salt budget for Aysén Sound was prepared (Tables 6.1 and 6.2; Figures 6.3, 6.6, 6.9).

Even though the area is very rainy (precipitation ≈2 m yr^{-1}), it shows some degree of seasonality in precipitation and river discharge (Table 6.1). Therefore, the available data were analyzed in two parts: a southern fall-winter (April to October) period and southern spring-summer (November to March) period. Figures 6.3 and 6.6 summarize the water and salt budgets for two cruises performed in late winter (October 1995 and 1998), and Figure 6.9 summarizes the water and salt budgets for a cruise performed in late summer (March 1999). The river flow and precipitation used in the budgets (Table 6.2) correspond to seasonal averages based on monthly historical data taken during several years (Dirección Meteorológica de Chile 1983-1996).

Table 6.1 Summary of the estimated and measured variables in the Aysén Sound system.

Estimated Parameter	*Values*
System Area (10^6 m^2)	470
Average depth (m)	142
System volume (10^9 m^3)	66.8
Average winter rain (mm day^{-1})	8
Average summer rain (mm day^{-1})	6
Average winter river flow (10^6 m^3 day^{-1})	10
Average summer river flow (10^6 m^3 day^{-1})	8

Table 6.2 Summary of estimated and measured values for the Cimar Fiordo cruises.

	OCEANOGRAPHIC CRUISES		
Estimated and measured variables	**Cimar Fiordo 1** (winter) - Oct 95	**Cimar Fiordo 4 - 1** (winter) - Oct 98	**Cimar Fiordo 4 - 2** (summer) - Mar 99
Flows (10^6 m^3 day^{-1})			
V_Q	10	10	8
V_P	4	4	3
V_{deep}	81	66	34
V_Z	37	30	8
V_{surf}	95	80	45
V_{deep}	81	66	34
Salinities (psu)			
S_{Syst-s}	27.9	27.3	25.1
S_{Syst-d}	31.2	31.3	31.7
S_{Ocn-s}	31.8	31.3	32.3
S_{Ocn-d}	32.7	33.1	33.3
S_Q	0.1	0.1	0.1
S_{Syst_tot}	29.3	29.3	28.4
S_{Ocn_tot}	32.2	32.2	32.8
Nutrients (mmol m^{-3})			
DIN_{Syst-s}	15.0	8.4	Data in process
DIN_{Syst-d}	17.6	17.5	Data in process
DIN_{Ocn-s}	10.5	6.9	Data in process
DIN_{Ocn-d}	15.9	16.7	Data in process
DIN_P	2	2	Data in process
DIN_Q	1	1	Data in process
DIP_{Syst-s}	1.5	0.9	Data in process
DIP_{Syst-d}	1.7	1.7	Data in process
DIP_{Ocn-s}	1.1	1.0	Data in process
DIP_{Ocn-d}	1.4	1.7	Data in process
DIP_Q	0.1	0.1	Data in process
Exchange time			
τ (days)	703	835	1,482
τ (years)	1.9	2.3	4.1

The average residence time of water in the Aysén basin was estimated to be around 3 years. However, due to the larger freshwater contribution in winter, the renewal is twice as fast as in the summer season (Table 6.2). Our estimated average exchange time results are somehow longer than the 12 months reported by Salinas and Hormazábal (1996). There is a strong need to get a better estimate of runoff not taken into account by the river discharge, and it would be preferable to use precipitation and runoff data for the period preceding the study rather than the long-term average data that are available. Evaporation and groundwater inflow are two variables that need a careful review to find out if the previously-stated assumptions on this matter can be kept or there is a need to get better estimates of them, to be substituted into the budgets.

Dissolved nonconservative materials budgets
Based only in nutrient data taken in the winter cruises (Cimar Fiordo 1 and 4-1), the nonconservative materials budgets were determined. The DIN budgets are shown in Figures 6.4 and 6.7, and the DIP budgets are shown in Figures 6.5 and 6.8.

For the DIN budget, only dissolved nitrate+nitrite were used, because the ammonium data, measured only in Cimar Fiordo 1, showed very low concentrations (< 1 mmol m^{-3}). In a general sense, DIN and DIP are provided to the fjord area from the ocean, since the rivers have very low nutrient concentrations (Silva *et al.* 1997).

The surface layer of Aysén Sound apparently behaves as a nitrogen fixation system, and the deep layer as a denitrifying system, for both winter cruises (Table 6.3). Nevertheless, the system as a whole did not show a constant behavior. During Cimar Fiordo 1, the whole system appeared to be denitrifying while in Cimar Fiordo 4-1 it showed to be fixing nitrogen. Both rates were low, and the average is near 0. It seems possible that slight differences in the timing of the spring bloom may at least partially account for the differences.

It is important to keep in mind that the budgets presented in this report are based on isolated measurements (cruises); therefore they have to be taken with caution and their results cannot be extrapolated to a full year conclusion for Aysén Sound.

Table 6.3 N:P stoichiometry for the CIMAR Fiordo winter cruises.

N:P STOICHIOMETRY			
N:P = 16	***(nfix-denit)***	***(nfix-denit)***	***net nitrogen status***
Cruises / layers	10^3 mol N day^{-1}	mmol N m^{-2} day^{-1}	
Cimar Fiordo 1			
Surface layer	-67	-0.1	Denitrification
Deep layer	-278	-0.6	Denitrification
System	-345	-0.7	Denitrification
Cimar Fiordo 4-1			
Surface layer	+276	+0.6	N-fixation
Deep layer	-58	-0.1	Denitrification
System	+218	+0.5	N-fixation

The net ecosystem metabolism *(p-r)* was estimated based on the behavior of *DDIP*, relative to the Redfield C:P ratio. It has been inferred that if *DDIP* shows a negative value, the system is autotrophic, producing organic matter and consuming dissolved inorganic carbon (DIC). This seems to be the situation for Aysén Sound surface layer in both cruises. As expected, the deep layer behaves as an heterotrophic system since *DDIP* is positive and *(p-r)* is negative (Table 6.4, Figures 6.5 and 6.8). In this case DIC is released due to the organic matter remineralization in the deep layer.

Table 6.4 C:P stoichiometry for the winter cruises.

C:P STOICHIOMETRY			
C:P = 106	***(p-r)***	***(p-r)***	***net trophic status***
Cruises / layers	10^3 mol C day^{-1}	mmol C m^{-2} day^{-1}	
Cimar Fiordo 1			
Surface layer	+318	+0.7	autotrophic
Deep layer	-3,392	-7.2	heterotrophic
System	-3,074	-6.5	heterotrophic
Cimar Fiordo 4-1			
Surface layer	+6,890	+14.7	autotrophic
Deep layer	-2,544	-5.4	heterotrophic
System	+4,346	+9.2	autotrophic

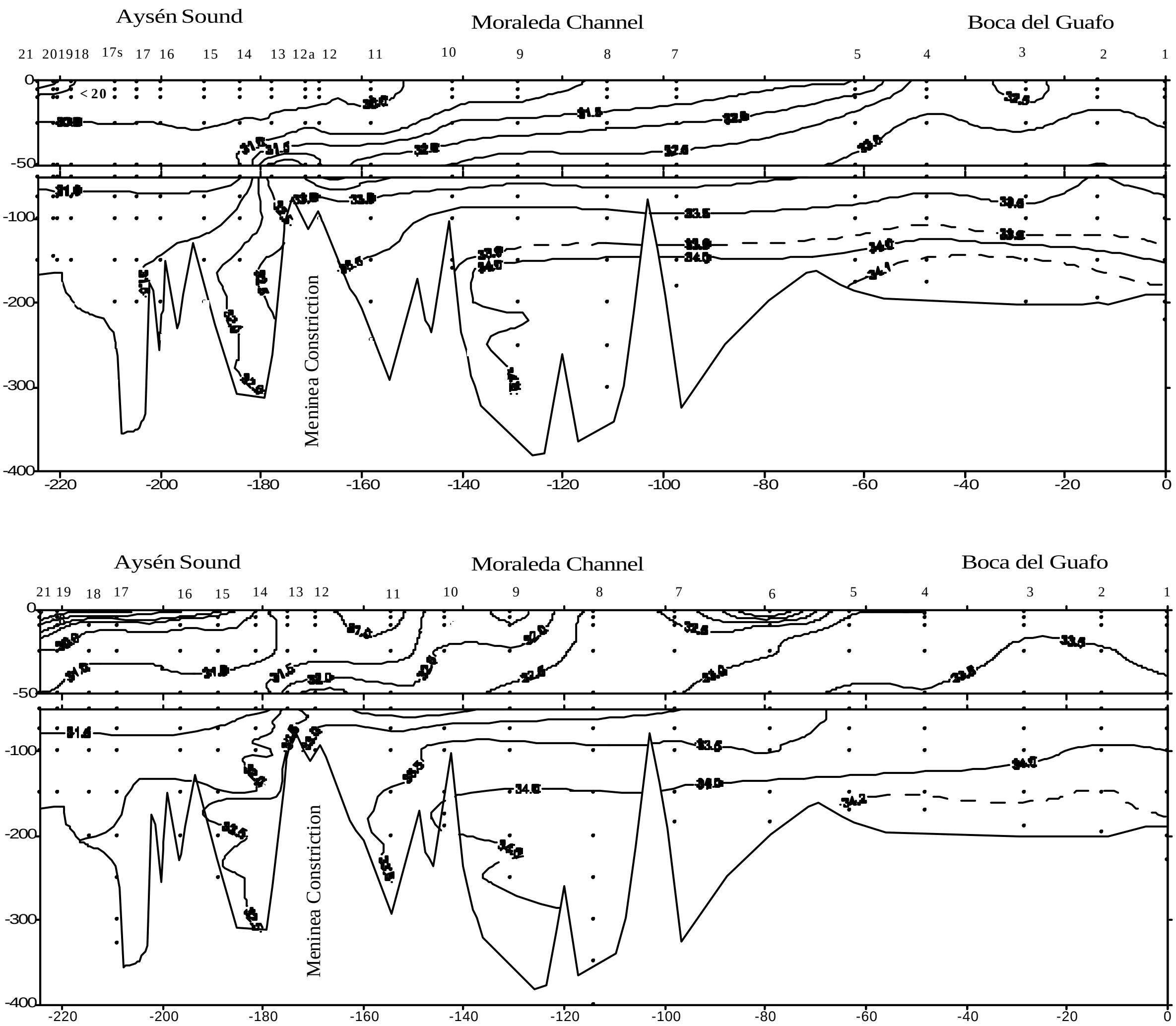

Figure 6.2 Vertical distribution of salinity for Cimar Fiordo 4-1 (upper) and Cimar Fiordo 4-2 (lower) cruises.

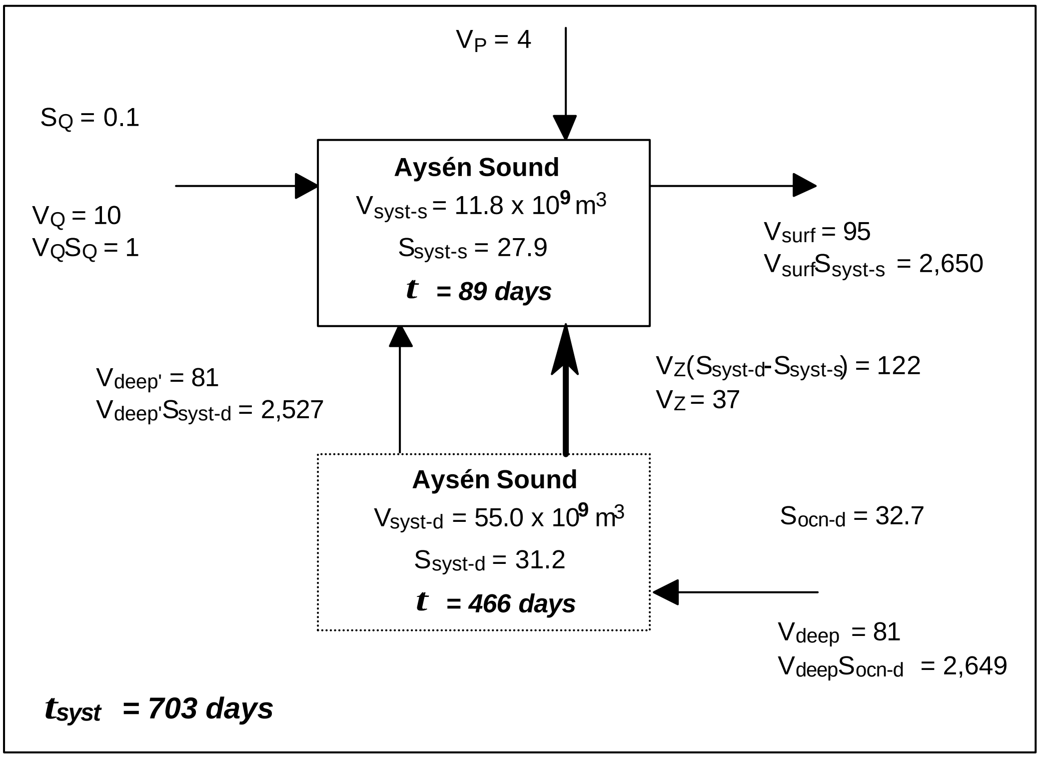

Figure 6.3 Box diagram for water and salt budget in a 1-box 2-layer model, for Aysén Sound (October 1995, southern winter, Cimar Fiordo 1 cruise)**.** Input and output fluxes (10^6 m^3 d^{-1}; 10^6 psu m^3 d^{-1}) and exchange time are indicated.

