LAND-OCEAN INTERACTIONS IN THE COASTAL ZONE (LOICZ)

Core Project of the
International Geosphere-Biosphere Programme: A Study of Global Change (IGBP)

Mexico Map showing lagoons

COMPARISON OF CARBON, NITROGEN AND PHOSPHORUS FLUXES IN MEXICAN COASTAL LAGOONS

LOICZ REPORTS & STUDIES No. 10

compiled and edited by S.V. Smith, S. Ibarra-Obando, P.R. Boudreau and V.F. Camacho-Ibar

LOICZ Core Project Office
Netherlands Institute for Sea Research (NIOZ)
P.O. Box 59, 1790 AB Den Burg
Texel, The Netherlands

Compiled & Edited by

Stephen V. Smith
School of Ocean and Earth Science and Technology
Honolulu, Hawaii 96822
United States of America

Silvia Ibarra-Obando
Center for Scientific Research and Higher Education of Ensenada (CICESE)
Ensenada
Baja California, Mexico

Paul R. Boudreau
LOICZ Core Project Office
Texel, The Netherlands

Víctor F. Camacho-Ibar
Institución de Investigaciones Oceanológicas
Universidad Autónoma de Baja California
(IIO-UABC)
Ensenada
Baja California, Mexico

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Cover: Map of the coast of Mexico published in 1616. Note that, by this date, many lagoons and coastal embayments were already being mapped along the Mexican coast.

The LOICZ Reports and Studies Series is published and distributed free of charge to scientists involved in global change research in coastal areas.

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1. OVERVIEW OF WORKSHOP AND BUDGET RESULTS

A central and essential objective of the Land Ocean Interactions in the Coastal Zone (LOICZ) Core Project of the International Geosphere-Biosphere Programme (IGBP) is 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 these fluxes through biogeochemical processes; and,
- characterise the relationship of these fluxes to human intervention (Pernetta and Milliman, 1995).

Coastal lagoons along the 12,000 km shoreline of Mexico are numerous, diverse, and well-studied. According to Contreras (1993) Mexico has about 180 coastal lagoons and other estuarine areas, with about 10,000 km^2 on the Pacific coast and 10,000 km^2 on the Gulf of Mexico. These lagoons are subject to extremely varied degrees and kinds of human pressure due to direct uses and indirect insults. Considerable scientific information exists for many of these systems, and the bibliographic information has been well summarised (see References - Section 4). All of these considerations led to the recognition by several members of the LOICZ Scientific Steering Committee that it would be appropriate to hold a regional workshop in order to develop budgets according to the LOICZ Biogeochemical Modelling Guidelines (Gordon *et al.,* 1996). Such a workshop seemed likely to yield several useful budgets, to generate interest in the region in developing further budgets, and perhaps to provide a formula for generating regional budgets to be compiled into the world-wide database being developed by the LOICZ Biogeochemical Modelling Node. That database is being posted on a World Wide Web Home Page (reachable through http://www.nioz.nl/loicz/modelnod). It was further recognised that an understanding of the functioning of these diverse and well-studied Mexican lagoons might be exported to other regions of the world with less well-studied lagoons.

The workshop was convened at the Center for Scientific Research and Higher Education of Ensenada (CICESE) in Ensenada, Mexico, on June 2-3rd, 1997. Five resource persons (S. Smith, F. Wulff, R. Buddemeier, V. Camacho-Ibar and P. Boudreau) worked with eleven scientists from a number of different institutions in Mexico. They were all familiar with lagoons throughout Mexico and brought with them much of the necessary data and experience required to carry out the work. It was a highly successful meeting that exceeded expectations and has laid a good framework for continued studies within the region.

Dr. S. Ibarra-Obando initiated the technical part of the workshop by presenting an overview of the natural history of Mexican coastal zone. A synopsis of that overview is presented in Appendix I. Drs. Smith and Wulff presented an overview of the LOICZ budgeting procedure and used this workshop as the inaugural presentation of the Biogeochemical Modelling Home Page. Dr. Camacho-Ibar presented a detailed budgetary analysis for Bahía San Quintín, Baja California, in order to guide the workshop participants through the budgeting procedure. This budget represents an extension, based on new (and more reliable) data, from the San Quintín budget originally presented in Gordon *et al*. (1996). Dr. Ibarra-Obando presented a comparison between the system-level budgets of net material flux and addition of components to obtain gross turnover of materials (see Appendix II).

Following these general introductory exercises, the group broke into three working groups, loosely structured around hydrological regimes of the Mexican coastal zone:

Group 1 - *Botello-Ruvalcaba, Boudreau, Camacho-Ibar, Delgadillo-Hinojosa, Lechuga-Devéze and Poumian-Tapia* - derived budgets for five coastal lagoons in the desert region of Baja California, Baja California Sur, Sinaloa and Sonora.

Group 2 - *Contreras-Espinosa, Flores-Verdugo, Ibarra-Obando, de la Lanza-Espino and Wulff* - developed budgets for two coastal lagoon systems (each with several individual lagoons) in the region with high-runoff in Nayarit, and Chiapas states.

Group 3 - *Buddemeier, Carriquiry, Gomez-Reyes and Vázquez-Botello* - developed a budget for Laguna de Terminos, Campeche, a large system lying in the transition region between the high runoff area of the lower part of the Gulf of Mexico coast and the Yucatán Peninsula, which is dominated by low surface runoff but high groundwater flow.

These eight budgets were partially or wholly developed during the workshop. In the subsequent two weeks following, details of the budgets were provided, as well as written descriptions for this report and for eventual posting on the World Wide Web page. Two additional budgets were also provided during that two-week period; two more were added while a draft of this report was under review; all four are included in this final report. Table 1 and Figure 1 summarise the lagoon systems which have been budgeted and the authorship on each.

Table 1. System for which budgets have been developed and reported in this document.

SYSTEM & STATE	**Num.**	**Abbr.**	**AUTHORS**	**Latitude N**	**Longitude W**
Estero de Punta Banda, *Baja California*	1	EPB	M. Poumian-Tapia, V. Camacho-Ibar, S. Ibarra-Obando.	31^{o} 44’	116^{o} 38’
Bahía San Quintín, *Baja California*	2	BSQ	V. Camacho-Ibar, J.D. Carriquiry, S.V. Smith.	30^{o} 27’	115^{o} 58’
Bahía San Luis Gonzaga, *Baja California*	3	SLG	F. Delgadillo-Hinojosa, J. A. Segovia-Zavala.	29^{o} 49’	114^{o} 23’
Estero La Cruz, *Sonora*	4	ELC	M. Botello-Ruvalcaba, E. Valdez-Holguín.	28^{o} 45’	111^{o} 53’
Bahía Concepción, *Baja California Sur*	5	BC	C. Lechuga-Devéze.	26^{o} 39’	111^{o} 30’
Ensenada de La Paz, *Baja California Sur*	6[1]	ELP	C. Lechuga-Devéze.	24^{o} 08’	110^{o} 22’
Bahía de Altata-Ensenada del Pabellón, *Sinaloa*	7[1]	EP	F. Flores-Verdugo, G. de la Lanza-Espino.	24^{o} 25’	107^{o} 38’
Teacapan-Agua Brava-Marismas Nacionales, *Sinaloa and Nayarit*	8	TAB	G. de la Lanza-Espino, F. Flores-Verdugo, F. Wulff.	22^{o} 08’	105^{o} 32’
Carretas-Pereyra, *Chiapas*	9[1]	CPBB	F. Contreras-Espinosa.	15^{o} 27’	93^{o} 10’
Chantuto-Panzacola, *Chiapas*	10	CP	F. Contreras-Espinosa, S. Ibarra-Obando.	15^{o} 13’	92^{o} 50’
Laguna Madre, *Tamaulipas*	11[1]	LM	S. Ibarra-Obando, F. Contreras-Espinosa.	24^{o} 00’	97^{o} 00’
Laguna de Terminos, *Campeche*	12	LT	E. Gomez-Reyes, A. Vázquez-Botello, J.D. Carriquiry, R. Buddemeier.	18^{o} 40’	91^{o} 35’

[1] These budgets were prepared subsequent to the workshop, but in sufficient time to be incorporated into the report.

At the time of printing, budgets are under active development for several additional systems in Mexico as a result of this workshop. These will be added to the modelling world wide web page when they are completed:

- Laguna Carmen-Machona, Tabasco, 18^{o} 16’ N , 93^{o} 50’ W;
- Laguna Mecoacan, Tabasco, 18^{o} 20’ N , 93^{o} 10’ W;
- Laguna Tampamachoco, Veracruz, 20^{o} 18’ N , 97^{o} 30’ W.

Additionally, there may be sufficient information to budget some systems in Mexico over time, in a manner that will document the interactions between material fluxes and human intervention.

The budgetary information for each system is discussed individually and reported in units which are convenient for that system (either as daily or annual rates). Subsequently, key aspects of the data are summarised into Tables 10-13, with all rates presented as “annualised rates.” Nonconservative fluxes are also reported per unit area, for ease of comparison among the systems.

As useful steps towards relating the biogeochemical fluxes to human intervention, many of the descriptions given here include socio-economic overviews. For two of these systems the socio-economic situations are explicitly discussed. Dr. S. Ibarra-Obando and others have laid out a brief overview of socio-economic pressures imposed on the Bahía San Quintín and watershed system (Appendix III). Dr. A Vázquez-Botello has provided a brief synopsis of the competing human uses and pressures acting on Laguna de Terminos, the second largest Mexican lagoon (Appendix IV). It is hoped that these supporting documents, together with the biogeochemical budgets which are the main focus points of this report, will help provide framework for realistic integration between understanding material fluxes, which is the central theme of IGBP and LOICZ, the roles that humans play in modifying those fluxes, and the implications of those modifications with respect to humans.

As another potentially useful product of this workshop, Dr. Gomez-Reyes has agreed to provide a simple and generalised method of dispersion analysis that can be used to estimate water exchange in lagoons and similar systems where there is no salt gradients between the lagoons and adjacent oceanic systems. This analysis will be added as a further link on the Biogeochemical Modelling Home Page.

The full meeting report, participants list and contact information is given in Appendix V and VI.

And a good time was had by all!

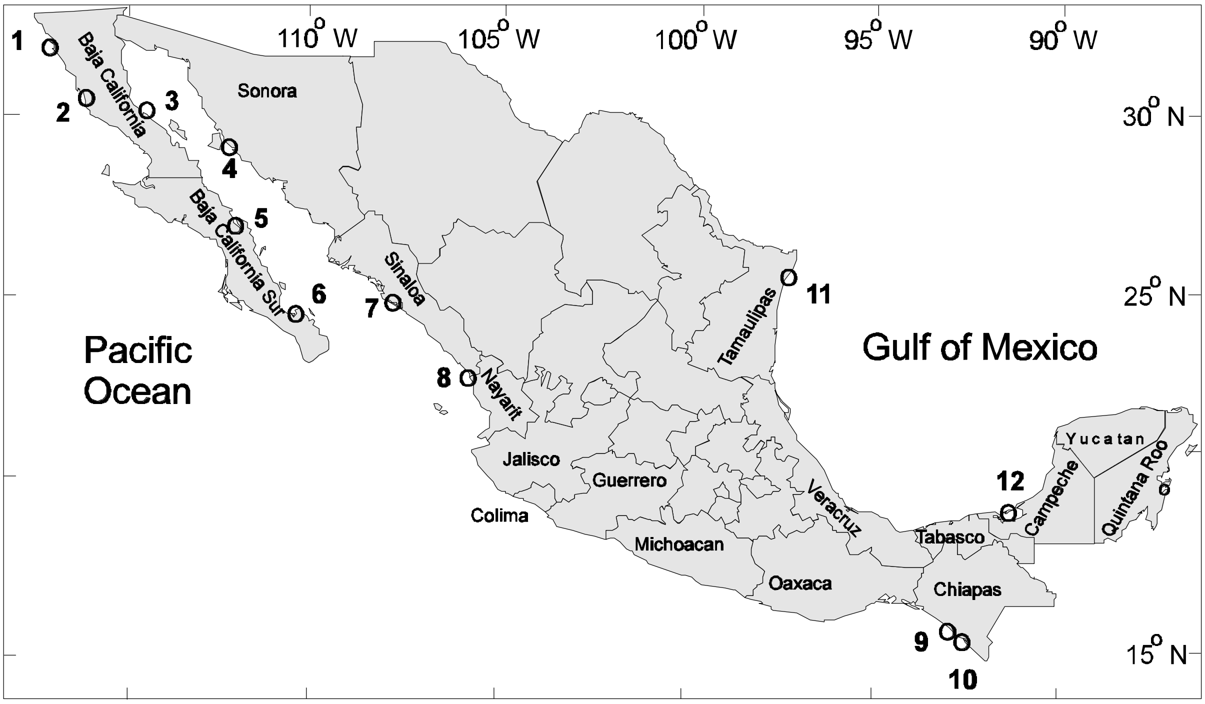


Figure 1. Map of Mexico showing names of coastal states and locations of budgeted lagoonal systems. See Table 1 for system numbers.

2. BUDGETS FOR MEXICAN COASTAL LAGOONS

2.1 Arid Pacific and Gulf of California coasts

2.1.1 Estero de Punta Banda, Baja California

M. Poumian-Tapia, S. Ibarra-Obando and V. F. Camacho-Ibar

Study Area Description

Estero de Punta Banda (Figures 1 and 2, 31^{o} N, $116\ ^{o}$ W) is located 12 km south of Ensenada in the Maneadero valley. The estuary receives drainage from the San Carlos and Las Animas rivers only during rainy winters. Annual average precipitation is about 20 cm per year (Ibarra-Obando and Poumian-Tapia, 1991). Evaporation exceeds precipitation, so the estuary functions as a negative estuary with salinity increasing from the mouth to the inland portion of the estuary (Acosta-Ruiz and Alvarez-Borrego, 1974; Celis-Ceseña and Alvarez-Borrego, 1975). The estuary and surrounding tidal flats cover an area of 12 km^2. The estuary has an “L” shape with a short portion extending inland in a south-easterly direction, and a channel 7.5 km long that opens into Todos Santos Bay. The mean depth of the system is estimated to be about 2 m, and the system volume to be 24×10^6 m^3. The position of the mouth relative to the other sites on the lagoon is considered to be an important factor in the maintenance of the circulation regime (Pritchard *et al*., 1978).

Salt marshes cover an area of about 3 km^2 and represent the main vegetation type, with *Spartina foliosa, Batis maritima* and *Salicornia virginica* as the most characteristic species (Ibarra-Obando and Poumian-Tapia, 1991; 1992). The estuary is used as spawning, nursery and feeding zone for permanent and temporary fish species. A total of 22 species have been reported, some of which are important for the small scale local fisheries (Ibarra-Obando and Escofet, 1987). About 80 bird species have been reported to use the estuary either temporarily or on a permanent basis with diversity increasing from the mouth to the head. The Clapper Rail (*Rallus longirostris*), the Savannah Sparrow (*Passerculus sandwichensis*) and the Brown Pelican (*Pelecanus occidentalis*), which are considered endangered species in the USA, are still found in the marshy habitats of Punta Banda (Ibarra-Obando and Escofet, 1987).

The estuary has been used for industrial and tourist purposes without any management plan. In 1983, an assembling plant for oil-drilling platform supports was installed in the south-west corner of the estuary. Its major impact was the construction of a dike which interrupted water circulation in that portion of the estuary, with the consequent habitat destruction (Ibarra-Obando and Escofet, 1987; Ibarra-Obando and Poumian-Tapia, 1991).The project was never finished due to the international oil prices crisis, otherwise the impact would have been greater. Around 1990, and a few km north of the industrial construction, a tourist development was initiated in an abandoned hotel in the sand bar. The original project included a marina inside the estuary and a gas station, landing field for small aeroplanes, and habitation area in the sand bar. The major impact of this project was dune destruction. The project was not successful because it was conceived for Southern California residents, who were afraid of investing in it because of land-tenure problems. However, house density along the sand bar is high with ownership mainly by United States citizens. Sport fishing is another important activity inside and around the estuary.

The Maneadero valley, adjacent to the bay, is mainly an agricultural and cattle raising area. In a 1995 census by the Baja California State Government, the Maneadero valley permanent population was estimated at about 13,000 inhabitants and 2,000 migrants during the agricultural crop season. Cultivable area is about 40 km^2 utilised for growing vegetables (tomatoes, peas, carrots, corn, potatoes, lettuce, etc.) and fruits (strawberry). Olives are also characteristic of the area. A small number of agro-industries exists in order to industrialise and commercialise these products. As in the San Quintín valley, agriculture relies mainly on ground-water exploitation. The cattle raising business is focused primarily on production of dairy products.

In this case, we calculated a summer budget using data from 1992-1993. Average precipitation is about 200 mm $year^{-1}$ and evaporation is about 1,000 mm $year^{-1}$. For this budget, the dissolved inorganic N and P data for this system are available from Martínez-Inostros (1994). Data for one station located near the estuary mouth were used for ocean data. The ocean salinity data used was estimated from several papers (Millán-Núñez *et al*., 1981; Segovia-Zavala *et al*., 1988; Bustos, personal communication); the system salinity data used was from Céliz-Ceseña (1975).

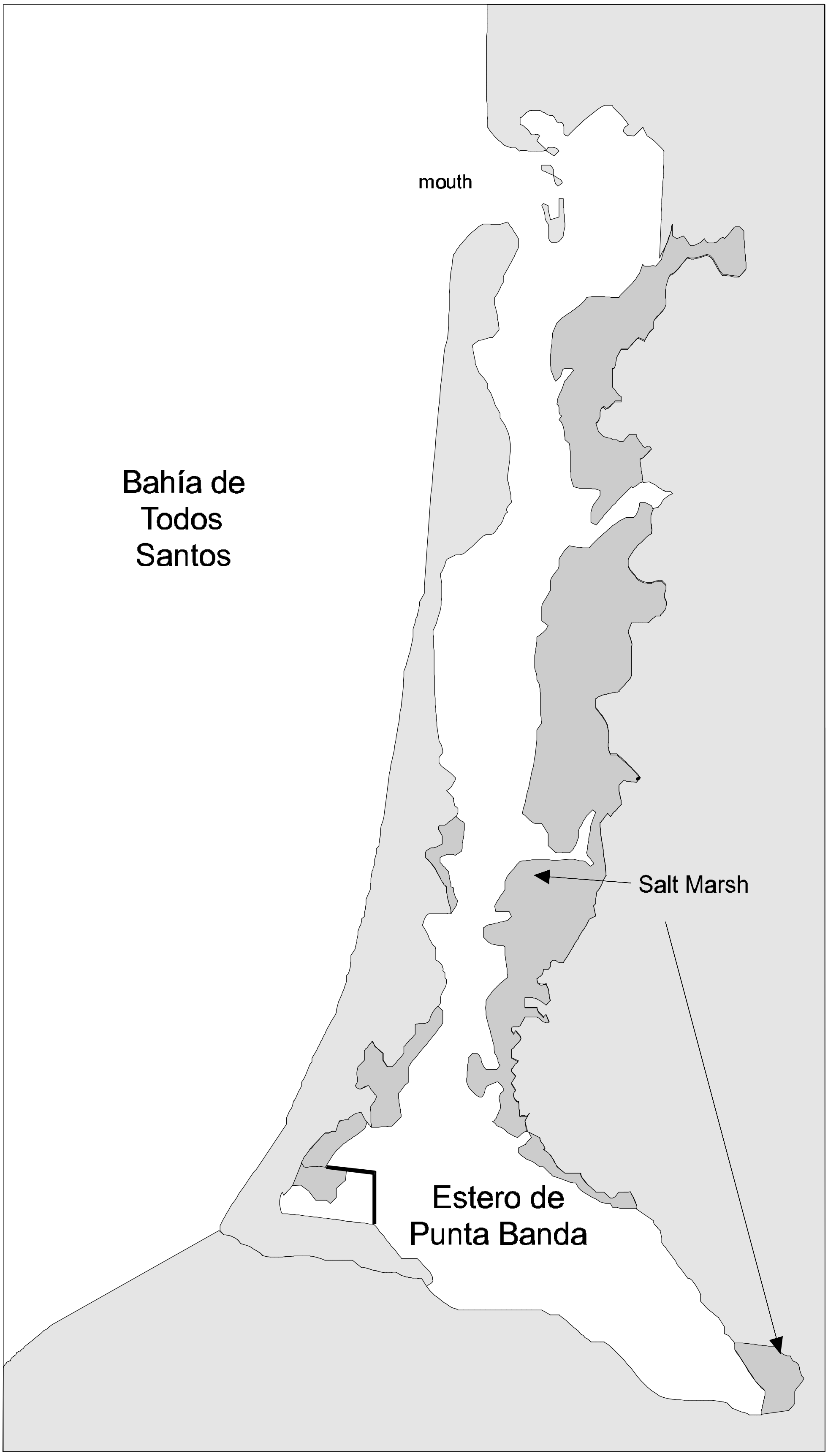


Figure 2. Map of Estero de Punta Banda, Baja California.

Water and Salt Balance

The box model (Figure 3), represent the terms included in the water and salt budget for the summer period. V_P is the volume of precipitation and is zero in summer, V_E is the volume of evaporation calculated from area of water, 12 km², and the evaporation rate of 4 mm day^{-1}. The V_Q (volume of stream runoff), V_G (groundwater inflows), and V_O (other inflows like sewage), are considered to be 0. So the loss of water from the system through evaporation must be balanced to maintain the volume system constant; this is the residual flow (V_R) and is made up by seawater inflow. In this case, V_R is positive, to balance water loss due to V_E.

For the salt balance, the change of salinity with time multiplied by water volume must equal zero. That is, the system is at steady state conditions. Input of salt with the residual flow from sea water is greater than zero (V_RS_R = +1,632 x 10^3 m^3 day^{-1}), so mixing between bay and ocean must balance the salt ($V_X[S_{Ocean}$-$S_{System}]$ = -1,632 x 10^3 m^3 day^{-1}). Mixing (V_X) is the only unknown, so it can be derived:

$$V_x = - V_RS_R / (S_2 - S_1) = -(4.8 \times 10^4 \text{ m}^3 \text{ day}^{-1})(34) / (33.6-34.4) = +2{,}040 \times 10^3 \text{ m}^3 \text{ day}^{-1} \quad (1)$$

Now, the exchange time of water in the system (τ, in days) can be calculated, as the total volume of the system divided by the sum of V_X plus the absolute value, $|V_R|$, the processes responsible for adding and removing water. Thus:

$$t = V_{sys} / (Vx + |V_R|) = 24{,}000 \times 10^3 \text{ m}^3 / (+2{,}040 \times 10^3 + 48 \times 10^3) \text{ m}^3 \text{ day}^{-1}) = 11 \text{ days} \quad (2)$$

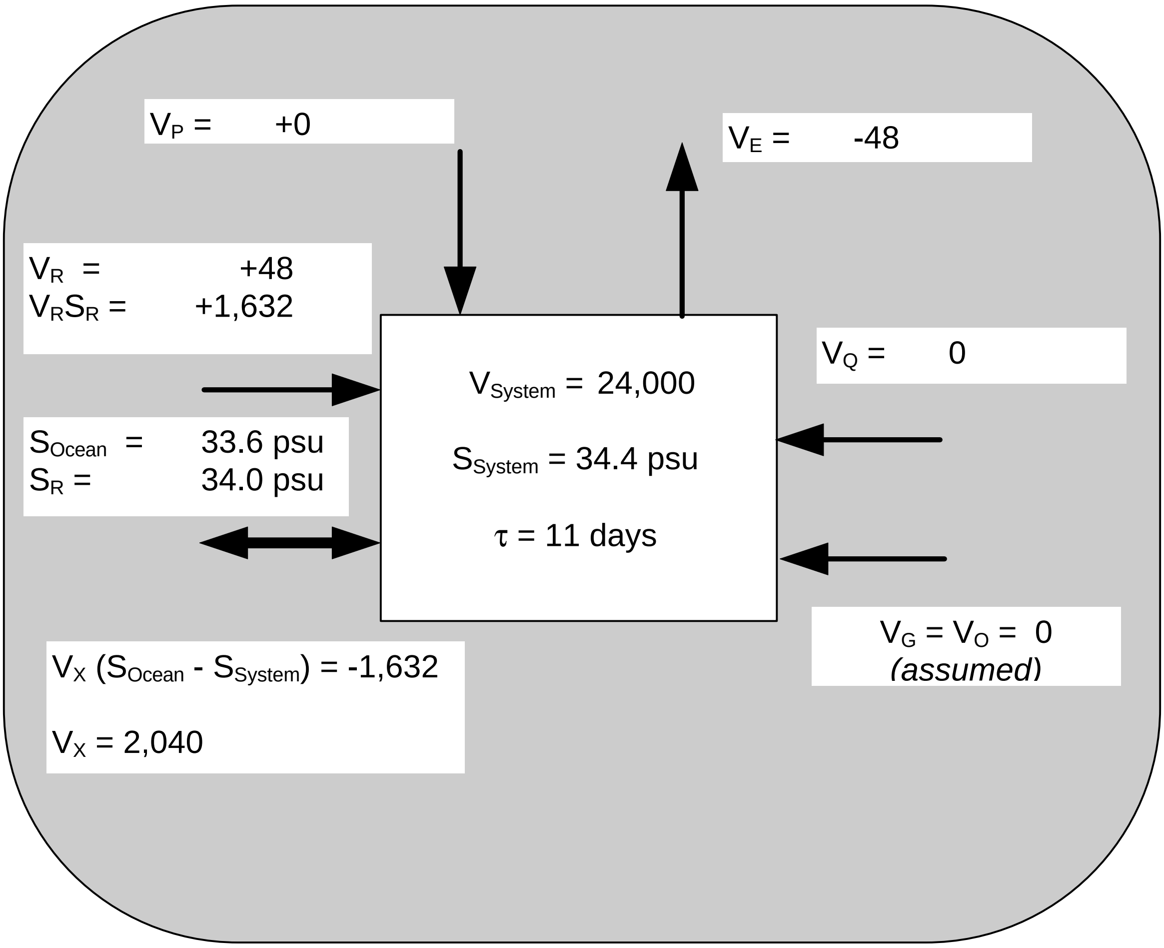


Figure 3. Water and salt budgets for Estero de Punta Banda, during the summer. System volume is in units of 10^3 m^3. Water fluxes in 10^3 m^3 day^{-1}. Salt fluxes in 10^3 psu m^3 day^{-1}.

Budgets of Nonconservative Materials

The balance of any nonconservative material (Y) (also at steady state) is calculated from:

$$dVY/dt = 0 = V_QY_Q + V_PY_P + V_GY_G + V_OY_O + V_EY_E + V_RY_R + V_X(Y_{Ocean} - Y_{System}) + DY \qquad (3)$$

where the various "V" terms involve fluxes of Y with water sources and DY represents the net internal source or sink of element Y. In the summer, the terrigenous sources of Y to Punta Banda Estuary are assumed to be zero. On the sand bar there is tourist development which may discharge some sewage into the bay, but these and other sewage sources are assumed to be relatively small in the net nutrient balances (although neither measured nor indirectly estimated). Therefore, the previous equation is simplified and solved for DY:

$$DY = -V_RY_R - Vx\ (Y_{Ocean}-Y_{System}) \qquad (4)$$

This is the general equation for calculating nonconservative fluxes of dissolved materials, in our case, and the results for DIP and DIN are illustrated in Figure 4.

P Balance

It can be seen that the system is a substantial net source of DIP (*DDIP* = +1,574 mol day^{-1}). The observed flux per unit area is *DDIP* divided by the bay area, or +0.13 mmol m^{-2} day^{-1}. We do not have winter data for comparison, but we suspect by analogy with Bahía San Quintín (Section 2.1.2; a physiographically rather similar system 200 km to the south), that the winter *DDIP* is lower. Nevertheless, we use this as at least an approximation of the annual average flux.

Some of the observed *DDIP* could be associated with direct discharge of sewage into the bay. Let us take 20 mol person^{-1} year^{-1} as an approximation of per capita domestic sewage discharge. The human population required to account for *DDIP* would be about 30,000 people--far greater than the population living immediately adjacent to the bay. We therefore assume that domestic discharge, while possibly of local importance, is a relatively small term in the DIP budget of this system.

N Balance

By contrast with *DDIP*, the system is a much smaller source of DIN (*DDIN* = +365 mol day^{-1}). Again extrapolating over the entire bay area, the rate is equivalent to *DDIN* = +0.03 mmol m^{-2} day^{-1}. As with *DDIP*, we suspect that the summer value is an overestimate of the annual rate but cannot evaluate this point with available data.

Stoichiometric Calculations of Aspects of Net System Metabolism

If the positive value for *DDIP* represents net organic matter oxidation and if the reacting organic matter has an N:P ratio approximating the Redfield Ratio of 16:1 (Redfield, 1934), then the expected *DDIN* value would be 16 x *DDIP*, or 16 x (+1,574) = 25,184 mol day^{-1}. We can estimate the net effect of nitrogen fixation - denitrification (*nfix - denit*) as the difference between the observed and expected values of *DDIN*:

(*nfix - denit)* = + 365 - 25,184 mol day^{-1} = -24,819 mol day^{-1}
(= -2.1 mmol m^{-2} day^{-1}, over the estuary area).

This rate might, again, be different if data were available for an annual average.

The value for *DDIP* can also be used to estimate net ecosystem metabolism (*NEM*¸ or [*p - r*]), again with the assumption that organic oxidation is the primary source of nonconservative DIP flux. This rate is estimated as the C:P ratio of the reacting organic matter (again assuming a Redfield Ratio; C:P = 106:1) multiplied by the negative of *DDIP*:

(*p - r*) = -1,574 x 106 = 166,844 mol day^{-1}
(= -14 mmol m^{-2} day^{-1}, over the estuary area).

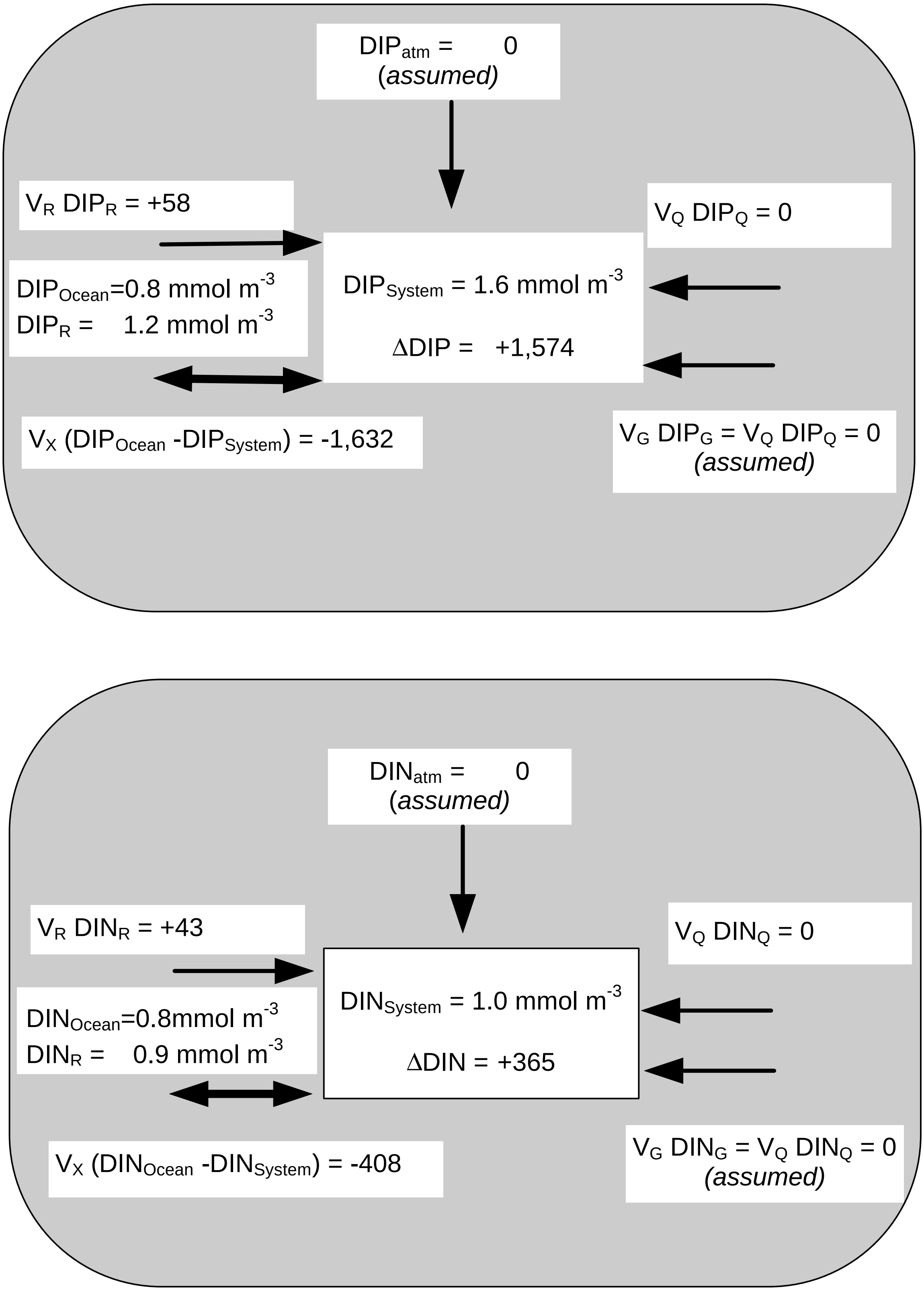


Figure 4. DIP and DIN budgets for Estero de Punta Banda, Baja California. Fluxes in mol day^{-1}.

2.1.2 Bahía San Quintín, Baja California (a teaching example)

V.F. Camacho-Ibar, J.D. Carriquiry and S.V. Smith

This system is described in some detail, because it was used as an introductory, illustrative example of the budgeting procedure. In addition to the detailed description of the budget itself, ancillary information about gross versus net metabolism in the system and the socio-economic status of the watershed are presented in Appendices II and III.

