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.

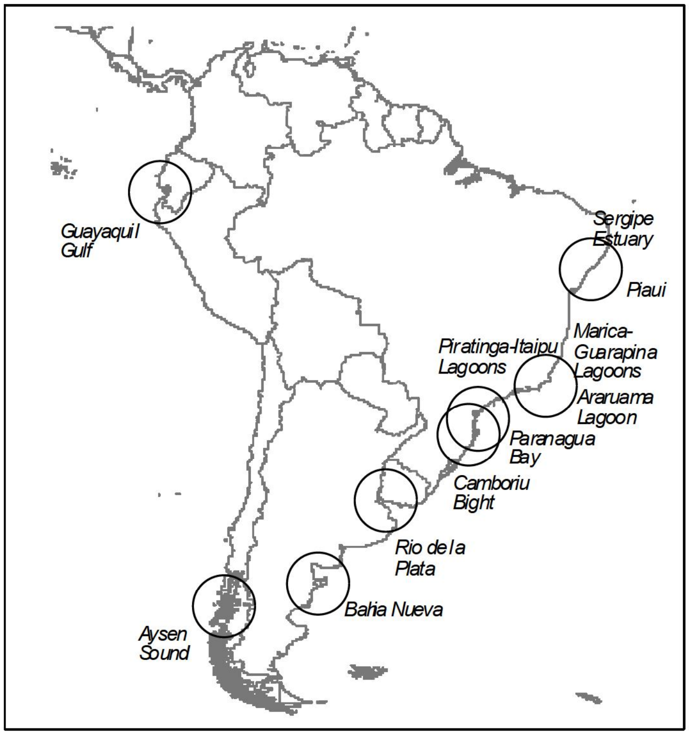

Figure 1.1 Map of budget sites developed by the Workshop.

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**	**ΔDIP**	**ΔDIN**	***(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

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.

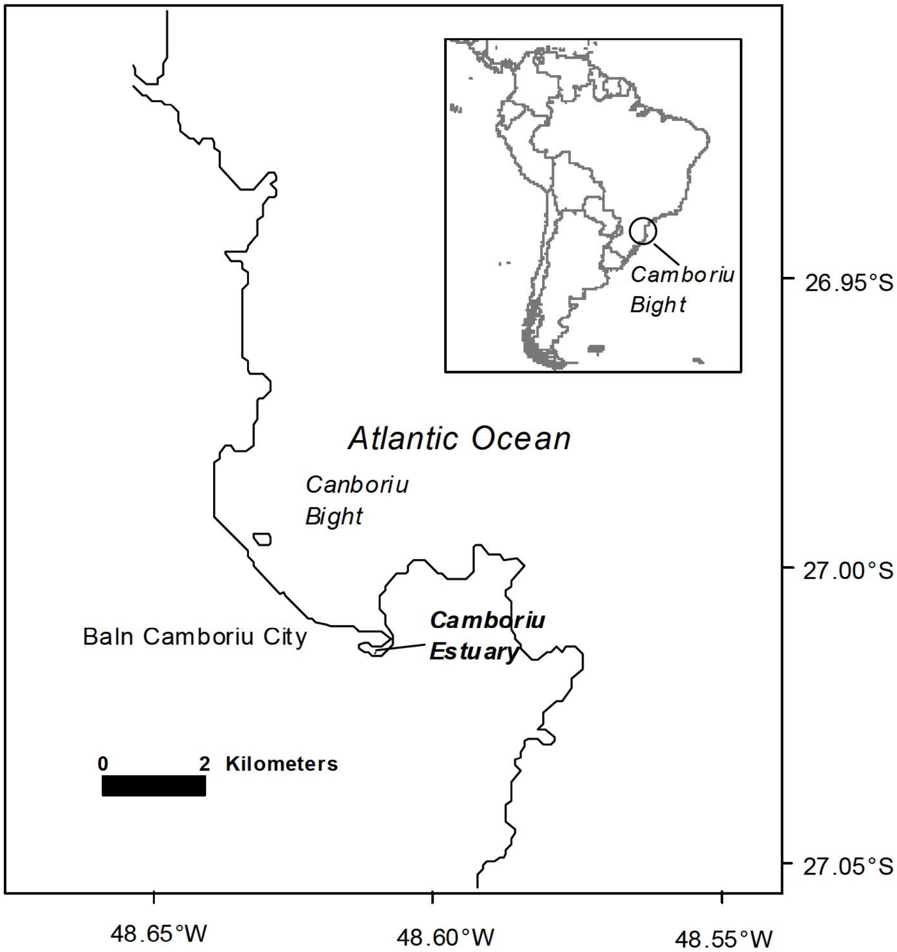

Figure 2.31 Map and location of the Camboriú River Estuary.

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 *ΔDIP*. 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 *ΔDIP* 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 *ΔDIP* 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 *ΔDIP* 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 *ΔDIN* 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 *ΔDIP* nor the *ΔDIN* 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.