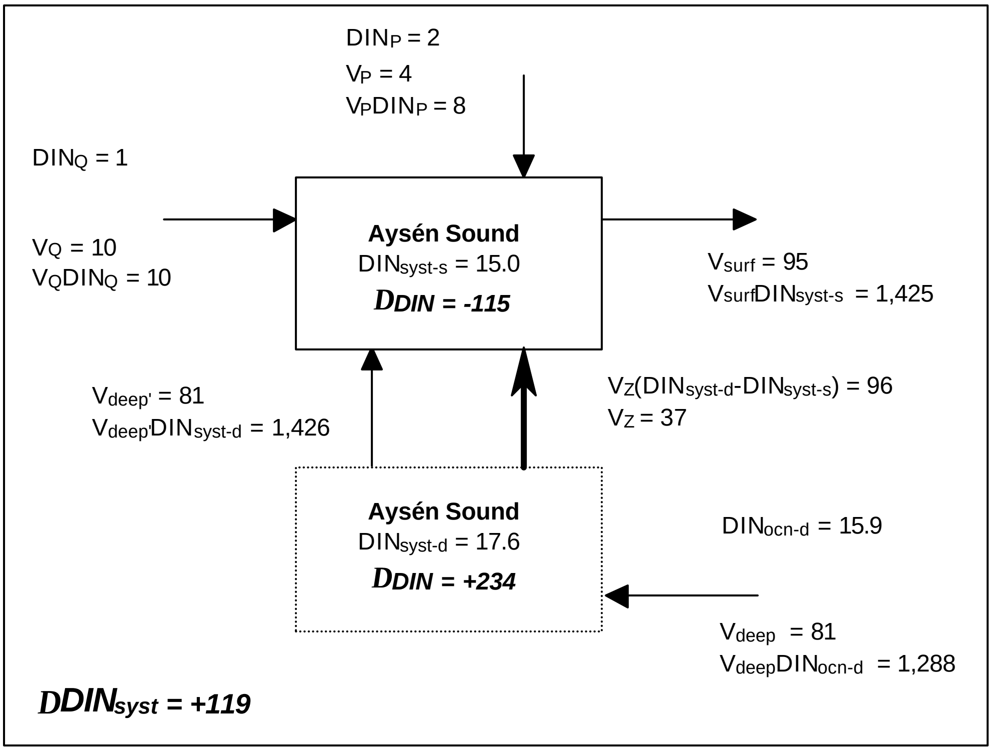

Figure 6.4 Box diagram for dissolved nitrate-nitrite budget in 1-box 2-layer model, for Aysén Sound (October 1995, southern winter, Cimar Fiordo 1 cruise)**.** Fluxes in 10^3 mol d^{-1}.

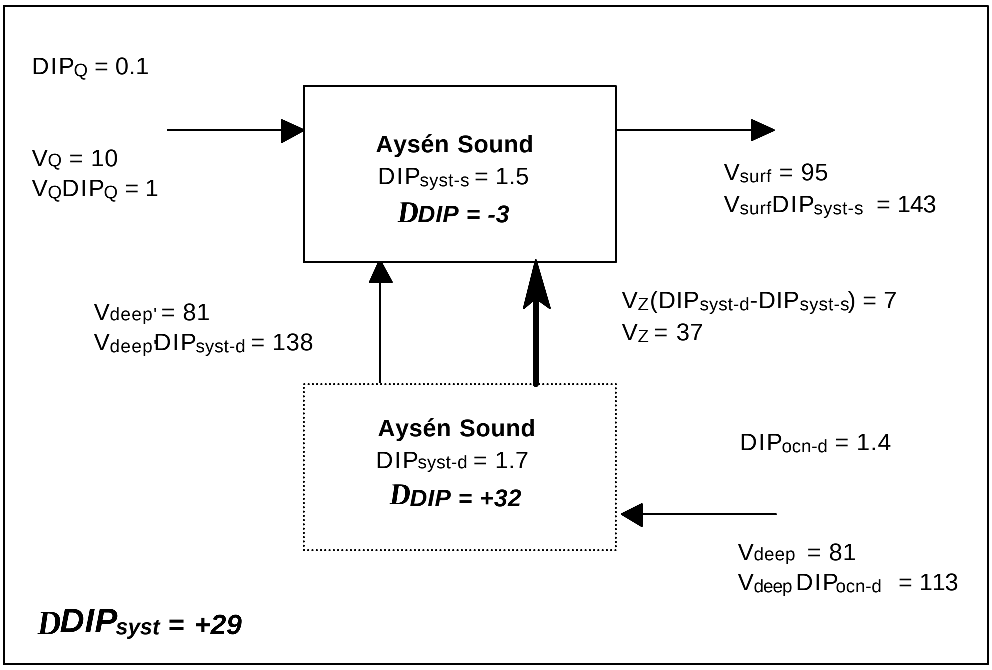

Figure 6.5 Box diagram for dissolved phosphate budget in 1-box 2-layer model, for Aysén Sound (October 1995, southern winter, Cimar Fiordo 1 cruise). Fluxes in 10^3 mol d^{-1}.

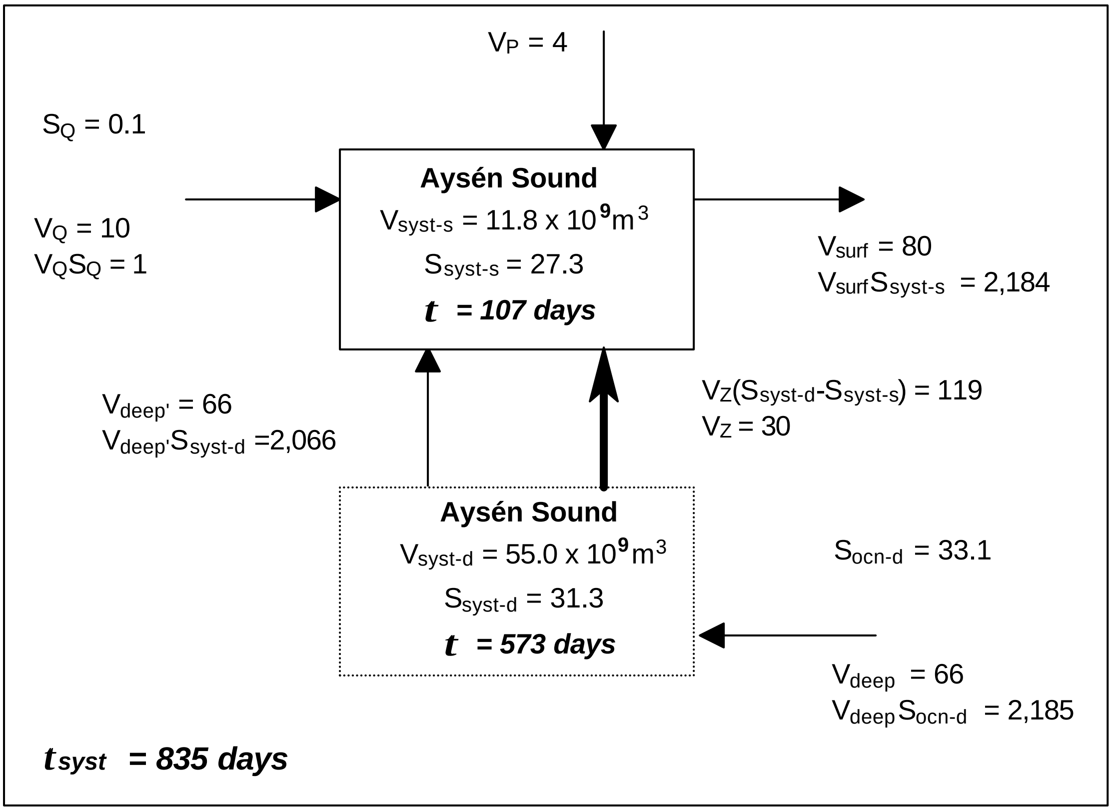

Figure 6.6 Box diagram for water and salt budget in 1-box 2-layer model, for Aysén Sound (October 1998, southern winter, Cimar Fiordo 4-1 cruise). Input and output fluxes (10^6 m^3 d^{-1}; 10^6 psu m^3 d^{-1}) and exchange time are indicated.

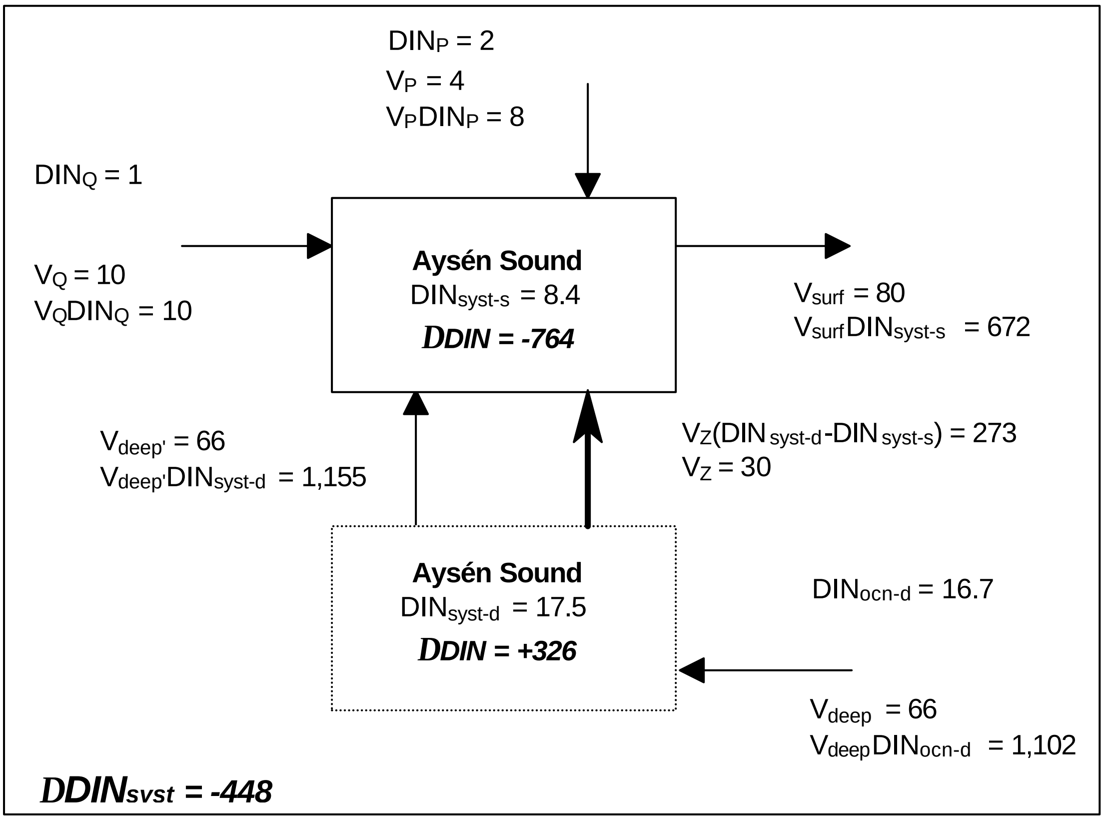

Figure 6.7 Box diagram for dissolved nitrate-nitrite budget in 1-box 2-layer model, for Aysén Sound (October 1998, southern winter, Cimar Fiordo 4-1 cruise). Fluxes in 10^3 mol d^{-1}.