Study Area Description

Bahía San Quintín (Figures 1 and 5) is a hypersaline coastal lagoon located in the western coast of the Baja California Peninsula, Mexico (30^o 27'N, 116^o 00'W). This bay is a net evaporative system and can be considered as a negative estuary since its salinity is always higher than that in the adjacent ocean. Average salinities in the bay range from 34.7 psu in the summer to 33.8 in the winter. In the ocean, salinity ranges from 33.8 psu in the summer to 33.6 in the winter. The bay area is 42 km^2 and has an average depth of ~ 2 m (volume ≈ 90 x 10^6 m^3). The watershed of the bay is ~ 2,000 km^2, of which an important part consists of agricultural lands (see discussion in Appendix III). Total evaporation (V_E) across the area of San Quintín is the vertical water loss multiplied area of the bay; V_E averages 164 x 10^3 m^3 day^{-1} during the summer and 91 x 10^3 m^3 day^{-1} during the winter. Calculated in a similar manner, total rainfall (V_P) averages 4 x 10^3 m^3 day^{-1} during the summer and 67 x 10^3 m^3 day^{-1} during winter. Although the watershed-area: bay-area ratio may be an important factor for land-bay hydrologic interactions, weather is dry and therefore contributions from runoff are not important year around (V_Q=0). The only significant surface flows into the bay occur during extreme rainfall events that last for only 2 to 3 weeks. In contrast, the groundwater contribution (V_G) from the San Simón hydrological basin seems to be more important than runoff, but it also occurs only during the cooler rainy season in winter (February to April). The estimated contribution from V_G to the bay is about 1 x 10^3 m^3 day^{-1} during the winter and decreases to nearly zero during the summer (National Water Commission Office, Ensenada, B.C., Mex.).

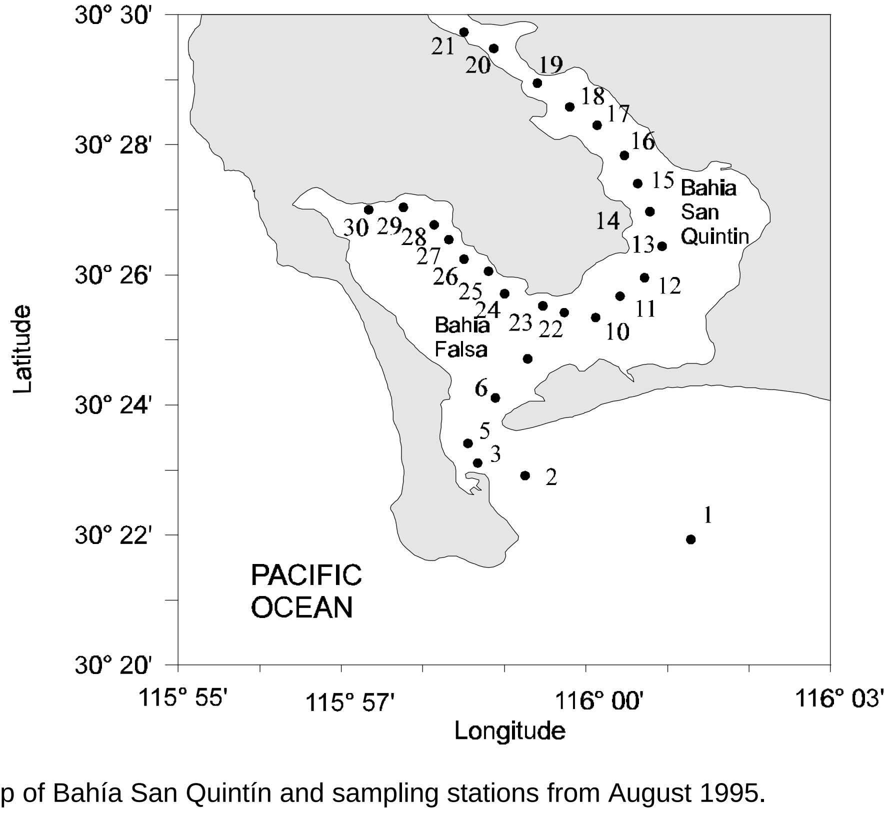


Figure 5. Map of Bahía San Quintín and sampling stations from August 1995.

Seagrasses are important components of the biotic community of Bahía San Quintín. It has been estimated that seagrasses cover up to 25% of the entire bottom of the bay (Ibarra-Obando and Huerta-Tamayo, 1987), but phytoplankton productivity is also important (Alvarez-Borrego *et al.,* 1977). A recent estimate (Appendix II) indicates that phytoplankton contribute about 60% of the gross primary production in the system (~ 38,380 tonnes C year^{-1}). Moreover, plankton detritus seems likely to be the dominant input of organic carbon from outside the system. Therefore, even though we do not have data on the C, N and P composition of particulate material in Bahía San Quintín, for the sake of this exercise we assumed that the C:N:P ratios of particulate material is similar to that of the "Redfield molecule", i.e., molar ratios of 106:16:1 (Redfield, 1934).

It is also important to point out that Bahía San Quintín, particularly the western basin, called Bahía Falsa (Figure 5), is an important site for aquacultural activities for oysters, clams, etc. (Appendix III). The specific characteristics of organic loading and internal cycling may have an important contribution to the overall ecosystem metabolism.

Sampling and Analyses

Surficial and near bottom water samples were collected at 30 stations in Bahía San Quintín (Figure 5) during August 1995, February 1996 and August 1996. Samples were filtered in the field through 0.45 µm glass fiber filters and stored frozen until analysis. Dissolved inorganic nutrient (NO_3^- + NO^-_2; NH_4^+; HPO_4^{2-} and SiO_2) determinations were based on standard analytical procedures. Groundwater nutrient concentrations in Table 2 represent an average of the water composition of 23 wells from the San Simón Valley that were sampled during June 1995. Summer and winter evaporation and rainfall data represent the daily average for the months of July and February of the last 10 years.

Table 2. Bahía San Quintín, freshwater inputs and composition.

	V (1000 m^3 day^{-1})	**NO_3^- + NO^-_2 (1) (mmol m^{-3})**	**DIP (mmol m^{-3})**
Surface runoff (V_Q)	0 (*assumed*)	-	-
Groundwater (V_G) (summer)	0 (*assumed*)	-	-
Groundwater (V_G) (winter)	1	31	1.4
Precipitation (V_P) (mean summer)	4	0 (*assumed*)	0 (*assumed*)
Precipitation (V_P) (mean winter)	67	0 (*assumed*)	0 (*assumed*)
Evaporation (V_E)(2) (mean summer)	-164	0 (*assumed*)	0 (*assumed*)
Evaporation (V_E) (2) (mean winter)	-91	0 (*assumed*)	0 (*assumed*)
Outfalls (V_O)	0	0	0

(1) NH_4^+ was below the detection limits

(2) Notice the minus sign for V_E, as this flux represents an output from the system.

Water and Salt Budgets

From data in Table 2 we can calculate the water balance for each season from equation (5) (from Gordon *et al*., 1996):

$$dV_1/dt = V_Q + V_P + V_G + V_O + V_E + V_R \tag{5}$$

assuming steady state, i.e., $dV_1/dt = 0$, then the residual volume (V_R) is estimated

$$V_R = -V_Q - V_P - V_G - V_O - V_E \tag{6}$$

Substituting terms in equation (6) with data in Table 2 we obtain a V_R of

$V_R = -(0) - (4) - (0) - (0) - (-164) =$ **$+160 \times 10^3$ m^3 day^{-1}**

for summer (1995 and 1996) and,

$V_R = -(0) - (67) - (1) - (0) - (-91) =$ **$+23 \times 10^3$ m^3 day^{-1}**
for winter.

Figure 6 shows the water and salt budget for the summer period.

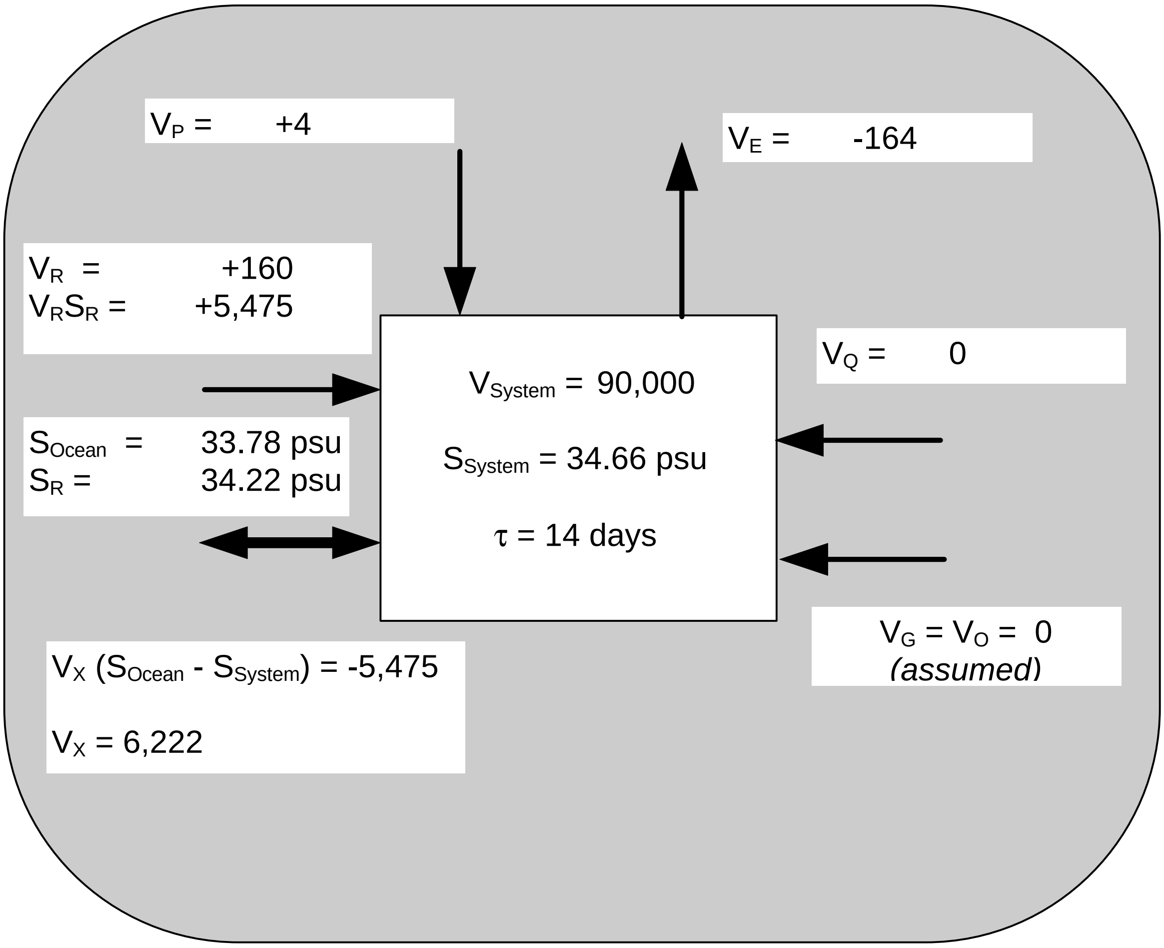


Figure 6. Water and salt budgets for Bahía San Quintín, August 1995. System volume is in units of 10^3 m^3 . Water fluxes in 10^3 m^3 day^{-1}. Salt fluxes in 10^3 psu m^3 day^{-1}.

Table 3 shows the chemical composition of Bahía San Quintín and the neighbouring ocean water. The seawater end-member represents an average of the composition of surface and near bottom samples collected at stations 1-5 (n=8; see Figure 5). The bay water concentration represents an average of the samples collected within the bay (stations 6-30, n=43). All the bay samples had salinities above 34.0 psu during the August 1995 campaign and all the marine samples, but one, had salinities below this value. Figure 6 illustrates the combined water and salt budgets for August 1995.

Table 3. Chemical composition of Bahía San Quintín water samples collected in August 1995. Standard deviations are shown in parenthesis.

	Salinity (psu)	**DIP (mmol m^{-3})**	**NO_3^- + NO_2^- (mmol m^{-3})**	**NH_4^+ (mmol m^{-3})**	**DIN (mmol m^{-3})**
Ocean	33.78 (0.20)	0.80 (0.35)	0.27 (0.14)	1.59 (2.60)	1.87 (2.61)
Bay	34.66 (0.46)	1.95 (0.39)	0.50 (0.50)	0.48 (0.48)	0.99 (0.80)

The salt balance is calculated from equation (7):

$$dV_1S_1/dt = V_QS_Q + V_PS_P + V_GS_G + V_OS_O + V_ES_E + V_RS_R + V_XS_2 - V_xS_1 \quad (7),$$

where V_X represents the mixing or exchange volume between the ocean and Bahía San Quintín, S_R (34.22 psu) represents the salinity of the residual flow, which is an average of the salinities of the ocean (S_2) and the bay (S_1). As the salinity of all of freshwater terms can be assumed as 0, then equation (7) can be simplified to:

$$dV_1S_1/dt = + V_RS_R + V_XS_2 - V_xS_1 = + V_RS_R + V_X(S_2 - S_1) \quad (8)$$

Assuming that S_1 remains constant through time (i.e. assuming steady state)

$$0 = + V_RS_R + V_X(S_2 - S_1) \quad (9)$$

we calculate the mixing volume (V_X) from

$$V_X = - V_RS_R / (S_2 - S_1) \quad (10)$$

substituting terms in equation (10) with salinity data in Table 3:

V_X = -[(160 x 10^3)(34.22)]/[33.78-34.66] = -(5,475 x 10^3)/ (-0.88) = **6,222 x 10^3 m^3 day^{-1}**

The exchange time (τ) of water in Bahía San Quintín for August 1995 can be calculated from equation (11), where $|V_R|$ is the absolute value of V_R:

$$\tau = V_{syst} / (V_X + |V_R|) \quad (11)$$

where V_{sys} is the total volume of the system (90 x 10^6 m^3).

τ = (90 x 10^6 m^3)/ (6,222 x 10^3 + 160 x 10^3) = **14 days**

The mixing volumes and exchange times for the February 1996 and August 1996 campaigns were:

February 1996: V_X = 3,230 x 10^3 m^3 day^{-1} and τ = 28 days
August 1996: V_X = 5,536 x 10^3 m^3 day^{-1} and τ = 16 days

Budgets of Nonconservative Materials

The balance of nonconservative materials is calculated from equation (12):

$$dV_1Y_1/dt = V_QY_Q + V_PY_P + V_GY_G + V_OY_O + V_EY_E + V_RY_R + V_XY_2 - V_xY_1 + \Delta Y \qquad (12)$$

where ΔY represents the net internal source or sink, that is, nonconservative flux, of element Y.

As groundwater is the only potentially important terrigenous source of Y in Bahía San Quintín (Table 2), equation (12) can be reduced to:

$$dV_1Y_1/dt = + V_GY_G + V_RY_R + V_X(Y_2 - Y_1) + \Delta Y \qquad (13)$$

Again assuming steady state, the general equation for calculating nonconservative fluxes of dissolved materials (without gaseous phase) is:

$$\Delta Y = - V_GY_G - V_RY_R - V_X(Y_2 - Y_1) \qquad (14)$$

P Balance

The nonconservative flux of P, ΔP, in Bahía San Quintín for the August 1995 campaign is calculated from data in Tables 2 and 3 and illustrated in Figure 7:

ΔP =-(0) - [(160 x 10^3)(1.38)] - [(6,222 x 10^3)(0.80-1.95)] = 6,934 x 10^3 mmol day^{-1} =**+6,934 mol day^{-1}**

In order to establish comparisons with other systems, ΔP can be reported as a rate by normalising by the area of the system (42 x 10^6 m^2), thus,

ΔP = +0.17 mmol m^{-2} day^{-1}

ΔP values for the other campaigns were:

February 1996: +586 mol day^{-1} (+0.01 mmol m^{-2} day^{-1})
August 1996: +7,767 mol day^{-1} (+0.19 mmol m^{-2} day^{-1})

N Balance

Separate budgets may be calculated for the different nitrogen species analysed in this study (NO_3^- + NO_2^- and NH_4^+), however, we only show here the budget for the total dissolved inorganic nitrogen (DIN) which is needed for looking at the stoichiometric linkages among nonconservative budgets and for the estimation of N metabolism in the system.

The nonconservative flux of N, ΔN, in Bahía San Quintín for the August 1995 campaign is calculated from data in Tables 2 and 3 and Figure 6, and illustrated in Figure 7:

ΔN =-(0) - [(160 x 10^3)(1.43)] - [(6,222 x 10^3)(1.87-0.99)] = -5,704 x 10^3 mmol day^{-1}= **-5,704 mol day^{-1}**

The ΔN normalised by the area of the system was,

ΔN = -0.14 mmol m^{-2} day^{-1}

ΔN values for the other campaigns were:

February 1996: -21,906 mol day^{-1} (-0.52 mmol m^{-2} day^{-1})
August 1996: +12,623 mol day^{-1} (+0.30 mmol m^{-2} day^{-1})

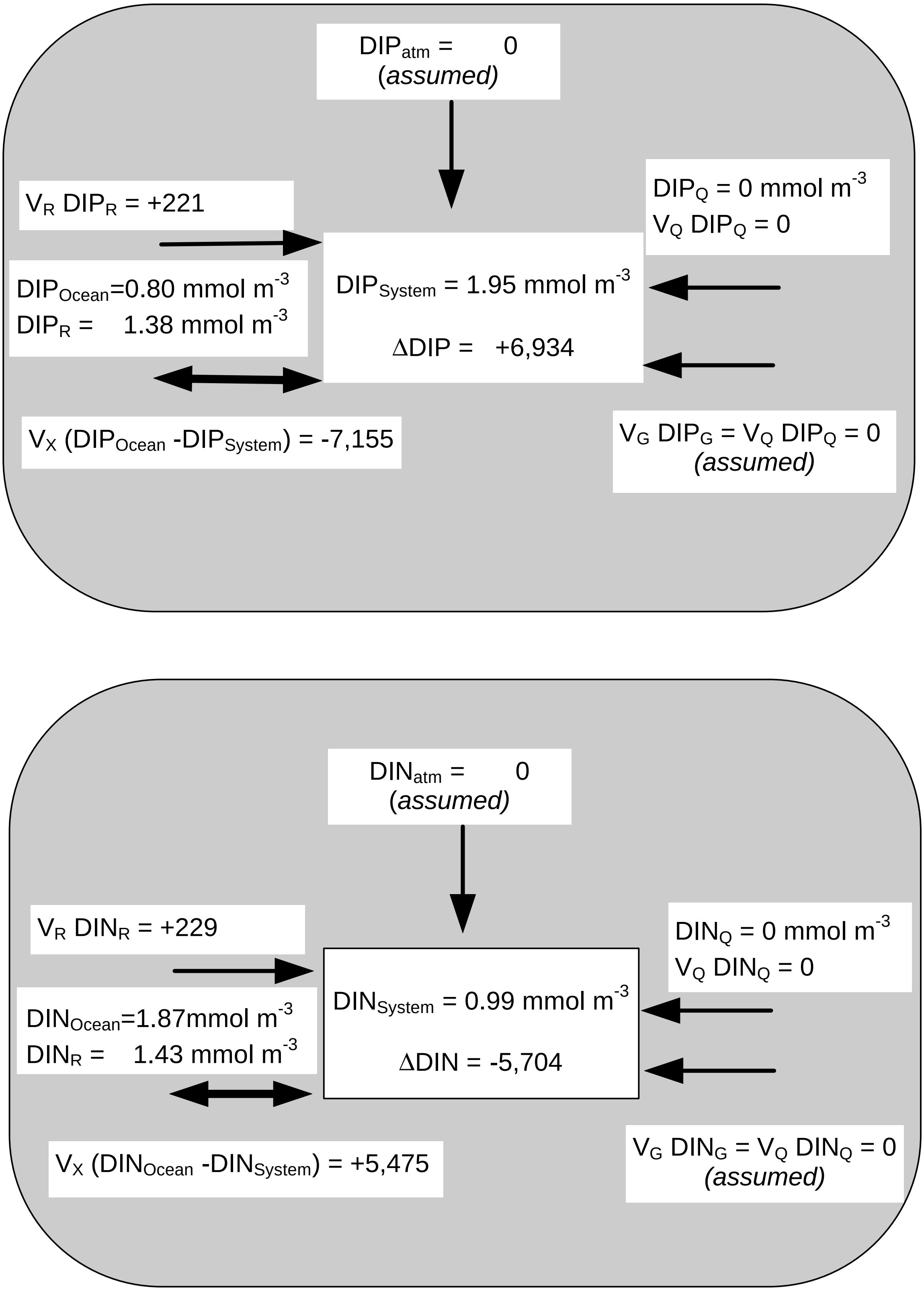


Figure 7. DIP and DIN budgets for Bahía San Quintín, August 1995. Fluxes in mol day^{-1}.

Stoichiometric Calculations of Aspects of Net System Metabolism

DP values in Bahía San Quintín are positive both in summer and in winter. This observation indicates that there is a net "production" of DIP within the system. If phosphate desorption from sediments does not contribute significantly to DP, then this DIP production probably results from organic matter oxidation.

Based on the Redfield N:P molar ratio, if the positive DP values in San Quintín are a measure of the net organic matter oxidation in the system, the expected DN value (DN_{exp}) would be 16 DP. For August 1995:

DN_{exp} = 16 x 6,934 mol day^{-1} = +110,944 mol day^{-1}

There is a discrepancy of -116,647 mol day^{-1} between DN_{exp} and the DN calculated with the DIN balance (DN_{obs}). Assuming that N cycling in Bahía San Quintín is comparable to that of Tomales Bay, where a relatively small proportion of the "missing" DIN can be accounted for by the DON balance (Smith and Hollibaugh, 1993), then the difference between DN_{obs} and DN_{exp} represents the difference between the nitrogen fixation and denitrification, i.e.,

$$(nfix\text{-}denit) = DN_{obs} - DN_{exp} \quad (15)$$

or

$$(nfix\text{-}denit) = DN_{obs} - DP_{\text{x}}\,(\text{N:P})_{part} \quad (16)$$

The (*nfix-denit*) calculations for the three sampling dates:

August 1995: -116,647 mol day^{-1} (-2.8 mmol m^{-2} day^{-1})
February 1996: - 31,282 mol day^{-1} (-0.7 mmol m^{-2} day^{-1})
August 1996: -111,649 mol day^{-1} (-2.7 mmol m^{-2} day^{-1})

suggest that Bahía San Quintín is a coastal system where denitrification exceeds N fixation throughout the year and is, therefore, an important sink of nitrogen.

The calculation of the net ecosystem metabolism, that is, the difference between organic carbon production (p) and respiration (r) within the system $(p-r)$, is made through equation (17):

$$(p - r) = -DP \times (\text{C:P})_{part} \quad (17)$$

Based on the Redfield C:P ratio (106:1) the estimates of (p-r) for each campaign was:

August 1995: -735,004 mol day^{-1} (-17 mmol m^{-2} day^{-1})
February 1996: - 62,116 mol day^{-1} (-1 mmol m^{-2} day^{-1})
August 1996: -823,302 mol day^{-1} (-20 mmol m^{-2} day^{-1})

These results indicate that Bahía San Quintín is a net heterotrophic system throughout the year, and that the net metabolism during winter is approximately an order of magnitude lower than the metabolism of the system during summer. Annual average $(p-r)$ is about 10 mmol m^{-2} day^{-1}, and p is estimated to be about 200 mmol m^{-2} day^{-1} (Smith and Ibarra-Obando, Appendix II). It follows that r is approximately 210 mmol m^{-2} day^{-1}, and p/r is about 0.95. That is, the system consumes about 5% more organic matter than it produces.

2.1.3) Bahía San Luis Gonzaga, Baja California

F. Delgadillo-Hinojosa and J. A. Segovia Zavala

Study Area Description

Bahía San Luis Gonzaga is located in Baja California, Mexico (29 ° 49' N and 114 ° 23' W) (Figures 1 and 8). It is a small, rapidly exchanging bay covering an area of approximately 3 km^2. It has a permanently open mouth 1 km length and 10 m deep and the average depth is 4 m. The north end is a rocky shore and sandy beaches predominate at the southern end. The system is macro-tidal with semi-diurnal tides. Tidal amplitudes at the entrance range from about 1 m at neap tide to about 4.8 m at spring tide. At high-water about 17.6×10^6 m^3 of water are contained within the area, and the tidal prism is in the order of 13×10^6 m^3. Water exchange time based on the tidal prism/bay volume ranges from an average of 2.6 days at neap tide to about 0.7 days at spring tides. Tide is the main force driving water exchange with the adjacent Gulf of California. Although we do not have a great deal of information on the biotic community composition, we assume that it is a plankton-dominated system. Bahía San Luis Gonzaga has little macroalgal biomass for most of its length; there is a small salt marsh at the southern end.

The bay is located in a region with two pronounced seasons: the summer condition, from May to October with high temperatures and the winter season from November to April with low temperatures. The temperature ranges from 5 to 45 ° C in winter and summer, respectively. The rainfall is scarce and the monthly average is less of 4 mm. Thus, the evaporation exceeds precipitation throughout the year.

The budget presented here is based on data collected between May 1985 and February 1986 (Mendoza-Espinosa, 1994). Four complete tidal surveys were made covering at least a tidal cycle. Water surface samples were collected at 2 stations located at the mouth (A) and inside (B) of the bay (Figure 8). Each value used represents an average of 9 to 13 samples for each sampling period. In particular, DIN represents NO_3^- + NO_2^- + NH_4^+. We assumed that a very small proportion of missing DIN can be accounted for by the DON balance, that is *DDON* = 0. Similarly, *DDOP* was assumed equal 0. Thus, with this general background, the fluxes of water, salt, phosphorus, and nitrogen can be calculated using a simple box model following Gordon *et al.* (1996).

Figure 8. Map of Bahía San Luis Gonzaga, Baja California (also known as Bahía Willard). "A" and "B" show locations of sampling stations

Water and Salt Budgets

Direct rainfall (V_P) and groundwater discharge (V_G) are small contributors to the water budget, because Bahía San Luis Gonzaga is located in the desert of Baja California. The catchment has a population of approximately 30 people in scattered places. There are no industries, agriculture and no sewage treatment plants (V_O) in the catchment with the total population using septic tanks. Thus, $V_P = V_G = V_Q = V_O = 0$. On the other hand, evaporation (V_E) exceeds freshwater inputs. The water lost is balanced by a net water input from the Gulf of California, that is $V_R = V_E$. The residual water flow (V_R) is into the bay year round. Figure 9 shows the summer data. The exchange flow (V_X) was calculated using the salinity gradients between the bay and the adjacent Gulf of California. This flow was the main route of transport of nutrients in Bahía San Luis Gonzaga throughout year. Figure 9 illustrates the water and salt budgets for the summer sampling period; Tables 10-13 summarise the data for each of the sampling periods. Note that the water exchange rate in this system is very fast, with the exchange time ranging between 1 and 4 days. As expected, the net exchange is somewhat smaller than the exchange volume calculated from the tidal prism, because tidal exchange is not 100% efficient in flushing the system.

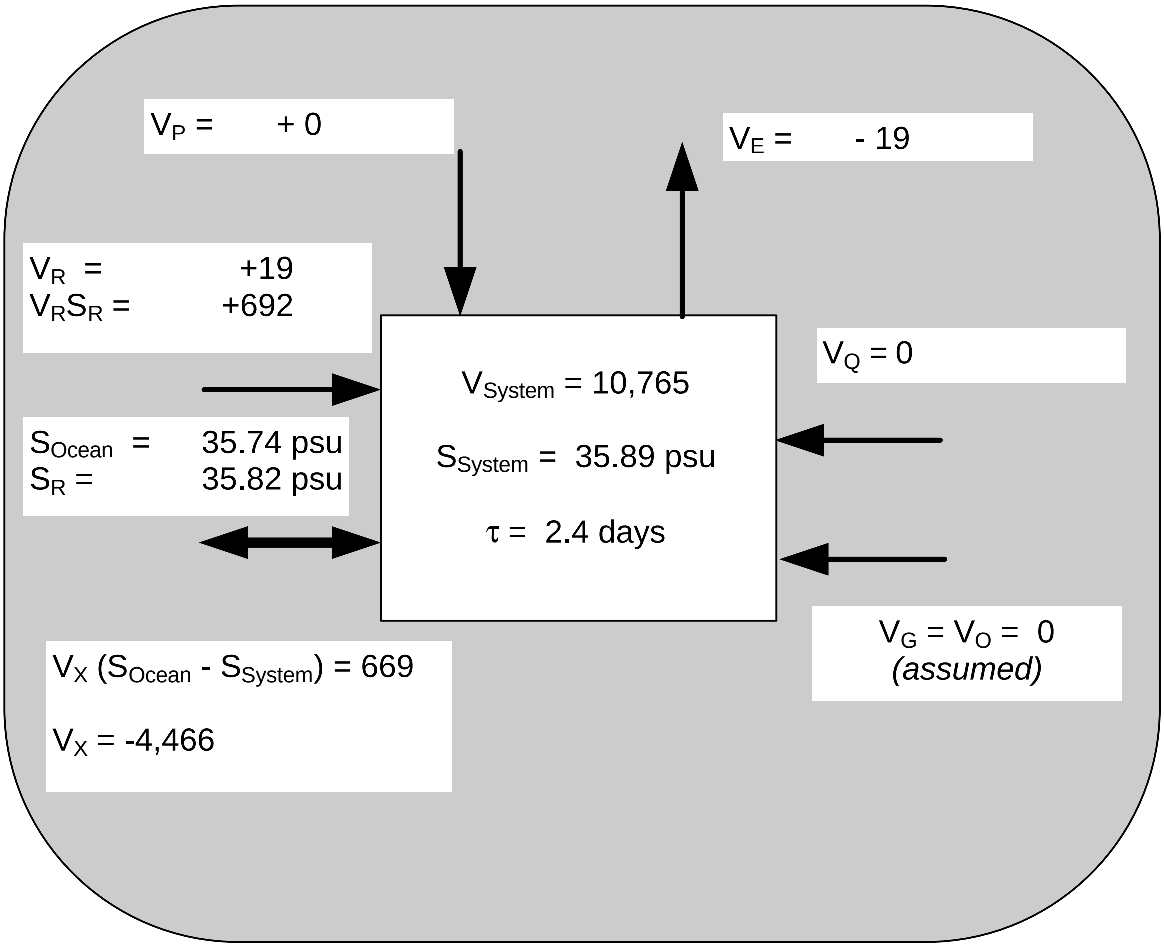


Figure 9. Water and salt budgets for Bahía San Luis Gonzaga, Summer 1985. System volume is in units of 10^3 m^3 . Water fluxes in 10^3 m^3 day^{-1}. Salt fluxes in 10^3 psu m^3 day^{-1}.

Budgets of Nonconservative Materials

Figure 10 illustrates the P and N budgets for the summer sampling period, and Tables 10-13 summarise the data for all four sampling periods.

P Balance

During three of four sampling dates, DIP concentration was higher in the bay than in the open Gulf, indicating there must be a DIP source within the bay. Winter sampling was an exception, with lower values within the bay than the ocean, suggesting that the bay was a DIP sink. The positive *DDIP* values in the Spring - Fall period indicates that there was a net production of DIP within the system, interpreted to be the result of net organic matter remineralization. We assume that the phosphate desorption from sediments does not contribute significantly to *DDIP*. During the winter the bay consumed DIP, apparently due a phytoplankton bloom.

The positive *DDIP* values in the spring through the fall period indicates that there was a net regeneration of DIP within the system, interpreted to be the result of net organic matter remineralization. We assume that the phosphate desorption from sediments does not contribute significantly to *DDIP*. During the winter Bahía San Luis Gonzaga also consumed phosphate, apparently due a phytoplankton bloom.

N Balance

During warmer conditions, in spring and summer, DIN was higher in the bay than in the open Gulf, indicating there must be a DIN source within the bay. In contrast, under colder conditions (fall and winter) lower values were found within the bay relative those the ocean, suggesting that the bay was a DIN sink.

Stoichiometric Calculations of Aspects of Net System Metabolism

If the positive *DDIP* values in San Luis Gonzaga are a measure of the net organic matter oxidation in the system, and based on the Redfield N:P ratio, then the expected *DDIN* value ($DDIN_{exp}$) would be 16 x *DDIP*. On the other hand, the *DDIN* calculated using the Water and Salt balance represent the *DDIN* observed ($DDIN_{obs}$). Thus, the difference between $DDIN_{exp}$ and $DDIN_{obs}$ represents the difference between nitrogen fixation and denitrification, that is:

$$(nfix - denit) = DDIN_{obs} - DDIN_{exp\backslash} \qquad (18)$$

or

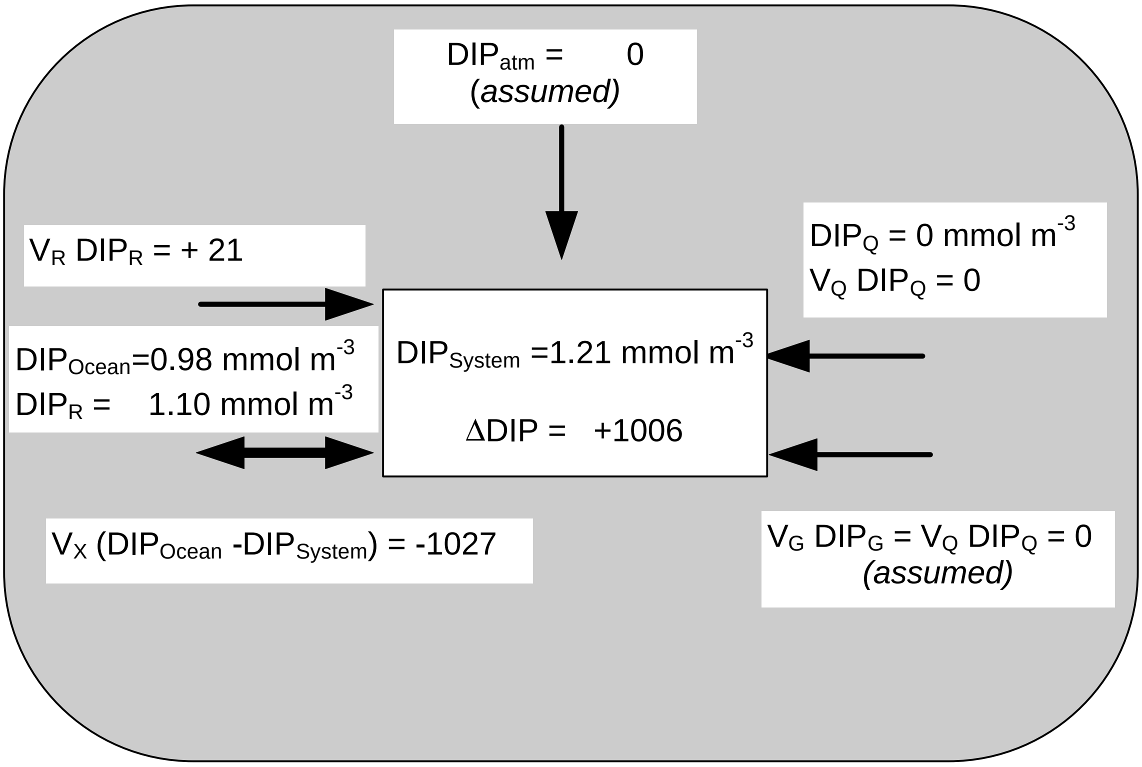
$$(nfix - denit) = DDIN_{obs} - DDIP \times (N{:}P)_{part} \qquad (19)$$

The *(nfix- denit)* estimates for Bahía San Luis Gonzaga during the 1985/86 period is shown in Table 4.

