1. OVERVIEW AND BUDGETS RESULTS

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

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

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

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

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

The Estuarine Systems of the South China Sea Region: Carbon, Nitrogen, Phosphorus Flux workshop builds on earlier work by LOICZ to assess material flux in the estuaries and coastal seas of global regions (Smith *et al.* 1997, Smith and Crossland 1999, Smith *et al.* 1999). The South China Sea is a region of important interaction between extensive watershed areas and the marginal sea, where a large number of riverine systems discharge a globally highly significant volume of materials into coastal waters (Appendix I). The intensity and effects of human activities on these discharges – rates, quality and nature of materials – are obviously undergoing great change; some 5% of the world population live in this maritime region. The South China Sea region is characterised by high population density and rapid continuing population growth and development in the coastal zone. The influence of these changes on natural processes and their impacts on regional socio-economic opportunity and the ramifications of these changes on global “budgets” for material transformation, are leading issues for science, policy and management. The Workshop seeks to provide a basis for initial assessment of coastal ecosystem performance in terms of carbon and nutrient fluxes, fates and, subsequently, to place the results into a global context.

The diverse land-use pressures and the array of coastal habitats and system regimes in the South China Sea region provide opportunity to derive a suite of models and budgets representative of tropical systems. Data sets of varying coherence are available for sites throughout the region. The results of this Workshop provide a first step in developing an understanding of the available information, and the LOICZ-UNEP project provides a platform on which regional scientists can continue focussed development and assessment of the relevant scientific information.

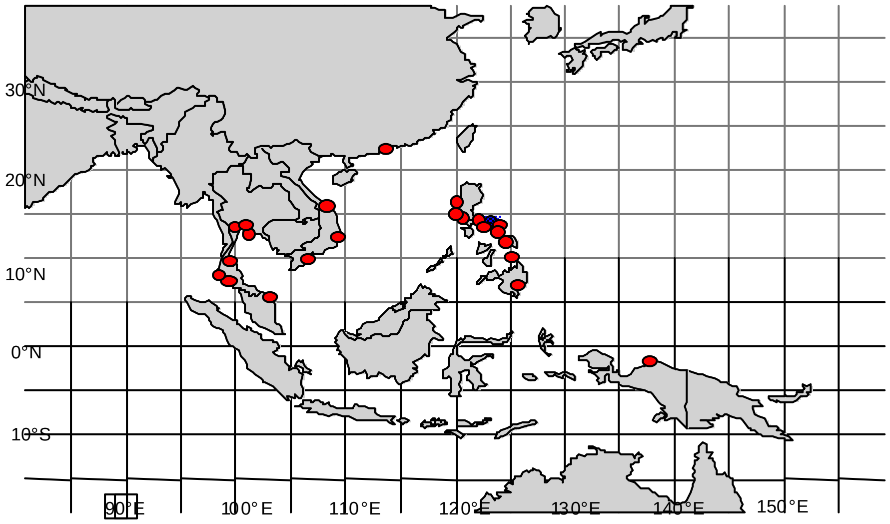

Figure 1.1 Map of budgets sites developed during the South China Sea Region Workshop, July 1999.

The Workshop was held in Manila, the Philippines on 19-22 July 1999. The objectives of the Workshop (Appendix VII) and the activities (Appendices IV and VI) are provided in this report. Three resource persons (Prof. Stephen Smith, Ms Vilma Dupra, Dr Chris Crossland) and three regional resource persons (Dr Laura David, Dr Maria Lourdes San Diego-McGlone, Dr Gullaya Wattayakorn) worked with participants from coastal science agencies and universities, representing six countries (China, Indonesia, Malaysia, Philippines, Thailand, Vietnam), to consider, develop and assess biogeochemical budgets for 25 coastal ecosystems in the region. In addition to the resultant budget descriptions, the Workshop provided a vital training forum that is resulting in further system budgets developments. To assist in this extension work, a regional mentor centre has been established at the Marine Science Institute, University of the Philippines (resource persons: Dr Laura David, Dr Maria Lourdes San Diego-McGlone), and is funded by the UNEP/GEF supported project. Mr Nguyen Huan, a workshop participant, took up the South China Sea Workshop Scholarship, which involves additional training in budget analyses at the University of Hawaii for the month of October 1999, before returning to Vietnam and contributing to the resource person activities.

Beyond the success of the budgets production and training was the development of additional methodologies (Appendix II and III) that allow detailed assessment of waste load contributions to nutrient budgets and estimation of catchment delivery, in localities where direct data are sparse. Consideration was made of an initial typology (or classification) of regional watersheds (Appendix I); this is being pursued as part of the project and within the broader LOICZ initiatives as a vital approach to regionalise and globalise the budget site information to data-poor locations.