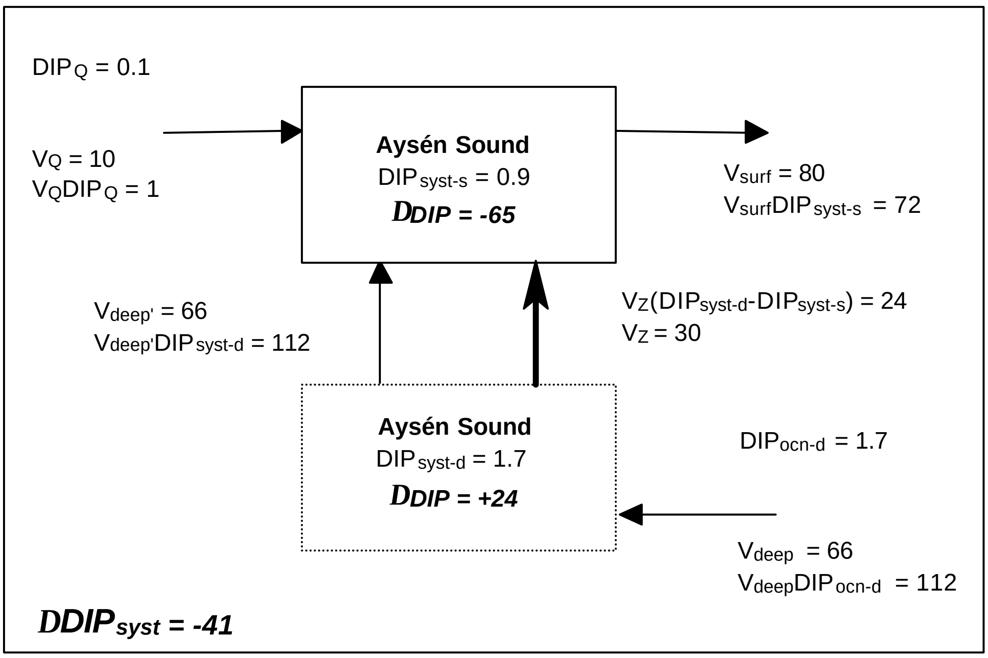

Figure 6.8 Box diagram for dissolved phosphate in 1-box 2-layer model, for Aysén Sound (October 1998, southern winter, Cimar Fiordo 4-1 cruise). Fluxes in 10^3 mol d^{-1}.

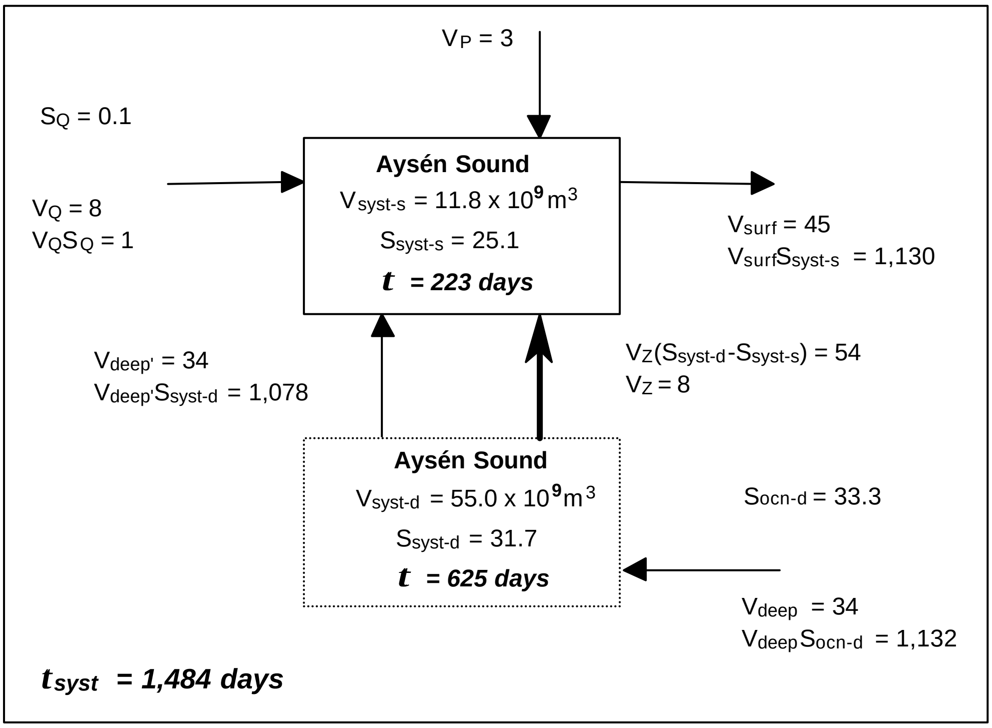

Figure 6.9 Box diagram for water and salt budget in 1-box 2-layer model, for Aysén Sound (March 1999, southern summer, Cimar Fiordo 4-2 cruise)**.** Input and output fluxes (10^6 m^3 d^{-1}; 10^6 psu m^3 d^{-1}) and exchange time are indicated.

7. REFERENCES

ADEMA 1984 Levantamento da flora e caracterização dos bosques de mangue do estado de Sergipe. *Technical report, ADEMA*, Aracaju, 208 pages.

Alcântara, A.V., Rocha, C.E.F. and Santos, M.A. 1979 Caracterização hidrológica e biológica do estuário do Rio Sergipe. *Technical report, ITPS/UFS/CNPq*, Aracaju, 151 pages.

Alves, J.P.H. 1989 Características físico-químicas da água e comportamento dos nutrientes. Projeto integrado para a avaliação da potencialidade do estuário dos rios Piauí-Fundo-Real. *Technical report, NEM/UFS*, Vol. **II**, Aracaju, 74 pages.

Andrade, R.C.B., Souza, M.F.L. and Couto, E.C.G. 1998 Influência de efluentes têxteis e alimentícios sobre o metabolismo e propriedades físicas e químicas do Rio Piauitinga. *Química Nova* **21**(4):424-427.

André, D.L. 1990 Análise dos parâmetros hidroquímicos na ressurgência de Cabo Frio. *MSc. Thesis. Universidade Federal Fluminense, Departamento de Geoquímica, Niterói.*

APHA (eds) 1980 Standard methods for the examination of water and wastewater. 15^{th} Ed., 1134 pages.

Barbiéri, E.B. 1985 Condiçoes climáticas dominantes na porção oreintal da lagoa de Araruama (RJ) e suas implicações na diversidade do teor de salinidade. *Caderno de Ciências da Terra* **59**:3-35.

Blanco, A.C. 1989 Balance de masa de los silicatos en la superficie del Río de la Plata y su área de influencia en el Mar Epicontinental uruguayo. *Tesis para optar a la Licenciatura en Oceanografía Biológica. Facultad de Humanides y Ciencias, Montevideo, Uruguay*, 91 pages.

Borgel, R. 1970-1971 Geomorfología de las regiones australes de Chile. *Revista Geológica de Chile* **21**:35-140.

Brandini, F.P. 1985 Ecological studies in the Bay of Paranaguá I. Horizontal distribution and seasonal dynamics of the phytoplankton. *Bol. Inst. Oceanogr., S. Paulo* **33**:139-147.

Calvete, C. 1997 Distribución de temperatura, salinidad, oxígeno disuelto, pH y nutrientes inorgánicos, en la zona de canales australes de Chile, entre Puerto Montt y Laguna San Rafael en la primavera de 1995. *Tesis de Titulación de Oceanógrafo, Escuela de Ciencias del Mar, Universidad católica de Valparaíso*, 136 pages.

Campos, R.C., Queiroz, M.I., Lacerda, R.E.D. and Okuda, T. 1979 Conteúdo de fósforo total, carbono e nitrogênio na forma orgânica, nos sedimentos da lagoa de Araruama. Instituto de Pesquisas da Marinha, Ministério da Marinha, Brazil **142**, 7 pages.

Carmouze, J-P., D'Elia, C.S., Farias, B., Silva, S. and Azevedo, S. 1993 Ecological changes of a shallow Brazilian lagoon related to distrophic crisis. *Verhandlungen Internationaler Verein der Limnologie* **251**: 23-25.

Carmouze, J-P., D'Elia, C.S., Farias, B., Silva, S. and Azevedo, S. 1993 Ecological changes of a shallow Brazilian lagoon related to distrophic crisis. *Verhandlungen Internationaler Verein der Limnologie* **251**:23-25.

Carneiro, M.E. 1992 Ciclo anual do aporte fluvial e o estoque de matéria biogênica no sistema lagunar de Piratininga. *M.Sc. thesis, Departamento de Geoquímica, Universidade Federal Fluminense, Niterói - RJ, Brazil.*

Carneiro, M.E., Knoppers, B.A., Valentim, L.S., Ramalho, N.M., Duarte, C.A. and Kirstein, K.O. 1990 Distribuição e comportamento dos nutrientes na bacia de drenagem do sistema lagunar Piratininga-Itaipu, Niteroi, RJ. In*: An. II Simp. Ecos. Costa Sul Sudeste Bras., Acad. Cienc. São Paulo* **2**:108-116.

Carvalho, J.L.B, Klein, A.H.F., Schettini, C.A.F. and Jabor, P.M. 1996 Marés Meteorológicas em Santa Catarina: Influência do Vento na Determinação de Parâmetros de Projeto para Obras Costeiras**.** *Proceedings of III Simpósio sobre Oceanografia* - IOUSP, *Resumos* p. 380.

Charpy-Roubaud, C.J., Charpy, L.J. and Maestrini, S.Y. 1982 Fertilité des eaux côtières nord-patagoniques: facteurs limitant la production du phytoplancton et potentialités d´exploitation mytilicole. *Oceanologica Acta* Vol. **5**, N°2.

Clirsen 1986 *Estudio Multitemporal de Manglares.*

Clirsen 1987 *Estudio Multitemporal de Manglares.*

CONDESE 1973 Levantamento dos recursos hídricos de superfície do Estado de Sergipe. *Technical report, CONDESE/Instituto de Tecnologia e Pesquisa de Sergipe*, Aracaju, 765 pages.

Couto, E.C.G. 1989 Produção, decomposição e composição química de *Typha dominguensis* Pers (Typhaceae) na Lagoa de Guarapina, RJ. *M.Sc. Thesis, Departamento de Geoquímica, Niterói, RJ*, 249 pages.
Cunha, L.C. 1996 Dinâmica de nutrientes e biomassa algal no sistema lagunar de Piratininga, Niterói, RJ: efeitos da instalação de uma comporta. *M.Sc. Thesis, Departamento de Geoquímica, Universidade Federal Fluminense, Niterói - RJ, Brazil.*
De Vido, N. and Esteves, J.L. 1978 Estudio preliminar de la variación estacional de parámetros físicos y químicos en el área de Bahía Nueva (Golfo Nuevo, Provincia de Chubut). Centro Nacional Patagónico. *Consejo Nacional de Investigaciones Científicas y Técnicas* Contribución N° **26**.
Dirección meteorológica de Chile 1983-1996 *Anuarios meteorológicos.* Santiago de Chile.
Dohms, V.H. 1983 Zusammensetzung und verteilung des Phytoplanktons in beziehung zu den wassermassen der Subtropischen konvergenzzone im Südwestatlantik. *Dissertation zur Erlangung des Doktorgrades der Matematisch Naturwissenchaftlichen. Fakultat der Christian-Albrechts-Univeristät zu Kiel*, 116 pages.
EMAG (Empresa Municipal de Agua Potable Guayaquil) 1985 Reporte interno. Guayaquil, Ecuador, 10 pages.
Epler, B. and Olsen, S. 1993 *A Profile of Ecuador's Coastal Region.* The University of Rhode Island, Government of Ecuador, U.S. Agency for International Development, 139 pages.
Esteves, J.L., Solís, M., Gil, M.N., Santinelli, N., Sastre, V., González Raies, C., Hoffmeyer, M. y Commendatore, M. 1997 Evaluación de la contaminación urbana de la Bahía Nueva (Provincia del Chubut). Informes Técnicos del Plan de Manejo Integrado de la Zona Costera Patagónica - *Fundación Patagonia Natural (Puerto Madryn, Argentina)* N° **31**: 1-32. [ISSN N° 0328 - 462X].
Esteves, P.C.D. 1992 Variação sazonal da qualidade da água na Laguna de Maricá (RJ). *M.Sc. Thesis, Departamento de Geoquímica, Niterói, RJ*, 161 pages.
FEEMA (Fundação Estadual do estudo do Maio Ambiente) 1987 Qualidade das águas do estado do Rio de Janeiro. *Technical report* **II**, 86 pages.
Fernex, F., Bernat, M., Fernandes, L.V. and Marques, A.N. 1992 Ammonification rates and ^{210}Pb in sediments from a lagoon under a wet tropical climate, Maricá, Rio de Janeiro, Brazil. *Hydrobiologia* **242**: 69-76.
Figueiredo, R.O., Castro, S.S.G. and Ovalle, A.R. 1996 Efeitos do uso da terra no fluxo de nitrogênio inorgânico dissolvido em três bacias de drenagem de um sistema flúvio-lagunar costeiro em região tropical. *Geochim. Brasil* **10** (2): 325-334.
Fillmann, G. 1990 Caracterizacao química das Massas de Agua da Plataforma Continental do Sul do Brasil. *Tese de Mestre em Ciências - Oceanografía Biológcia. FURG, Rio Grande, Brasil*, 44 pages.
Fundación Chile 1996 *Compendio de Acuicultura.*
Gomes, V.R., Freitas, S.S., Andrade, R.C.B. and Souza, M.F.L. 1998 Influence of industrial effluent discharge in dissolved nutrient concentrations in river Piauí, SE (Northern Brazil). *R. Esc. Minas* **51**(3):24-27.
Gómez-Erache, M., Lagomarsino, J.J., Vizziano, D. and Nagy, G.J. 2000 First assessment of phytoplanktonic primary productivity in the outer Río de la Plata: Canal Oriental frontal zone. *Conference on Sustainability of Estuaries and Mangroves: Challenges and Prospects,* poster. Universidade Federal de Penrambuco/ISME/Brasil-International Society for Mangrove Ecosystems-Instituto Internacional de Ecología (IIE). (paper in press).
Gómez-Reyes E., Vázquez Botello A., Carriquiry J. and Buddemeier R. 1997 Laguna de Terminos, Campeche. In: Smith S.V., Ibarra Obando S., Boudreau P.R. and Camacho-Ibar V.F. (eds) Comparison of carbon, nitrogen and phosphorus fluxes in Mexican coastal lagoons. *LOICZ Reports & Studies* N° **10**, LOICZ, Texel, The Netherlands, 84 pages. [ISSN: 1383-4304].
Gordon, D.C. Jr, Boudreau, P.R., Mann, K.H., Ong, J.-E., Silvert, W.L., Smith, S.V., Wattayakorn, G., Wulff, F. and Yanagi, T. 1996 LOICZ Biogeochemical Modelling Guidelines. *LOICZ Reports & Studies* **5**, LOICZ, Texel, The Netherlands**,** 96 pages.
Grasshoff, K., Ehrhardt, M. and Kremling, K. 1983 *Methods of seawater analysis*. Verlag Chemie, Weinheim, 419 pages.