Table 4. Estimated rates of nonconservative observed DIN fluxes and *(nfix - denit)* in Bahía San Luis Gonzaga.

Season/year	**$DDIN_{obs}$ (mmol N m^{-2} day^{-1})**	**$DDIN_{exp}$ (mmol N m^{-2} day^{-1})**	***(nfix - denit)* (mmol m^{-2} day^{-1})**
Spring/85	+0.1	+5.2	-5.1
Summer/85	+1.0	+5.1	-4.1
Fall/85	-2.1	+3.6	-5.7
Winter/86	-4.6	-8.5	+3.9

These calculations indicate that the nonconservative flux of dissolved inorganic nitrogen ($DDIN_{obs}$) was lower than would be predicted from decomposition of organic matter with an N:P ratio of 16 ($DDIN_{exp}$). If the decomposing organic matter with a N:P ratio of 16 is the main source of *DDIP*, then there must be an additional process taking DIN from the bay. This system was denitrifying more nitrogen than it is fixing. However, under winter conditions Bahía San Luis Gonzaga appears to be a net nitrogen fixing system. We suspect that the variation in *(nfix-denit)* in this system at least partially



reflects variability associated with short water exchange times, so that each sampling period represents a relatively brief “snapshot” of system metabolism.

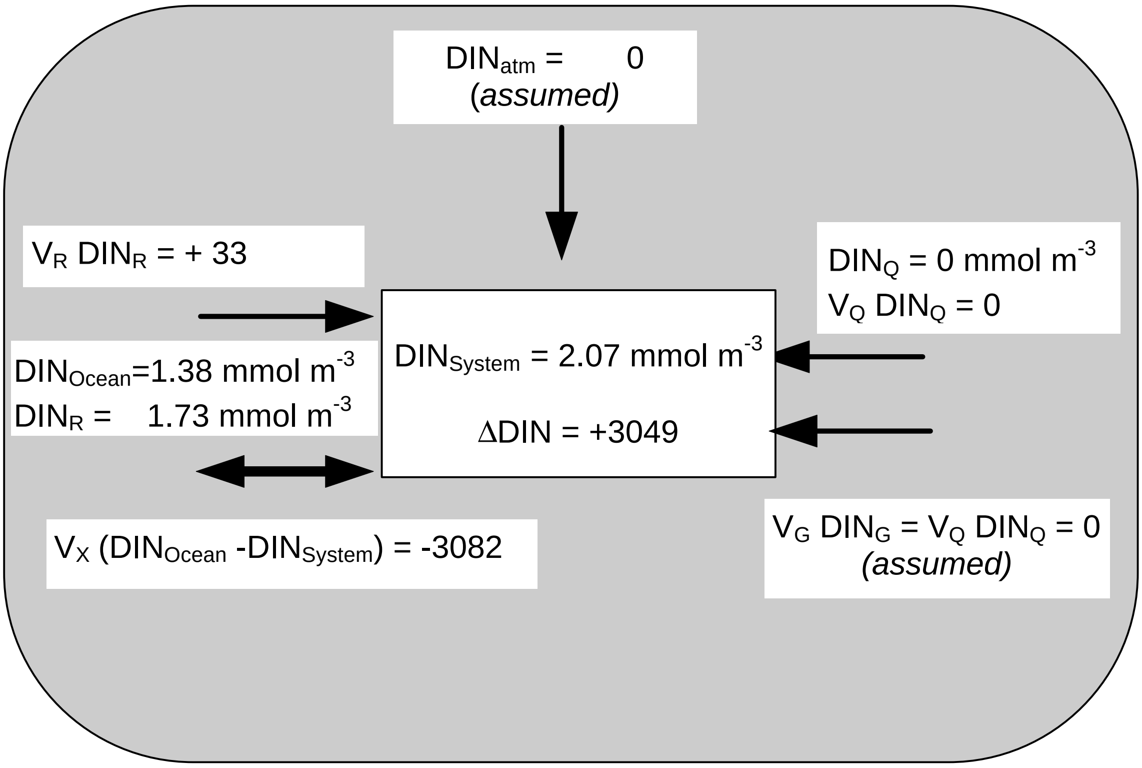


Figure 10. DIP and DIN budgets for Bahía San Luis Gonzaga, Summer 1985. Fluxes in mol day^{-1}.

The difference between organic carbon production (*p*) and respiration (*r*) within the system *(NEM)* is calculated using:

$$(p\text{-}r) = -\ DDIP \times (C{:}P)_{part}$$

where $(C{:}P)_{part}$ represents the composition of particles decomposing in the system. Taking the particle composition as the Redfield ratio (C:N:P = 106:16:1), since Bahía San Luis Gonzaga is plankton-dominated, the estimates of *DDIP* and *NEM* for each season of the year were (Table 5):

Table 5. Estimated rates of nonconservative DIP fluxes and *NEM* in Bahía San Luis Gonzaga.

Season/year	***DDIP*** **(mmol m^{-2} day^{-1})**	***NEM*** **(mmol C m^{-2} day^{-1})**
Spring/85	+0.32	-34
Summer/85	+0.32	-34
Fall/85	+0.23	-24
Winter/86	-0.53	+56

That is, the bay appears to oxidise more organic matter than it produces. Simultaneously, Merino-Paredes (1987) measured the primary production rates in SLG using the Light/Dark bottle method. Her gross primary production rates (GPP) ranged between 127 mmol C m^{-2} day^{-1} in fall to 193 mmol C m^{-2} day^{-1} in winter (Table 6). From this independent primary production data set, *r* can be estimated to be 137 mmol C m^{-2} day^{-1} in winter to 173 mmol C m^{-2} day^{-1} in summer. As expected, the lower *r* values were found under colder condition and higher values warmer conditions. Those numbers compare favourably with the respiration rates measured with the light and Dark bottle technique by Merino-Paredes (1987). The respiration rates measured ranged from 283 mmol C m^{-2} day^{-1} in summer to 142 mmol C m^{-2} day^{-1} in winter (Table 6). These results support the assumption we made that the phytoplankton is the main contributor to the total metabolism in SLG. On the other hand, the *p/r* ratio was estimated to be about 0.8 during summer and fall periods (Table 6). That is, the bay consumes about 20% more organic matter than it produces. These results support the conclusion that Bahía San Luis Gonzaga is a net heterotrophic system.

On the other hand, one may expect that lower NEM rates were found under colder conditions. However, the lower (*p-r*) value was found in the fall, and a positive NEM value was calculated for the winter data (Table 5). In this sampling period phytoplankton bloom was recorded. The phytoplankton biomass, measured as chlorophyll *a*, within the bay was 3 times higher those found during the precedent sampling periods. There was a remarkable similarity between the respiration measured and the respiration estimated using the budgetary approach to net metabolism (Table 6). The measured respiration rate using the incubation method was 142 mmol C m^{-2} day^{-1}, and the respiration estimated from GPP - NEM was 137 mmol C m^{-2} day^{-1} (Table 6). Thus, if we use the gross photosynthetic rate measured during winter as 193 mmol C m^{-2} day^{-1}, then the estimated *p/r* ratio for this period is calculated to be about 1.4 (Table 6). Similarly, the *p/r* ratio measured using the light-dark incubation method was 1.4. These result indicates that the phytoplankton dominates the primary production in SLG. That is, both methods indicate that SLG bay produced more organic matter than it consumed during the winter sampling. Thus, SLG Bay was a net autotrophic system under winter conditions. Even though we had a very limited data set, we cannot tell if this represents average conditions for the winter or an anomaly associated with the short-term bloom. However, it is important to note the remarkable similarity between the results given by the incubation technique and the budgetary approach to net metabolism in SLG. We think that these results are a strong support for the NEM budgetary approach in a plankton-dominated bay as Bahía San Luis Gonzaga.

Table 6. Gross primary production (GPP), Respiration (*r*) and Photosynthesis/respiration ratio measured and estimated in Bahía San Luis Gonzaga. The $r_{est.}$ was calculated as GPP - NEM. The $p{:}r_{est\ .}$ ratio was calculated as GPP/r_{est}.

Season/ year	**GPP (mmol C m^{-2} day^{-1})**	***r*** **measured (mmol C m^{-2} day^{-1})**	***r*** **estimated (mmol C m^{-2} day^{-1})**	***p:r*** **measured**	***p:r*** **est.**
Summer/85	139.3	283.3	173.3	0.50	0.80
Fall/85	127.0	168.0	161.0	0.76	0.79
Winter/86	193.3	141.6	137.3	1.36	1.41

2.1.4) Estero La Cruz, Sonora

M. Botello-Ruvalcaba and E. Valdez-Holguín

Study Area Description

La Cruz is a characteristic desert coastal lagoon from the north-west of Mexico. In lagoonal systems within this region the evaporation is an order of magnitude higher than freshwater input from precipitation. Also, groundwater is characterised by saline intrusion, and the circulation is mainly determined by tide and wind induced forces (Botello-Ruvalcaba and Valdez-Holguín, 1990; Valdez-Holguín, 1994). In addition, these systems represent the northern frontier for some mangrove species such as *Avicenia germinais* and *Rhizophora mangle* in the American pacific coast (Castro-Longoria *et al*., 1989)

La Cruz is located at 28° 45´ N and 111° 53´ W, in the central-oriental coast of the Gulf of California (Figures 1 and 11). Following the Pritchard (1967) criteria for estuary classification, the lagoon can be classified as an anti-estuarine system. The total lagoon area is 23 km^2 with an average depth of 1.4 m and a semidiurnal tide type. The population living in the basis is approximately 10,000, with fisheries and tourism as their main activity. In the coastal lagoon itself, there are several socio-economic activities such as fisheries, oyster culture and salt extraction that represents an income for the people living in the area. Nevertheless, considering the low intensity of the above activities, La Cruz can be regards as a not heavy impacted system. Therefore it offers the opportunity to obtain a general budgetary approach before the lagoon can be heavily impacted by projected developments.

The hydrographic and biological characteristics of the lagoon are mainly related with the tide and seasonal condition of the adjacent sea. The temperature reaches up to 34° C during summer and 12° C in winter, values for dissolved oxygen are from 2.6 to 8.6 ml l^{-1}, and chlorophyll *a* is in the range of 0.06 to 7 mg m^{-3} (Botello-Ruvalcaba, 1992; Valdez-Holguín, 1994). Phytoplankton primary productivity estimations within the lagoon are from 40 to 80 mg C m^{-3} h^{-1} and seems to dominate the primary production within the system, although mangrove contribution to primary production is also important (Gilmartin and Relevante, 1978; Castro-Longoria *et al.*, 1989; Botello-Ruvalcaba, 1992; Valdez-Holguín and Martínez-Cordova, 1993). We estimate that daily primary production may be approximately 100 mmol C m^{-2} day^{-1}

In order to establish budgetary calculations, data for salinity, dissolved N and P, and other physical characteristics were available from various sources (Gilmartin and Relevante, 1978; Botello-Ruvalcaba, 1992; and Valdez-Holguín and Martínez-Cordova, 1993). For these desert coastal lagoons, there is a sudden transition between summer and winter conditions (Valdez-Holguín and Martínez-Cordova, 1993; Botello-Ruvalcaba, 1996). Therefore, a weekly one year period time series performed from 1988 to 1989 for two stations, inside the coastal lagoon and in the adjacent sea (Figure 11), was split in data sets representing summer and winter.

Figure 11. Study area showing the two sampling sites, ⊗, for the hydrology monitoring program in La Cruz lagoon during 1988-1989.

Water and Salt Budgets

Figure 12 summarises the water and salt budgets for the summer, and Tables 10-13 include both the summer and winter data. La Cruz basin has problems with saline intrusion into the groundwater, so groundwater input (V_G) can be considered to be 0. River inflow (V_Q) is also 0. Precipitation is highly seasonal and very low. Finally, evaporation dominates the freshwater budget throughout the year, resulting in high salinity values within the system, which can be up to 4 psu above that of the adjacent sea. The water exchange time was 21 days in the summer and 43 days in the winter.

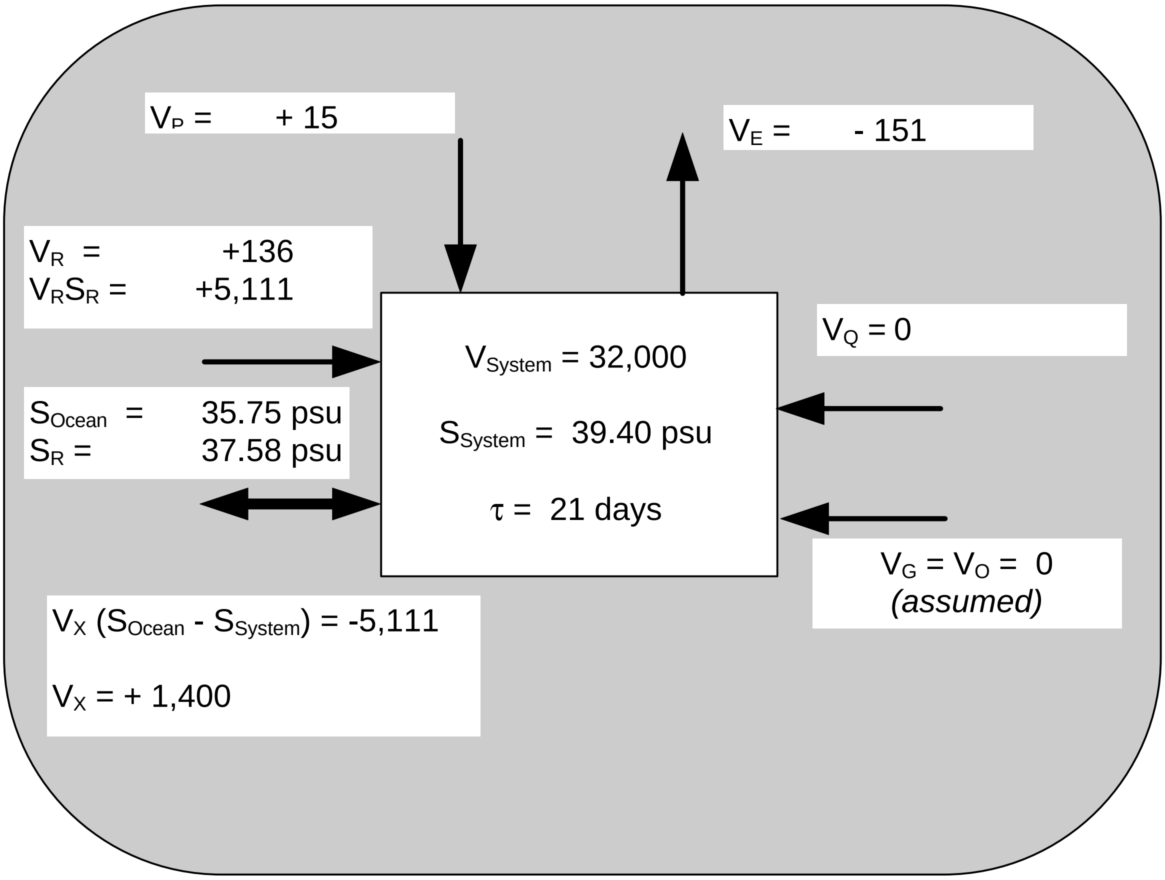


Figure 12. Water and salt budgets for Estero La Cruz, Summer. System volume is in units of 10^3 m^3. Water fluxes in 10^3 m^3 day^{-1}. Salt fluxes in 10^3 psu m^3 day^{-1}.

Budgets of Nonconservative Materials

The DIP and DIN budgets for the summer period are shown in Figure 13, and Tables 10-13 include both the summer and winter nutrient budgets.

P Balance

The system is a slight net phosphorus source during both the summer and winter (summer *DDIP* = +563 mol day^{-1}; winter *DDIP* = + 199 mol day^{-1}; average = +381 mol day^{-1} = +0.02 mmol m^{-2} day^{-1}), with the summer flux being substantially higher than the winter flux.

N Balance

The system is a slight net nitrogen sink during the summer (*DDIN* = -830 mol day^{-1}) and a nitrogen source during the winter (*DDIN* = +3,382 mol day^{-1}). The average, +1,276 mol day^{-1} or +0.06 mmol m^{-2} day^{-1}, clearly does not differ from 0.

Stoichiometric Calculations of Aspects of Net System Metabolism

The rates of nonconservative DIP and DIN flux can be used to estimate the apparent rate of nitrogen fixation minus denitrification *(nfix-denit)* as the difference between observed and expected DIN production ($DDIN_{obs}$-$DDIN_{exp}$), where $DDIN_{exp}$ is *DDIP* multiplied by the N:P ratio of the reacting particulate organic matter. We assume that this reaction ratio is the Redfield N:P ratio of 16:1, for plankton. During the summer:

$(nfix\text{-}denit) = DDIN_{obs}\text{-}DDIN_{obs} = DDIN_{obs} - (N:P)_{part} \times DDIP$ (20)

(nfix-denit) = -830 – 16 x (+563) = -9,838 mol day^{-1} (-0.4 mmol m^{-2} day^{-1}).

And in the winter:

(nfix-denit) = +3,382 – 16 x (+199) = +198 mol day^{-1} (+0.0 mmol m^{-2} day^{-1})

Thus, the system appears to denitrify in the summer and show *(nfix-denit)* near 0 in the winter. Averaged over the area of the bay for the two seasons, the bay net denitrification rate is about 0.2 mol N m^{-2} day^{-1}.

In a similar fashion, *DDIP* multiplied by the negative of the C:P ratio of the reacting organic matter can be used to estimate net ecosystem metabolism *(NEM)*, or production minus respiration *(p-r)*. The reacting organic matter is assumed to have a C:P ratio equal to the Redfield C:P ratio of 106:1. Averaged over the annual cycle, the rate is:

$NEM = [p\text{-}r] = [C:P]_{part} \times DDIP$ (21)

NEM = -106 x 381 = -40,000 mol day^{-1} (-2 mmol m^{-2} day^{-1}).

The system is slightly net heterotrophic. These data are also summarised in Tables 10-13.

If *p* is approximately 100 mmol m^{-2} day^{-1}, then *r* would be about 102. The *p/r* ratio would be 0.98; the system appears to consume about 2% more organic matter than it produces.

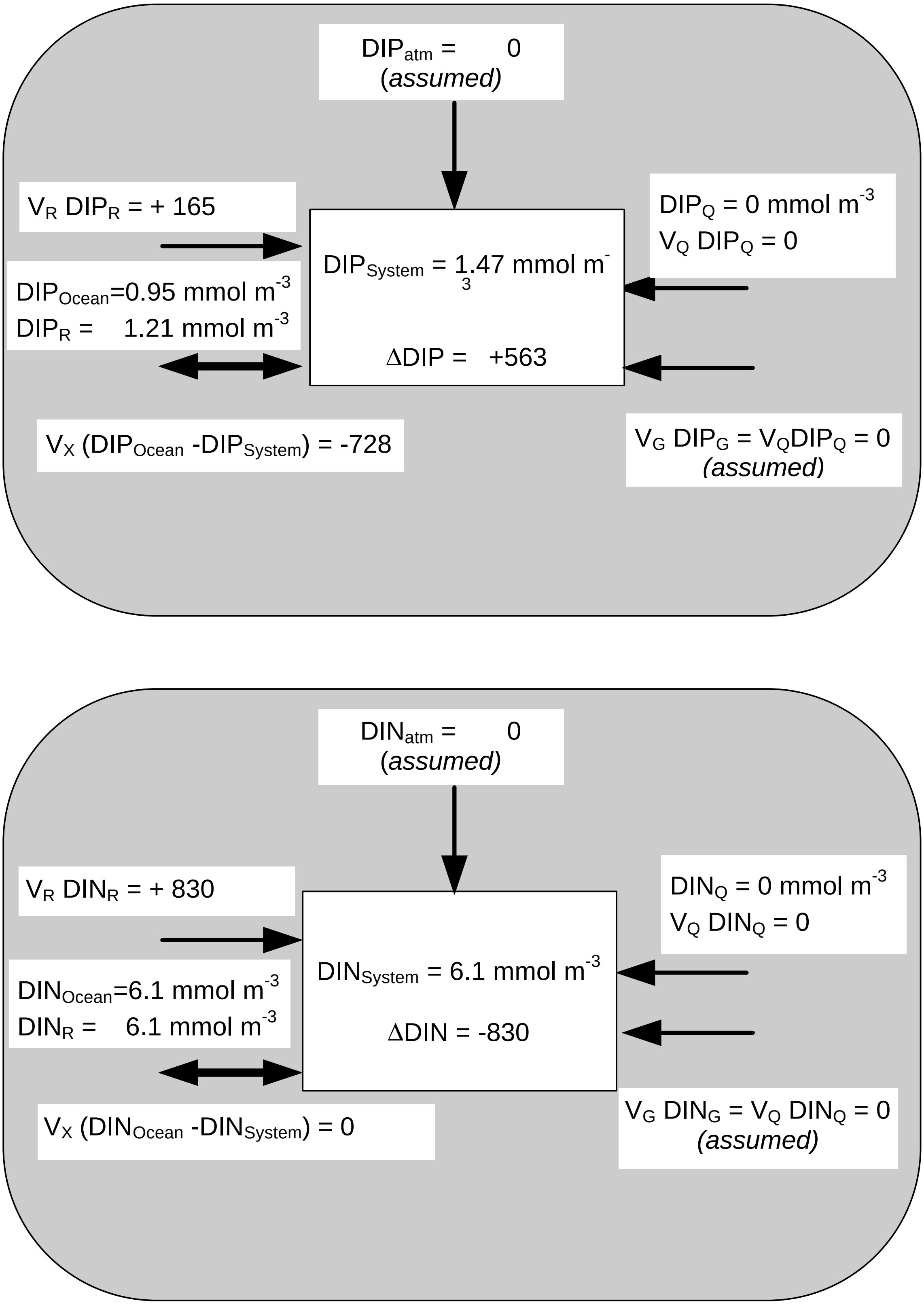


Figure 13. DIP and DIN budgets for Estero La Cruz, Summer. Fluxes in mol day^{-1}.

2.1.5) Bahía Concepción, Baja California Sur

C.H. Lechuga-Devéze

Study Area Description

Bahía Concepción (26° 30' N, 111° 30" W; Figures 1 and 14), the largest and deepest coastal embayment in the Gulf of California (282 km^2; 4,553 x 10^6 m^3), has insignificant human influences including scarce tourist facilities. Continental runoff is absent, although small hot springs are dispersed along the shoreline. The fluxes of these springs have not been studied; we assume that they are refluxing seawater.

Two parts to the annual cycle are well identified. In winter (November-March), the bay is vertically well mixed. In summer, April-October, the central basin (33 m maximum depth) develops a strong thermocline that isolates the water below 20 m. This leads to anoxia and hydrogen sulphide production during August and September (Lechuga-Devéze *et al*., 1997; Reyes-Salinas, 1994). During this dystrophic period, high amounts of pigment are present, mainly chlorophyll *b* (Lechuga-Devéze, 1994). This indicates rapid metabolic cycling, perhaps chemoautotrophic.

The water, salt, N, and P budgets developed here are only for the well-mixed period; the data were collected by our research group. It would also be useful to establish a separate set of budgets for the stratified period, although the long water exchange time (below) suggests that the budgets for the well-mixed period may characterise the annual average. For now, the annual summary budgets (Tables 10-13) are based on the data from this single period.

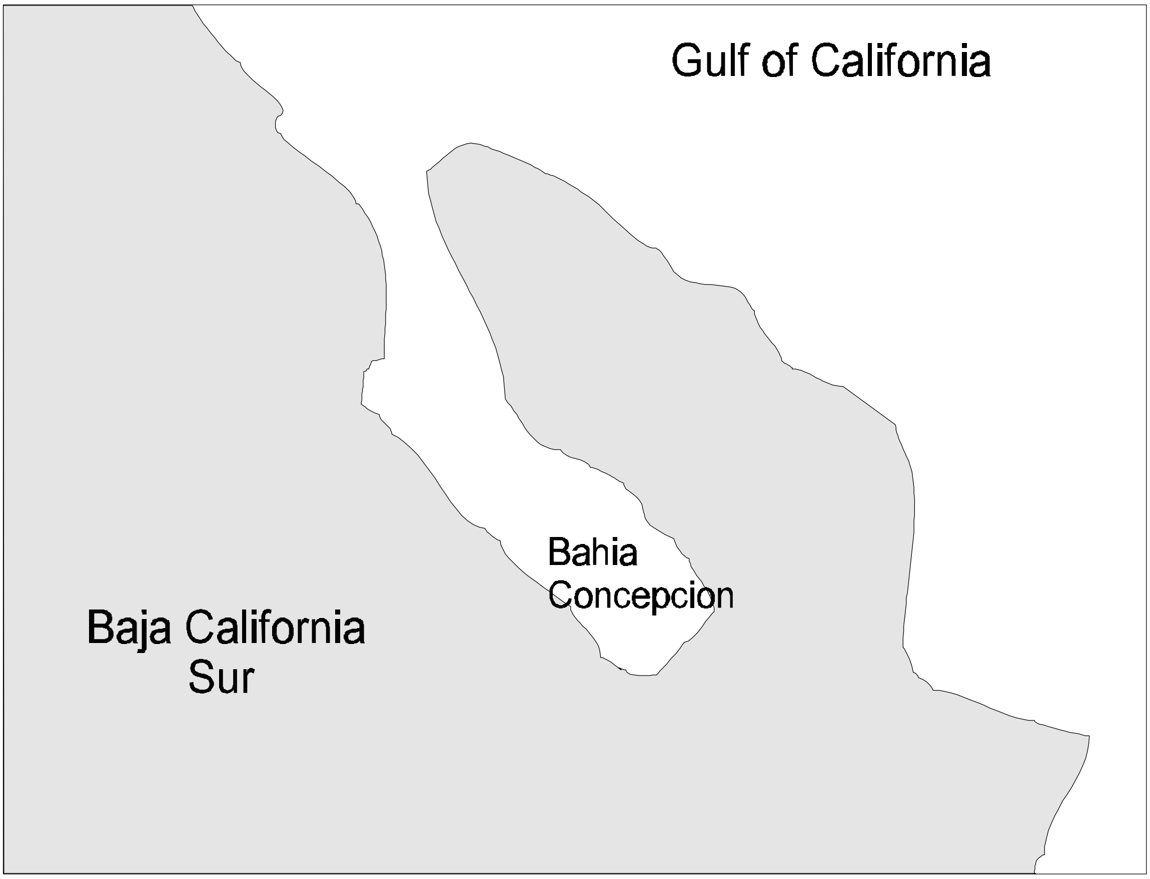


Figure 14. Map of Bahía Concepción, Baja California Sur.

Water and Salt Budgets

There is no runoff and apparently no groundwater or other land-derived freshwater input; evaporation totals about 217 x 10^3 m^3 day^{-1}, and precipitation totals about 65 x 10^3 m^3 day^{-1}. Oceanic salinity at the entrance of the bay averages 35.3 psu, while the system salinity averages 35.9 psu. Since the system is net evaporative, residual water flow totalling about 152 x 10^3 m^3 day^{-1} is into the bay. Figure 15 summarises the water and salt budgets. According to this budget, the water exchange time is about 500 days.

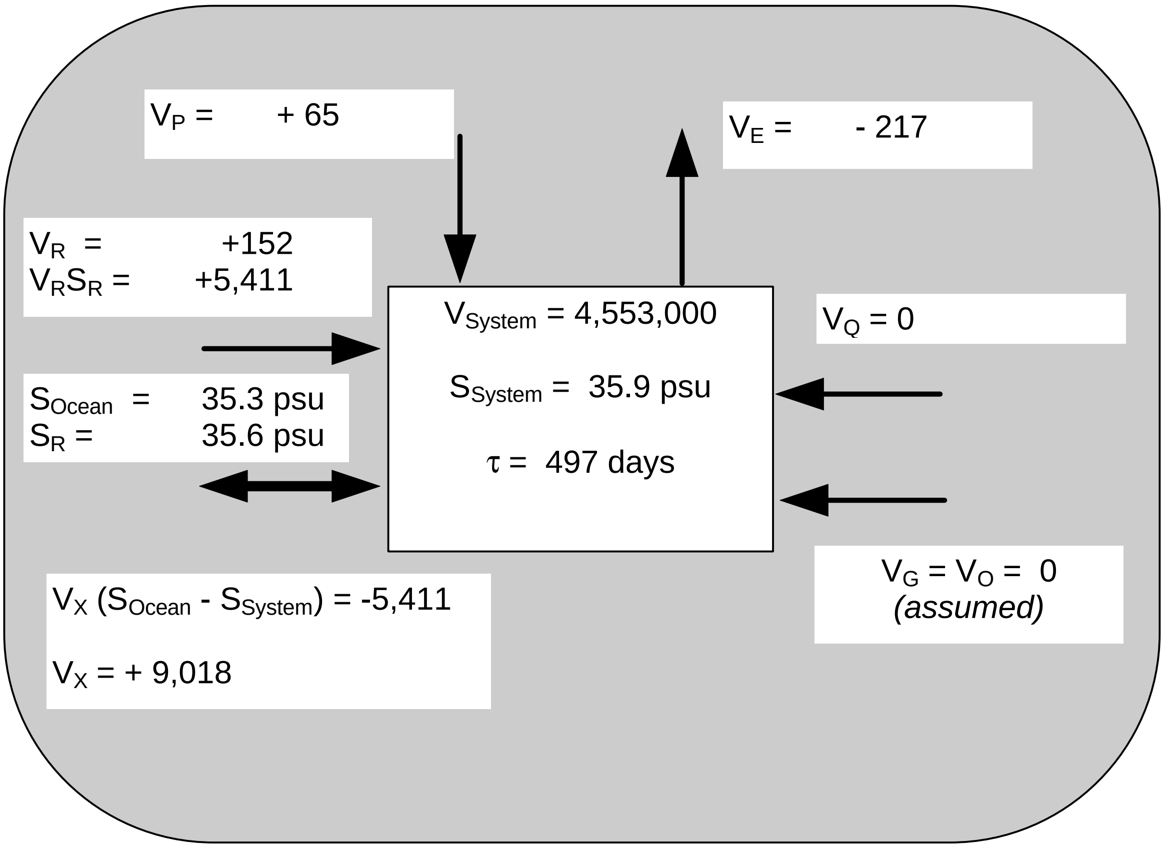


Figure 15. Water and salt budgets for Bahía Concepción, winter. System volume is in units of 10^3 m^3. Water fluxes in 10^3 m^3 day^{-1}. Salt fluxes in 10^3 psu m^3 day^{-1}.

Budgets of Nonconservative Materials

P Balance

Figure 16 illustrates the P and N budgets for this system The mixing outflow of DIP from this system is substantially larger than the residual inflow and demonstrates that there must be DIP production (*DDIP*) of approximately +2,637 mol day^{-1} in the system. We assume that this represents decomposition of organic matter. Because of the long water residence time, we assume that this decomposition rate is averaged over a period longer than one year.

N Balance

Similarly, the system shows strong net export of DIN (+10,371 mol day^{-1}; Figure 16). Again, this outward mixing represents DIN production (*DDIN*) and is assumed to represent decomposition of organic matter.

Stoichiometric Calculations of Aspects of Net System Metabolism

The rates of DIP and DIN production can be used to estimate the apparent rate of nitrogen fixation minus denitrification *(nfix-denit)* as the difference between observed and expected DIN production ($DDIN_{obs}$-$DDIN_{exp}$), where $DDIN_{exp}$ is *DDIP* multiplied by the N:P ratio of the reacting particulate organic matter. We assume that this reaction ratio is the Redfield N:P ratio of 16:1, for plankton. Thus:

$$(nfix\text{-}denit) = DDIN_{obs} - DDIN_{obs} = DDIN_{obs} - (N{:}P)_{part} \times DDIP \qquad (22)$$

$(nfix\text{-}denit) = +10{,}276 - 16 \times (+2{,}637) = -31{,}916$ mol day^{-1}

Averaged over the area of the bay, *(nfix-denit)* equals -0.1 mmol N m^{-2} day^{-1}. This system appears to be denitrifying at a relatively slow rate, although the nonconservative flux signal for DIN integrated over longer than a year is a strong signal.

In a similar fashion, *DDIP* multiplied by the negative of the C:P ratio of the reacting organic matter can be used to estimate net ecosystem metabolism *(NEM)*, or production minus respiration *(p-r)*. The reacting organic matter is assumed to have a C:P ratio equal to the Redfield C:P ratio of 106:1:

$$NEM = [p-r] = [C{:}P]_{part} \times DDIP \qquad (23)$$

$NEM = -106 \times 2{,}637 = -279{,}522$ mol day^{-1}.

Over the bay area, *NEM* equals –1 mmol m^{-2} day^{-1}; that is, the system is slightly net heterotrophic. These data are also summarised in Tables 10-13.