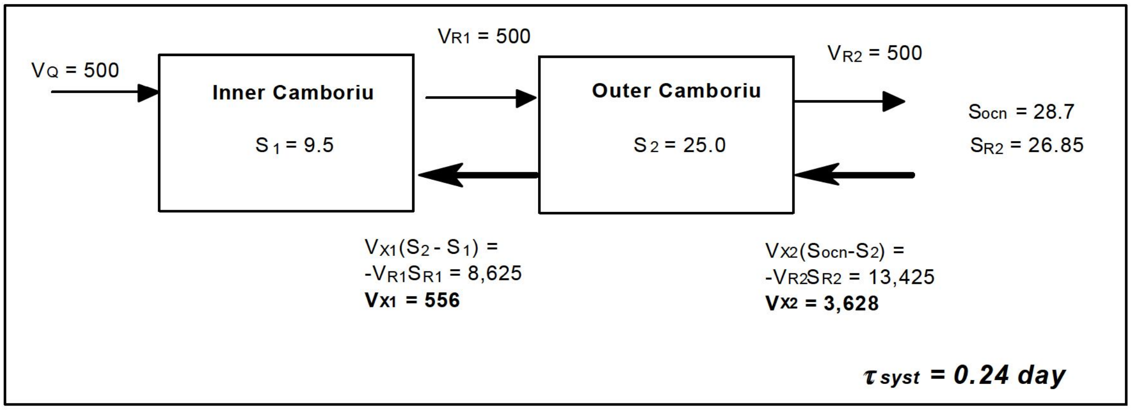

Figure 2.32 Steady-state water and salt budget for Camboriú River estuary, based on a 2-box model. Water fluxes in thousand m^3 day^{-1}; salt fluxes in thousand psu m^3 day^{-1}.

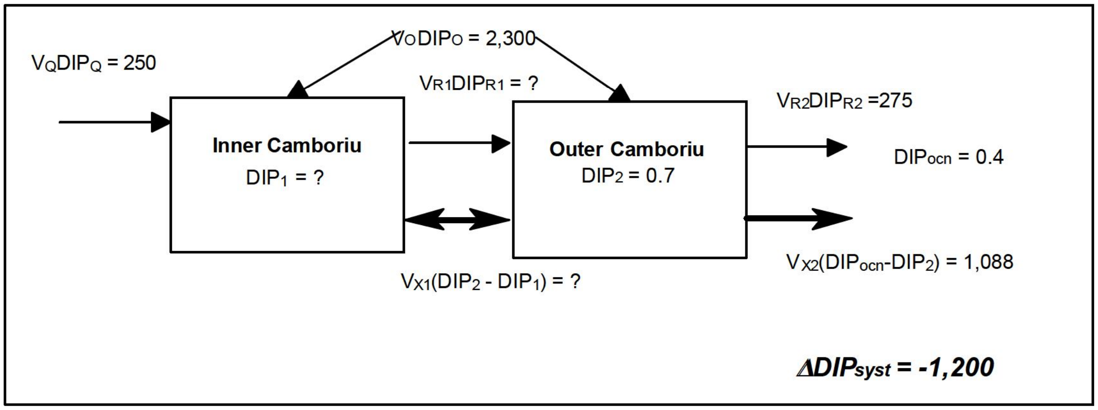

Figure 2.33 Steady-state DIP budget for Camboriú River estuary; two-box model. Arrows indicate directions of hydrographic fluxes. Fluxes in mol day^{-1}.

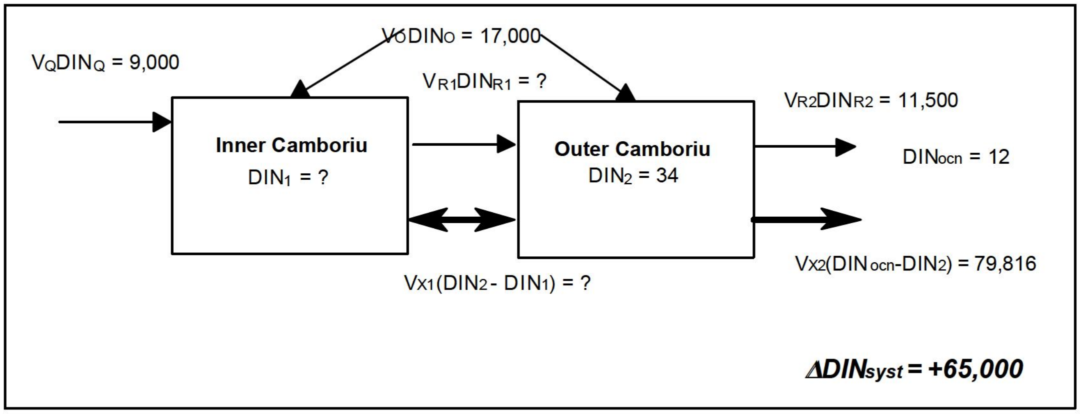

Figure 2.34 Steady-state DIN budget for Camboriú River estuary; two-box model. Arrows indicate directions of hydrographic fluxes. Fluxes in mol day^{-1}.