Grimm, G. and Esteves, J.L. 1997 Estudio de la clasificación y cuantificación de los residuos urbanos, industriales, patológicos, cloacales y de mataderos. Tratamiento y distribución. *Bases para la Carta Ambiental de Puerto Madryn,* Volumen **1**, 66 pages.

Harleman, D.R.F. 1979 Estudo de dispersão dos efluentes da fábrica de amônia-uréia da Petrobrás Fertilizantes S.A., no Rio Sergipe. *Technical report, CDTN/Nuclebrás/Petrobrás,* Aracaju, 69 pages.

Holland, H.D. 1978 *The Chemistry of the Atmosphere andOoceans*. John Wiley & Sons, New York, 351 pages.

Hubold, G. 1980 Second report on hydrography and plankton off southern Brazil and Rio de la Plata. Autumn cruise: April-June 1978. *Atlántica, Rio Grande* **4**:23-42.

IBGE. Censo Demográfico 1991 Rio de Janeiro, IBGE v. **20**, 281 pages.

IESAP 1988 Análise Climática. Balanço Hídrico de Sergipe. *Technical report, SEPLAN/IESAP*, Aracaju, 152 pages.

INOCAR 1992 *Atlas Meteorológico del Mar Ecuatoriano 1971-1991.* Instituto Oceanográfico de la Armada del Ecuador, Departamento de Ciencias del Mar, División de Meteorología, 27pages.

IPARDES, 1989 *Zoneamento do Litoral Paranaense*. Instit. Paranaense de Desenvolvimento Econômico e Social. Fund. Édison Vieira. Curitiba, 176 pages.

JICA 1998 The Study on Water Resources Development in the State of Sergipe. *Progress Report (1),* **December 1998**. JICA/SEPLANTEC: Yachiyo Engineering Co. Ltd, 166 pages.

JICA 1998 The study on water resources development in the state of Sergipe. *Progress Report* **1**, JICA/SEPLANTEC/Yachiyo Engineering Co. Ltd, 166 pages.

Kjerfve, B. 1990 *Manual for investigation of hydrological process in mangrove ecossystems*. UNESCO/UNDP Regional Mangrove Project RAS 79/002 and RAS 86/120, Occasional paper. New Delhi, 79 pages.

Kjerfve, B. and Knoppers, B.A. 1991 Tidal choking in a coastal lagoon. *In*: Parker, B.B. (ed.) *Tidal hydrodynamics*, John Wiley and Sons, New York.

Kjerfve, B., Schettini, C.A.F., Knoppers, B., Lessa, G. and Ferreira, H.O. 1996 Hydrology and salt balance in the world's largest hypersaline coastal lagoon: lagoa de Araruama, Brazil. *Estuarine, Coastal and Shelf Science* **42**:701-727.

Knoppers, B., Landim de Souza, W.F., Souza, M.F.L., Rodriguez, E.G., Landim, E.F.C.V. and Viana, A.R. 1997 *In situ* measurements of benthic primary production, respiration and nutrients fluxes in a hypersaline coastal lagoon of SE Brazil. *Revista Brasileira de Oceanografia* **44** (2):155-165.

Knoppers, B.A. and Kjerfve, B. *in press* Coastal lagoons of southeastern Brazil: physical and biogeochemical characteristics. In Perillo, G. (ed.): *Estuaries of South America*, Springer-Verlag, Berlin.

Knoppers, B.A. and Moreira, P.F. 1988 The short term effect of physical process upon nutrients, primary production and sedimentation in Guarapina Lagoon (RJ), Brazil. *Acta Limnologia Brasiliensia* **2**:405-433.

Knoppers, B.A. and Moreira, P.F. 1990 Material em suspensão e a sucessão de fitoplâncton na Lagoa de Guarapina (RJ). *Acta Limnologia Brasiliensia* **3**: 291-317.

Knoppers, B.A., Brandini, F.P. and Thamm, C.A. 1987 Ecological studies in the Bay of Paranaguá. II. some physical and chemical characteristics. *Nerítica* **2**(1):1-36.

Knoppers, B.A., Kjerfve, B. and Carmouze, P.P. 1991 Trophic state and water turnover time in six choked coastal lagoons in Brazil. *Biogeochemistry* **14**: 149-166.

Knoppers, B.A., Kjerfve, B. and Carmouze, P.P. 1991 Trophic state and water turn-over time in six chocked coastal lagoons in Brazil. *Biogeochemistry*, **14**:149-166.

Krepper, C.M. and Rivas, A.L. 1979 Dinámica de las aguas costeras en Golfo Nuevo. Parte I: Medición de corrientes con superficies derivantes. *Acta Oceanographica Argentina* **2 (2):** 83-106.

Kuroshima, K., Bellotto, V., Barreiro, M. and Chevarria, G. 1996 Elaboração de um índice para monitoramento da qualidade de água na enseada de Camboriú-SC. *III Simpósio sobre Oceanografia – IOUSP, Resumos*, p. 304.

Kuroshima, K.N. 1995 Decomposição da matéria orgânica no sedimento da Lagoa da Barra - Maricá - RJ. *M.Sc. Thesis, Departamento de Geoquímica, Niterói, RJ*, 102 pages.

Landim de Souza, W.F., Viana, E.F.C., Souza, M.F.L and Knoppers, B.A. 1995 O impacto antropogênico á lagoa de Araruama - RJ. *V Congresso Brasileiro de Geoquímica*, Niterói, Sociedade Brasileira de Geoquímica. Abstracts, CD-ROM.

Lanfredi, N. 1974 Corrientes superficiales en aguas costeras del Golfo Nuevo. *Informes Científicos Centro Nacional Patagónico* **1**, 37 pages.

López Laborde, J. and Nagy, G.J. 1999 Hydrography and sediment transport characteristics in the Río de la Plata. In: Perillo, G.M.E., Piccolo, M.C. and Pino-Quivira, M. (eds): *Estuaries of South America: Their Geomorphology and Dynamics.* Springer-Verlag, Berlin Heidelberg, 7:133-159.

Machado, E.C. 1989 Desoxigenação e regeneração de nutrientes pelo sedimento na Lagoa de Guarapina, RJ. *M.Sc. Thesis, Departamento de Geoquímica, Niterói, RJ*, 104 pages.

Machado, E.C. and Knoppers, B.A. 1988 Sediment oxygen consumption in an organic-rich subtropical lagoon, Brazil. *The Science of the Total Environment* **75**: 341-349.

Machado, E.C., Daniel, C.B., Brandini, N. and Queiroz, R.L.V. (in press). Temporal and spatial dynamics of nutrients and particulate suspended matter in Paranaguá Bay, PR, Brazil. *Nerítica.*

Mantovanelli, A. 1999 Caracterização da Dinâmica Hídrica e do Material em Suspensão na Baía de Paranaguá e em sua Bacia de Drenagem. *Dissert. Mestrado, Depto Geologia, UFPR,* 149 pages.

Ministerio de obras públicas 1997 *Balance hídrico de Chile*, 24 pages.

MMA, 1996 *Macrodiagnóstico da Zona Costeira Brasileira, na Escala da União*. Ministério do Meio Ambiente, dos Recursos Hídricos e da Amazônia Legal. Coordenação Técnico Científica: MMA, UFRJ, FUJB, LAGET. Brasil: Programa Nacional do Meio Mar. Santos, Brazil.

Moreira, P.F. 1988 Ciclo anual de nutrientes e produção primária na Lagoa de Guarapina, RJ. *M.Sc. Thesis, Departamento de Geoquímica, Niterói, RJ*, 106 pages.

Moreira, P.F. and Knoppers, B.A. 1990 Ciclo anual de produção primária e nutrientes na Lagoa de Guarapina, RJ. *Acta Limnologia Brasiliensia* **3**: 275 – 291.

Morelli, F. 1997 Dinâmica de nutrientes inorgânicos na Enseada de Camboriú, Balneário Camboriú-SC. *Monography of Course Conclusion, Universidade do Vale do Itajaí, Brasil*, 82 pages.

Nagy, G.J, Martínez, C.M., Caffera, R.M., Pedrosa, G., Forbes, E.A., Perdomo, A.C. and López Laborde, J. 1997. Hydroclimatic setting of the Río de la Plata. In P.G. Wells and G.R. Daborn (eds): *The Río de la Plata: An Environmental Overview. An EcoPlata Project Background Report.* Dalhousie University, Halifax, Nova Scotia, Canada, 256 pages.

Nagy, G.J. and Blanco, A.C. 1987 Balance de los silicatos disueltos del Río de la Plata. 2º *Cong. Latinoam. Ciencias del Mar, Res*., p.132.

Nagy, G.J. and Martínez, C.M. 1996 Series temporales geofísicas en la costa Uruguaya. *Country Study Uruguay Project Report.* Comisión Nacional de Cambio Global, Montevideo, Uruguay, 15 pages.

Nagy, G.J., López Laborde, J. and Anastasía, L. 1987 Caracterización de ambientes en el Río de la Plata Exterior (salinidad y turbiedad óptica*). Inv. Oceanológicas* **1**(1):31-56.

Nagy, G.J., Martínez, C.M. and Forbes, E.A. 1996 Physical environment variability at the Montevideo coastal zone I: Historical evolution. *EcoPlata Project Conference*, poster, Montevideo, Uruguay. http://www.idrc.ca/lacro/does/conferencias/eposter2.html.

Pickard, G. 1971 Some physical oceanographic features of inlets of Chile. *J. Fish. Res. Board. Can.* **28**:1077-1106.

Pizarro, M.J., and Orlando, A.M. 1985 Distribución de fósforo*. Serv. Hidrografía Naval, Secr. de Marina, Publ.* **H-625**: 1-57.

PMRC 1989 Programa de Manejo de Recursos Costeros. *Ecuador, Visión Global Del Desarrollo De La Costa*. Guayaquil, 73pages.

Rivas, A.L. 1983 Análisis de la circulación costera en Golfo Nuevo. *Acta Oceanographica Argentina* **8 (2):**49-66.

Rivas, A.L**.** 1985 Balance estacional de calor y sal en Golfo Nuevo, Argentina. *Tesis de Maestro en Ciencias en Oceanología. Ensenada, Baja California, México,* 117 pages.

Salinas, S. and Hormazábal, S. 1997 Circulación en la constricción de Meninea en el canal Moraleda 45º 15'S. *Resultados Crucero Cimar Fiordo 1, Resumenes Ampliados, 8-9 Septiembre 1996.*

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 Workshop on Comparative Studies of Temperate Coast Estuaries*, pages 29-32.

Siegle, E., Klein, A.H.F, Toldo, E.E. and Abreu, J.G. 1998 Morphology and stability of the Camboriú River Inlet, Santa Catarina, Brazil. *Journal of Coastal Research, SI* **26**:94-100.