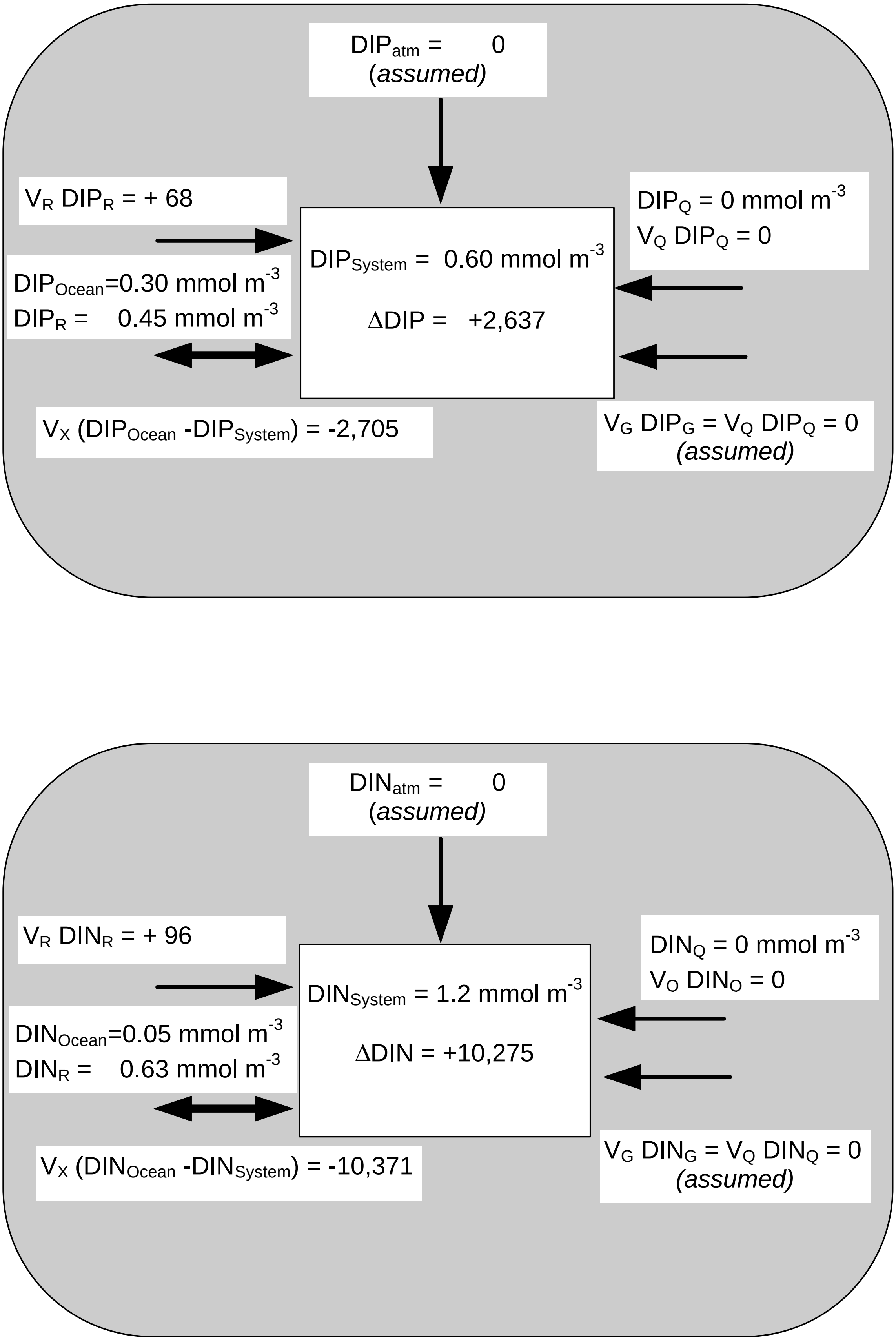


Figure 16. DIP and DIN budgets for Bahía Concepción, winter. Fluxes in mol day^{-1} .

2.1.6) Ensenada de La Paz, Baja California Sur

C.H. Lechuga-Devéze

Study Area Description

The Ensenada de La Paz (24° 14’ N, 110° 29’ W; Figures 1 and 17), is an anti-estuarine coastal lagoon without freshwater inputs. There are no groundwater fluxes but saline intrusion towards underground freshwater reserves. Sewage is treated and used to irrigate small agricultural fields. About 150,000 people live adjacent to the main entrance of the lagoon in La Paz, but it is assumed that no sewage effluent flows directly into the lagoon. The total lagoon area is around 45 km^2 (Lechuga-Devéze *et al.,* 1986) with a depth of about 3 m and a total volume of 145 x 10^6 m^3 (Gilmartin and Revelante, 1978).

The climate is arid, with summer showers averaging 1.15 mm day^{-1} and highest evaporation averaging 5.71 mm day^{-1} (average for July to September). In the spring, the scarce rain averages 0.04 mm day^{-1}, and evaporation averages about 3.56 mm day^{-1} (average for March to May).

During the 1970's, the natural shellfish banks (*Argopecten circularis*) inside the lagoon disappeared, and to-date no new populations have developed. Primary production of the system is about 1.2 g C m^{-2} day^{-1} (Lechuga-Devéze *et al*., 1986), that is, about 100 mmol m^{-2} day^{-1}. Some data have shown that the adjacent waters of the Bahía de La Paz are the main source of nitrate, phosphate and silicate for the lagoon (Lechuga-Devéze *et al.,* 1986; Cervantes-Duarte, 1981), meaning that the lagoon does not support enough oxidative process to provide the inorganic nutrients for primary production.

Salinity, nitrate and phosphate data gathered by our research group (Morquecho-Escamilla and Murillo-Murillo, 1995; Lechuga-Devéze *et al*., 1990) were used for the budgetary calculations to compare the summer to spring condition, representing the wet and dry season for the system.

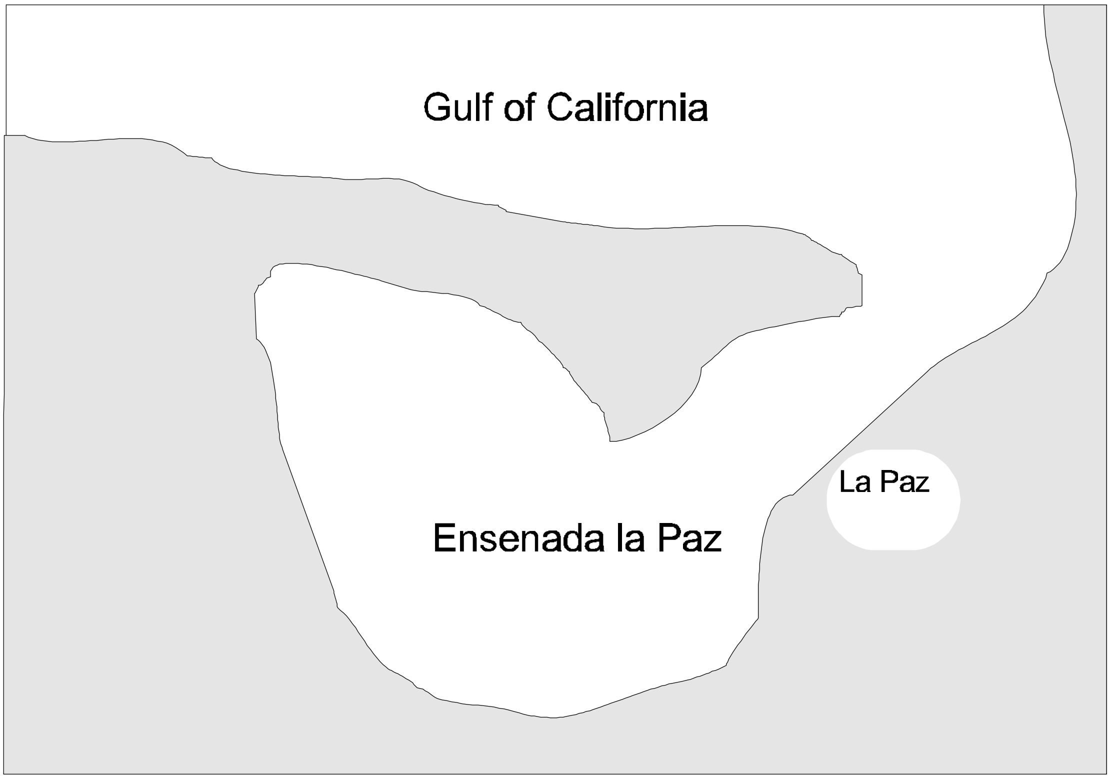


Figure 17. Map of Ensenada de La Paz, Baja California Sur.

Water and Salt Budgets

Figure 18 illustrates the water and salt budgets for this system for the spring, and Tables 10-13 summarise the data for both the spring and summer. The water exchange time for this system appears to be about a month.

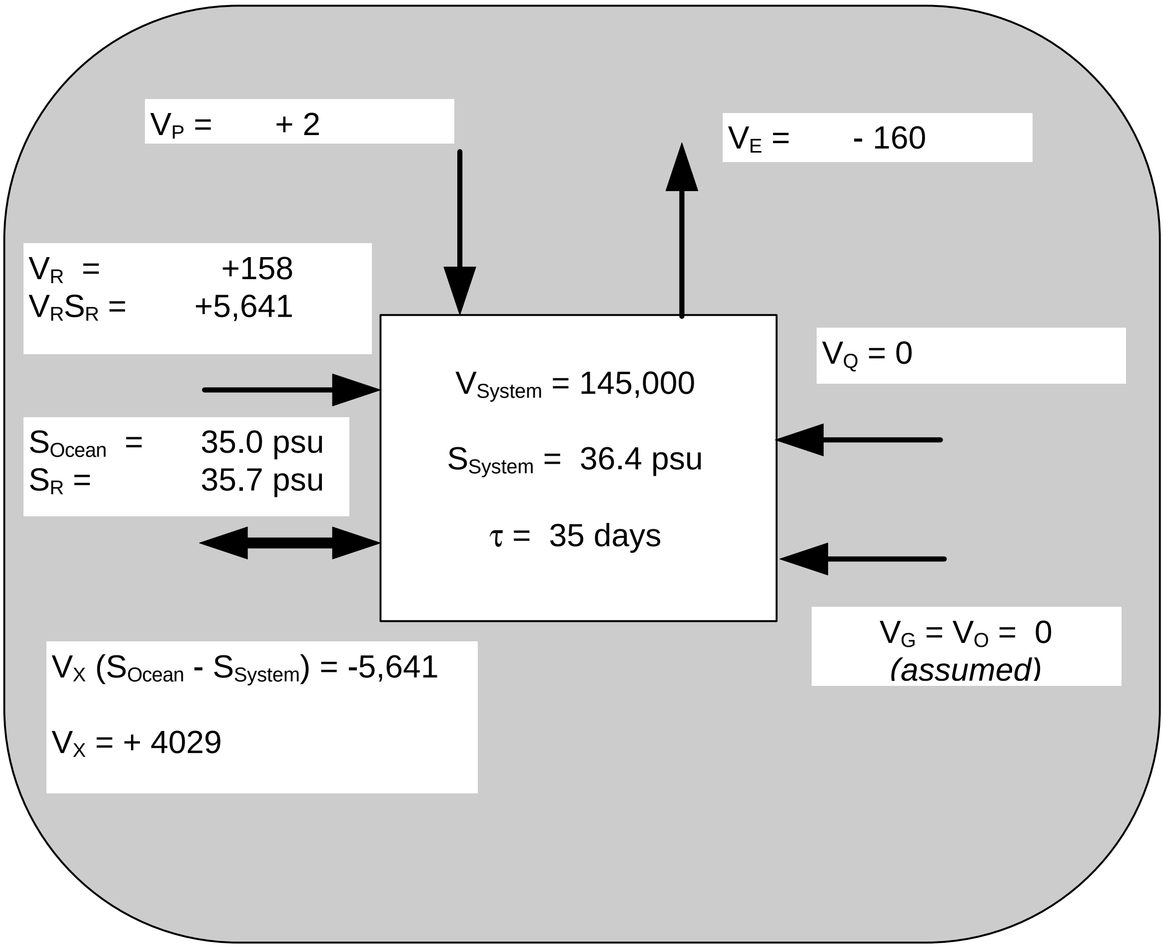


Figure 18. Water and salt budgets for Ensenada de La Paz, spring. System volume is in units of 10^3 m^3. Water fluxes in 10^3 m^3 day^{-1}. Salt fluxes in 10^3 psu m^3 day^{-1}.

Budgets of Nonconservative Materials

P Balance

Figure 19 illustrates the P and N budgets for the spring, and Tables 10-13 summarise the data for both spring and summer. With particular respect to *DDIP***,** there appears to be substantial variation; DIP uptake occurs and is higher during the summer than the spring. The average *DDIP* of the two sampling periods is –1,914 mol day^{-1}. Thus the system appears to be a net sink for DIP, mostly derived from the ocean.

N Balance

The bay appears to be a net DIN source during the spring and about neutral with respect to DIN during the summer. The average *DDIN* of the two sampling periods is +2,706 mol day^{-1}.

Stoichiometric Calculations of Aspects of Net System Metabolism

Nitrogen fixation minus denitrification *(nfix-denit)* is calculated from the difference between observed and expected *DDIN*, where the expected *DDIN* is calculated as 16 x *DDIP*. It is assumed that the major sink for DIP is plankton. Table 7 illustrates these calculations for Ensenada de La Paz. The system appears to fix nitrogen in excess of denitrification, by a rate averaging about 0.8 mmol m^{-2} day^{-1}.

Table 7. Estimated rates of nonconservative observed DIN fluxes and *(nfix - denit)* in Ensenada de La Paz.

Season	**$DDIN_{obs}$ (mmol N m^{-2} day^{-1})**	**$DDIN_{exp}$ (mmol N m^{-2} day^{-1})**	***(nfix – denit)*** **(mmol m^{-2} day^{-1})**
Spring	+0.11	-0.32	+0.4
Summer	-0.01	+1.10	+1.1

The difference between organic carbon production, *p,* and respiration, *r*, within the system *(NEM)* is calculated using:

$$(p\text{-}r) = - DP \text{ x } (C{:}P)_{part} \tag{23}$$

where $(C{:}P)_{part}$ represents the composition of particles reacting in the system. Taking the particle composition as the Redfield ratio (C:N:P = 106:16:1), since Ensenada de La Paz is assumed to be a plankton-dominated system, the estimates of *DP* and *NEM* are shown in Table 8:

Table 8. Estimated rates of nonconservative DIP fluxes and *NEM* in Ensenada de La Paz.

Season	***DP*** **(mmol m^{-2} day^{-1})**	***NEM*** **(mmol C m^{-2} day^{-1})**
Spring	-0.02	+2
Summer	-0.07	+7

This system appears to be net autotrophic by approximately 5 mmol m^{-2} day^{-1}.

Primary production has been estimated to be about 100 mmol m^{-2} day^{-1}, implying that respiration is about 95 and that the *p/r* ratio is about 1.05. This system appears to produce about 5% more organic carbon that it consumes**.**

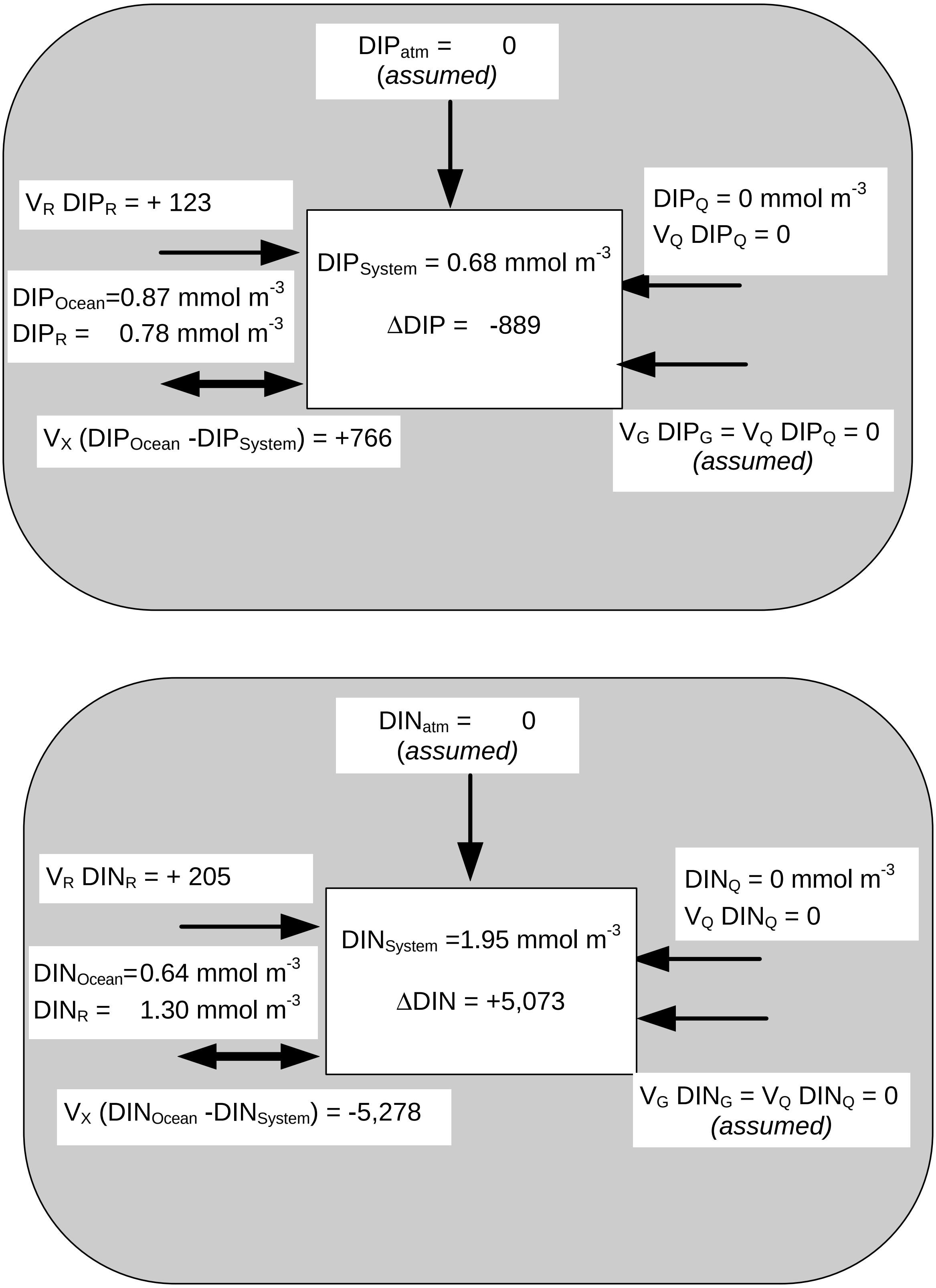


Figure 19. DIP and DIN budgets for Ensenada de La Paz, spring. Fluxes in mol day^{-1}.

2.2 Humid Pacific Coast

2.2.1) Bahía de Altata-Ensenada del Pabellón, Sonora

F.J. Flores-Verdugo and G. de la Lanza-Espino

Study Area Description

This site lies in Region B (as modified from Lankford, 1977; see Appendix I of this report). Within the organisation of this report, it is included the site among systems of the "humid Pacific Coast," because, unlike the previously discussed systems, rainfall plus runoff clearly exceeds evaporation. An important aspect of this system, again in contrast to the previously cited arid coast systems, this site includes the clear influence of agricultural activities on inflowing water composition.

Agricultural development around coastal lagoons is increasing without enough consideration of the environmental implications with respect to biodiversity and other aspects of ecological change. River diversions by dams and the artificial channelisation for the agricultural development increase problems of siltation inside the lagoons, erosion in the sand barriers and eutrophication and pesticides from agriculture waste waters toward drainage channels as non-point pollution sources.

The estuarine complex of Bahía de Altata-Ensenada del Pabellón lies near 107° 38' N and 24° 25' W (Figures 1 and 20). Bahía de Altata is a long, narrow lagoon running parallel to the coast, with sandy sediments, mean water depth of 5 meters with mainly marine conditions (32 psu). Ensenada del Pabellón is joined to this bay and is wider than Altata, with silt and clay sediments and a mean depth of 1 m and display mainly estuarine conditions wit salinities between 10 to 28 psu. The annual mean salinity for the whole system is approximately 28 psu. The adjacent marine water averages 35 psu. Water temperature varies from 20° C in January to 32° C in August. The area of the complex is approximately 460 km^2, including 100 km^2 of mangrove swamps. The Culiacan River discharge to the lagoon has a mean annual flow of (V_Q) about 3,400 x 10^6 m^3.

The depth of the system varies from less than 25 cm in the mangroves to 15 meters in La Tonina inlet. We estimate a mean depth of 3 meters for the whole system, giving a total volume of approximately 1,400 x 10^6 m^3. The system is separated from the sea by a narrow sand barrier interrupted with two inlets: a small and relatively recent one (called La Palmita) and the main one (La Tonina). The estuarine complex is located in the valley of Culiacan and received the agriculture discharges of the district by several drainage channels. This district comprises more than 2,700 km^2 of irrigated agricultural lands used mainly for horticultural production. The production of this district comprises one third of the total national horticultural export. Also three sugar cane industries and a paper mill discharges their waste into ponds connected to the system. Several authors have reported the presence of pesticides and heavy metals in the lagoon. Relatively recent the system is receiving a new impact from the waste waters of shrimp farms. The lagoon sustains an important fishing activity of shrimp (*Penaeus spp*), oyster (*Crassostrea corteziensis*), clam (*Chione subrugosa*) and fish such as snappers, mullets, etc. The borders of the lagoon and interior islands are covered by mangroves (*Rhizophora mangle*, *Laguncularia racemosa* and *Avicennia germinans*). The latter is the dominant mangrove species with 86% of the total density (from 4,800 to 7,600 trees ha^{-1}). Landward of the mangroves predominates a belt of seasonal floodplains with high salinity soils with no vegetation at all or with patches of the terrestrial halophytes (saltworts) *Salicornia spp* and *Batis sp*. locally known as "marismas". There is a special place where an extensive (100 km^2) freshwater marsh of cattail (*Thypha spp*) occurs (Chiricahueto) located in the SE of Pabellón and where several hundreds thousands ducks from Canada and the United States of America arrive during the winter. This freshwater swamp has increased in area as consequences of the agricultural waste waters displacing what use to be a seasonal flood plain The mean annual rainfall of the region is 670 mm and the mean annual evapotranspiration is 1,500 mm.

Concentrations of DIP vary in Pabellón from 3.1 (August) to 13 mmol m^{-3} (April) and in Altata from 2.5 to 5.8 mmol m^3. We estimate a mean annual values for the whole system of 7.2 mmol m^{-3}. In the adjacent ocean a mean value of 0.6 mmol m^{-3} can be observed and in the Culiacan river a mean value of 7.5. For DIN (nitrate + nitrite + ammonia) the values vary in Pabellón from 4.4 (February) to 6.3 mmol m^{-3} (August) and in Altata from 0.6 (February) to 0.8 (August). A DIN mean annual value of 3.7 mmol m^{-3} was estimated for the entire system, 0.6 for the ocean, 40 in the river. Nutrients are always lower in Altata compared to Pabellón as consequences of a higher oceanic water influences in Altata. In Ensenada del Pabellón there is more freshwater influence, mainly from the agricultural drainage.

Nutrients cycling from the sediments to the water were estimated to be as high as 0.6 mmol m^{-2} day^{-1} for ammonium and of 0.05 mmol m^{-2} day^{-1} for phosphate. In lagoon sediments influenced by sugar cane waste water values as high as 16 mmol m^{-2} day^{-1} for ammonium and 2,2 mmol m^{-2} day^{-1} for phosphate were detected, demonstrating that eutrophication is a clear problem in some parts of this system.

Plankton net annual productivity (*p*) was estimated to be of 267 g C m^{-3} $year^{-1}$, equivalent to about 70 mol C m^{-2} $year^{-1}$ The water column has a *p*/r ratio of 2.0 describing this part of the system as autotrophic in general.

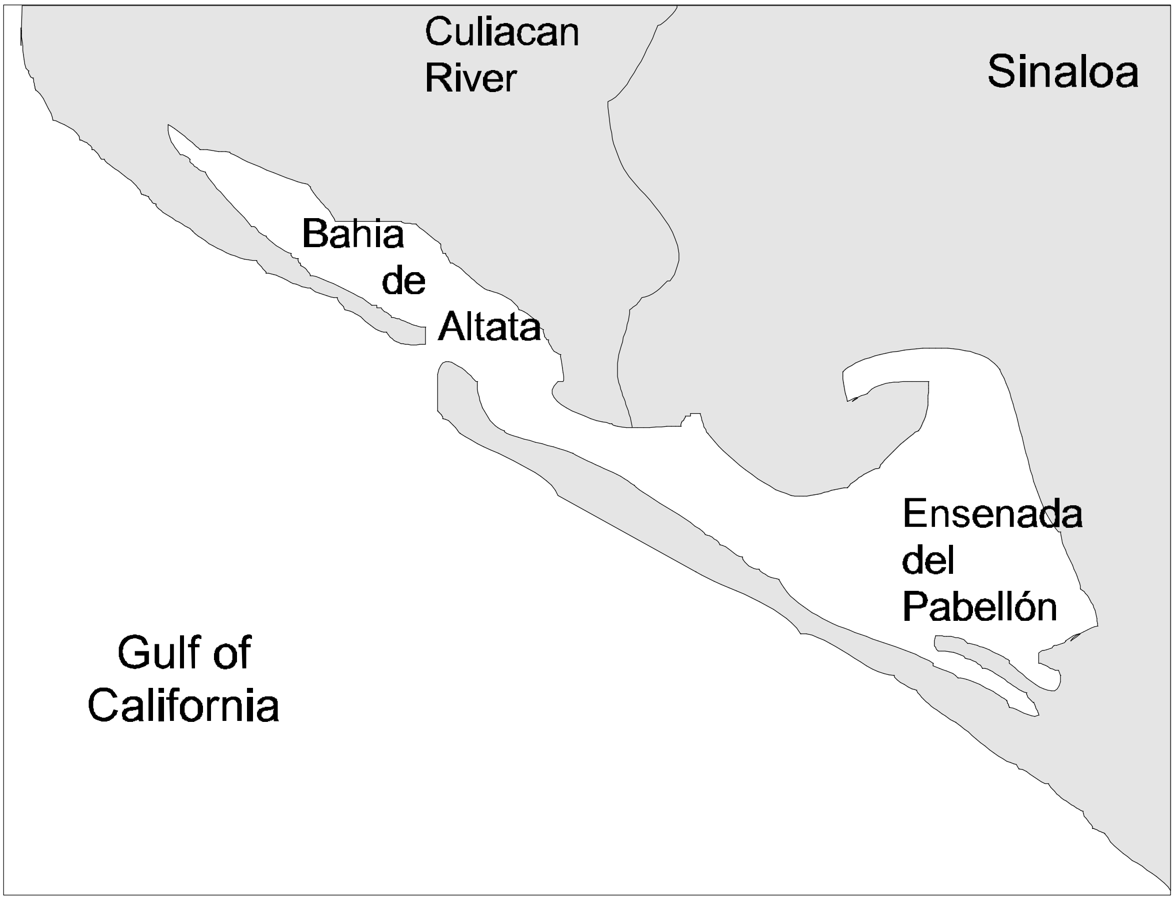


Figure 20. Map of Bahía de Altata-Ensenada del Pabellón.

Water and Salt Budgets

Figure 21 summarises the water and salt budgets for this system. Runoff (V_Q) + precipitation (V_P) substantially exceed evaporation (V_E), and groundwater input (V_G) is assumed to be zero. In order to balance the water budget, residual flow removes water and salt from the system ($V_R = -3{,}000 \times 10^6$ m^3 $year^{-1}$; $V_RS_R = -94{,}500 \times 10^6$ psu m^3 $year^{-1}$). In order to maintain a steady state salinity (that is $V_{system}dS_{system}/dt = 0$), salt must mix into the system ($V_X[S_{ocean}-S_{system}] = +94{,}500 \times 10^6$ psu m^3 $year^{-1}$). S_{ocean} and S_{system} are known, so we can solve for mixing ($V_X = 13{,}500 \times 10^6$ m^3 $year^{-1}$). The volume of the system is $1{,}400 \times 10^6$ m^3, so water exchange time can be calculated as $\tau = V_{system}/(|V_R| + V_X) =$ 0.08 year. That is, the water exchange time is about 1 month.

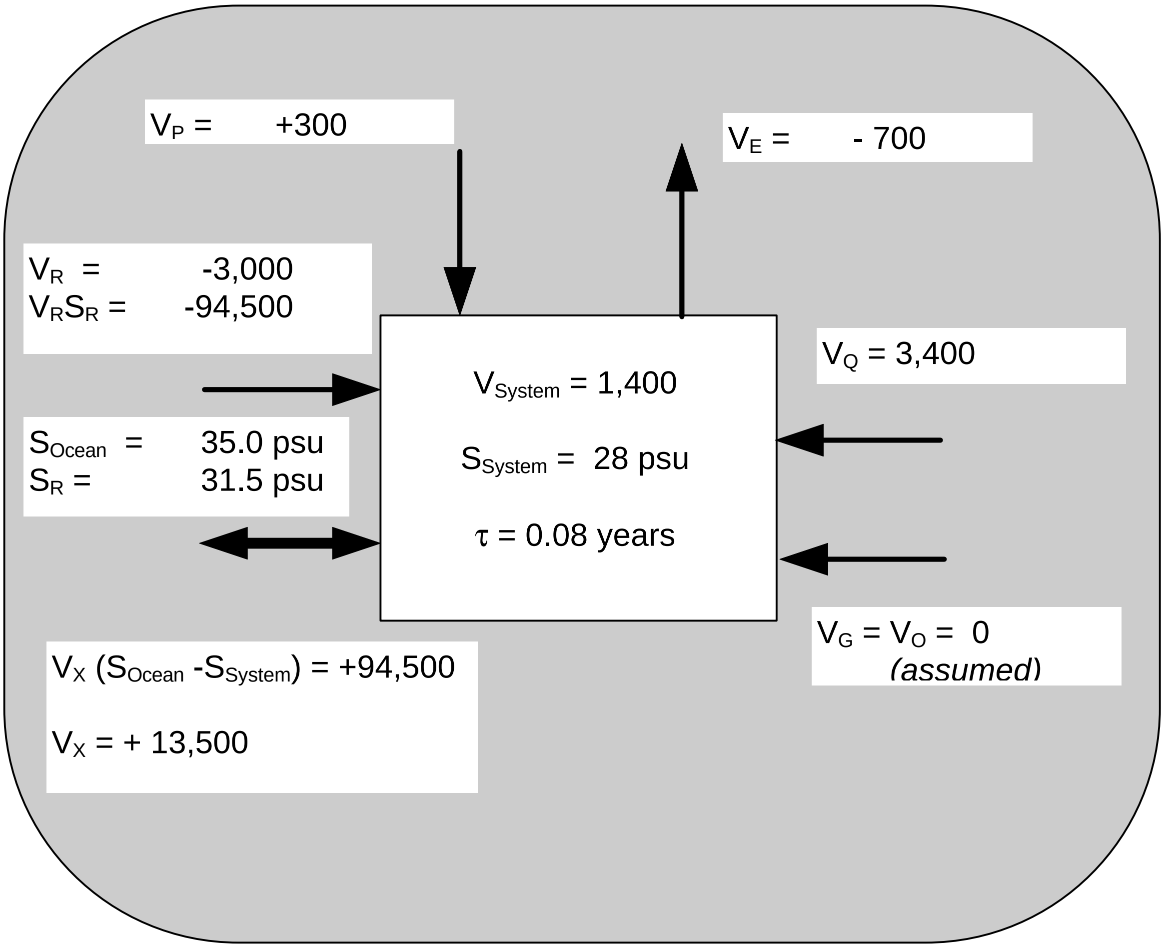


Figure 21. Water and salt budgets for Bahía Altata-Ensenada del Pabellón, annual average. System volume in 10^6 m^3. Water fluxes in 10^6 m^3 $year^{-1}$. Salt fluxes in 10^6 psu m^3 $year^{-1}$.

Budgets of Nonconservative Materials

Figure 22 summarises the DIP and DIN budgets for the system.

P Balance

Concentration and flux of DIP in river water flowing into this system are high, apparently reflecting the product of agricultural drainage into the system. System concentrations are also very high, and outward transport of DIP occurs via both residual flow and mixing. These outward fluxes greatly exceed the estimated river inflow of DIP, so there apparently is an internal source of DIP (*DDIP* = +75 x 10^{6} mol year^{-1} = +0.19 mol m^{-2} year^{-1}). We have observed that there is very high release of DIP, especially from the sediments associated with sugar cane wastes, so this and other organic discharges into the system are assumed to support the high nonconservative flux of DIP.

N Balance

Concentration and flux of DIN in river water are also high. While there is export of DIN both in the residual flow and in the mixing, this outward flux is substantially lower than the river DIN import. There must therefore be a substantial sink of DIN in this system (*DDIN* = -118 x 10^{6} mol year^{-1} = -0.46 mol m^{-2} year^{-1}). There is thus a clear discrepancy between the nonconservative fluxes of DIP and DIN.

Stoichiometric Calculations of Aspects of Net System Metabolism

Net nitrogen fixation minus denitrification in this system (*nfix-denit*) is calculated as the difference between observed and expected *DDIN*. Expected *DDIN is ∆DIP* multiplied by the N:P ratio of the reacting particulate organic matter. We do not know that N:P ratio. If this material were plankton, the expected ratio would be near the Redfield Ratio of 16:1. Waste from sugar cane or other terrestrial plant material might have a higher ratio, while animal wastes might be somewhat lower. Lacking a definitive value, we assume that the appropriate N:P ratio of decomposing organic matter is near the Redfield Ratio, and therefore that the expected value for *DDIN* is 16 x (75 x 10^{6}) mol year^{-1}. Thus:

(*nfix-denit*) = -118 x 10^{6} - 16 x (75 x 10^{6}) mol year^{-1} = -1,082 x 10^{6} mol year^{--1}
(-2.4 mol N m^{-2} year^{-1} over the area of the system).

Thus, the system appears to be denitrifying at a substantial rate.

We can also estimate net ecosystem metabolism (*NEM*), that is the difference between primary production and respiration (*p-r*), as the negative of the nonconservative DIP flux multiplied by the C:P ratio of the reacting material. Again, we do not know the C:P ratio of the reacting material, but it seems likely to equal or exceed the C:P ratio of plankton. Thus:

(*p-r*) = -106 x (75 x 10^{6} mol year^{-1}) = -7,950 x 10^{6} mol C year^{-1}
(-17 mol m^{-2} year^{-1} over the system area).

This is a substantial rate of net respiration, especially when compared with the estimated of primary production (17 mol C m^{-2} year^{-1}). Moreover, if the reacting material is terrigenous plant organic matter, the likely rate of (*p-r*) may well exceed what is estimated here. Nevertheless, we believe that these numbers make sense in view of the discharge of sugar cane and other agricultural waste products into this system.

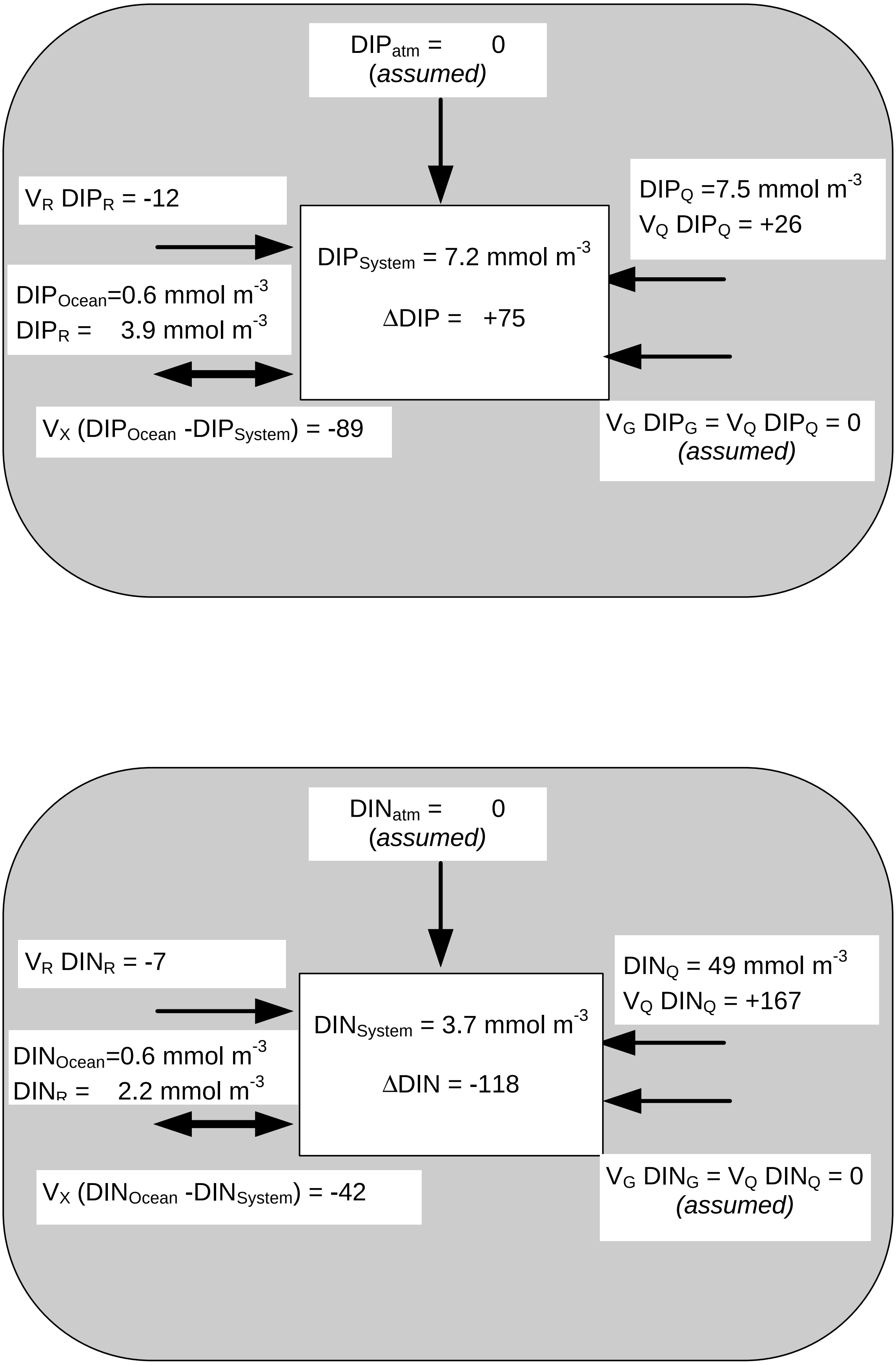


Figure 22. DIP and DIN budgets for Bahía Altata-Ensenada del Pabellón, annual average. Fluxes in 10^6 mol $year^{-1}$.

2.2.2) Teacapan-Agua Brava- Marismas Nacionales, Sinaloa and Nayarit

G. de la Lanza-Espino, F. J. Flores-Verdugo and F. Wulff

Study Area Description

Figures 1 and 23 illustrate the location and principal features of the mangrove-estuarine complex of Teacapan-Agua Brava-Marismas Nacionales (22° 08' N, 105° 32' W). A brief historical and natural history perspective is presented in the next paragraphs.

The region of Teacapan-Agua Brava-Marismas Nacionales has an ancient story for human settlements. There are evidences of considerable human populations over more than 1,500 years, in the forms of small hills of shells (*Tivela* sp.). Near the town of Mexcaltitan a tribal group migrated to the upper lands and founded the city of Tenochtitlan (now Mexico city), the capital of the Aztec empire. When the Spaniards arrived in the region in the 16th century, they estimated a population of more than 300,000 inhabitants; this can be considered extremely high for rural standards of those days. This high population density was sustained by the fertility of the land in the alluvial plain but also to the richness of seafood as oyster, shrimp and fishes. The region has been a used by several generations for multiple uses. Mangroves where mainly used for fuel and rustic construction, during the colonial age, an important industry of tannins for cow hide treatment was developed until the 19th century. The region was an important hunting ground up to the 1950's for jaguar and crocodile. In the winter, more than the 20% of the total migratory birds of the Pacific arrive enroute from Alaska, Canada and the United States. It is also possible to find areas with subhumid tropical forest and low human impact between the mangroves on some islands. The region indirectly supports one of the most important shark fishery in Mexico in the adjacent marine waters. Shrimp fishing is an important economical activity and recently shrimp farming is developing. In the beginning of the 1970's an artificial inlet was opened (Cuautla Channel) with the idea to allow the shrimp post-larvae get inside the Agua Brava lagoon more directly, but the channel widened uncontrollably from 40 m wide 3 m depth, as was planned, to more than 1,200 m wide and 18 m depth. The drastic change in the hydrological pattern killed more than 50 km^2 of mangroves. The aquaculture development without planning with an environmental sound management, the river dam construction programs together with the agricultural activities and the opening of artificial inlets, will put at risk the basic structural functions of the ecosystem and this actual and potential resources as important cultural values.

The area comprises approximately 2,000 km^2 of tidal channels, seasonal flood plains, more than 150 semi-parallel coastal lagoons formed by stranded beach ridges, big estuarine water bodies and mangrove swamps. The mangroves, small tidal channels and the semi-parallel coastal lagoons occupies approximately 1,100 km^2. The waterways occupy 500 km^2 (total area of the mangrove-estuarine complex 1,600 km^2). Water depths of the waterways vary from below 1 m to 18 m near the inlets, with a mean depth of 2 m. The mangrove water depth varies according to the species, being 0.40 m above mean sea level for the dominant species, the white mangrove (*Laguncularia racemosa*) and 0.7 m for the black mangrove (*Avicenia germinans*) we assume that during the flooding periods (flows) a mean value of 0.5 m is reasonable. Obviously 0.0 m depth is assumed during low ebb tides. A mean value (flows and ebbs) of 0.25 m is considered here to be appropriate. The total volume (V_1) of the mangrove-estuarine complex comprises 1,266 x 10^6 m^3.

There are 5 stream flows that discharge to the system: The Cañas, Rosamorada, Bejuco, Acaponeta and San Pedro rivers. But only the last two have flow all year around, with an annual flow of 3,000 x 10^6 m^3 $year^{-1}$ for the Acaponeta and 2,456 x 10^6 m^3 $year^{-1}$ for the San Pedro river. The other rivers are seasonal with flows below 180 x 10^6 m^3 $year^{-1}$. Precipitation is estimated to be about 1,459 mm $year^{-1}$ and evapotranspiration of 1,991 mm $year^{-1}$ (mean annual values of more than 10 years). Data on groundwater flow and non-point agriculture waste-waters that discharge to the system are not available.

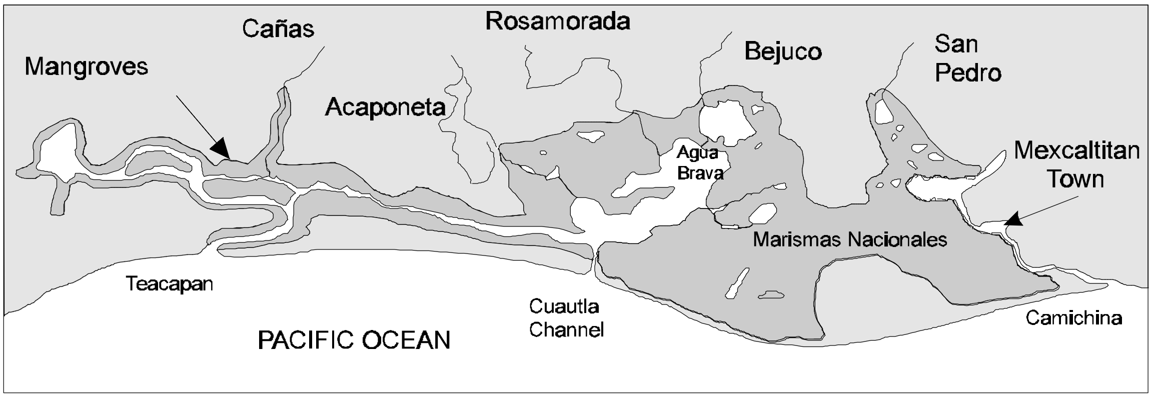


Figure 23. Teacapan-Agua Brava- Marismas Nacionales lagoon system.

Salinity: Salinities of freshwater from rivers and rainfall was assumed to be 0 psu, estuarine annual average salinity is about 20 psu, and adjacent coastal marine water (Pacific ocean) averages 34 psu.

Nutrients and other non conservative components: Data are available for DIP, DIN (nitrate, nitrite and ammonia) in this system Table 10. The freshwater nutrient concentration data have been weighted according to the relative flow rates of the two major rivers.

Other: Mangrove litter-fall in three sites averages about 1,200 g m^{-2} year^{-1}. If 40% of this material is considered carbon it is equivalent to approximately 40 mol C m^{-2} year^{-1}. Leaf degradation rate varied from about 2 in the soil to 5 year^{-1} in the water. Humid substances (DOC) can be greater than 100 mg l^{-1} with a mean value of 30 mg l^{-1}. Mean daily net plankton productivity in the Agua Brava lagoon is estimated to be of 0.4 g C m^{-2} d^{-1} equivalent to 12.5 mol C m^{-2} year^{-1}. In general the respiration rate in the water column is higher than the productivity so the water column is heterotrophic for most of the year (Gross Productivity/24 hour Respiration = 0.64), a reflection of the influence of high organic matter from rivers and mainly the adjacent mangroves swamps.

From these data we present the budgetary analysis as follows:

Table 9. Average nutrient concentration (mmol m^{-3}) for components of the Teacapan-Agua Brava-Marismas Nacionales mangrove-estuarine complex.

	Seawater (Y_2)	**System (Y_1)**	**Freshwater (Y_Q)**
DIP	0.5	0.7	32
DIN	2.5	4.0	93

Water and Salt Budgets

Figure 24 illustrates the average annual water and salt budgets for Teacapan-Agua Brava-Marismas Nacionales. Freshwater flow (V_Q) is estimated by adding the flows of the Acaponeta and San Pedro rivers (5,456 x 10^6 m^3 $year^{-1}$). Direct precipitation (Vp) and Evaporation (V_E) are estimated as 2,412 x 10^6 m^3 $year^{-1}$ and 3,223 x 10^6 m^3 $year^{-1}$, respectively, considering the area of the complex (1,619 x 10^6 m^2). The other components (V_G and V_o) are assumed to be small. The system shows substantial net residual outflow of water, as expected from the freshwater inputs to the system. It can be seen from these calculations that the water exchange time in this system is about a month.

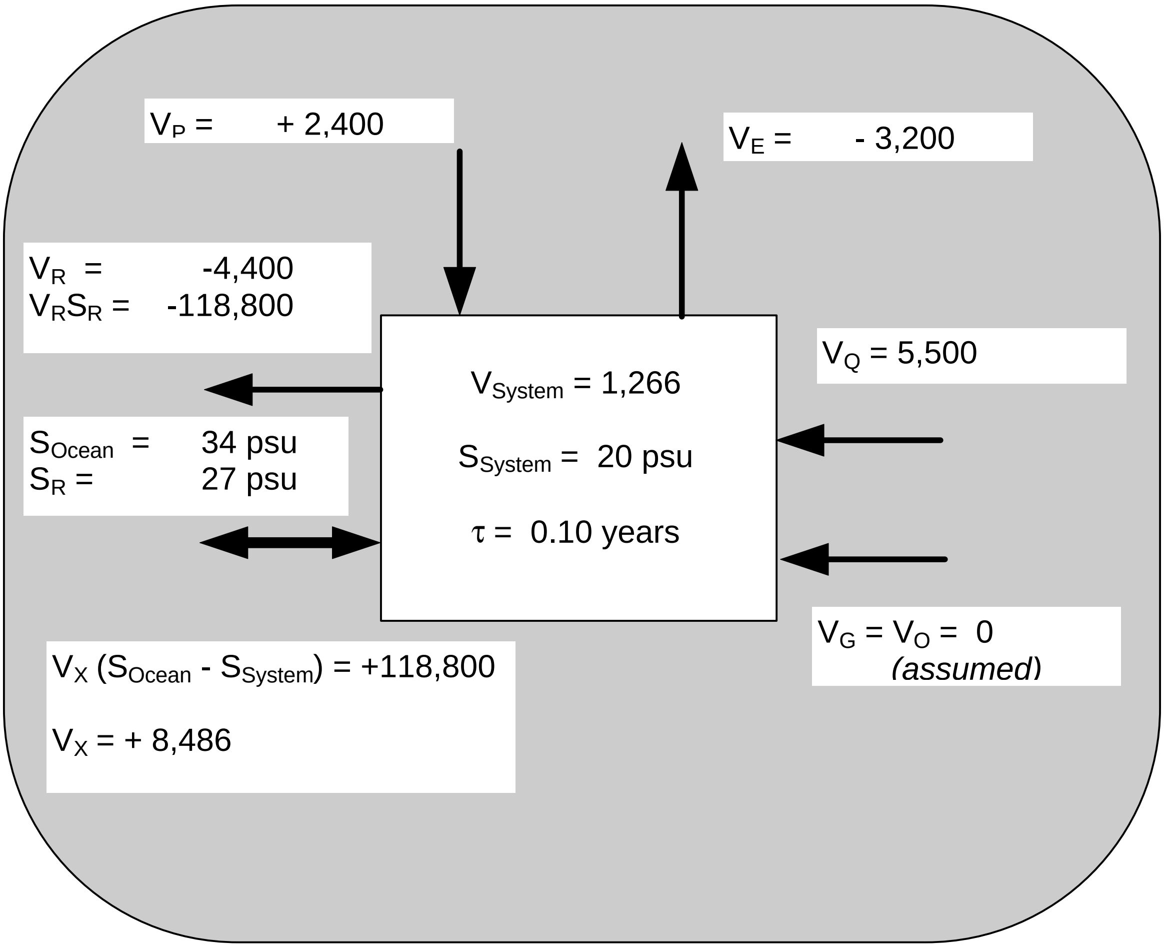


Figure 24. Water and salt budgets for Teacapan-Agua Brava-Marismas Nacionales, annual average. System volume is in units of 10^6 m^3. Water fluxes in 10^6 m^3 $year^{-1}$. Salt fluxes in 10^6 psu m^3 $year^{-1}$.

Budgets of Nonconservative Materials

Figure 25 illustrates the DIP and DIN budgets for these systems. The data are also listed in Tables 10-13.

P Balance

Substantial DIP comes in from terrigenous runoff into this system, but very little P exchanges with the ocean with either residual flow or exchange flow. Clearly the system takes up most of the DIP delivered to it. The system is a sink for virtually all of the land derived DIP (Figure 25). Thus, *DDIP* = -170 x 10^{6} mol year^{-1} = -0.11 mol m^{-2} year^{-1} over the mangrove-estuary area.

N Balance

Similarly to DIP, DIN comes in from land and is mostly trapped in the system (Figure 25). Thus, *DDIN* = -452 x 10^{6} mol year^{-1} = -0.28 mol m^{-2} year^{-1} over the mangrove-estuary area.

Stoichiometric Calculation of Aspects of Net System Metabolism

We can calculate net nitrogen fixation minus denitrification *(nfix-denit)* as the difference between observed and expected *DDIN*. Expected *DDIN* is *DDIP* multiplied by the N:P ratio of the reacting particulate organic matter. In a mangrove-dominated system, it is not entirely obvious what the dominating reactive organic matter is, so we use two N:P values. First, we employ the Redfield N:P ratio of plankton (16:1). Then we use a reactant which has an N:P ratio of 30:1, more typical of various land plants. Thus, with plankton:

(nfix-denit) = -452 x 10^{6} – 16 x (-170 x 10^{6}) = +2,268 x 10^{6} mol N year^{-1}
(+1.4 mol N m^{-2} year^{-1} over the estuary-mangrove area).

With land plants:

(nfix-denit) = -452 x 10^{6} – 30 x (-170 x 10^{6}) = +46,448 x 10^{6} mol N year^{-1}
(+2.9 mol N m^{-2} year^{-1} over the estuary-mangrove area).

Note that, with either material, the system appears likely to be fixing nitrogen in excess of denitrification.

Similarly, we can estimate net ecosystem metabolism (*NEM* = *p-r*) as the negative of the nonconservative DIP flux multiplied by the C:P ratio of the reacting organic matter. If the net reacting material is plankton, the particulate C:P ratio is about 106:1. If it is mangrove litter, then the ratio may be as high as 1000:1. With plankton:

(p-r) = -106 x (-170 x 10^{6}) = +18,020 x 10^{6} mol C year^{-1}
(+11 mol C m^{-2} year^{-1}).

With mangroves dominating the net production:

(p-r) = -1,000 x (-170 x 10^{6}) = +170,000 x 10^{6} mol C year^{-1}
(+106 mol C m^{-2} year^{-1}).

This latter figure is about double the rate of mangrove litter production, and that production should approach an upper limit of net primary production. We therefore suggest that the lower figure more accurately reflects the likely rate of net ecosystem production. In either case, if the DIP uptake primarily represents net organic metabolism, rather than inorganic sorption or precipitation of P, this system is strongly net autotrophic.

We assume that the lower value more accurately reflects (*p-r*). Primary production was estimated above to be about 30 mol C m^{-2} year^{-1}, implying that respiration is approximately 30. These numbers suggest that the *p/r* ratio of the system is about 1.3.

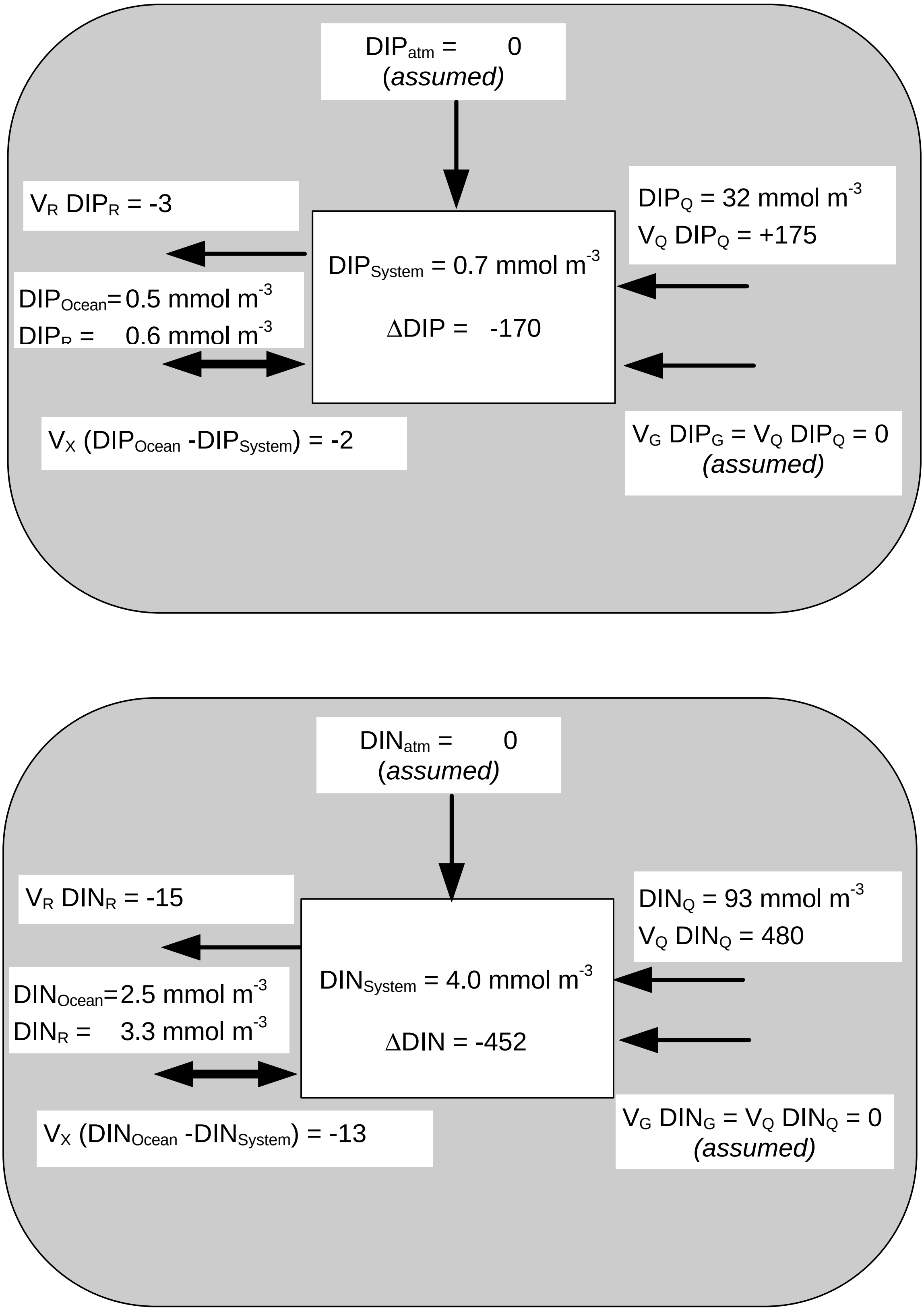


Figure 25. DIP and DIN budgets for Teacapan-Agua Brava-Marismas Nacionales, annual average. Fluxes in 10^6 mol $year^{-1}$.

2.2.3) Carretas-Pereyra, Chiapas

F. Contreras-Espinosa

System Description

The Carretas - Pereyra coastal system (15° 27' N, 93° 10' W; Figures 1and 26), is formed by 4 small lagoons (Pereyra, Carretas, Bobo and Buenavista). Total size of system is about 35 km^2. The depth is about 1.5 m, so the volume is estimated to be 53 x 10^6 m^3. Rainfall is about 2.3 m $year^{-1}$, and evaporation is about 0.8 m $year^{-1}$. Runoff totals about 240 x 10^6 m^3 $year^{-1}$. The system has a rates of primary production that measured as ranging from 288 to 764 mg C m^{-3} $hour^{-1}$ (Contreras, 1993).

Ecological conditions are similar to Chantuto system (Section 2.2.4), because the two systems are close to one another (seasonal variations by wet and dry seasons with strong influences over productivity and fisheries; mangrove vegetation is dominant). Both systems are within “La Encrucijada” Biosphere Reserve. Social and economic consideration from Chantuto are same for this system. Shrimp fisheries is the principal economic activity and the problem of excessive sedimentation is similar to Chantuto.

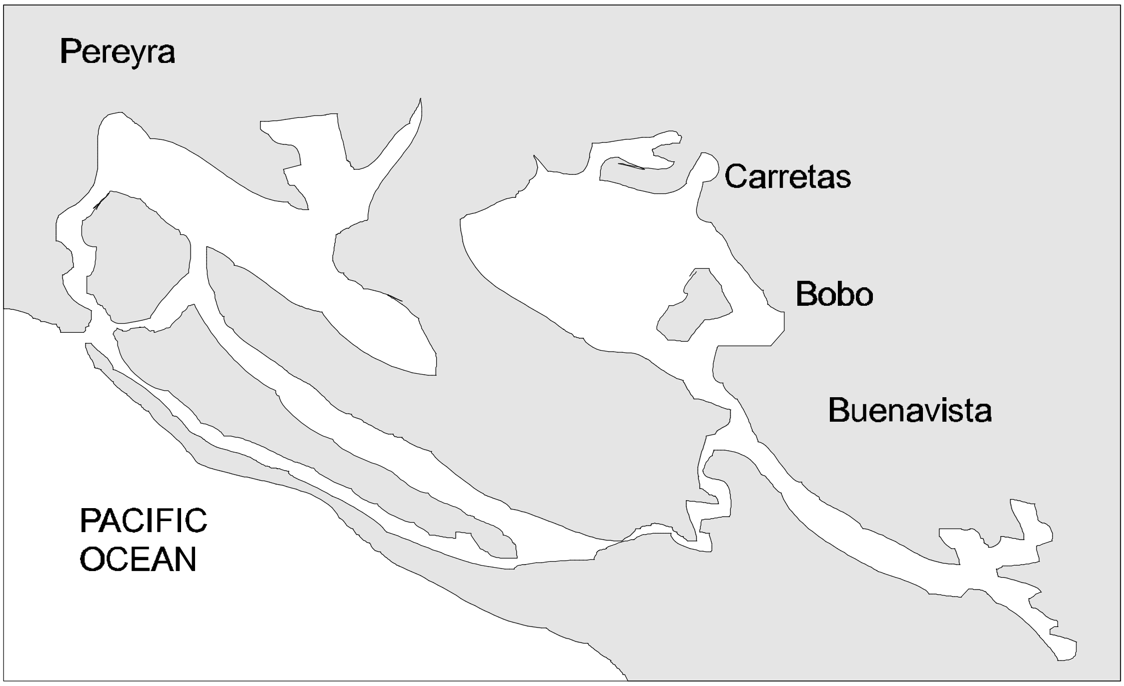


Figure 26. Map of the Carretas-Pereyra System.

Water and Salt Budgets

Figure 27 summarises the water and salt budgets for this system. Runoff into this system is about 230 x 10^6 m^3 $year^{-1}$; rainfall is about 80 x 10^6 m^3 $year^{-1}$; and evaporation is about 20 x 10^6 m^3 $year^{-1}$. Therefore residual flow out of this system totals about 300 x 10^6 m^3 $year^{-1}$. We assume that freshwater inflow has a salinity of 0 psu. Oceanic salinity adjacent to the lagoon is estimated to have a salinity of about 21.6 psu, and the average lagoon salinity is about 10.8 psu. With these figures a water exchange time of about 0.07 years (~ 26 days) is calculated.

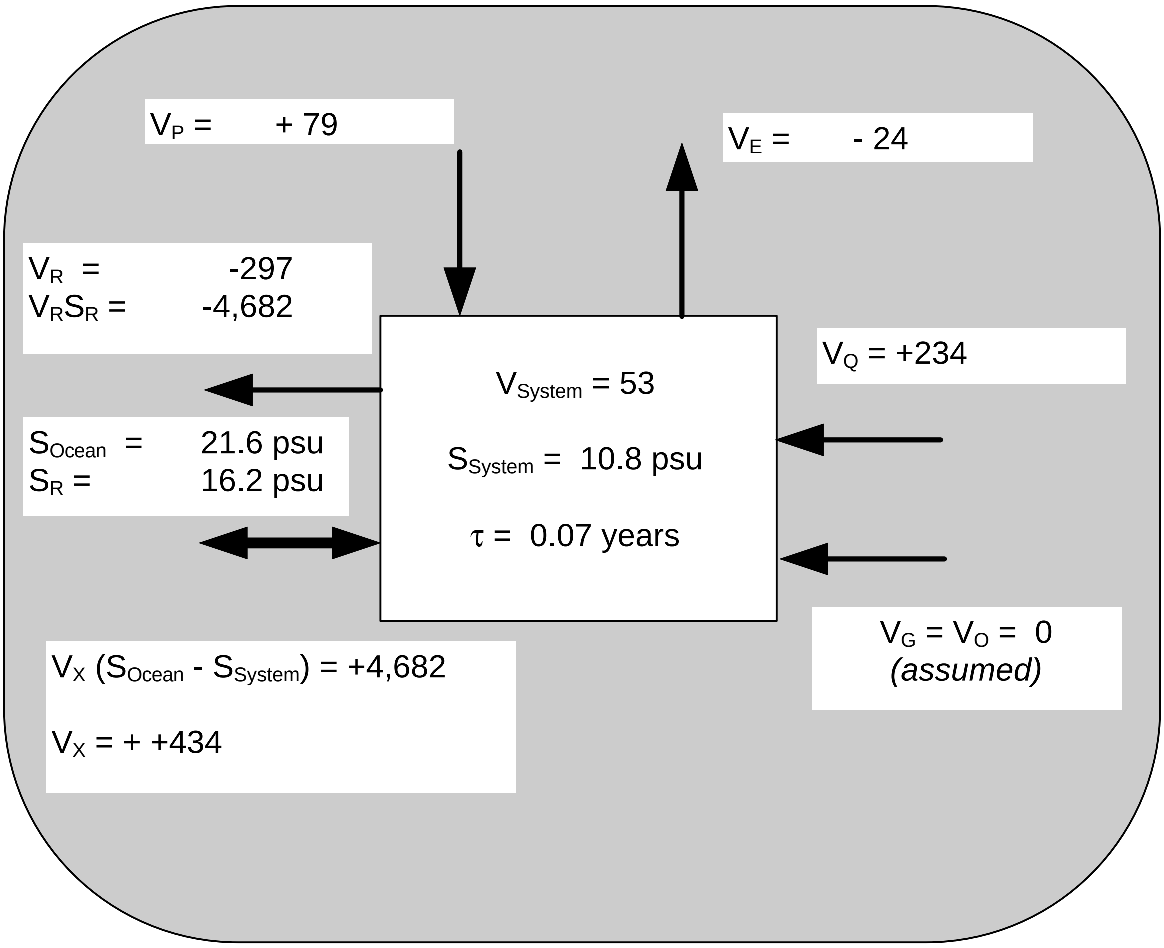


Figure 27. Water and salt budgets for Carretas-Pereyra, annual average. System volume is in units of 10^6 m^3 . Water fluxes in 10^6 m^3 $year^{-1}$. Salt fluxes in 10^6 psu m^3 $year^{-1}$.

Budgets of Nonconservative Materials

Figure 28 summarises the DIP and DIN budgets for this system.

P Balance

DIP concentration in the Carretas-Pereyra lagoonal complex is relatively high and riverine input is low. As a result, the calculations indicate that *DDIP* is positive (+3 x 10^6 mol $year^{-1}$). This is equivalent to a flux of 0.09 mol m^{-2} $year^{-1}$.

N Balance

Similarly, there is a positive nonconservative flux of DIN within this system (*DDIN* = 3 x 10^6 mol $year^{-1}$; 0.09 mmol m^{-2} $year^{-1}$).

Stoichiometric Calculations of Aspects of Net System Metabolism

Net nitrogen fixation minus denitrification *(nfix-denit)* is calculated as the difference between observed and expected *DDIN*. Expected *DDIN* is *DDIP* multiplied by the N:P ratio of the reacting particulate organic matter. In a mangrove-dominated system, it is not entirely obvious what the dominating reactive organic matter is, so we use two N:P values. First, we employ the Redfield N:P ratio of plankton (16:1). Then we use a reactant which has an N:P ratio of 30:1, more typical of various land plants. Thus, with plankton:

(nfix-denit) = +3 x 10^6 – 16 x (+3 x 10^6) = -45 x 10^6 mol N $year^{-1}$
(-1.2 mol N m^{-2} $year^{-1}$ over the estuary area).

With land plants:

(nfix-denit) = +3 x 10^6 – 30 x (3 x 10^6) = -87 x 10^6 mol N year-1
(-2.5 mol N m^{-2} $year^{-1}$ over the estuary area).

Note that, with either material, the system appears likely to be a net denitrification system.

Similarly, we can estimate net ecosystem metabolism (*NEM* = *p-r*) as the negative of the nonconservative DIP flux multiplied by the C:P ratio of the reacting organic matter. If the net reacting material is plankton, the particulate C:P ratio is about 106:1. If it is mangrove litter, then the ratio may be as high as 1000:1. With plankton:

(p-r) = -106 x (+3 x 10^6) = -318 x 10^6 mol C $year^{-1}$
(-9 mol C m^{-2} $year^{-1}$)

With mangroves dominating the net metabolism:

(p-r) = -1,000 x (+3 x 10^6) = +3,000 x 10^6 mol C $year^{-1}$
(+86 mol C m^{-2} $year^{-1}$).

This latter figure is about double the likely rate of mangrove litter production (based on data from Agua Brava), and that production should approach an upper limit of net primary production. We therefore suggest that the lower figure more accurately reflects the likely rate of net ecosystem production. In either case, if the DIP uptake primarily represents net organic metabolism, rather than inorganic sorption or precipitation of P, this system is net heterotrophic.