Siegle, E., Schettini, C.A.F., Klein, A.H.F. and Toldo Jr., E.E. 1999 Hydrodynamics and suspended sediment transport at Camboriu Estuary, Brazil. ASCE. *Coastal Sediments'99*. Vol. **1**:675-687.

Siegle, E., Schettini, C.A.F., Klein, A.H.F. and Toldo, E.E. Jr. 1998a Estuário do Rio Camboriú: Hidrografia e sedimentos em Suspensão. In: *Anais XI Semana Nacional de Oceanografia*, FURG, Rio Grande, RS, pages 463-465.

Sievers, H. y Prado, R. 1994 Contraste de las características oceanográficas del seno Aysén, Chile, entre invierno y verano (Lat. 45º 20`S). *Rev. Biol. Mar, Valparaíso* **29**(2):167-209.

Silva N., Maturana, J., Sepúlveda, J.I. and Ahumada, R. 1998 Materia orgánica, C y N, su distribución y estequiometría, en sedimentos superficiales de la región norte de los fiordos y canales australes de Chile (Crucero CIMAR Fiordo 1). *Ciencia y Tecnología del Mar* **21**: in press.

Silva, N., Calvete, C. y Sievers, H. 1997 Características oceanográficas físicas y químicas de canales australes chilenos entre Puerto Montt y laguna San Rafael (Crucero Cimar Fiordo 1). *Ciencia y Tecnología del Mar* **20**: 23-106.

Silva, N., Salinas, S. y Palma, S. 1990a Informe del crucero de otoño, Proyecto: "Estudios base para la instalación de piscicultura (muestreos estacionales)." *Estud. Doc. Univ. Católica de Valparaíso* Nº10\90, 39 pages.

Silva, N., Salinas, S. y Palma, S. 1990b Informe del crucero de invierno, Proyecto: "Estudios base para la instalación de piscicultura (muestreos estacionales)" Ensenada Acantilada, *Seno Aysén. Estud. Doc. Univ. Católica de Valparaíso* Nº14\90, 41 pages.

Silva, N., Sievers, H. and Prado, R. 1995 Características oceanográficas y una proposición de circulación, para algunos canales australes de Chile entre 41º 20`S y 46º 40`S. *Rev. Biol. Mar, Valparaíso* **30**(2):207-254.

Smith, S.V. 1997 NP budget for the Río de la Plata estuary, Argentina/Uruguay. LOICZ Biogeochemical Modelling Node. http://data.ecology.su.se./MNODE/

Souza, M.F.L. 1999 Metabolismo e balanço de massa do estuário do Rio Piauí, Sergipe. *Ph.D. thesis. Departamento de Geoquímica/Universidade Federal Fluminense, Niterói*, 145 pages.

Souza, M.F.L. and Couto, E.C.G. 1999 Short-term changes and longitudinal distribution of carbon metabolism in the Piauí river estuary (Sergipe, Brazil). *Rev. Bras. Biol.* **59**(2):95-202.

Souza, M.F.L. and Smith, S.V. 1998 Lagoa de Araruama, Brazil. http://data.ecology.su.se/MNODE/South%20America/araruama/Araruamabud.htm

Souza, M.F.L., Kjerfve, B., Knoppers, B., Landim de Souza, W.F. and Damasceno, R.N. (submitted) Biogeochemistry of nutrients in a hypersaline coastal lagoon: lagoa de Araruama, Brazil. *Estuarine and Coastal Shelf Science.*

Souza, W.F.L. 1997 Dinâmica de nutrientes na laguna hipersalina de Araruama, RJ. *MSc. Thesis. Universidade Federal Fluminense, Departamento de Geoquímica, Niterói.*

Stevenson, M. 1981 Seasonal variations in the Gulf of Guayaquil, a tropical estuary. *Boletin Científico y Tecnico.* Instituto Nacional de Pesca, Guayaquil Ecuador **5** (1), 133 pages.

Strickland, J.D.H. and Parsons, T.R. 1972 A Practical Handbook of Seawater Analysis. *Fish. Res. Bd. Canada*, Bulletin **167** (Second Edition).

Tchobanoglous, G. and Schroeder, E.D. 1987 *Water Quality*. Addison-Wesley, Reading, 768 pages.

Tutivén, I. 1993 Calidad de Agua en el Estero Cobina. Parámetros Fisicos-Quimicos del Estero Cobina. *Tesis de Oceanógrafo, Escuela Superior Politécnica del Litoral, Guayaquil, Ecuador* 144 pages.

UFS 1979 *Atlas do estado de Sergipe.* UFS/SEPLAN, Aracaju, 95 pages.

Von Sperling, Marcos (ed.) 1996 *Introdução à Qualidade das Águas e ao Tratamento de Esgotos.* Segrac Ed., Belo Horizonte, 243 pages.

Weber, R., Knoppers, B. and Fillman, R. 1994 Oceanografia química: descrição e importância dos parâmetros químicos utilizados. In *Diagnostico ambiental oceânico e costeiro das regiões sul e sudeste do Brasil.* Petrobras:Rio de Janeiro. c.14-24, vol. **3**:254-363.

World Bank 1995 Managing Environmental Pollution: Issues and options. *Technical Report Nº 14070-AR.* Volume **II**.

APPENDICES

Appendix I Computer Assisted Budget Analysis for Research, Education and Training - LOICZ-CABARET.

L.T. David, S.V. Smith, J. de Leon, C. Villanoy, V.C. Dupra and F. Wulff

The coastal zone is the interface where land and ocean meet. Systems in the coastal zone are dynamic and strongly modulate the interactions between the land and the ocean. Specifically, the transport of nutrients through these systems and the transformation of these nutrients while inside these systems are integral to studies of interactive processes on the global scale. Moreover, the increasing anthropogenic impact on our coastal areas must be taken into consideration when addressing issues of global change.

To address these concerns, Land-Ocean Interactions in the Coastal Zone (LOICZ), a core project of the International Biosphere-Geosphere Programme (IGBP), was established to (1) gain a better understanding of the global cycles of the key nutrient elements carbon, nitrogen, and phosphorus; (2) understand how the coastal zone affects material fluxes through biogeochemical processes; and (3) characterize the relationship of these fluxes with the environmental change, including human intervention (Pernetta and Milliman 1995). In order to achieve these objectives, LOICZ organizes regional workshops to acquaint and educate researchers following the established LOICZ Biogeochemical Modelling Guidelines (Gordon *et al*. 1996, and expanded on the LOICZ Modelling worldwide web page: http://data.ecology.su.se/MNODE/), publishes workshop reports, posts new budgets on the worldwide web and develops tutorials for budget calculations. The latest version of these tutorials is based on Excel spreadsheets and is now currently available through the above web address.

These approaches have made LOICZ successful in compiling approximately 100 site-specific budgets worldwide. It is recognized, however, that there still exists a large unused amount of data around the world that can be further integrated into the existing database and eventually further scaled-up to evaluate coastal changes at global levels. In order to encourage more contributions to this effort, the LOICZ **C**omputer **A**ssisted **B**udget **A**nalysis for **R**esearch, **E**ducation, and **T**raining (LOICZ-CABARET) has been designed to simplify the process of calculations and is under continuing development. A no-frills version of LOICZ-CABARET was presented during the South American Budget Workshop held at Bahia Blanca, Argentina, 10-12 November 1999.

The current version can assist in the calculation of the water, salt and nutrient budgets of single-box or multi-box, single layer systems with up to four seasons. It can also assist in the calculation of the area and volume of a system in its entirety or treated as sub-systems through its on-screen digitization. Finally, to circumvent complications found by previous users in unit conversions, LOICZ-CABARET automatically transforms units into annual rates for easier comparison among systems. Results are displayed in the familiar LOICZ box-diagram format.

In order to make use of this programme, as well as to contribute to the LOICZ endeavour, the following information is essential:

1) A brief accurate description of the system of interest including geographic location, average depth and seasonality.

2) A bitmap file (*.bmp) of the location map in Mercator projection, with either a scale length for calibration or two latitude marks.

3) Data for the salinity of the system and of the adjacent ocean.

4) Freshwater fluxes (precipitation, evaporation, river flow and (if quantitatively significant) groundwater, and/or other sources).

5) Concentrations of dissolved inorganic nitrogen and phosphorus for the system, the adjacent ocean and freshwater sources.

6) As an option, calculations can also be made using concentrations of dissolved organic nitrogen and phosphorus for the system, the adjacent ocean and the freshwater sources.

The program LOICZ-CABARET will run on MS WINDOWS 95 with 16 Mb RAM. All associated files, including the bitmap file, must reside in the same folder as the program. A sample calculation is presented here as a guide:

Consider a single-box, single-layer, four-season system.

>In Windows 95 go to START, RUN, BROWSE.

>Choose CABARET.exe. Enter a filename (up to 8 alphanumeric characters with no extension).

>Go to ALPHA, PERSONAL (Figure I.1). Enter contact details then go to FILE, SAVE.

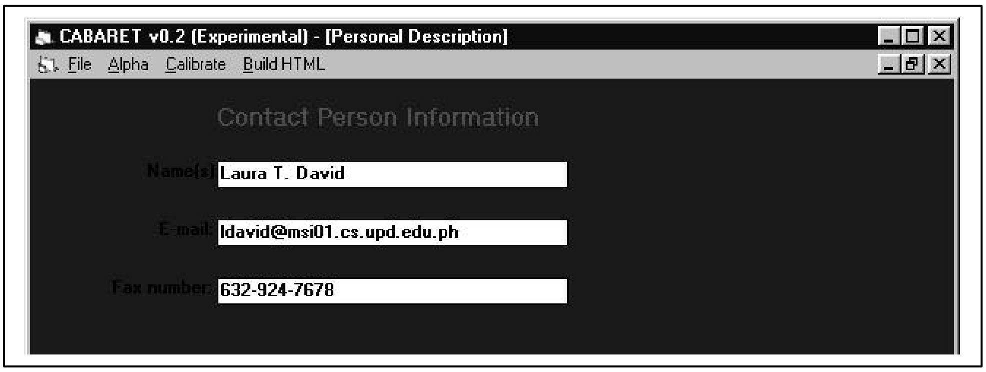

Figure I.1 Window of Alpha-Personal, where the user's contact information is entered.

>Go to ALPHA, DESCRIPTION (Figure I.2). Enter details. Months are entered as numbers (1,2,...,12) and the duration is automatically computed. Latitudes and longitudes should be in decimal degrees. FILE, SAVE.

>Go to CALIBRATE (Figure I.3). Enter length of scale segment in km (Our *.bmp image has a 10 km segment). Double-click inside calibration box. This should open the *.bmp image (Figure I.4). Click on each end of scale length. Then click DONE.

>Still in CALIBRATE, select type of model. Afterwards, calibrate area by double-clicking on the corresponding area box. Digitize boxes on-screen (Figure I.5). Take note, for now it is more practical to draw in respective boxes on the *.bmp image in order to

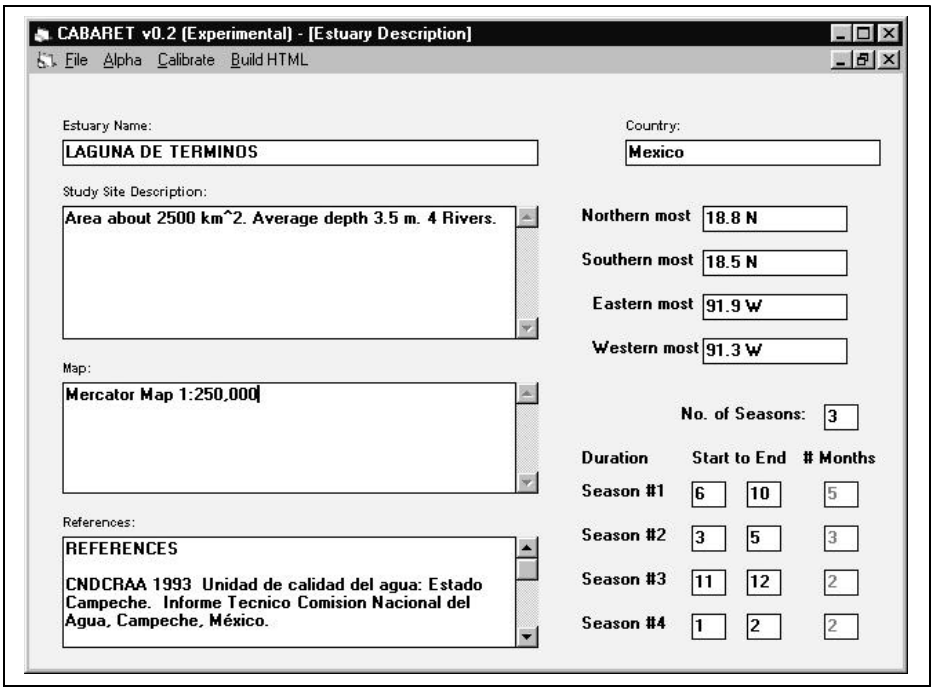

Figure I.2 Window of Alpha-Description (system details are entered here).