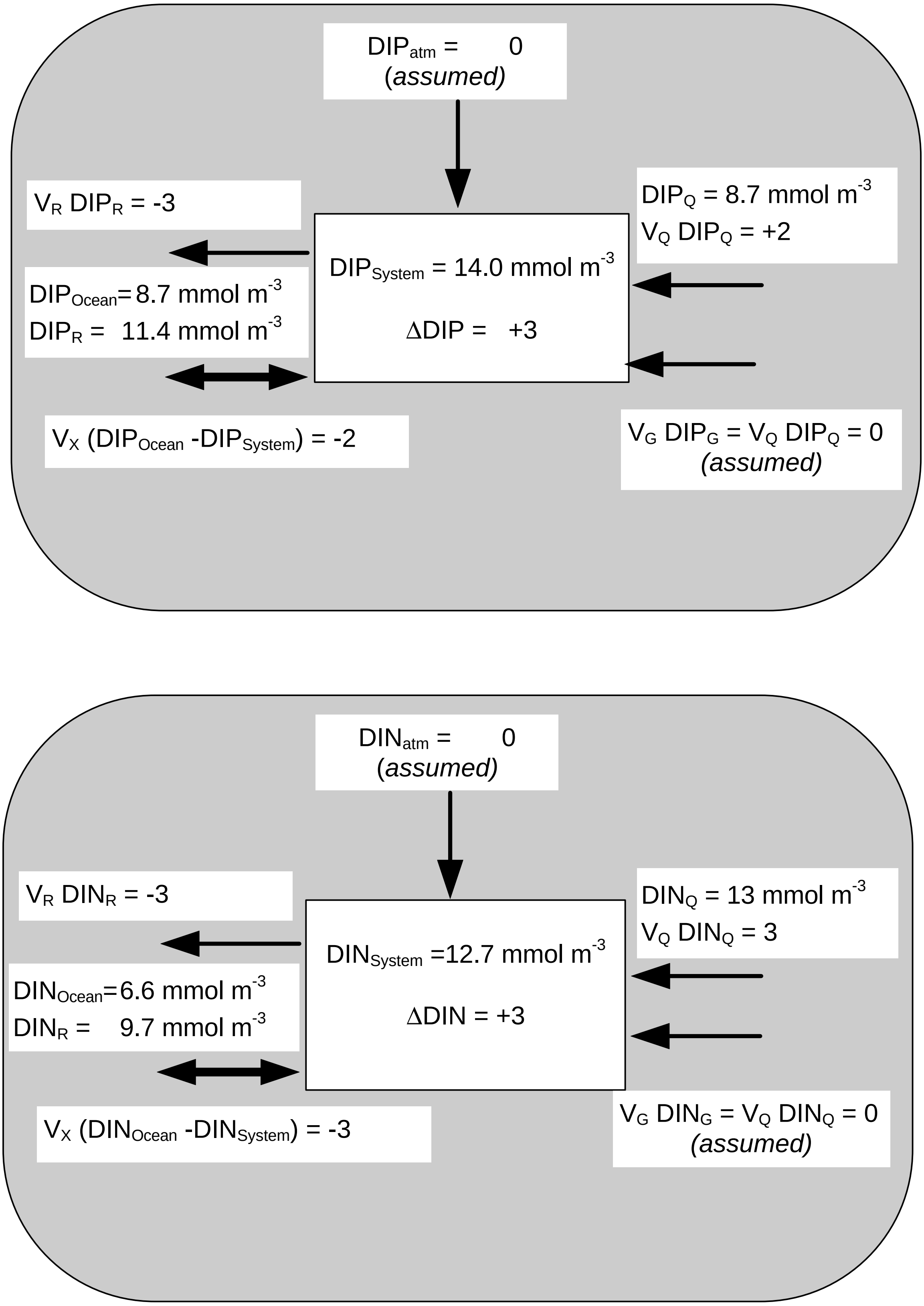


Figure 28. DIP and DIN budgets for Carretas-Pereyra, annual average. Fluxes in 10^6 mol $year^{-1}$.

2.2.4 Chantuto-Panzacola, Chiapas

F. Contreras-Espinosa and S. Ibarra-Obando

Study Area Description

The Chantuto-Panzacola estuarine system (15° 13’ N, 92° 50’ W; Figures 1 and 29), is located in the state of Chiapas, The system is formed by five major lagoons: Chantuto, Campon, Teculapa, Cerritos and Panzacola and received drainage from six rivers: San Nicolas (Payacal), Ulapa, Cacaluta, Dona Maria, Cintalapa and Vado Ancho. The drainage basin is about 300 x 10^6 m^3 and the average flow (V_Q) is about 725 x 10^6 m^3 $year^{-1}$. Rainfall averages about 3,000 mm $year^{-1}$, and evaporation about 800 mm $year^{-1}$. About 20,000 people live in the municipality where the system is located (Acapetahua). The total estuary + mangrove extension is about 180 km^2; of this, approximately 30 x 10^6 m^2 is open water. The open water area averages only about 1.5 m in depth. The mouth is permanent and communicates with the sea and there is also a long estuarine belt parallel to the sand bar.

The biotic community is dominated by mangroves (*Rhizophora mangle)* and during the rainy season freshwater vegetation is characteristic in the Cerritos lagoon (*Nymphae blanda*, *Cabomba* sp., *Pistia stratiotes*, *Salvinia* sp., *Azola* sp. *Eichornia crassipes* and *Neptunia* sp.). Primary production values range from about 50 to 260 mg C m^{-3} h^{-1} and chlorophyll *a* values from 8-35 mg m^{-3}.

Information on the physico-chemical variables is available in Contreras (1993) and, for purposes of this exercise is spelled out in the box diagrams.

The upper basin still has native vegetation, as these areas are protected under a Biosphere Reserve status. Inhabitants in these areas are largely isolated therefore have few basic services. Recent road construction has accelerated erosion processes. Adjacent areas include precious wood forests that are exploited (red cedar, mahogany) and areas where secondary vegetation and agricultural fields have replaced the original vegetation. Coffee represents an important crop from the economic point of view but it is grown in areas where the soil layer is very thin, causing lost of vegetative cover during the rainy period. Areas of the basin devoted to both agriculture and cattle raising have lost their original vegetation as a result of erosion processes. Erosion is presently a major threat to the area, and no management plan exists to control the situation.

The main activities in the coastal zone of Chiapas include agriculture, cattle raising and fisheries. Among the fisheries, prawn fisheries inside the estuaries is the most important activity to such a degree that 70% of the local annual income is due to this activity.

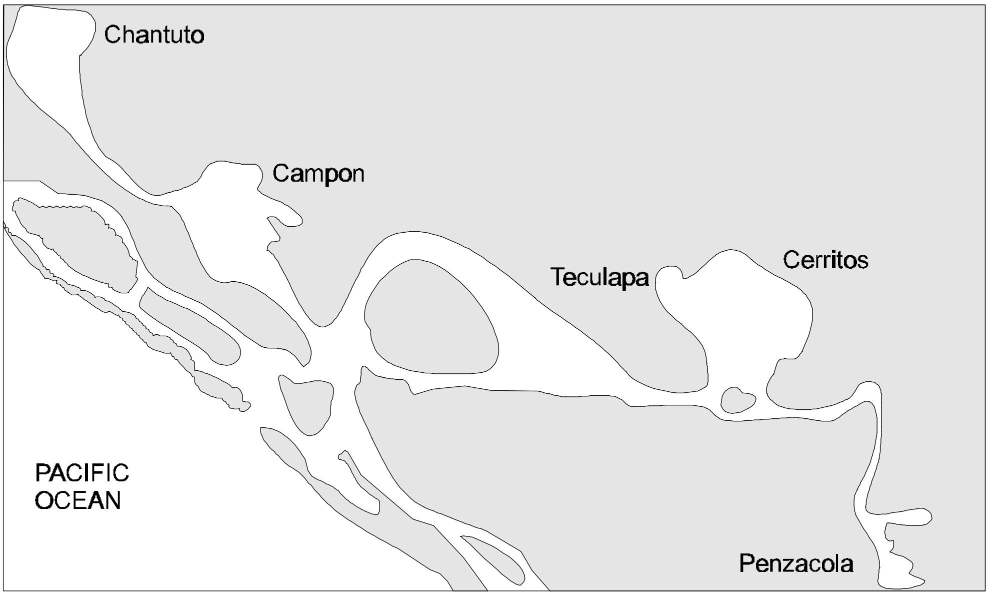


Figure 29. The Chantuto-Panzacola estuarine system

Water and Salt Budgets

Figure 30 summarises the water and salt budgets for the system. Freshwater inflow is assumed to have a salinity near 0 psu. Salinity in the system averages about 14 psu, and salinity of the coastal ocean exchanging with this system average about 22 psu over the year. Runoff is estimated to be 690 x 10^6 m^3 $year^{-1}$; rainfall is about 90 x 10^6 m^3 $year^{-1}$; and evaporation is about 24 x 10^6 m^3 $year^{-1}$. With these values, the estimated water exchange time is about 0.02 year, or about a week.

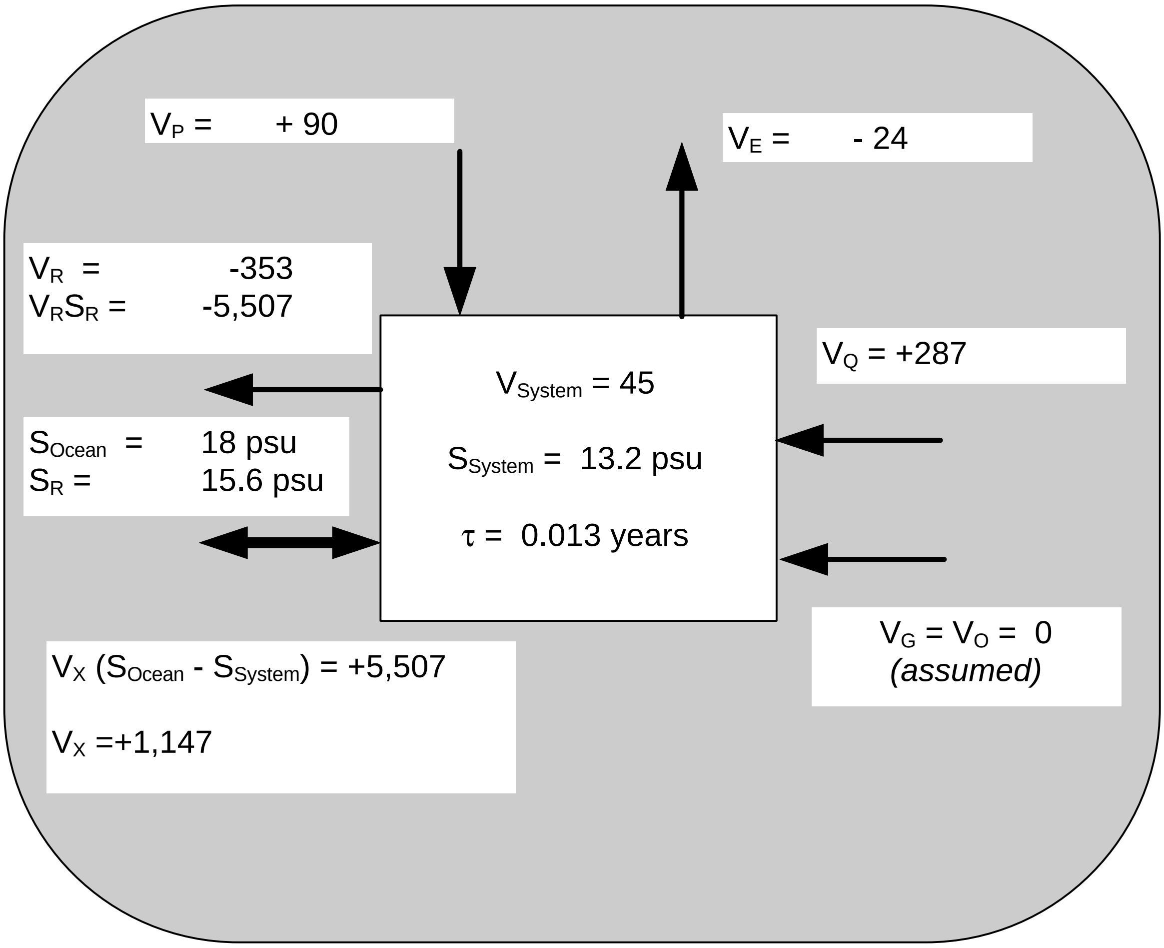


Figure 30. Water and salt budgets for Chantuto-Panzacola, annual average. System volume is in units of 10^6 m^3 . Water fluxes in 10^6 m^3 $year^{-1}$. Salt fluxes in 10^6 psu m^3 $year^{-1}$.

Budgets of Nonconservative Materials

Figure 31 summarises the P and N budgets for the Chantuto- Panzacola lagoonal system, Chiapas.

P Balance

This system appears to be approximately neutral with respect to *DDIP*, perhaps reflecting the relatively short water exchange time.

N Balance

The system is a very slight net producer of DIN (*DDIN* = +4 x 10^{6} mol year^{-1} = +0.14 mol m^{-2} year^{-1} across the open-water area of the system.

Stoichiometric Calculations of Aspects of Net System Metabolism

These rates are too near 0 to be confident of stoichiometric calculations. However, the system apparently has a net organic production rate near 0 and suggests a rate of (*nfix-denit*) of +4 x 10^{6} mol year^{-1}, or about +0.15 mol m^{-2} year^{-1}. At least qualitatively, the system seems to be a net nitrogen fixer, although we are not confident of the absolute rate.

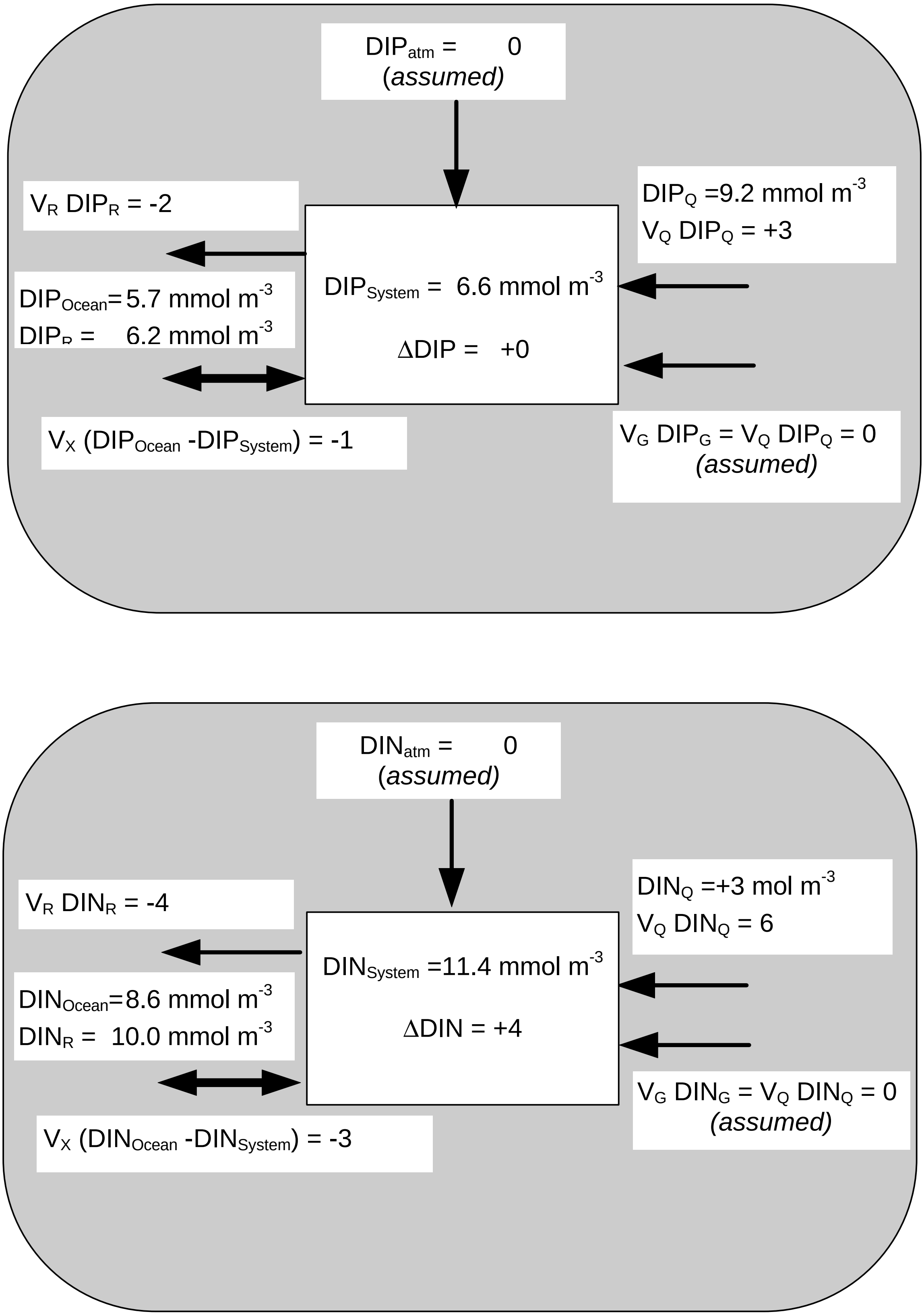


Figure 31. DIP and DIN budgets for Chantuto-Panzacola, annual average. Fluxes in 10^6 mol $year^{-1}$.

2.3 Gulf of Mexico

2.3.1) Laguna Madre, Tamaulipas

S. Ibarra-Obando and F. Contreras-Espinosa

Study Area Description

Laguna Madre (Figures 1 and 32, 23-25° N, 97° W) is located on the Gulf of Mexico shoreline. Its northern limit is the Rio Bravo delta, and its southern limit the mouth of the Soto La Marina river. It occupies a shallow basin that has an average depth of 0.7 m, and an area of about 2,000 km^2; it is the largest Mexican lagoon. It is separated from the sea by a sand bar. The San Fernando river mouth divides the lagoon into two sub-basins, known as North and South. The lagoon presents 13 mouths that communicate with the sea only on a temporal basis, as sediment accumulation after cyclones and hurricanes promotes their closure (Contreras, 1993).

Climate is arid with evaporation being far more important than freshwater input from rivers. As a consequence, the lagoon is drying out, with increasing salinity in the remaining water body, and salt deposition in its margins. Average evaporation is 1,900 mm $year^{-1}$, and average precipitation 600 mm $year^{-1}$. River freshwater input which might flow into the system is diverted for agricultural and urban purposes, so none gets into the lagoon (Estado de Tamaulipas, 1996).

Dune vegetation exists at the lagoon margins, being represented by the following species: *Uniola paniculata*, *Ipomoea pescaprae* and *Croton punctulatus*. Halophytes like *Spartina spartinae*, *Suaeda nigrica*, *Salicornia ambigua* and *Distichlis spicata*, are also found. Upland areas present both spiny shrubs and low forest spiny species, like mesquite and ebony. Submerged vegetation consist of algae and seagrasses, which have been greatly reduced by the desiccation process and hypersaline conditions. Only after heavy rains and mouth openings, salinity decreases, but this effect is only temporary (Contreras, 1993). Halophytes are also disappearing from the lagoon margins, promoting erosional areas that also contribute to lagoon infilling (Estado de Tamaulipas, 1996).

The icthyofauna comprises 78 species, among which prawns, croakers, snooks, mullets and houndsharks are the most representative (Contreras, 1993). Oyster and prawn aquacultural projects have failed due to poor water quality conditions (lack of freshwater input, and lack of a free water exchange with the ocean). For the same reasons, crab harvest has declined. The lagoon is also well known for being a resting, feeding and reproductive site for migratory waterfowl, mainly ducks: *Aythya americana* and *Anas discors* (Estado de Tamaulipas, 1996).

Urban wastewater, as well as pesticides, herbicides and fertilisers residues represent the main pollution source. Boat traffic contributes to pollution by oil and fuel spill, as well as boat washing. Pollutant products are spilled in the open ocean without any regulation. All these products are carried away by currents and end up in the lagoon (Tamaulipas State Government, 1996).

About 80,000 people inhabit the area around the lagoon. The coastal plain represents one of the most important agricultural areas of the country, being among the most important crops: cotton, cereals, leguminous and oily crops. Cattle raising is also an economically important activity. Besides the artesanal fishery, large scale fisheries are represented by tuna and prawn fisheries. For the Laguna Madre area, fisheries represent the most important economic activity, although the volume captured is small (Estado de Tamaulipas, 1996).

Phytoplankton primary production for this system has been estimated to be about 600 g C m^{-2} $year^{-1}$ (i.e., about 50 mol C m^{-2} $year^{-1}$).

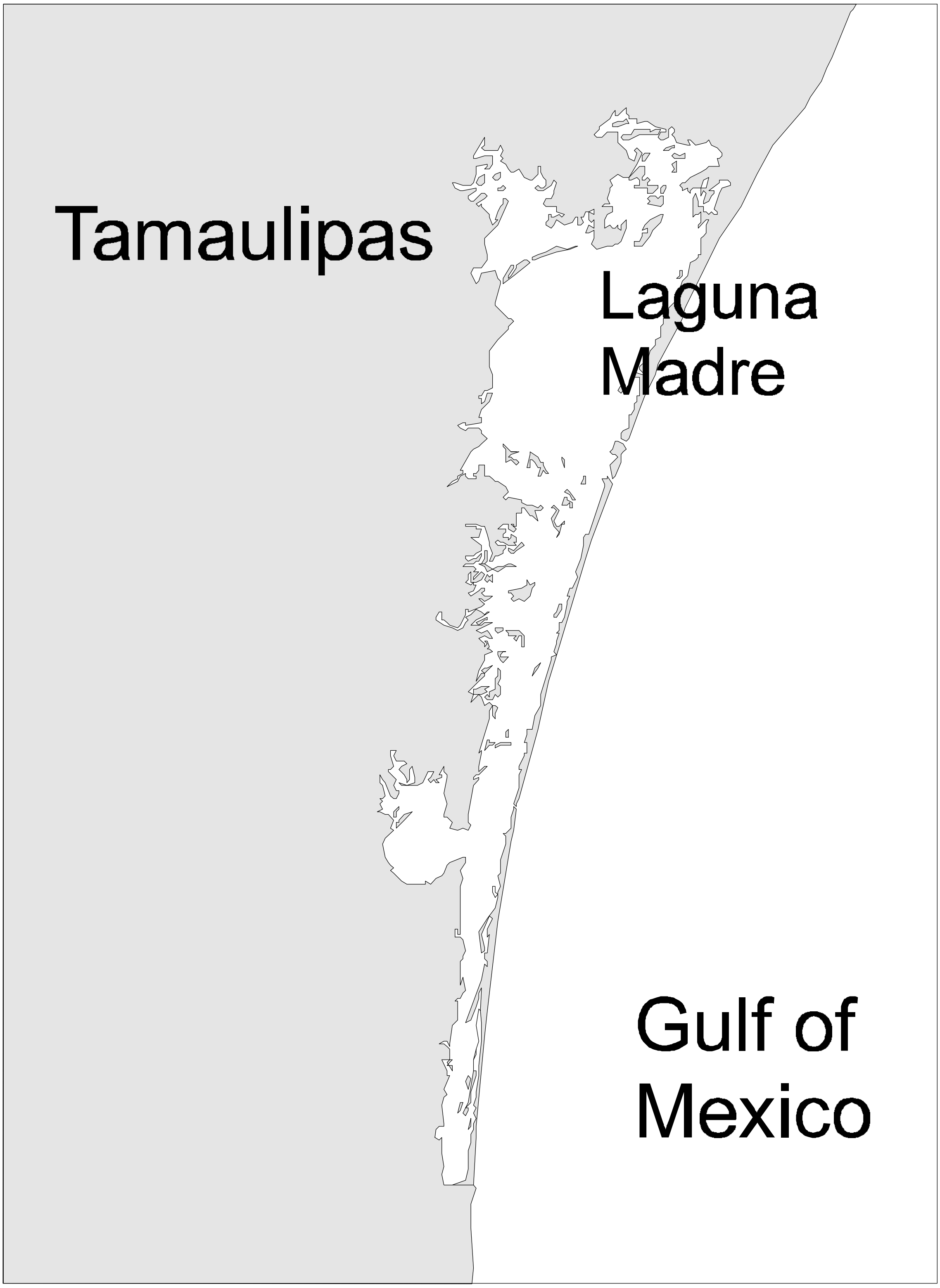


Figure 32. Map of Laguna Madre.

Water and Salt Budgets

Figure 33 summarises the water and salt budgets for Laguna Madre. Like the systems for the arid Pacific (Section 2.1) and unlike the humid Pacific (Section 2.2), Laguna Madre is a net evaporative system and shows penetration of water from the ocean. This seawater penetration delivers salt, so salt mixing is outward in order to maintain a steady-state salinity in the system. The estimated water exchange time (τ) is determined as has been discussed in other sections and is about 0.09 year, that is, about 1 month.

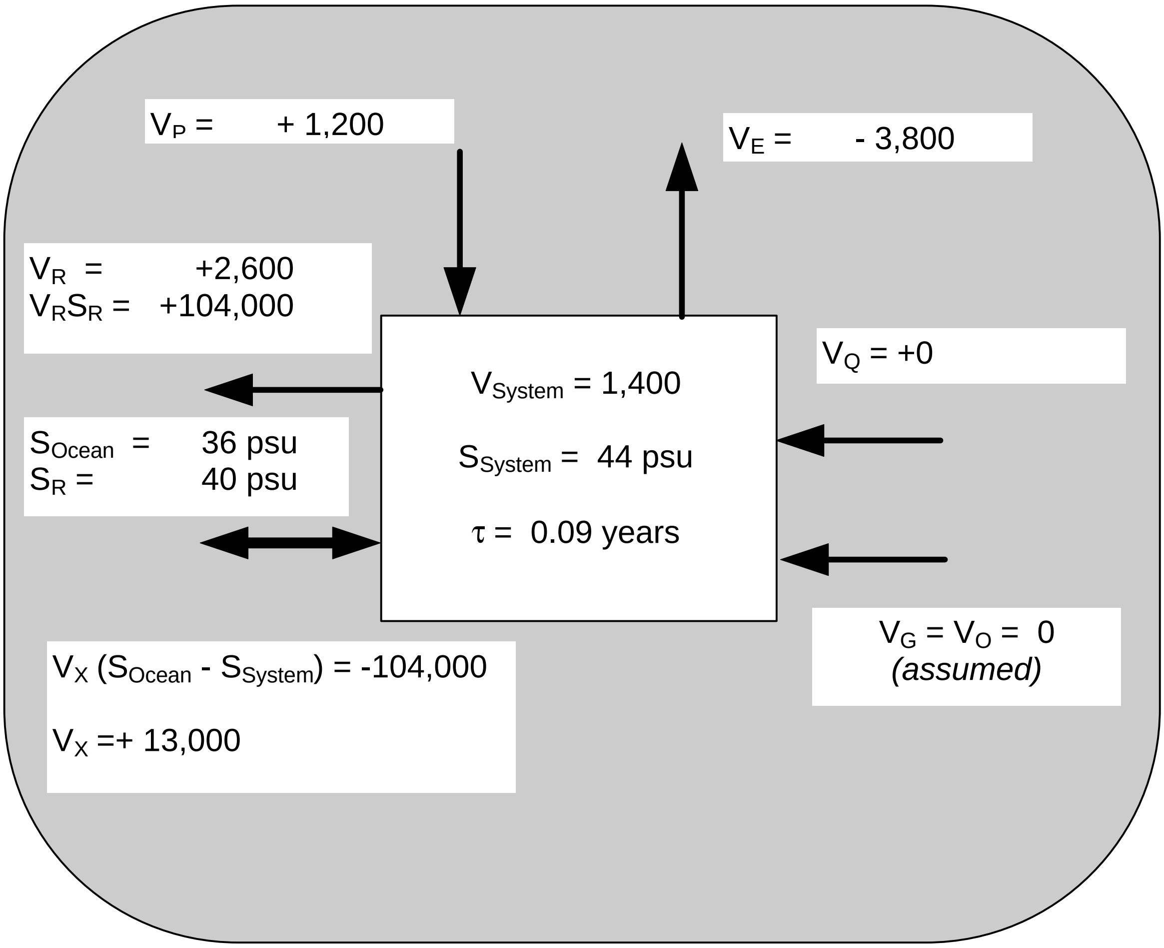


Figure 33. Water and salt budgets for Laguna Madre, annual average. System volume is in units of 10^6 m^3 Water fluxes in 10^6 m^3 $year^{-1}$. Salt fluxes in 10^6 psu m^3 $year^{-1}$.

Budgets of Nonconservative Materials

Figure 34 summarises the DIP and DIN budgets for this system.

P Balance

This system is a clear net source for DIP. Even though the rate of nonconservative DIP flux is relatively small (*DDIP* = +31 x 10^6 mol year^{--1} = 0.02 mol m^{-2} year^{-1}), this rate results in a strong concentration gradient between the system and the coastal ocean. The first consideration was that this DIP production is consistent with the production seen for the various arid systems of the arid Pacific coast (section 2.1). That analogy seems to be an unlikely explanation for this phenomenon in Laguna Madre, because the oligotrophic coastal ocean waters seem unlikely to be a major source of oceanic organic matter delivery to the lagoon. The next alternative considered was direct discharge of human wastes. This source would deliver both organic and inorganic P; as long as the organic P decomposed to inorganic material, the two would be indistinguishable in the budget. If we consider the human population living adjacent to the lagoon (80,000) and use an approximate per capita P discharge of 20 mol person^{-1} year^{-1}, then this P source would amount to only approximately 2 x 10^6 mol DIP year^{-1}. It therefore seems certain that there are other sources of either direct discharge of DIP into this system or organic P discharge and decomposition of that organic matter. Hydrocarbon pollutants and agricultural waste seem the most plausible sources. In either case, the decomposition of these materials would constitute DIP sources to sustain the apparently net heterotrophic conditions of this system.

N Balance

This system is also a source of DIN (*DDIN* = +61 x 10^6 mol year^{--1} = 0.03 mol m^{-2} year^{-1}). Both NO_3 and NH_4 are elevated well above oceanic values ($NO_{3System}$ = 2.8; NO_{3Ocean} = 0.3; $NH_{4System}$ = 4.6; NH_{4Ocean} = 1.5; all units in mmol m^{-3}). The relatively high concentrations of NH_4 also tend to suggest that the nutrient source is at least partially the result of organic decomposition.

Stoichiometric Calculations of Aspects of Net System Metabolism

Estimation of nitrogen fixation - denitrification (*nfix-denit)* is made from the difference between observed and expected *DDIN*, where the expected value is given by *DDIP* x N:P ratio of the decomposing organic matter. Although we do not know the source of this material, we assume that it has an N:P ratio approximating the Redfield Ratio (16:1). Therefore:

(*nfix-denit*) = +61 x 10^6 - 16 x (+31 x 10^6) = -435 x 10^6 mol year^{-1}
(-0.2 mol m^{-2} year^{-1} averaged over the entire lagoon).

This value is obviously uncertain, because we cannot readily predict the nature of the decomposing organic matter. Nevertheless, the calculated rate seems reasonable.

Net ecosystem metabolism (*NEM* = [*p-r*]) can also be estimated from *DDIP*, again with the uncertainty as to the nature of the primary organic matter which is apparently decomposing. This quantity is estimated as the negative of *DDIP* multiplied by the C:P ratio of the reacting organic matter. For the sake of this calculation, we assume that the reacting organic matter has an approximately Redfield C:P ratio of 106:1. Thus:

(*p-r*) = -106 x (+31 x 10^6) = 3,286 x 10^6 mol year^{-1}
(-2 mol m^{-2} year^{-1} over the lagoon area).

That is the system appears to be net heterotrophic by approximately 2 mol m^{-2} year^{-1}. This value is about 4% of the estimated annual primary production; thus the *p/r* ratio of this system is about 0.96.

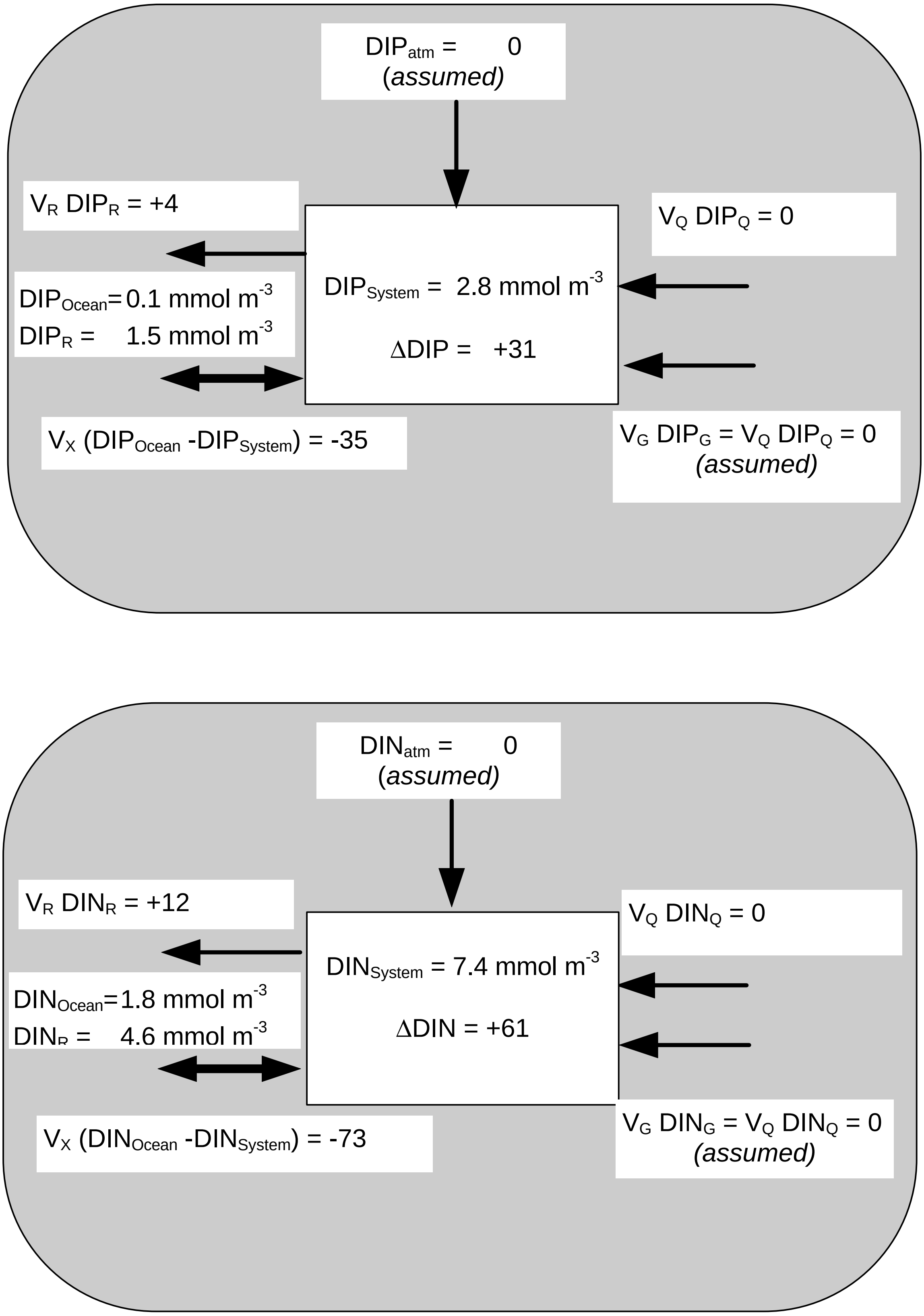


Figure 34. DIP and DIN budgets for Laguna Madre, annual average. Fluxes in 10^6 mol year^{-1}.