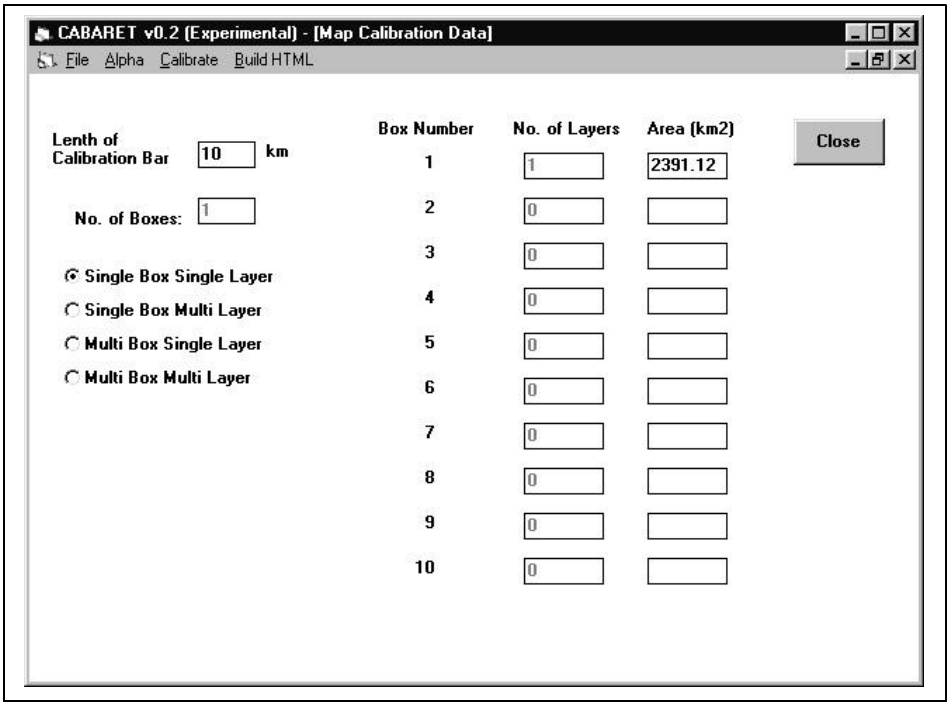

Figure I.3 Window of Calibration. Designate calibration line length, type of system, and - in the improved version - the number of layers per box.

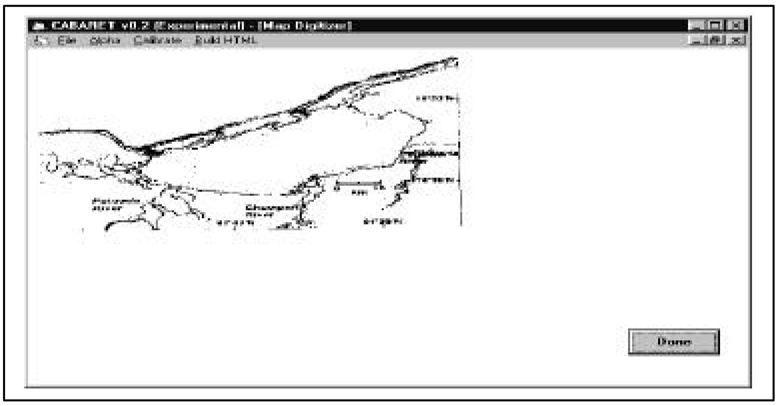

Figure I.4 Window of bitmap image of system (the length scale bar is calibrated).

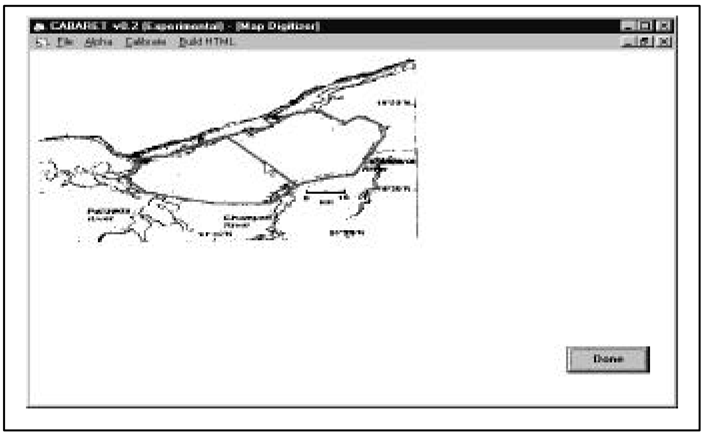

Figure I.5 Window of bitmap image of system (total area of the system or of the areas of each sub-system are calculated from on-screen digitization).

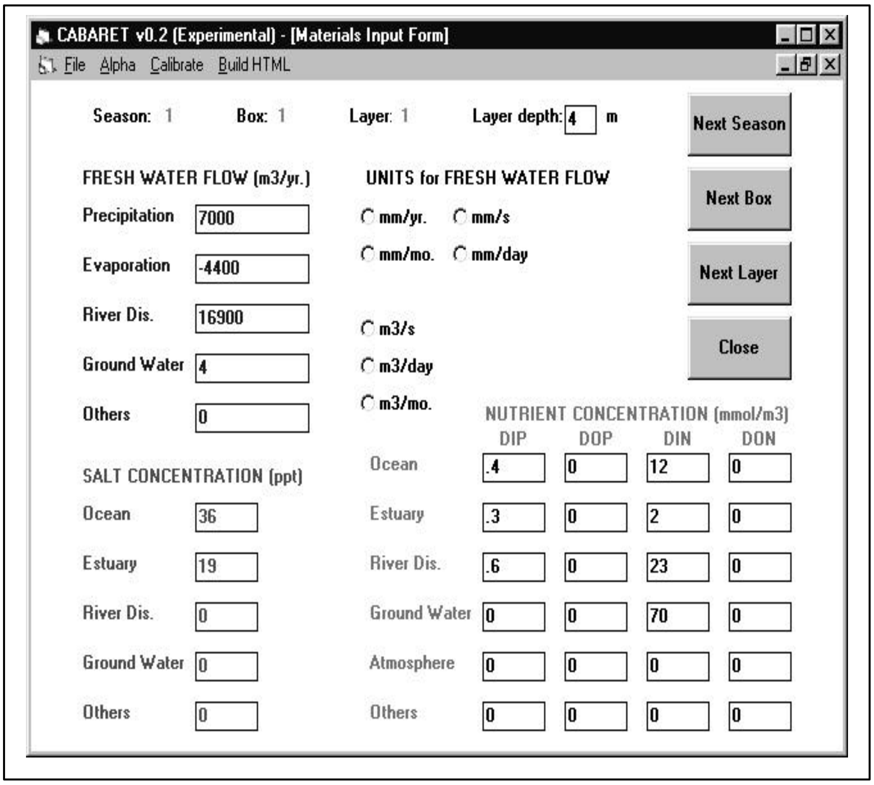

Figure I.6 Window of Alpha-Material (water, salt, and nutrient data are entered here).

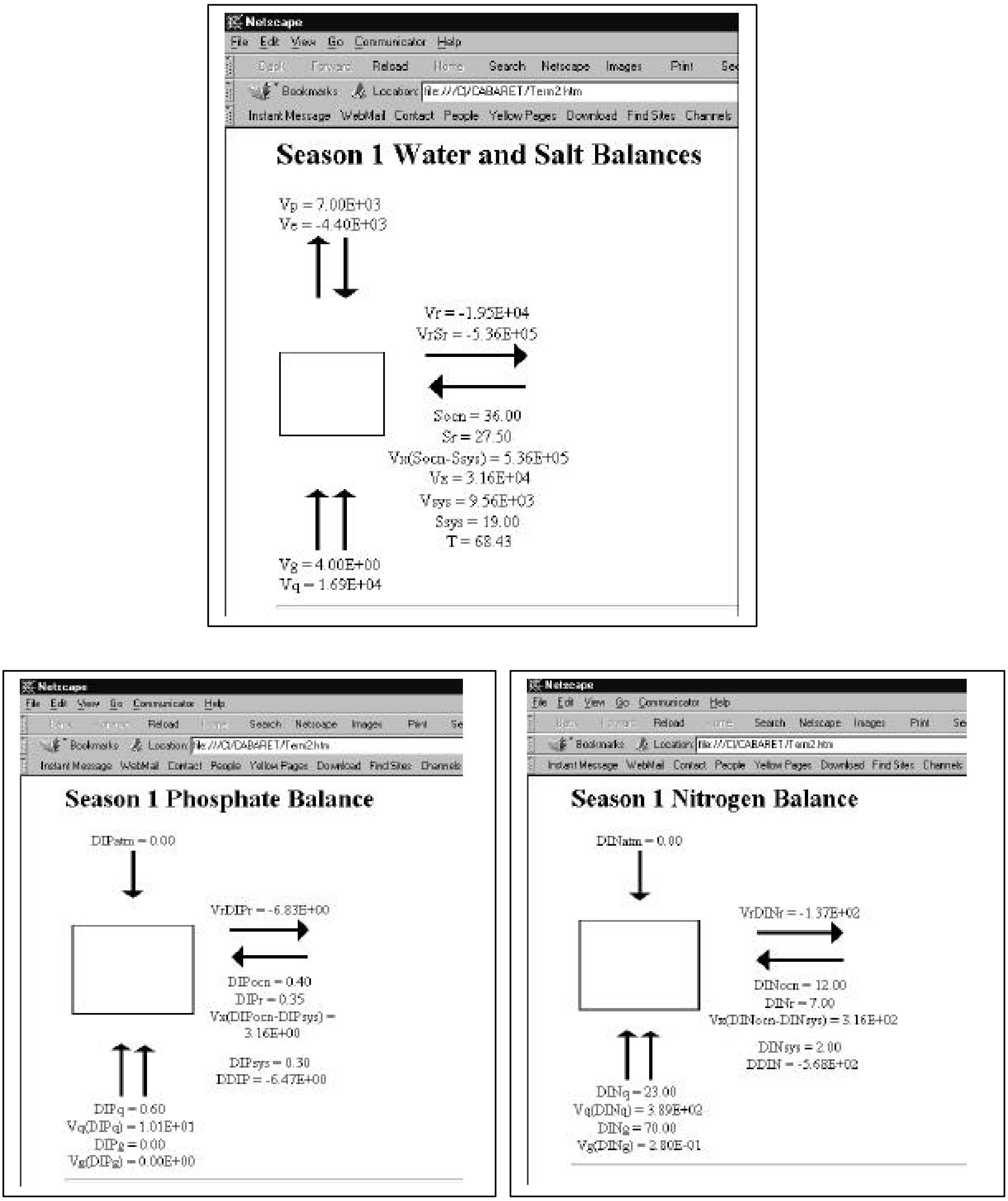

Figure I.7 Sample outputs: (a) water and salt, (b) phosphate, and (c) inorganic nitrogen budgets.

avoid overlaps during on-screen digitization. The lines will close automatically to form polygons. The corresponding areas are automatically computed (Figure I.4). FILE, SAVE.

>Go to ALPHA, MATERIAL (Figure I.6). Fill in the appropriate boxes. For the freshwater flux, if the available data is not in m^3/yr, click on appropriate units first before filling in the corresponding box. Hit ENTER to automatically transform the data to m^3/yr. After filling up the data for each box, layer, and season save inputs in FILE, SAVE.

>Build. If all inputs are appropriate, this should result in answers in box-diagram format (see Figure I.7). Otherwise you will get a warning box. Check your inputs if this happens. Open box-diagram with web browser.

It is hoped that LOICZ-CABARET will not only encourage the users to contribute to the LOICZ endeavour but also to experiment with the forcing functions and the response sensitivity of their systems. Finally, LOICZ-CABARET is also envisioned as a teaching tool in studies of estuaries and coastal lagoons.

An improved version of LOICZ-CABARET, based on the comments and suggestions received during the South American Budget Workshop, is also planned to handle additional types of systems such as complex multi-layer, multi-box, and multi-season systems. The new version should soon be available from the LOICZ Modelling webpage for perusal and evaluation. Visit the LOICZ page periodically for further announcements.

Please contact Dr Laura David (ldavid@msi01.cs.upd.edu.ph) or Professor Stephen V. Smith (svsmith@soest.hawaii.edu) for comments and/or suggestions.

References

Gordon, D.C. Jr, Boudreau, P.R., Mann, K.H., Ong, J.-E., Silvert, W.L., Smith, S.V., Wattayakorn, G., Wulff, F. and Yanagi, T. 1996 LOICZ Biogeochemical Modelling Guidelines. *LOICZ Reports & Studies* **5**, LOICZ, Texel, The Netherlands, 96 pages.

Pernetta, J.C. and Milliman, J.D. (eds.) 1995 Land-Ocean Interactions in the Coastal Zone: Implementation Plan. *IGBP Global Change Report* No. 33, International Geosphere-Biosphere Programme, Stockholm, 215 pages.

Appendix II Typology and Budgets/Budget Sites Information

Robert W. Buddemeier

In order to generalise budget data according to coastline classifications (or typology), summaries and classes of key budget information must be extracted to relate to the global data sets. Time constraints and the need for experimental development of the optimal approaches necessitate emphasis on prompt development of data readily available from the budget workups and extractable from a standard presentation format/database.

This Appendix presents an initial draft outline for the data compilation, defining three classes of variables:

Primary: calculated biogeochemical function indicators and time-scale information.

Descriptive: system description data not derivable from global sets; information needed to transform between absolute and area-normalised primary values.

Comparison: system level data that can be estimated at a coarser scale from global data sets, for comparison and calibration of classification scales.

Table II.1 Primary Budget and Budget Site Variables – Biogeochemistry and Time Constants

Primary Variable	Units	Notes
Residence time	days	<1, 1-10,…; months, year+
Period calculated		Length of time, season
(p – r)	mmoles m^{-2} yr^{-1}	
(nfix – denit)	mmoles m^{-2} yr^{-1}	
Load (N)	mmoles m^{-2} yr^{-1}	
Load (P)	mmoles m^{-2} yr^{-1}	
ΔDIN	mmoles m^{-2} yr^{-1}	
ΔDIP	mmoles m^{-2} yr^{-1}	

Table II.2 Site and budget unique local descriptors and scaling factors

Descriptive Variable	Units	Notes
Primary production	mmoles m^{-2} yr^{-1}	
Primary producer		e.g., phytoplankton (see footnote)
Other significant producer		(see footnote)
Area (marine)	km^2	
Area (catchment basin)	km^2	
Volume	m^3	
Point coordinates	decimal degrees	standard selection criteria; corners
Horizontal boxes in model	number #	maximum number
Vertical layers	number #	maximum number
Salinity	psu	habitat/system determinant
Geology		e.g., karst, carbonate-phosphate
Special "flag" *re*. system		atypical system, special case

Notes to Table II.2.
Primary/secondary producer – Can these be rank-ordered in one or more series according to relevant function or characteristic? (If data are semi-quantitative, clustering may be permitted).
Salinity – Which values are critical; mean, lower extreme?

Desirable information includes second-tier descriptive data about the system and habitats, e.g., biomass, % cover.

Table II.3 Local Budget and Site Variables (that can be estimated from global/regional-scale data)

Comparison Variable	**Units**	**Notes** (Values can be estimated, or at least ranked, from global data sets)
Seawater in	$m^3 yr^{-1}$	
Seawater P in	mmoles $m^{-2} yr^{-1}$	area of marine/estuarine system
Seawater N in	mmoles $m^{-2} yr^{-1}$	area of marine/estuarine system
Groundwater in	$m^3 yr^{-1}$	
Groundwater P in	mmoles $m^{-2} yr^{-1}$	area of marine/estuarine system
Groundwater N in	mmoles $m^{-2} yr^{-1}$	area of marine/estuarine system
Tidal range	m	type e.g., semi-diurnal
Precipitation	mm yr^{-1}	seasonal options
Evaporation (evapotranspiration)	mm yr^{-1}	seasonal options
Water balance	mm yr^{-1}	seasonal options
Seasonality		(see footnote)
“Flashiness” of system		(see footnote)
“Openness” of system		(see footnote)
Human dimensions		(see footnote)

<u>Notes to Table II.3.</u>
Variation/seasonal issues – Probably need to code all budgets for a season. For systems with data on multiple seasons, data categories are needed for each.
Seasonal possibilities/issues include: stratification, monsoonal seasons (wet/dry), human inputs.
Intra-annual variations include temperature, PAR, water balance.
“Flashiness” is stochastic variability in time scales of days; seasonality is systematic variation in time scales of months.
“Openness” relates to energy and residence time, and is very important in terms of habitat classification.
Human dimension – Limited data are available with budgets; perhaps it is possible to rank (even retrospectively) in terms of anthropogenic impacts (from direct influence on inputs and communities measures e.g., land use, urbanisation).
Desirable data include basin/catchment scale, socio-economic drivers for inputs/change (such as urban development, agriculture, tourism, industry, fisheries).

Appendix III Workshop Report

Welcome

Participants (Appendix IV) were welcomed to the Instituto Argentino de Oceanografia in Bahia Blanca, Argentina by Dr Gerardo Perillo. The workshop leader, Prof. Stephen Smith, convened the workshop and, following a round-table introduction of participants, provided an outline of the purpose of the workshop and expected outcomes. The issues of publication and website use were addressed, and the mechanisms and processes for continuing regional training and budgets development were described. The agenda (Appendix V) was introduced and working documents and diskettes of electronic information and tutorial materials were distributed.

Introduction and Background

The LOICZ goals and approaches were presented by Dr Chris Crossland, and a context for the Workshop outcomes was provided against the broad questions of the Programme. The joint support of UNEP and financial assistance of GEF were acknowledged and the global biogeochemical budgets-typology project was outlined. Emphasis was given to the central questions of evaluating material fluxes, the influence of the human dimension on global changes in process and function within the coastal zone, and the use of typological tools to develop a global picture of system responses and change.

Prof Fred Wulff and Mr Dennis Swaney described and illustrated the LOICZ Modelling website, explaining its vital use and function as a publication focus for the global biogeochemistry site evaluations. The dynamic nature of information and the author attribution elements were emphasised. Existing and planned developments for the site, including tutorial materials, were outlined.

A prototype electronic programme for calculation and assessment of site-specific local budgets was provided to participants and demonstrated by Dr Laura David. The CABARET program (Computer Assisted Budget Analysis for Research, Education and Training, see Appendix I) is being developed as part of the UNEP/GEF project, and the current version was discussed and trialled by participants. Further developments are underway to include a rigorous multiple-box, multiple-layer and multiple-season capability with user-friendly tutorial background. The programme was well-received by participants as a valuable tool. Feedback from the workshop participants on ease of use and understandability are to be incorporated.

Prof. Smith outlined the tools that have been developed and information available from previous workshops, making participants aware of support materials which can contribute to budget calculations, including: assessment of errors and sensitivity of the LOICZ approach (LOICZ R&S 12, 1999), estimation of groundwater by silicate proxy (LOICZ R&S 13, 1999), run-off calculations and waste-water analyses (LOICZ R&S 14, in press). These tools also are available on the LOICZ Modelling website.

The Regional Mentor for the Latin American region, Dr Victor Camacho, outlined the role of the regional mentor in continuing training, education and as a focal point for further development of estuarine budgets throughout the region. The position (along with similar appointments in two other regions of the world) has been established under the UNEP GEF project and will further encourage awareness and contribution to the project efforts in describing the global nutrient flux changes. Dr Camacho demonstrated the use of the LOICZ modelling approach using the San Quintin model as a training example, showing its evolution with increased data through time and its application as a tool for addressing socio-economic issues and coastal zone management.

The LOICZ-developed coastal typology (or classification) approach was described by Dr Robert Buddemeier, emphasising application of the approach to the question of scaling and integration to meet regional and global needs for assessment of material flux changes. The approach allows measured proxy information to be applied to unmeasured sites and regions leading to an ability for up-scaling and prediction of systems performance. Key elements were considered, including: standardisation of data sets, proxy development, algorithms for scaling and weighting of parameters, and sensitivity analyses and variables. Some initial products relevant to the region provided an illustration of application of the approach.

Presentation of Biogeochemical Budgets

The contributing budgets brought by the participants were briefly considered, including an overview of the system settings, data availability and quality, approaches being taken to build budgets, and the status and problems in making the model assessments. System sites included:

Brazil
Araruama Lagoon
Camboriu River estuary
Marica-Guarapina Lagoon and estuary
Paranagua Bay
Piaui River estuary
Piratininga-Itaipu coastal lagoons
Sergipe River
Uruguay
Rio de la Plata
Argentina
Bahia Nueva
Ecuador
Guayaquil Gulf
Chile
Aysen Sound

Budgets Development

Break-out groups worked interactively on the development of these site budgets, supplemented with methodological and site/issue-based tutorials and discussions. Estimates for sites and evolution of assessment approaches were made, and budgets refinement emerged from resolution of techniques, application of derivative data and assessment of watershed information.

Plenary and discussion sessions were held throughout the workshop. These enabled review of the status of budgets development and discussion of key issues raised by participants, as well as allied topics, such as: C:N:P ratio and stoichiometry, limits and "reasonable" values in budget assessments, scaling variables and typology (see Appendix II).

Outcomes and Wrap-up

Budgets for all systems were developed to a final or interim draft stage of completion during the workshop; additions to text descriptions and a check on data sources were required by most budgets before final contribution. A schedule for contribution and publication of the printed and CD-ROM report, and posting to the LOICZ website, was agreed.

A number of additional sites was identified for which data is available and which may yield budgets. Participants committed to making other site budgets, subject to data availability, and to encourage others to make further site assessments. A national training workshop was foreshadowed for Colombia, based on discussions with national research leaders during the associated LOICZ Open Science Meeting. The workshop will be run by the Regional Mentor and is expected to involve several additional scientists from Chile. Mr Weber Landim de Sousa is expected to spend 4-6 weeks at the Universidad Autonoma de Baja California, Mexico, working with the Regional Mentor, Dr Camacho, on allied system analyses (subject to organisational agreement), and supported by the LOICZ/UNEP Regional Training Scholarship (South America).

The participants joined with LOICZ in expressing thanks to Dr Gerardo Perillo and his group from the Instituto Argentino de Oceanografia for support and hosting of the workshop in Bahia Blanca. The financial support of the Global Environment Facility was gratefully acknowledged.

Appendix IV List of Participants and Contributing Authors

External Resource Persons

Dr Robert W. Buddemeier
Kansas Geological Survey
University of Kansas
1930 Constant Ave
Lawrence, Kansas 66047-3720
USA
phone +1 785 864 3965
fax +1 785 864 5317
buddrw@kgs.ukans.edu

Dr Paul Boudreau
Department of Fisheries and Oceans
Bedford Institute of Oceanography
PO Box 1006
Dartmouth, Nova Scotia B2Y 4A2,
CANADA
Phone: +1 902 426 7464
Fax: +1 902 426 6695
Boudreaup@mar.dfo-mpo.gc.ca

Dr Victor Camacho-Ibar
Instituto de Investigaciones Oceanológicas
Universidad Autónoma de Baja California
Apartado Postal 453
Ensenada, Baja California 22860
MEXICO
phone +52 61 744601 x 123
fax +52 61 745303
vcamacho@bahia.ens.uabc.mx

Dr Chris J. Crossland
LOICZ International Project Office
Netherlands Institute for Sea Research
PO Box 59
1790 AB Den Burg, Texel
THE NETHERLANDS
phone +31 222 69404
fax +31 222 69430
ccross@nioz.nl

Dr Laura David
Marine Science Institute
University of the Philippines
Roces Ave, Diliman, Quezon City
PHILIPPINES
Tel +63 2 922 3544
Fax +63 2 924 7678
LTdavid@eudoramail.com
Ldavid@msi01.cs.upd.edu.ph

Vilma Dupra
School of Ocean and Earth Science and Technology
University of Hawaii
1000 Pope Road
Honolulu, Hawaii 96822
USA
phone +1 808 956 2354
fax +1 808 956 7112
vdupra@soest.hawaii.edu

Prof. Stephen V. Smith
School of Ocean and Earth Science and Technology
University of Hawaii
1000 Pope Road
Honolulu, Hawaii 96822
USA
phone +1 808 956 8693
fax +1 808 956 7112
svsmith@soest.hawaii.edu

Dennis Swaney
Boyce Thompson Institute for Plant Research
Tower Rd
Cornell University
Ithaca, New York 14853
USA
phone +1 607 524 1216
dennis@system.ecology.su.se

Prof. Fred Wulff
Department of Systems Ecology
University of Stockholm
106 91 Stockholm
SWEDEN
phone +46 8 16 42 50
fax +46 8 15 84 17
fred@system.ecology.su.se