2.3.2) Laguna de Terminos, Campeche[1]

E. Gomez-Reyes, A. Vázquez-Botello, J. Carriquiry and R. Buddemeier

Study Area Description

Laguna de Terminos (Figures 1 and 35; 18-19° N, 91-92° W), is located in the southern portion of the Gulf of Mexico and in the south west side of the Yucatan peninsula. The northern limit of the lagoon is the Del Carmen Island in whose ends are located the two mouths that assure permanent communication with the sea: Puerto Real in the east side and El Carmen in the west side. The lagoon is in the transition zone between the low-lying limestone topography and the alluvial plains of the Gulf of Mexico (Coll de Hurtado, 1975). The lagoon has an ellipsoidal shape in an east- west direction; is 70 km in length and 30 km in its widest portion; its area is 1,700 km^2. The Terminos lagoon receives drainage mainly from the Candelaria-Panlau system and the Chumpan-Balchacah system. The Candelaria-Panlau system is formed by the confluence of the Candelaria and Mamantel rivers. The Candelaria river itself represents an input of 700×10^6 m^3 $year^{-1}$. The Chumpan-Balchacah system is formed by the Chumpan river and the Balchacah lagoon. The river bed of the Chumpan river occupies an area of about 1,900 km^2 and its annual runoff volume is of about $1,400 \times 10^6$ m^3. Other inputs are represented by the Palizada river, the Sabancuy river and the streams Colax, Lagartero, Chivoj Chico and Chivoj Grande. The Palizada river and its arms form inner lagoons known as the East Palizada system and the Pom-Atasta system (Contreras, 1993). The mean annual total river discharge to the Terminos lagoon has been estimated to be 6×10^9 m^3 (Phleger and Ayala-Castañares, 1971).

Ocean water enters the lagoon through the Puerto Real mouth and exits via the Del Carmen mouth with a net flux of up to 1,350 m^3 s^{-1} in an East-West direction (Mancilla and Vargas, 1980).

Physico-chemical and biological characteristics of the lagoon can be found in Contreras (1993). In general, it can be mentioned that the margins are covered by mangroves. In those sectors of the lagoon characterised by its high salinity (south-west, east and in the south-south-east section of the Del Carmen Island), the red mangrove *Rhizophora mangle*, is more abundant. In areas with high river influence, the black mangrove is characteristic. Vegetation distribution is a function of water transparency and $CaCo_3$ content in the sediments. In clear waters seagrasses are abundant: *Thalassia testudinum*, *Halodule wrightii* and *Syringodium filiforme*. Among the fauna, prawns, echinoderms, decapodes, and fish (103 species) have been reported. Commercially important species include: oysters (*Crassostrea rhizophora* and *C. virginica*), fish (*Rangia cuneata*) and sharks.

Net phytoplankton production in the estero averages about 300 g C m^{-2} year $^{-1}$ and in the lagoon about 200 g C m^{-2} year $^{-1}$ (i.e., 25 and 17 mol C m^{-2} $year^{-1}$, respectively) (Day *et al.,* 1988)

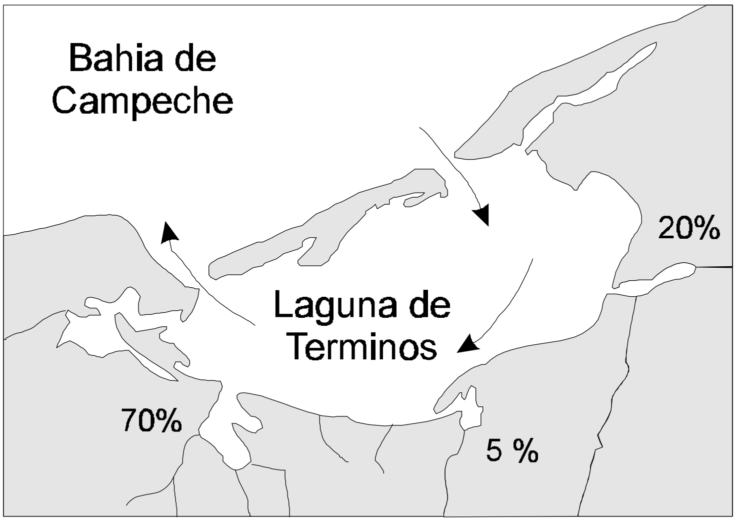


Figure 35. Map of Laguna de Terminos showing major circulation pattern and percentage of river inputs into the Bahía.

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[1] This initial draft budget was prepared at the workshop. A more recent budget has been prepared that is more accurate and detailed. The reader is advised to contact the authors or the LOICZ WWW home page at : http://www.nioz.nl/loicz/modelnod for the more recent information.

The Terminos lagoon is located in front of an extensive continental platform fringe known as Sonda de Campeche, that has an average width of 120 km from its shoreline to its inner margin (Gutiérrez-Estrada, 1967). This zone represents one of the most important marine fisheries areas in the country. It is also a place where oil extraction activities take place, and has therefore been impacted by oil-spills. During the 1976 oil-spill, Vázquez-Botello (1980) documented that although hydrocarbons accumulated in the sediment and their values were quadrupled, the oysters beds were not impacted. This lagoon is the most studied system in the whole country, with more than 300 references (Contreras, 1993). The socio-economic situation is described in Appendix IV.

Water and Salt Budgets

The mean climatic conditions of Laguna de Terminos can be separated into a 5-month dry season, which extends from approximately January to June, and a 7-month wet season from June to January. The data which were available for budgeting were for the wet season, during which about 88% of the river inflow into the lagoon occurs. Approximately 5 x 10^9 m^3 of runoff occurs during this period; three rivers dominate this flow (Figure 35). For budgeting purposes and comparison with other sites, we have expressed this wet season flow as an annual rate of 9 x 10^9 m^3 $year^{-1}$. In a similar manner, we convert 7-month rainfall and evaporation rates to annualised water fluxes of +3 x 10^9 and –2 x 10^9 m^3 $year^{-1}$, respectively, for the wet season.

A modification of the standard budget calculations is required. There are two entrances to Laguna de Terminos. Water flows into the lagoon through the eastern entrance; there is an east-to-west net circulation, with most outflow through the western entrance (Figure 35). Therefore, for calculation of residual fluxes and exchange fluxes, oceanic composition is based on water composition near the eastern entrance and both lagoonal and residual composition is based on water in the western portion of the lagoon. It is useful for the calculations to characterise the inflowing water as V_{in} and the outflowing water as V_{out}. These terms can be related to the "standard" exchange terms of residual flow and exchange flux (V_R, V_X) for ease of comparison with other systems.

If we represent all of the freshwater inputs minus evaporative output as V_{Q*} (i.e., $V_{Q*} = V_Q + V_P – V_E + V_G + V_O$), we can write the steady-state water and salt balance equations as follows:

$$V_R = -V_{Q*} = V_{in} - V_{out} \qquad (14)$$

$$V_{in} S_{ocn} = V_{out} S_{syst} \qquad (15)$$

By rearrangement:

$$V_{in} = \frac{V_{Q*} S_{syst}}{\left(S_{ocn} - S_{syst}\right)} \qquad (16)$$

It follows that V_{in} is the equivalent of V_X, and V_{out} is $V_X + V_{Q*}$.

Figure 36 illustrates the water and salt budgets for Laguna de Terminos, as derived according to this procedure. Lagoon water exchange time is calculated as the lagoon volume divided by $V_{out,}$. For this system, the exchange time is 0.22 year, or almost 3 months. We recognise that there is one shortcoming in the budget as we have developed it. That shortcoming is that the Yucatán peninsula is a major site of groundwater flow, and this volume flux may be significant in the budget (Perry and Velazquez-Oliman, 1996). We suspect that this is not a serious problem for the water budget during the wet season, but it may well be significant during the dry season.

Budgets of Nonconservative Materials

The mass balance equations for any material Y are modified in a manner analogous to the salt balance equation, with some significant differences. First, the various freshwater sources are explicitly identified, because they would be likely to have different concentrations of Y. Second, the unknown in the equation is the biogeochemical flux, DY:

$$\Delta Y = V_{out} Y_{syst} - V_{in} Y_{ocn} - V_Q Y_Q - V_P Y_P - V_G Y_G - V_o Y_O \qquad (27)$$

Figure 37 summarises the DIP and DIN budgets for Laguna de Terminos.

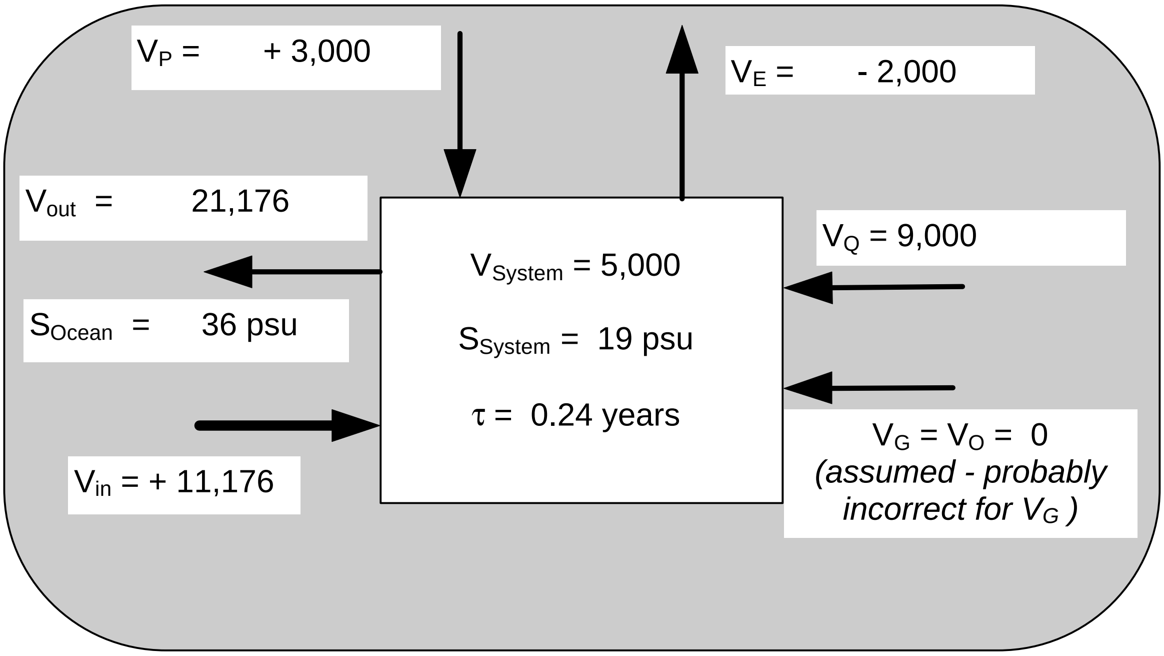

Figure 36. Water and salt budgets for Laguna de Terminos based on data for the wet period (June - January), but expressed as annual rates. See text for details of flux calculations. System volume is in units of 10^6 m^3 . Water fluxes in 10^6 m^3 $year^{-1}$. Salt fluxes in 10^6 psu m^3 $year^{-1}$.

P Balance

It can be seen that the system is net sink for DIP, based on the loading data that we have (*DDIP* = 146 x 10^6 mol $year^{-1}$). It is possible that there are local inputs of DIP associated with agricultural activities and not included in the budget, and there might be some groundwater input of DIP. These inputs are judged not to be large, at least during the wet season when runoff-derived DIP seems likely to dominate. In general, DIP flux in groundwater flowing through carbonate terrain is low.

N Balance

The system is also a net sink for DIN (*DDIN* = -1,400 x 10^6 mol $year^{-1}$). DIN is often very high in groundwater, so it seems plausible that this additional DIN source is significant. If there is such additional DIN loading, then we have underestimated *DDIN*.

Stoichiometric Calculations of Aspects of Net System Metabolism

These P and N fluxes can be used to calculate nitrogen fixation minus denitrification *(nfix-denit)* according to the procedures laid out in the previous sections. We calculate *(nfix-denit)* as the difference between observed and expected *DDIN*. Expected *DDIN* is *DDIP* multiplied by the N:P ratio of the reacting particulate organic matter. We assume that the appropriate ratio is the Redfield N:P ratio of plankton (16:1). Thus:

$(nfix\text{-}denit) = -1{,}400 \times 10^6 - 16 \times (-146 \times 10^6) = +936 \times 10^6$ mol N $year^{-1}$
(+0.6 mol N m^{-2} $year^{-1}$ over the lagoon area).

Note that the system appears likely to be fixing nitrogen in excess of denitrification.

Similarly, we can estimate net ecosystem metabolism (*NEM* = *p-r*) as the negative of the nonconservative DIP flux multiplied by the C:P ratio of the reacting organic matter. If the net reacting material is plankton, the particulate C:P ratio is about 106:1:
$(p\text{-}r) = -106 \times (-146 \times 10^6) = +15{,}476 \times 10^6$ mol C $year^{-1}$ = (+9 mol C m^{-2} $year^{-1}$)

The system appears to be net autotrophic.

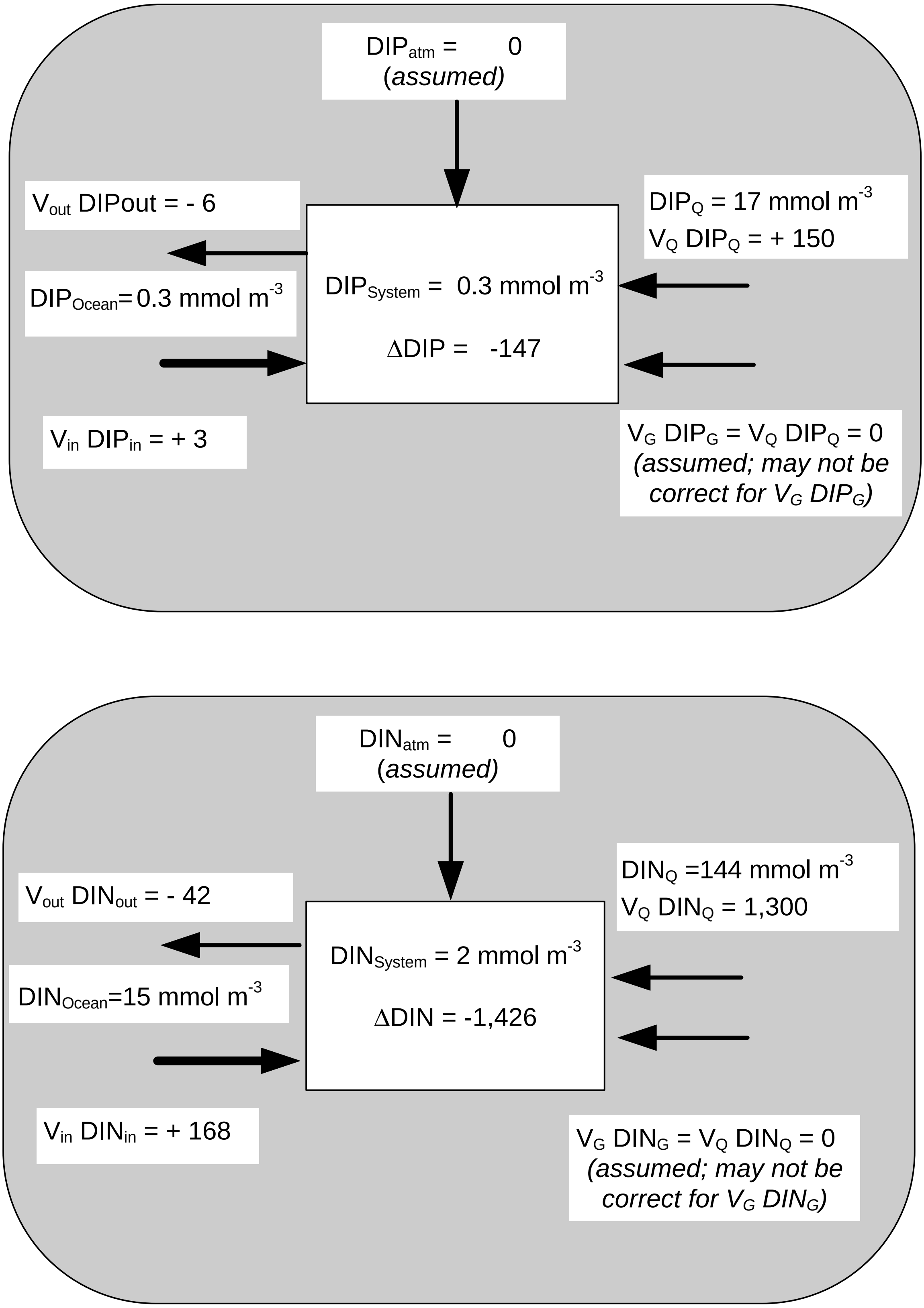

Figure 37. DIP and DIN budgets for Laguna de Terminos based on data for the wet period between June and January, but expressed as annual rates. See text for details of flux calculations. Fluxes in 10^6 mol $year^{-1}$.

3. CONCLUSIONS AND IMPLICATIONS FOR LAGOON COMPARISONS

Tables 10-13 summarise key data for the lagoons budgeted during the workshop and post-workshop exercises. The diversity of sites, in terms of size, hydrological and hydrographical regime, and net biogeochemical function is evident. Not evident in these tables but described in the site write-ups is the range of variation in biotic composition of the sites (plankton-dominated, major seagrass component, major mangrove communities). The degree of human impact on these systems also varies tremendously.

Within the strict context of the biogeochemical budgeting, some features appear to be emerging. In general, there seems to be a trend from systems which release DIP at the northern end of the Baja California peninsula and mainland side of the Gulf of California, to systems which take up DIP to the south and across into the wet lagoons of the Mexican tropical Pacific coast. Laguna Madre and Laguna de Terminos, on the Gulf of Mexico, seems to fit this trend of DIP release in the north and uptake in the south. If the nonconservative DIP flux is accepted as an index of net organic carbon metabolism, then this trend can be interpreted as a general shift from systems which are net heterotrophic to the north, to net autotrophic systems to the south.

A similar latitudinal trend exists with respect to the nonconservative flux comparison between DIN flux which is observed and DIN flux which is expected from the DIP flux. The more northerly sites show evidence of net denitrification, at rates which are ecologically reasonable. The southern sites generally appear to be sites of net nitrogen fixation—again at reasonable rates.

It would be very useful to test these trends further, with additional budgets. Looking at the map of coastal Mexico (Figure 1), we can recognise other areas in which coastal lagoons do exist and for which budgets would be very useful: the coasts of Tamaulipas through Tabasco, and most of the Yucatan peninsula; the Pacific mainland coast between Jalisco and Oaxaca; southern Sonora; and the Pacific coast of Baja California Sur.

If the trends which are noted here stand up to further examination, then the next obvious step in comparison among coastal lagoons world-wide would be to collect selected data from other geographic regions which might be represented by a few sites amenable to budgets. How well do these Mexican systems represent warm temperate and tropical coastal lagoons biogeochemically? If the match looks good, then this study provides the framework for extrapolating from Mexico to other regions.

An interesting reminder arose in the case of an attempted budget of Laguna Alvarado, a large system in the State of Veracruz (~ 120 km^2; 200 x 10^6 m^3; 18° 45'N, 95° 45' W). This lagoon receives flows from the Papaloapan River (one of the largest rivers in Mexico) as well as other large rivers. The water flow through that system was sufficiently large (~50 x 10^9 m^3 year^{-1}) that the estimated water exchange time was less than 0.5 days. For a system like that, the water and salt approach simply will not work. With such a rapid water exchange, slight mismatches between nutrient concentrations and freshwater inflow result in extreme (and clearly unreasonable) estimates of nonconservative nutrient fluxes. This example provides an important cautionary note that the budgetary approach employed here is not universally applicable.

Table 10. Freshwater discharges and nutrient loadings to Mexican coastal lagoons. All rates expressed as annual rates, for ease of intercomparison. The numbers in the table reflect the different accuracies used for the different systems.

System[1] (Num.)	**Season**	**V_P (10^6 m^3 $year^{-1}$)**	**V_E (10^6 m^3 $year^{-1}$)**	**V_Q (10^6 m^3 $year^{-1}$)**	**V_QP_Q (10^6 mol $year^{-1}$)**	**V_QN_Q (10^6 mol $year^{-1}$)**	**V_G (10^6 m^3 $year^{-1}$)**	**V_GP_G (10^3 mol $year^{-1}$)**	**V_GN_G (10^3 mol $year^{-1}$)**
EPB (1)	Summer	+0.0	-17.5	+0	+0	+0	+0	+0	+0
BSQ (2)	Summer	+1.5	-59.9	+0	+0	+0	+0	+0.0	+0
	Winter	+24.5	-33.2	+0	+0	+0	+0	+0.4	+11
SLG (3)	Spring	+0.0	-4.9	+0	+0	+0	+0	+0	+0
	Summer	+0.0	-7.0	+0	+0	+0	+0	+0	+0
	Fall	+0.5	-3.3	+0	+0	+0	+0	+0	+0
	Winter	+0.1	-3.5	+0	+0	+0	+0	+0	+0
ELC (4)	Summer	+5.5	-55.1	+0	+0	+0	+0	+0	+0
	Winter	+1.5	-25.6	+0	+0	+0	+0	+0	+0
BC (5)	Winter	+23.7	-79.2	+0	+0	+0	+0	+0	+0
ELP (6)	Spring	+0.7	-58.4	+0	+0	+0	+0	+0	+0
	Summer	+19.0	-93.8	+0	+0	+0	+0	+0	+0
EP (7)	Average	+300	-700	+3,400	+26	+167	+0	+0	+0
TAB (8)	Average	+2,100	-3,200	+5,500	+175	+480	+0	+0	+0
CPBB (9)	Average	+79	-24	+234	+2	+3	+0	+0	+0
CP (10)	Average	+90	-24	+287	+3	+3	+0	+0	+0
LM (11)	Average	+1,200	-3,800	+0	+0	+0	+0	+0	+0
LT (12)	June-January	+3,000	-2,000	+9,000	+150	+1,300	+0	+0	+0

[1] See Table 1 for system abbreviations and Figure 1 for system locations.

Table 11. Salinities and inorganic nutrient concentrations in lagoon waters (syst) and adjacent ocean (ocn) of Mexican coastal lagoons. The numbers in the table reflect the different accuracies used for the different systems.

System[1] (Num.)	**Season**	**S_{ocn} (psu)**	**S_{syst} (psu)**	**DIP_{ocn} (mmol m^{-3})**	**DIP_{syst} (mmol m^{-3})**	**DIN_{ocn} (mmol m^{-3})**	**DIN_{syst} (mmol m^{-3})**
EPB (1)	Summer	33.6	34.4	0.8	1.6	0.8	1.0
BSQ (2)	Summer	33.78	34.66	0.80	1.95	1.87	0.99
	Winter	33.59	33.84	1.09	1.28	13.54	6.84
SLG (3)	Spring	35.26	35.32	1.24	1.36	1.35	1.39
	Summer	35.74	35.90	0.98	1.21	1.38	2.07
	Fall	35.50	35.59	1.38	1.60	7.88	5.89
	Winter	35.34	35.39	1.74	1.26	6.23	2.32
ELC (4)	Summer	35.75	39.40	0.95	1.47	6.1	6.1
	Winter	37.45	41.33	0.27	0.61	8.6	14.8
BC (5)	Winter	35.3	35.9	0.3	0.6	0.05	1.2
ELP (6)	Spring	35.7	36.4	0.87	0.68	0.64	1.95
	Summer	34.7	36.2	0.70	0.11	0.50	0.45
EP (7)	Average	35	28	0.6	7.2	0.6	3.7
TAB (8)	Average	34.0	20.0	0.5	0.7	2.5	4.0
CPBB (9)	Average	10.8	21.6	11.4	14.0	6.6	12.7
CP (10)	Average	22	14	5.7	6.6	8.6	11.4
LM (11)	Average	36	44	0.1	2.8	1.8	7.4
LT (12)	June-January	36	19	0.3	0.3	15	2

[1] See Table 1 for system abbreviations and Figure 1 for system locations

Table 12. Water and salt budget calculations for Mexican coastal lagoons. All rates are expressed as annual rates, for ease of intercomparison. The numbers in the table reflect the different accuracies used for the different systems.

System[1] (Num.)	**Season**	**Area (10^6 m^2)**	**Volume (10^6 m^3)**	**V_R (10^6 m $year^{-1}$)**	**V_X (10^6 m^3 $year^{-1}$)**	**Exchange Time (year)**
EPB (1)	Summer	12	24	+18	+745	.03
BSQ (2)	Summer			+58	2,271	0.04
	Winter			+8	1,179	0.08
	Average	42	90			
SLG (3)	Spring			+5	3,005	0.004
	Summer			+7	1,553	0.007
	Fall			+3	1,152	0.009
	Winter			+4	1,288	0.009
	Average	3	11			
ELC (4)	Summer			+50	511	0.06
	Winter			+24	245	0.12
	Average	23	32			
BC (5)	Winter	282	4,553	+55	3,292	1.36
ELP (6)	Spring			+58	1,471	0.10
	Summer			+75	1,766	0.08
	Average	45	145			
EP (7)	Average	460	1,400	-3,000	13,500	0.08
TAB (8)	Average	1,600	1,266	-4,645	8,958	0.09
CPBB (9)	Average	35	53	-297	434	0.07
CP (10)	Average	30	45	-353	1,147	0.013
LM (11)	Average	2,000	1,400	+2,600	13,000	0.09
LT (12)	June-January	1,700	5,000	-10,000	11,176	0.24

[1] See Table 1 for system abbreviations and Figure 1 for system locations

Table 13. Nonconservative flux calculations for P and N, and stoichiometric derivations from those fluxes for Mexican coastal lagoons. All rates are expressed as annual rates, for ease of intercomparison. Averages are reported only for nonconservative fluxes and metabolic rates derived from those nonconservative fluxes.

System[1] (Num.)	**Season**	**Area (10^6 m^2)**	**Vol. (10^6 m^3)**	**ΔDIP (10^3 mol year^{-1})**	**ΔDIN (10^3 mol year^{-1})**	**ΔDIP (mol m^{-2} year^{-1})**	**ΔDIN (mol m^{-2} year^{-1})**	***nfix-denit* (mol m^{-2} year^{-1})**	***p-r* (mol m^{-2} year^{-1})**
EPB (1)	Summer	12	20	+575	+133	+0.05	+0.01	-0.8	-5
BSQ (2)	Summer			+2,683	+1,263	+0.06	+0.03	-0.9	-6
	Winter			+214	-7,996	+0.01	-0.19	-0.4	-1
	Average	42	90	+1,449	-3,366	+0.04	-0.08	-0.7	-4
SLG (3)	Spring			+354	+113	+0.12	+0.04	-1.9	-13
	Summer			+350	+1,100	+0.12	+0.37	-1.6	-12
	Fall			+249	-2,198	+0.08	-0.73	-2.0	-8
	Winter			-581	-4,710	-0.19	-1.57	+1.5	+21
	Average	3	11	+93	-1,425	+0.03	-0.48	-1.0	-3
ELC (4)	Summer			+205	-299	+0.01	-0.29	-0.5	-1
	Winter			+73	+975	+0.00	+0.04	+0.0	-0
	Average	23	32	+139	+338	+0.01	+0.02	-0.1	-1
BC (5)	Winter	282	4,553	+963	+3,751	+0.00	+0.01	-0.0	-0
ELP (6)	Spring			-324	+1,852	-0.01	+0.04	+0.2	+1
	Summer			-1,072	-124	-0.02	-0.00	+0.3	+2
	Average	45	145	-699	-864	-0.02	-0.02	+0.3	+2
EP (7)	Average	460	1,400	+75,000	-118,000	+0.16	-0.26	-2.4	-17
TAB (8)	Average	1,600	1,266	-170,000	-452,000	-0.11	-0.28	+1.5	+11
CPBB (9)	Average	35	53	+3,000	+3,000	+0.09	+0.09	-1.3	-9
CP (10)	Average	30	45	+0	+4	+0.00	+0.14	+0.2	0
LM (11)	Average	2,000	1,400	+31,000	+61,000	+0.02	+0.03	-0.2	+2
LT (12)	June-January	1,700	5,000	-147,000	-1,426,000	-0.09	-0.81	+0.6	+10

[1] See Table 1 for system abbreviations and Figure 1 for system locations

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APPENDIX I

MEXICAN COASTAL LAGOONS OVERVIEW

S. Ibarra-Obando, S.V. Smith and F. Contreras -Espinosa

In about 12, 000 km of coastline, Mexico has about 180 coastal lagoons and other estuarine areas. These occupy an area of approximately 16,000 km^2 and span a climatic regime ranging from warm (arid) temperate to both wet and dry tropics (Lankford, 1977; Mee, 1977; Contreras, 1985, 1993; Contreras and Zabalegui, 1988).

Mexican coastal lagoons have been used extensively as sites of fisheries, aquaculture development, and tourism. Activities incidental to the ecology of these systems have had profound and largely negative impacts: for example, waste discharges, including spills associated with petroleum exploration; disturbance associated with agriculture, deforestation, and other coastal land development; dredging, marina development and other development activities within the lagoons themselves; extraction industries such as salt collection, and so forth. As a result, many Mexican lagoonal systems are under threat of damage, severely damaged, or already destroyed.

Mexico has a long tradition of research on the ecology of its coastal lagoons. Presented here is an overview of their main characteristics, pollution status and research effort. Much of the background information can be traced to a paper by Lankford (1977), describing Mexican coastal lagoons. Several books by Contreras (the most recent one being 1993; with an accompanying CD-ROM compiled by Castañeda and Contreras, 1997) summarise most of the scientific literature and much of the data on Mexican coastal lagoons.

Lankford (1977) identified seven regions in which the Mexican coastline could be subdivided. His divisions were based on physiography but approximated State boundaries. For the purposes of using INEGI statistical data, we have found it convenient to modify his boundaries slightly and collapse the regions down to 5 regions coincident with State Boundaries (Figure 38). Summary statistics by region are presented in Tables 14-16.

Region A - *Baja California and Baja California Sur States* - comprises the Baja California peninsula (human population ~2,000,000) and contains about 60 coastal lagoons and other estuarine water bodies. The estuarine surface area represents about 19% of nation's total. Climate is hot and arid, with winter rains to the north and summer rains to the south. Mean annual precipitation and runoff are low. Groundwater extraction exceeds recharge, so saline intrusion occurs in some areas. Human impacts include salt and phosphate rock extraction, excessive boat traffic, increasing tourist activities, domestic and industrial sewage discharge, fisheries resource exploitation, locally intensive aquaculture, structural modifications such as dredging for industrial and tourist purposes. Research effort in these regions (as measured by the number of scientific references listed by Contreras, 1993) has been considerable, due to the presence of research institutions and universities.

Region B - *Sonora and Sinaloa States* - These two states are home to approximately 4,000,000 persons. The estuarine surface area in this region represents 17% of the nation's total and includes about 40 lagoons and estuaries. Weather is arid in the north and semi-arid in the south, with limited runoff. Also in this region, groundwater extraction exceeds recharge, and saline intrusion occurs. Shrimp fisheries and aquaculture represent among the most important activities that take place in these lagoons. Resultant impacts include mangrove destruction, eutrophication and sediment accretion. Other impact sources are agrochemical pollution, increasing human settlements, tourism, industrial and urban wastewater discharge. Research effort in this region has been relatively minor.

Region C - *Nayarite, Jalisco, Colima, Michoacan, Guerrero, Oaxaca and Chiapas States* - extends from Nayarit to Chiapas (~20,000,000 persons) and contains about 40 lagoons and estuaries. Its estuarine surface represents 20% of the national total. Climate varies from semiarid in the north to very humid in the south. There are numerous rivers with small drainage basins and runoff is important. Groundwater recharge exceeds extraction. Changes in river course are promoting lagoon water salinity increase, accretion processes and migratory waterfowl reduction. Industrial pollution, tourism, urban and industrial wastewater discharge, road construction, human settlements, salt extraction and fisheries are also common impacts. In its northern portion, shrimp aquaculture is an important activity. Research effort in the region has been low.

Region D comprises the states of *Tamaulipas, Veracruz and Tabasco* (~10,000,000 persons). The estuarine area is the largest in the country, about 24% of the national total. About 30 coastal lagoons and estuaries are present in this region. Climate is semiarid in the north and subhumid in the south. Summer is the rainy season. There are large rivers with high flow. Precipitation and runoff are important, as are groundwater recharge and storage. This region is well known for oil extraction and resultant pollution. Other activities include oil refineries, natural gas extraction, cattle raising, shrimp fisheries, tourism, untreated urban and industrial waters. The research effort in this region is the highest in the nation.

Region E includes the states of *Campeche, Yucatán and Quintana Roo* (~3,000,000 persons). Its estuarine surface represents 19% of the national total and contains about 15 coastal lagoons and estuaries. Climate varies from arid to subhumid. Rain is present during summer but it is not heavy. The area is characterised by low-lying limestone topography, with much of the water flow being groundwater. There are few rivers in this region. Groundwater extraction and recharge are low and of the same magnitude. Deleterious activities include oil and salt extraction, human settlements, urban wastewater discharge, road construction, tourism and fisheries. A moderate amount of the national research effort has been devoted to this area.

Table 14. Statistics about the dimensions lagoons and estuaries of Mexico, and about the number of scientific studies. (From Contreras, 1993; Castañeda and Contreras, 1997).

Geographic Region	**Coastline Length (km^2)**	**Number of Estuaries**	**Estuarine Surface (km^2)**	**Number of References**
A	4,300	58	3,000	1,303
B	1,800	40	2,700	567
C	2,400	40	3,200	487
D	1,400	30	3,800	1,306
E	1,700	15	3,000	642
TOTAL	11,600	183	15,700	4,305

Table 15. Mean annual precipitation and runoff per geographic region (INEGI, 1994).

Geographic Region	**Mean Annual Precipitation ($10^6 m^3$)**	**Runoff ($10^6 m^3$)**
A	20,800	300
B	168,000	25,000
C	359,100	126,700
D	569,400	192,800
E	172,200	29,100
TOTAL	1,289,500	373,900

Table 16. Regional distribution of groundwater. * indicates areas with saline intrusion (INEGI, 1994).