Regional Participants

Argentina

Dr J.L. Esteves
Centro Nacional Patagónico (CONICET)
Bv. Brown 3000 (9120)
Puerto Madryn, Chubut
ARGENTINA
phone +54 2965 451024, 451026
fax +54 2965 451543
esteves@cenpat.edu.ar

Monica Noemi Gil
Centro Nacional Patagónico (CONICET)
Bv. Brown 3000 (9120)
Puerto Madryn, Chubut
ARGENTINA
phone: 54 2965 451024, 451026
fax: 54 2965 451543
noemi@cenpat.edu.ar

Brazil

Erminda C. G. Couto
Universidade Federal de Sergipe
Departamento de Biologia
Campus Universitário
Jardim Rosa Elze
São Cristóvão Sergipe
CEP49100-000
BRAZIL
phone +55 79 212 6693
fax =55 79 212 6660
minda@uol.com.br

Jurandir Pereira Filho
CTT Mar, Universidade do Vale do Itajai
R. Uruguai 458
Itasai -Sc.
88302-202 Itajai SC
BRAZIL
phone +55 47 341 7633
fax +55 47 341 7633
jura@cttmar.univali.rct-sc.br

Marcelo F. Landim de Souza
Departamento de Ciências Exactas e Tecnológicas
Universidade Estadual de Santa Cruz
CEP 45.650-000
BRAZIL
phone +55 73 680 5012
Malandin@hotmail.com
Marland@jacaranda.vesc.com.br
marland@uol.com.br

Weber Friederichs Landim de Souza
Universidade Federal Fluminense
Programa de Geoquímica
Morro do Valonguinho, s/n Centro-Niterói
Rio de Janeiro
CEP 24020-007
BRAZIL
phone +55 21 620 1313
fax +55 21 620 7025
geowfls@vm.uff.br
wlandim@altavista.net

Eunice de Costa Machado
Universidade Federal Do Parana - Centro De Estodos do Mar
Av. Beiramar Sin, Pontal Dosul
Pontal Do Parana
83255000-PR
BRAZIL
phone +55 41 455 1333
fax +55 41 455 1105
e-mail: eunice@aica.cem.ufpr.br

Chile

Nelson Silva S.
Escuela de Ciencias del Mar
Universidad Católica de Valparaíso
Casilla 1020 Valparaíso
CHILE
Phone +56 32 274246
Fax +56 32 274205
nsilva@ucv.cl

Isabel Tutivén Ubilla
Facultad de Ciebcias Naturales y Oceanografía
Universidad de Concepción
Casilla 160-C, Concepción
CHILE
Phone +56 41 204 239/230 929
Fax +56 41 256571
itutiven@udec.cl

Uruguay

Dr Gustavo J. Nagy
PCMYA
Facultad de Ciencias
Igua 4225
Montevideo
URUGUAY
fax +59 82 525 8617
gunab@fcien.edu.uy

Contributing Authors

Brazil

Regina Celia Bastos Andrade
Universidade Federal Fluminense
Programa de Pos-Graduacao em Geoquimica
Niteroi RJ
CEP 24.007-000
BRAZIL
Dr Bastiaan Adriaan Knoppers
Universidade Federal Fluminense
Programa de Pos-Graduacao em Geoquimica
Niteroi RJ
CEP 24.007-000
BRAZIL

Simone Santana de Freitas
Univeridade Federal de Sergipe
Departamento de Engenharia Quimica
Sao Cristovao SE
CEP 49.100-000
BRAZIL

Vivianne Ramos Gomes
Universidade Federal de Sergipe
Departamento de Engenharia Quimica
Sao Cristovao SE
CEP 49.100-000
BRAZIL

R.M. Lopes
Centre for Marine Studies
Universidade Federal do Parana
Av. Beira Mar s/n
Pontal do Parana PR
83255-000
BRAZIL

Dr Eduardo Marone
Centre for Marine Studies
Universidade Federal do Parana
Av. Beira Mar s/n
Pontal do Parana PR
83255-000
BRAZIL

E.T. Silva
Centre for Marine Studies
Universidade Federal do Parana
Av. Beira Mar s/n
Pontal do Parana PR
83255-000
BRAZIL

Carlos Augustos Schettini
Ctt. Mar/Univali
R. Uruguai, 458
Itasai -Sc.
88302-202
BRAZIL

Nicole A.C. Zyngier
Universidade Federal de Sergipe
Departamento de Biologia
Campus Universitário
Jardim Rosa Elze
São Cristóvão Sergipe
CEP49100-000
BRAZIL

Chile

Dafne Guzman Z.
Escuela de Ciencias del Mar
Universidad Católica de Valparaíso
Valparaíso
CHILE

Alexander Valdenegro M.
Escuela de Ciencias del Mar
Universidad Católica de Valparaíso
Valparaíso
CHILE

Philippines

J. de Leon
Marine Science Institute
University of the Philippines
Quezon City
PHILIPPINES

C.Villanoy
Marine Science Institute
University of the Philippines
Quezon City
PHILIPPINES

Appendix V Workshop Agenda

South America Biogeochemical Budgeting Workshop
Bahia Blanca
10-12 November 1999

Wednesday, November 10

0830 Convene Workshop - Stephen Smith
General greeting and introduction to Bahia Blanca - Gerardo Perillo
General housekeeping, introductions - Chris Crossland
Introduction to LOICZ and GEF - Chris Crossland
Introduction to LOICZ web pages - Dennis Swaney
Presentation of CABARET (**C**omputer **A**ssisted **B**iogeochemical **A**nalysis, **R**esearch, **E**ducation and **T**raining) - Laura David

1030 Coffee Break

1100 Introduction to typology: what, why, and how - Bob Buddemeier

Begin brief (<10 minutes each) presentations of budgets: Give general site information (location, size, important characteristics), budget status (not details; we want to know the following: finished? problems? questions?) – participants.

1230 Lunch

1400 Convene for afternoon. Continue presentations, as needed.

1500 Plenary discussion to "see where we are at." Identify data for additional budgets, work on synthesis and typology. Resource persons work with one or more tutorial groups, as needed.

1530 Coffee

1600 Continue, as appropriate, until 1730. The remainder of the schedule for this afternoon and the next two days is largely set by the outcome of the Wednesday afternoon plenary.

Thursday, November 11

0900-1700 Breakout groups or plenary, as required, to refine and present budgets. Coffee and lunch breaks and discussion as above.

Friday, November 12

0900-1230 Break out groups and plenary, to develop preliminary synthesis.
1230-1330 Lunch break and discussion.
1330-1630 Afternoon: Plenary wrap-up discussion (Chair: S. Smith).
1630-1730 Closing announcements (S. Smith & others, as needed).

The session times for each day will be as laid out here, for organizational convenience, unless there proves to be good reason to change them.

We will, as a minimum, have a 15-minute plenary each morning and at the end of each morning and afternoon session to update our status.

All “promised budgets” that were your basis for admission to the workshop should be turned in, on electronic copy, to Vilma Dupra before the end of the day on November 12. Submissions this week should be near-final versions, with no more than very minor repairs that will need to be made and emailed to us no later than December 1.

If, as a result of discussion, persons agree to furnish materials beyond their promised budgets (additional budgets, appendix material, or other writing assignments), these materials will need to be in hand no later than January 1.

TERMS OF REFERENCE
LOICZ/UNEP WORKSHOP ON
ESTUARINE SYSTEMS OF THE SOUTH AMERICAN REGION
Instituto Argentino de Oceanografia
Bahia Blanca, Argentina
10-12 November 1999

Primary Goals:
To work with researchers dealing with estuarine systems of the South American region, in order to extract C,N and P budgetary information from as many systems as feasible from existing data. The South American systems extend around some of the perimeter of two of the Earth's major oceans. Moreover, many of these estuarine systems have relatively detailed data. The workshop provides the opportunity to characterize terrigenous inputs to the estuaries of the region, and outputs from the estuaries - hence the net role of the estuarine zone of this region as a source or sink for carbon, nitrogen, and phosphorus.

This workshop will complement earlier, successful workshops in Ensenada, Mexico, in June 1997, a second Mexican workshop in January 1999 (Merida, Mexico), an Australasian workshop (Canberra, Australia) in October 1998, and a South China Sea region workshop (Manila, the Philippines) in July 1999.

It is hoped that each workshop participant will be able to bring the data for at least two budgets: one from a "pollution hot spot" region within his/her country, and one from a physiographically fairly similar region which is apparently subjected to less pollution. By this strategy, we hope to compile a set of sites that will represent a relatively wide range of human pressures in the South American region.

It is expected that further work on biogeochemical budget approaches will be generated in the region as a result of the products and training components of this workshop.

Anticipated Products:
1. Develop budgets for as many systems as feasible during the workshop.
2. Examine other additional data, brought by the researchers or provided in advance, to scope out how many additional systems can be budgeted over an additional 2 months.
3. Prepare a LOICZ technical report and a CD-ROM summarizing this information.
4. Contribute data/budgets from these sites to 1-2 papers to be published in the refereed scientific literature.
5. It is anticipated that one participant from the workshop will be offered the opportunity to spend up to two months, probably in either Hawaii or Stockholm, getting further experience and developing additional budgets for the region.

Participation:
The number of participants will be limited to fewer than 18, to allow the active involvement of all participants. Nominees include:
- External resource persons (Stephen Smith, Vilma Dupra, Laura David, Chris Crossland);
- Approximately 13 researchers from the region (see below).

Workplan:
Participants will be expected to come prepared to participate in discussions on coastal budgets. Preparation should include reading the LOICZ Biogeochemical Modelling Guidelines (Gordon *et al.* 1996), the Mexican Lagoons Workshop Report (Smith *et al.* 1997), examination of the budgets and tutorials presented on the LOICZ Modelling web page (http://data.ecology.su.se/MNODE/), and arriving with preliminary budgets, electronic maps and 1-3 page write-ups from "their" sites. In order to be included in the workshop report, the budgets should conform as closely as possible to the budgeting protocol laid out in the above documentation.

Further Details:
The primary seasonal pattern of the region is at least one wet season and one dry season per year. Ideally, a budget for each season would be developed. If a system is vertically stratified, then a 2-layer budget is preferred over a single-layer budget. If a system has a strong land-to-sea salinity gradient, then it is preferable to break the system along its length into several boxes.

Minimum data requirements to construct a satisfactory water and salt budget include: salinity of the system and the adjacent ocean, runoff, rainfall, evaporation and (if likely to be important) inputs of other freshwater sources such as groundwater or sewage. Preferably, the salinity and freshwater inflow data are for the same time period (for example, freshwater inflow data for a month or so immediately prior to the period of salinity measurement).

Minimum data requirements for the nutrient budgets are: concentrations of dissolved nutrients (phosphate, nitrate, ammonium and dissolved organic N and P if available) for the system and the adjacent ocean, concentrations of nutrients in in-flowing river water and (if important, in groundwater), some estimate of nutrient (or at least BOD) loading from sewage or other waste discharges. If atmospheric deposition (particularly of N) is likely to be important, an estimate of this is also useful.

Workshop Schedule (All participants are expected to stay for the entire workshop):

Nov 9: Arrival

Nov 10: General introduction to the budgeting procedure and related issues; presentation of preliminary budgets (no details, simply a quick summary to see who has what.)
Breakout groups to revise, refine budgets. This will vary as needed from tutorial, through detailed help, to procedural discussions.

Nov 11: Continue breakouts; afternoon plenary to evaluate progress.

Nov 12: Breakouts/plenary as required to develop synthesis.

Background Documents:

1. 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 Studies* **5**, 96 pages.;
2. Smith, S.V., Ibarra-Obando, S., Boudreau, P.R. and Camacho-Ibar, V.F. 1997 Comparison of Carbon, Nitrogen and Phosphorus Fluxes in Mexican Coastal Lagoons. *LOICZ Reports and Studies* **10**, 84 pages.;
3. LOICZ Modelling web page, for everyone with www access:
(http://data.ecology.su.se/MNODE/)

Appendix VII Glossary of Abbreviations

NH_4	Ammonium
NO_3	Nitrate
DIN	Dissolved inorganic nitrogen
DON	Dissolved organic nitrogen
DIP	Dissolved inorganic phosphorus
DOP	Dissolved organic phosphorus
PTN	Particulate total nitrogen
PTP	Particulate total phosphorus
ON	Organic nitrogen
OP	Organic phosphorus
TN	Total nitrogen
TP	Total phosphorus
DOC	Dissolved organic carbon
DIC	Dissolved inorganic carbon
POC	Particulate organic carbon
OC	Organic carbon
SiO_4	Silicate
nfix	Nitrogen fixation
denit	Denitrification
p	Primary production
r	Respiration
TDN	Total dissolved nitrogen
TDP	Total dissolved phosphorus
CTD	Conductivity Temperature Depth