Geographic Region	**Extraction $10^6 m^3 year^{-1}$**	**Recharge $10^6 m^3 year^{-1}$**	**Storage $10^6 m^3$**
A (*)	1,700	1,200	10,600
B (*)	3,000	2,100	32,600
C	1,400	2,700	
D	2,700	4,000	46,750
E	500	500	
TOTAL	9,300	13,200	

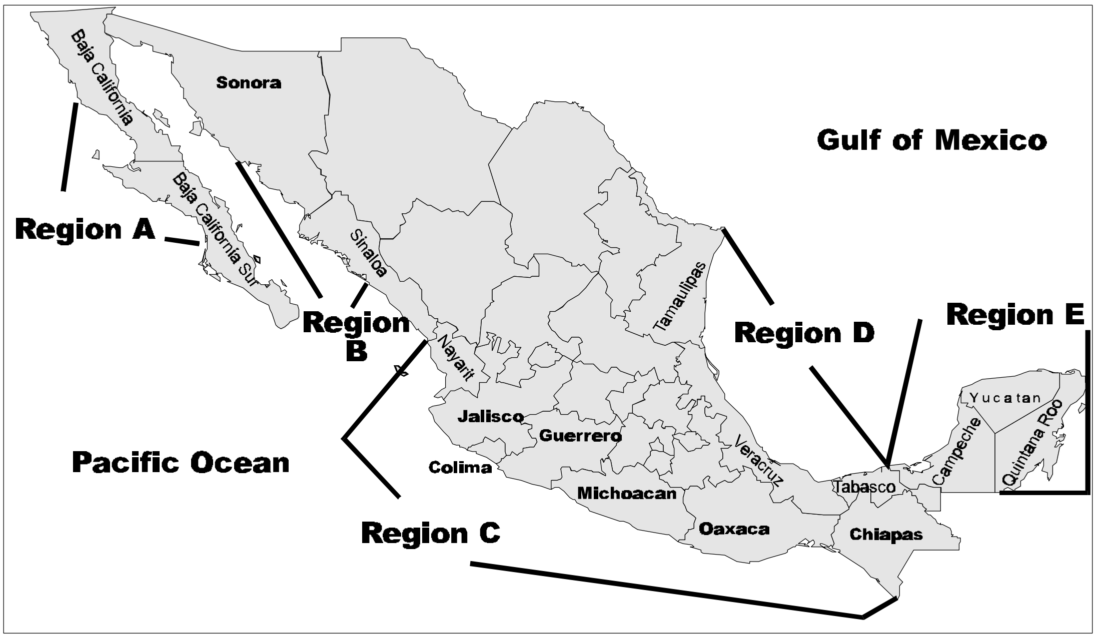

Figure 38. Map of Mexico, showing the coastal states and the major coastal physiographic regions; slightly modified from Lankford (1977) in his paper on classification of coastal lagoons.

APPENDIX II

COMPARISON OF NET & GROSS BUDGET FOR BAHÍA SAN QUINTÍN

S.V. Smith and S. Ibarra-Obando

These calculations are intended to put the gross and net metabolism of Bahía San Quintín into perspective, in order to illustrate the utility of direct estimates of gross metabolism for estimating turnover of materials and the utility of direct estimates of net metabolism for estimating primary production – respiration. In Tables 17-20, biomass (B) is only estimated to the nearest order of magnitude and is intended only as a crude index of material turnover.

The first points to note are (from Table 17) that plankton and seagrass apparently dominate the primary production (*p*), as derived from various literature data for San Quintín and other sites. The plankton have relatively low primary production but occur throughout the bay. By contrast, the seagrass occupy only about 25% of the bay area but have high rates of production. Other plants appear minor primary producers.

Seagrass respiration (*r*, Table 18) is apparently likely to consume most of the seagrass primary production. We made “direct” estimates of both plankton respiration and benthic sediment respiration. Plankton respiration, which is difficult to measure anyway, appears too low, because a plankton *p/r* ratio of 3.5 seems abnormally high. This value dominates the estimated net system metabolism and yields a total system *p/r* ratio of 1.35 (Table 17). If we adjust the plankton *p/r* ratio to a more realistic value of 1.4 (Table 19), we derive a system *p/r* ratio of 1.02. The point is that this single, difficult-to-measure term dominates estimates of *p/r* by “adding up the pieces,” although the gross metabolism is relatively stable at values of about 30,000 to 40,000 tonnes C year^{-1}.

If, by contrast, we use the estimated value for *p*, and the value for (*p* - *r*) from Camacho *et al.* (Section 2.1.2) as 1,840 tonnes C year^{-1}, we can calculate the *p/r* ratio of the whole system to be 0.95. Even assuming that the estimated value for *p* might be in error by a factor of 2, we only perturb this estimate between 0.98 and 0.91. As long as the assumption that the nonconservative flux of DIP is a measure of net system metabolism, this method gives a robust estimate for this critical characteristic of system metabolism (Table 21).

It follows that the combination of conventional estimates of component metabolism, together with the budgetary approach to net metabolism, allows the estimate of both the turnover characteristics and the net reservoir characteristics of the system.

Table 17. “Measured” metabolism for Bahía San Quintín expressed per area.

Community	**Area**	**%**	**B**	**p**	**r**	**(p-r)**	**p/r**
	(km^2)		**(g C m^{-2})**	**(g C m^{-2} day^{-1})**	**(g C m^{-2} day^{-1})**	**(g C m^{-2} day^{-1})**	
Seagrass							
Shallow	6	14	100	3.00	2.50	0.50	1.20
Deep	6	14	100	2.00	2.50	-0.50	0.80
"Bare" sediment.							
Shallow	2	5	10	3.00	3.00	0.00	1.00
Deep	27	61	1	0.05	0.63	-0.58	0.08
Plankton	42	95	1	1.40	0.40	1.00	3.50
Benthic algae	1	2	100	3.00	3.00	0.00	1.00
Salt marsh	2	5	100	3.00	2.50	0.50	1.20
TOTAL	44	100	36	2.39	1.77	0.62	1.35

Table 18. “Measured” metabolism for Bahía San Quintín expressed as totals and percentages for ecosystem.

Community	**Area**	**%**	**B**	**%**	**p**	**%**	**r**	**%**	**(p-r)**
	(km^2)		**(t C)**		**(t C year^{-1})**		**(t C year^{-1})**		**(t C year^{-1})**
Seagrass									
Shallow	6	14	600	38	6,570	17	5,475	19	1,095
Deep	6	14	600	38	4,380	11	5,475	19	-1,095
"Bare" sediment									
Shallow	2	5	20	1	2,190	6	2,190	8	0
Deep	27	61	27	2	493	1	6,209	22	-5,716
Plankton	42	95	42	3	21,462	56	6,132	22	15,330
Benthic algae	1	2	100	6	1,095	3	1,095	4	0
Salt marsh	2	5	200	13	2,190	6	1,825	6	365
TOTAL	44	100	1,589	100	38,380	100	28,401	100	9,979

Table 19. “Likely” metabolism for Bahía San Quintín expressed per area.

Community	**Area**	**%**	**B**	**p**	**r**	**(p-r)**	**p/r**
	(km^2)		**(g Cm^{-2})**	**(g C m^{-2} day^{-1})**	**(g C m^{-2} day^{-1})**	**(g C m^{-2} day^{-1})**	
Seagrass							
Shallow	6	14	100	3.00	2.50	0.50	1.20
Deep	6	14	100	2.00	2.50	-0.50	0.80
"Bare" sediment.							
Shallow	2	5	10	3.00	3.00	0.00	1.00
Deep	27	61	1	0.05	0.63	-0.58	0.08
Plankton	42	95	1	1.40	1.00	0.40	1.40
Benthic algae	1	2	100	3.00	3.00	0.00	1.00
Salt marsh	2	5	100	3.00	2.50	0.50	1.20
TOTAL	44	100	36	2.39	2.34	0.05	1.02

Table 20. “Likely” metabolism for Bahía San Quintín expressed as totals and percentages for ecosystem.

Community	**Area**	**%**	**B**	**%**	**p**	**%**	**r**	**%**	**(p-r)**
	(km^2)		**(t C)**		**(t C year^{-1})**		**(t C year^{-1})**		**(t C year^{-1})**
Seagrass									
shallow	6	14	600	38	6,570	17	5,475	15	1,095
deep	6	14	600	38	4,380	11	5,475	15	-1,095
"Bare" sediment.									
shallow	2	5	20	1	2,190	6	2,190	6	0
deep	27	61	27	2	493	1	6,209	17	-5,716
Plankton	42	95	42	3	21,462	56	15,330	41	6,132
Benthic algae	1	2	100	6	1,095	3	1,095	3	0
Salt marsh	2	5	200	13	2,190	6	1,825	5	365
TOTAL	44	100	1,589	100	38,380	100	37,599	100	781

Table 21. Summary of budget results for Bahía San Quintín expressed in terms of gross and net metabolism.

	p	**r**	**p/r**	**p/r**
	(t C year^{-1})	**(t C year^{-1})**	**(direct)**	**(from budget)**
			(not robust)	**(robust)**
	gross estimate	gross estimate		
		(TABLE 3)		
	38,380	28,401	1.35	
		(TABLE 4.)		
	38,380	37,599	1.02	
(p-r)	gross estimate	(gross p - [p-r])		
(transect budget)	38,380	40,220		0.95
-1,840				
(t C year^{-1})				
	gross p x 2	(gross p - [p-r])		
	76,760	78,600		0.98
	gross p / 2	(gross p - [p-r])		
	19,190	21,030		0.91

APPENDIX III

ECOLOGICAL SERVICES AND SOCIO-ECONOMIC SUSTAINABILITY -
A case study: Bahía San Quintín

Introduction

The overall aim of IGBP is "to describe and understand the interactive physical, chemical and biological processes that regulate the total Earth system, the unique environment that it provides for life, the changes that are occurring in the system and the manner in which they are influenced by human actions" (Pernetta and Milliman, 1995).

LOICZ is that component of the IGBP which focuses on the area of the earth's surface where land, ocean and atmosphere meet and interact. The overall goal of this project is to determine at regional and global scales: the nature of that dynamic interaction; how changes in various components of the Earth system are affecting coastal zones and altering their role in global cycles; to assess how future changes in these areas will affect their use by people; and to provide a sound scientific basis for future integrated management of coastal areas on a sustainable basis (Pernetta and Milliman, 1995).

One of the ways in which the LOICZ project is achieving the required integration to reach its goal is budgeting water, C, N and P in the coastal zone. Human populations and economic activities alter C, N, P, water, and sediment inventories, and their fluxes within and through the coastal zone. These same fluxes and inventories represent and control the processes that define the living resources -- terrestrial, aquatic and marine -- that provide direct and indirect economic goods and services to humankind. This link between natural science and socio-economics has yet to be successfully addressed by any of the IGBP core project elements. For this reason we have decided to undertake an integrative study using Bahía San Quintín as a study case.

The San Quintín system is represented by the San Simon valley and a coastal lagoon known as Bahía San Quintín (Figure 5). This system is located in the Baja California Peninsula (30^{o} N); its watershed covers an area of approximately 2,000 km^2, and the surface area of the Bay itself is about 40 km^2. The system is very arid, with an average annual rainfall of approximately 200 mm $year^{-1}$ and pan evaporation of 1,500 mm $year^{-1}$ near the coast. There is no significant surface runoff from land into the bay except during major storms. Groundwater represents the only freshwater source and is heavily exploited in order to sustain agriculture. Agriculture (dominated by tomato growing) represents the most important economic activity in the region, providing jobs for local people and migrants coming from the southern part of Mexico (mainly Oaxaca).

This agricultural activity is far more intensive than can be sustained naturally, and virtually all of the produce is exported. Water use is about 12×10^6 m^3 $year^{-1}$ greater than the recharge of 30×10^6 m^3 $year^{-1}$, and the aquifer is being drawn down by about 3% per year. This is causing saline intrusion along the coast, where the human population lives and relies on the groundwater for domestic, municipal and industrial water supplies. Further, this activity is relying heavily on the import of inorganic fertilisers. Some of the fertiliser nutrient elements enter the aquifer, further contaminating the remaining fresh water.

The human population of the region is readily divided into two groups: a permanent population of about 25,000 persons, most of whom live in 3 towns in the San Quintín valley, and about that same number of migrant labourers, who are there an average of about half the year and who mostly live in camps. There is no sewage treatment for the wastes from either of these groups, so their discharge largely percolates into the top of the aquifer.

The marine part of the system, known as Bahía San Quintín, is a hypersaline coastal lagoon; its area consists of two sub-basins: Bahía Falsa (west) and Bahía San Quintín (east) (Figure 5). The bay has a permanent mouth and exchanges nutrients and organic materials with the coastal ocean. The system is a net exporter of dissolved inorganic phosphorus, apparently derived from the decomposition of particulate organic matter exported from outside the system.

Two economic activities are significant in extracting living resources from the marine system, but both are sustained naturally. The first of these is an artesanal harvesting of the natural population of clams. Second, since about 1970 Bahía Falsa has been used for oyster culture, with this being the most important economic activity for the marine part of the system. There is some question as to whether these two extractive industries compete with one another. Other relevant activities using include tourism, especially sport fishing (outside the bay) and duck hunting.

APPENDIX IV

SOCIO-ECONOMIC SITUATION OF LAGUNA DE TERMINOS

A. Vázquez-Botello

General

The Mexican State of Campeche covers 2.6% of the total land surface of Mexico; in 1995 its population represented 0.7% of the total population of the country with a density of 12.4 inhabitants km^{-2}. The rural population is 28% of the total state population and the urban population is mainly located in Campeche City and Isla del Carmen City.

Campeche state belongs to the 1V Region according to the classification of the fishing zones in Mexico. There were 374 shrimp fishing boats of high level registered in 1993, and Del Carmen city is considered as one of main fishing ports. Its land surface covers about 13,000 km^2, with humid warm climate and heavy rainy season lasting 7 months.

The county's population increased 2.3 times (234%) in 25 years, from about 80,000 inhabitants in 1979 to 180,000 in 1995; with an annual growth rate of nearly 4%.

Agriculture

The area of cultivation is 1,600 km^2, 93% of which is temporal and 7% uses both irrigation and temporal systems. Subsistence agriculture is the mainly practised type and the most important crops are: corn, rice, sorghum and green pepper.

Cattle

Cattle ranching is practised in the Atasta peninsula, Sabancuy and Candelaria regions. It is of the extensive type and dairy cattle is very important with 260,000 head by 1993 (45 % of the state's participation). There are also pigs, sheep, horses, chickens and bees raised for commercial purposes.

Forests

Forest exploitation has not been done carefully; wood production has significantly decreased, from 55,000 m^3 in 1993 to 4,000 in 1997 of wood roll. There are precious woods such as cedars and mahogany. The only products removed from the forests are gum and palm.

Fishing

There are two main fishing zones in Campeche state: Del Carmen Island and The Sonda the Campeche. In 1993 the total fishing production was 20,000 tons. The fishing centres produced 2,000,000 oysters larvae. There are 50 co-operative societies, 19 are for shrimp fishing and 31 for scale fish. The fishing fleet has 228 shrimp fishing boats and 2,700 shore fishing boats.

Industry

Extraction of crude oil and natural gas is truly the main industrial activity. In 1995 the Mexican oil company had registered 10,573 workers. In the Sonda de Campeche there are 413 productive oil wells in activity. The average daily production in the zone is 2,681,000 barrels of crude oil which is equivalent to 75% of the country production and 30% of natural gas nation wide.

Other important industries are metal products, food and drink production, tobacco, chemical industry as well as charcoal, rubber and plastics.

APPENDIX V

LOICZ WORKSHOP ON MEXICAN COASTAL LAGOONS
CICESE, Ensenada, Mexico
2-3 June 1997

MEETING REPORT

1. Official Opening of the Workshop

Dr. Silvia Ibarra-Obando, Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE), co-chair of the workshop, welcomed the participants (Appendix VI) to CICESE and graciously explained that although the working language for the meeting is English, participants should feel free to make enquiries in Spanish.

Dr. Ibarra-Obando introduced Prof. Stephen Smith, LOICZ Scientific Steering Committee (SSC) Member and co-chair of the workshop.

The LOICZ Scientific Steering Committee (SSC) Members who are acting as resource persons in were identify, Dr. Robert Buddemeier and Prof. Fred Wulff. Mr. Paul Boudreau, LOICZ Core Project Scientist was identified as providing support for the workshop. Dr. Victor Camacho-Ibar was also identified as a resource person.

2. Administration and Organisation of the Workshop

2.1 Administrative and organisational matters

Dr. Ibarra-Obando informed the participants on a number of matters concerning the logistics of the workshop. Ms. Amelia Chavez, CICESE librarian, was introduced and her offer to assist participants in locating data and information in the library was gratefully accepted.

2.2 Introduction of Workshop participants

Prof. Smith invited all of the participants to briefly introduce themselves and to say a few words about their scientific background and geographic area of interest.

2.3 Purposes, expected outcome and schedule of the workshop

Prof. Smith then summarised the purposes of the workshop. He pointed out that Mexican coastal lagoons span a climatic regime ranging from cool arid temperate to both wet and dry tropics. They range from relatively little to high degree of perturbation from human activities and that many of the lagoons are relatively very well studied. This range in conditions, the large number of lagoons and the small but active scientific community of researchers make Mexico an excellent region to develop a core of biogeochemical budget models that can be used to investigate patterns of fluxes of carbon, nitrogen and phosphorus in coastal lagoons.

The expected outcome of the workshop is a number of biogeochemical budgets for a number of lagoons spanning the various regions in Mexico. It is hoped that a sufficient number of budgets (hopefully four but at least two) will be produced to allow for a useful comparison of non-conservative fluxes within and between regions. The workshop participants are asked to prepare as many budgets as possible with the data available within the time of the workshop and that any additional budgets prepared after the workshop will be considered for inclusion in the workshop report (this document).

Prof. Smith pointed out that the running of the workshop will be informal and scheduling of the agenda items (Appendix VII) will be determined as agreed by the participants. He suggested that the general approach should be that following the opening plenary, participants would be broken into groups by region to carry out budgeting exercises with the help of the resource persons. The results of these exercises would then be presented to the full group in a closing plenary as a means of sharing the results among all participants and promoting intercomparison. This proposal was accepted by the participants.

3. Brief background and status of the International Geosphere-Biosphere Programme (IGBP) and to the Land Ocean Interactions in the Coastal Zone (LOICZ) Core Project of IGBP

Mr. Boudreau provided a very brief overview of the background and status of the International Geosphere-Biosphere Programme (IGBP) and to the Land Ocean Interactions in the Coastal Zone (LOICZ) Core Project of IGBP. He pointed out that the main focus of the programme is the study of global material flux related to global change. The LOICZ Project is one of eleven programme elements in the IGBP and has as its goal the study of flux in the coastal zone. It includes research on drainage basins, rivers, estuaries and continental shelves of the world. Although the present workshop is primarily focused on biogeochemistry, the integration of natural and socio-economic research in the study of changes in the coastal zone is an important component of LOICZ.

4. Natural history background of Mexican lagoons

Primarily for the benefit of the resource persons who may not be familiar with the natural history of Mexican lagoons, Dr. Ibarra-Obando presented a brief background (Appendix I). She pointed to the wide range in climate conditions. It was suggested that the major coastal physiographic regions as shown in Figure 38 be used to group participants for the small workgroups.

5. Brief background and LOICZ Biogeochemical Modelling Initiative

5.1 General background and introduction

Prof. Smith provided a brief background to the LOICZ biogeochemical modelling initiative. He pointed out that the LOICZ Biogeochemical Modelling Guidelines (Gordon *et. al*, 1996) that were circulated to the participants before the workshop present a methodology for calculating budgets of carbon, nitrogen and phosphorus flux in coastal systems in a standard way. The application of such methodologies provides results that can then be compared among systems globally in an effort to establish the importance of the coastal waters to the overall global flux and changes in these fluxes.

The participants were reminded that the LOICZ guidelines will not be applicable to all situations and they were instructed to use their own experience and knowledge in generating the budget results.

A major initiative within the LOICZ Project is the compilation of as many budgets as possible for as many regions of the world. The on-going results this compilation effort are to be made available on the World Wide Web (WWW) home page (see next section). All budgets prepared by the workshop participants, either during or after the workshop, will be considered for inclusion in this compilation exercise. Submitted budgets will be reviewed for accuracy and completeness and, if they are judged to be of sufficiently high quality, will be placed on the home page with full credit given to the original authors. As this effort greatly benefits the global LOICZ research, assistance is offered to authors who may require help. Budgets and or requests for additional information, assistance should be directed to either the LOICZ CPO, Prof. Smith or Prof. Wulff (addresses in Appendix VI).

5.2 LOICZ Biogeochemical Modelling Node WWW Home Page Demonstration

In an effort to introduce the participants to the specifics of budget preparation and to the end goal of the budgeting work, Prof. Wulff presented an introduction to the LOICZ Biogeochemical Modelling Node WWW Home Page. He showed the participants the present status of the home page and explained that it is a very valuable source for researchers interested in generating such budgets. The budgets documented provide numerous examples of the data, calculations and presentation of results that are required for use by LOICZ. The home page can be accessed through the LOICZ Home page at http://www.nioz.nl/loicz/modnod. All participants were encouraged to review the home page and provide comments to Prof. Wulff. Budgets provided by the participants will be considered for addition to the home page.

6. Budget for Bahía San Quintín

6.1 Overall (Net) Biogeochemical Budgets

Dr. Victor Camacho-Ibar presented a budget model for Bahía San Quintín, Baja California, as an introduction to the details of the budget modelling. The presentation and associated documentation (Section 2.1.2, above) provided an excellent description of the modelling methodology. The documentation provided was used by the participants in the working groups in developing their budgets. This work which updates and improves on the original Bahía San Quintín results published in Gordon *et al.* (1996) will be incorporated into the LOICZ biogeochemical analysis and home page.

6.2 Component Gross budgets

Dr. Ibarra-Obando presented a component gross budget for Bahía San Quintín (Appendix II). In this budget she attempted to estimate overall production and respiration for comparison with the values for net flux presented by Dr. Camacho-Ibar. In her presentation she pointed out community respiration was particularly difficult to measure directly and that this poorly estimated value had significant impact on the gross budget results. She contrasted this with the results for the net budget as derived following the LOICZ approach with was much more robust.

7. Application of LOICZ Modelling Approach to Mexico Lagoon Situations

Smaller working groups were set up to carry out the budget modelling for specific Mexican lagoons. Based on the geographic areas of interest of the participants the following groups were formed to attempt to address the budgeting in the different regions (resource persons in italics):

GROUP	REGION *(see Figure 38)*	AREA *(see Figure 1)*	CONDITIONS
1	A	Baja California Peninsula	Arid
	B	Sonora and Sinaloa	
Botello-Ruvalcaba			
Delgadilla			
Lechuga-Devéze			
Poumian-Tapia			
Boudreau			
Camacho-Ibar			
2	C	Nayarit to Chiapas	Humid
Flores-Verdugo			
Ibarra-Obando			
de la Lanza-Espino			
Wulff			
3	D	Tamaulipas, Veracruz & Tabasco	Semiarid
	E	Campeche, Yucatan & Quintana Roo	Sub-humid
Carriquiry			
Contreras Espinosa			
Gomez-Reyes			
Vázquez-Botello			
Buddemeier			

The groups worked more or less independently, with the help of the resource persons. In all cases, the groups identified lagoons with sufficient data at hand to budget and proceeded to complete as much of the budgets as possible.

As a result of data availability, expertise and complexity of the systems chosen to budget, the different groups were able to produce different numbers with different levels of completeness. In summary, budgets were produced for the following areas:

GROUP	LAGOON
1	Arid Baja California and Gulf of California coasts
	1.1) Bahía San Quintín, Baja California (a teaching example)
	1.2) Estero de Punta Banda, Baja California
	1.3) Bahía San Luis Gonzaga, Baja California
	1.4) Bahía Concepción, Baja California
	1.5) Estero La Cruz, Sonora
2	Humid Pacific Coast
	2.1) Teacapan-Agua Brava-Marismas Nacionales, Sinaloa and Nayarit
	2.2) Chantuto-Panzacola, Chiapas
3	Sub-Humid- Gulf of Mexico
	3.1) Laguna de Terminos, Campeche

Four additional budgets were provided immediately following the workshop:

LAGOON	AUTHOR(S)
1) Carretas-Pereyra	Contreras-Espinosa;
2) Ensenada La Paz	Lechuga-Devéze;
3) Bahía de Altata-Ensenada del Pabellón	Flores-Verdugo and de la Lanza-Espino; and,
4) Laguna Madre	Ibarra-Obando and Contreras-Espinosa.

8. Presentation and review of budgets

Each group presented the results of their work in a closing plenary. The authors took the suggestions from the discussion to revise and improve the initial draft budgets.

9. Workplan and timetable for future activities

The co-chairs made it clear to the participants that submission of budgets for additional lagoons not considered during this workshop was greatly encouraged as soon as they become available. In addition, Prof. Smith presented a number of recommendations for future action:

- each research group to furnish at least one complete budget to the LOICZ CPO by June 15th. Additional budgets submitted within this time frame would be welcomed and included in the report;
- the LOICZ CPO will circulate to all participants a copy of the report by July 1st for their review, comments and corrections;
- participants to submit additional budgets to the LOICZ CPO by August 1st for possible inclusion in the final report;
- LOICZ CPO to circulate final report to the full network of LOICZ contacts by September 1st;
- if a minimum of four budgets are submitted for each of the three regions, Prof. Smith will take the lead in writing an article, co-authored by all participants and submitted to a refereed journal comparing net ecosystem metabolism among Mexican coastal lagoons.

Participants agreed with these recommendations and the timetable proposed and committed to providing additional budgets.

In addition to these specific recommendations, a number of more general suggestions were agreed to:

- all participants were encouraged to continue to submit budgets;
- the process of regional budgeting workshops should be used in other areas to generate within regional comparisons; and
- results so far support the development of a typology of matching lagoonal ecosystem types with ecosystem functions.

10. Approval of the report of the Workshop

It was agreed that the meeting report would be prepared by the workshop organisers and circulated to the participants by July 1st. Participants agreed to review the draft meeting report and provide corrections, comments, additions and changes to the LOICZ CPO no later than August 1st. It was agreed that the workshop resulted in sufficient scientific results that a LOICZ Reports & Studies document be produced. It was agreed that the workshop report be published as an appendix of the R&S document. It was also agreed that the document should be widely circulated to the LOICZ community as a means of supporting the LOICZ modelling approach.

11. Closure of the Workshop

Dr. Ibarra-Obando, co-chair of the meeting, thanked the participants of the workshop for their efforts before and during the workshop. She also thanked the staff of the local organising committee for their organisation and administrative support to the workshop and in particular Mrs. Maria Eugenia Ovies.

There being no further business Dr. Ibarra-Obando and Prof. Smith closed the meeting at 14:30 hours on 3 June 1997.

APPENDIX VI

LOICZ WORKSHOP ON MEXICAN COASTAL LAGOONS
CICESE, Ensenada, Mexico
2-3 June 1997

PARTICIPANTS AND CONTRIBUTORS TO BUDGETS

Mr. Martín BOTELLO-Ruvalcaba
Depto. de Investigaciones Científicas
y Tecnológicas
Universidad de Sonora (DICTUS-UNISON)
Rosales y Niños Héroes s/n
Hermosillo, Sonora, MEXICO
E-Mail: mbotello@guayacan.uson.mx
present mailing address:
Dept. of Applied Biology
Hull University
Hull, UNITED KINGDOM
Phone: 04180-465513
Fax: 04182-465458
E-Mail:
M.A.Botello-Ruvalcaba@appbiol.hull.ac.uk

Mr. Paul BOUDREAU
LOICZ Core Project Office
Netherlands Institute for Sea Research
P. O. Box 59
1790 AB Den Burg, Texel
THE NETHERLANDS
Phone: 31-2223 69404
Fax: 31-2223 69430
E-Mail: loicz@nioz.nl

Dr. Robert W. BUDDEMEIER
Kansas Geological Survey
University of Kansas
1930 Constant Ave.
Campus West
Lawrence, Kansas, 66047-3720
Phone: 1-913-864-3965
Fax: 1-913-864-5317
(after 20/7/97 area code is 785)
E-Mail: buddrw@kgs.ukans.edu

Dr. Víctor CAMACHO-Ibar*
Inst. de Investigaciones Oceanológicas
Universidad Autónoma de Baja California
(IIO-UABC)
Km. 103 Carretera Tijuana-Ensenada
Apartado Postal 453
Ensenada, Baja California 22830 MEXICO
Phone: 1-61-74 4601 ext. 123
Fax: 1-61-74 5303
E-Mail: vcamacho@bahia.ens.uabc.mx

Dr. José D. CARRIQUIRY*
Inst. de Investigaciones Oceanológicas
Universidad Autónoma de Baja California
(IIO-UABC)
Km. 103 Carretera Tijuana-Ensenada
Apartado Postal 453
Ensenada, Baja California, 22830 MEXICO
Phone: 1-61-74 4601 Ext. 123
Fax: 1-61-74 5303
E-Mail: jdcarriq@bahia.ens.uabc.mx

Prof. Francisco CONTRERAS Espinosa
UAM-IZTAPALAPA
Centro de Documentación sobre Ecosistemas
Litorales Mexicanos
Michoacán y Purísima, Col. Vicentina
Apartado Postal 55-535
México, D. F. 09340 MEXICO
Phone: 52-5 724-4746
Fax: 52-5 724-4738
E-Mail: fce@xanum.uam.mx

Dr. Guadalupe de la LANZA Espino
Instituto de Biología
Universidad Nacional Atuónoma de México
(IB-UNAM)
Apartado Postal 70-153
04510 MEXICO, D. F.
Phone: 525-622 5716
Fax: 525 550 0164
E-Mail: gdlle@servidor.unam.mx

Mr. Francisco DELGADILLO Hinojosa*
Instituto de Investigaciones Oceanológicas
Universidad Autónoma de Baja California
(IIO-UABC)
Km. 103 Carretera Tijuana-Ensenada
Apartado Postal 453
Ensenada, Baja California 22830 MEXICO
Phone: 1-61-744601 Ext. 122
Fax: 1-61 74 53-03
E-Mail: fdelgad@faro.ens.uabc.mx

Dr. Francisco J. FLORES Verdugo
Instituto de Ciencias del Mar y Limnología
Universidad Nacional Autónoma de México
(ICML-UNAM)
Laboratorio de Trofodinámica en Lagunas Costeras
Explanada de la Azada y Cerro del Crestón
Mazatlán, Sinaloa 82240 MEXICO
Phone: 52-69 85 28 45
Fax: 52-69 82-61-33
E-Mail: verduz@mar.icmyl.unam.mx

Dr. Eugenio GOMEZ-Reyes
UAM IZTAPALAPA
División de Ciencias Básicas e Ing.
Depto. de Ingeriería de Procesos e Hidráulica
Michoacán y Purísima, Col. Vicentina
México, D. F. 09340 MEXICO
Phone: 52-5 724-4646, 52-5-723-6992
Fax: 52-5 724-4400
E-Mail: egr@xanum.uam.mx

Dr. Silvia IBARRA-Obando*
Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE)
Km. 107 Carretera Tijuana-Ensenada
Apartado Postal 2732
Ensenada, Baja California 22860 MEXICO
Phone: 52-61 74 42 00
Fax: 52-61 74 5154
E-Mail: sibarra@cicese.mx

Dr. Carlos H. LECHUGA-Devéze
Centro de Investigaciones Biológicas del Noroeste
Km. 0.5 a la Telefónica
Apartado Postal 128
La Paz, Baja California, Sur 23000 MEXICO
Phone: 52-112-53626 Ext. 136
Fax: 52-112-54710
E-Mail: clechuga@cibnor.mx

Ms. Miriam POUMIAN Tapia*
Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE)
Km. 107 Carretera Tijuana-Ensenada
Apartado Postal 2732
Ensenada, Baja California 22860 MEXICO
Phone: 52-61 74 4200
Fax: 52-61 74-5154
E-Mail: mpoumian@cicese.mx

J. A. SEGOVIA-Zavala**
contact through
Mr. Francisco DELGADILLO Hinojosa

Prof. Stephen V. SMITH
School of Ocean and Earth Science and Technology
University of Hawaii
1000 Pope Road
Honolulul, Hawaii 96822 UNITED STATES
Phone: 1-808-956 8693
Fax: 1-808-956 7112
E-Mail: svsmith@soest.hawaii.edu

Mr. E. VALDEZ-Holguín**
Depto. de Investigaciones Científicas y Tecnológicas
Universidad de Sonora (DICTUS-UNISON)
Rosales y Niños Héroes s/n
Hermosillo, Sonora, MEXICO
E-Mail: jvaldez@guayacan.uson.mx

Dr. Alfonso VÁZQUEZ-Botello
Instituto de Ciencias del Mar y Limnología
Universidad Nacional Autónoma de México
(ICMyL-UNAM)
Apartado Postal 70-305
04510 México, D. F. MEXICO
Phone: 52-5-622 5810
Fax: 52-5-616 0748
E-Mail: alfonsov@mar.icmyl.unam.mx

Prof. Fred WULFF
Department of Systems Ecology
Stockholm University
106 91 Stockholm SWEDEN
Phone: 46-8 16 42 50
Fax: 46-8 15 84 17
E-Mail: fred@system.ecology.su.se

***U. S. Mailing addresses:**
Instituto de Investigaciones Oceanológicas
Universidad Autónoma de Baja California
(IIO-UABC)
P. O. Box 189003-099
Coronado, Ca. 92178
United States

Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE)
P. O. Box 43-4844
San Diego, Ca. 92143-4844
United States

**** contributor to budgets**

APPENDIX VII

LOICZ WORKSHOP ON MEXICAN COASTAL LAGOONS
CICESE, Ensenada, Mexico
2-3 June 1997

AGENDA

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1. **Official Opening of the Workshop**

2. **Administration and Organisation of the Workshop**
    - **2.1 Administrative and organisational matters**
    - **2.2 Introduction of Workshop participants**
    - **2.3 Purposes, expected outcome and schedule of the workshop**

3. **Brief background and status of the International Geosphere-Biosphere Programme (IGBP) and to the Land Ocean Interactions in the Coastal Zone (LOICZ) Core Project of IGBP**

4. **Natural history background of Mexican lagoons**

5. **Brief background and LOICZ Biogeochemical Modelling Initiative**
    - **5.1 General background and introduction**
    - **5.2 LOICZ Biogeochemical Modelling Node WWW Home Page Demonstration**

6. **Budget for Bahía San Quintín**
    - **6.1 Overall (Net) Biogeochemical Budgets**
    - **6.2 Component Gross budgets**

7. **Application of LOICZ Modelling Approach to Mexico Lagoon Situations**

8. **Presentation and review of budgets**

9. **Workplan and timetable for future activities**

10. **Approval of the report of the Workshop**

11. **Closure of the Workshop**