The initial session of the Workshop dealt with the LOICZ approach to the global questions of horizontal fluxes of materials, and the previous work and current contributions being made by regional scientists. The Pelorus Sound, New Zealand, estuarine system was presented by Ms Vilma Dupra as a case study, including the stratified and segmented approach to the material flux budgets within the system. The typology approach and a preliminary “snapshot” of watersheds in the region was presented by Dr Liana Talaue-McManus. The LOICZ Budgets Modelling website was described by Prof. Stephen Smith, and the pivotal role of the electronic site and its use by global scientists in making budget contributions to the LOICZ purpose was emphasised. It was noted that contributing scientists are clearly attributed as authors of their contributed budgets, and that there is provision to updated and provide additional assessment of their budgets.

The group moved from plenary to further develop the site budgets individually and in small working groups, returning to plenary sessions to discuss the budget developments and to debate points of approach and interpretation. Nineteen budgets were developed during the Workshop, with six additional site completed after the workshop and in time to be included in this report (Figure 1.1).

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

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

Key outcomes and findings from the workshop include:

i) An initial suite of 25 site budgets reflecting the tapestry of watershed and climate regimes in the tropical South China Sea region. These, and subsequent site budgets, provide a vital opportunity for assessment of trends in patterns of estuarine performance and response to major forcing functions, both natural and anthropogenic. The number of sites and the further development of the site data, provide a basis for in-region evaluation of material flux characteristics and comparison with other tropical regions – from earlier workshops in Australasia and Central America, and planned workshops in Latin America, South Asia and Africa. Trend assessment continues as a vital plank in the LOICZ-UNEP project.

ii) Eight site budgets are partially resolved at this stage, reflecting short water residence time parameters and/or limited temporal or spatial data such that initial estimates are based on a part-segment of the site (e.g., upper estuary only) or a part season (e.g., dry season). Three major considerations are exemplified in these systems:

a) Ambient data (system concentrations) may be inadequate and introduce problems due to analytical quality, spatial resolution and/or temporal resolution.

b) Resolution of loads may be problematic, especially for waste load estimates such as domestic and industrial wastes (often via point source discharges), and various forms of agricultural and aquacultural discharges (usually as diffuse inputs). The methodology for estimation of waste loads (Appendix II) provides a first level of estimating these inputs. However, as loads greatly increase, small proportional errors can have major impacts on the site budget assessments.

c) **Table 1.1 Budgeted South China Sea sites, locations, sizes and water exchange times.**

System Name	**Long.** (E)	**Lat.** (N)	**Area** (km^2)	**Depth** (m)	**Exchange Time** (days)
China					
Pearl River estuary [a]	113.59	22.57	1180	7	1-3
Mirs Bay	114.70	22.50	346	12	>365
Indonesia					
Mamberamo estuary, Irian Jaya [a]	138.00	2.0 (S)		20	<<1
Malaysia					
Kuala Terengganu River estuary [a]	103.10	5.45	8	6	<1
Philippines					
Luzon Island					
Calauag Bay	122.17	14.15	400	87	>365
Lagonoy Gulf	123.88	13.52	1500	542	>365
Lingayen Gulf [b]	119.90	16.35	2100	46	32
Manila Bay	120.78	14.55	1700	17	31
Ragay Gulf	123.08	13.50	3600	179	>365
San Miguel Bay	123.16	13.93	1000	7	6
Sorsogon Bay	123.89	12.90	300	5	61
Subic Bay	120.21	14.79	324	20	325
Visayan Islands					
Carigara Bay	124.68	11.36	500	40	106
Mindinao Island					
Davao Gulf	125.78	6.74	6600	17	>365
Leyte Island					
Sogod Bay	125.12	10.7	1500	700	>365
Thailand					
Bandon Bay	99.67	9.20	480	3	45
Bangpahong River estuary	101.50	13.75	8700	9	6
Chao Phraya River	100.55	14.05	38	10	5
Mae Klong River [a,c]	99.80	13.66	1.5	9	1
Pakphanang River	100.18	8.37	8	6	14
Prasae River [a,c]	101.62	12.87	0.38	3	<1
Tachin River [a]	99.75	14.50	19.2	7	3
Vietnam					
Hau River	106.06	9.72	490	9	8
Cau Hai Lagoon	107.73	16.36	102	1.5	30
Nha Trang Bay	109.27	12.22	346		50

a exchange time too short to calculate reliable nonconservative fluxes
b calculations based on dry season only
c calculations based on dry season, upper estuary only

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

System Name	**DIP load**	**DIN load**	**DDIP**	**DDIN**	***(nfix-denit)***	***(p-r)***
	mmol m^{-2} yr^{-1}					
China						
Pearl River estuary [a]	340	5270	755	545	-11500	-79900
Mirs Bay	190	2420	<+1	-15	-18	-30
Indonesia						
Mamberamo estuary, Irian Jaya [a]					**a**	**a**
Malaysia						
Kuala Terengganu River estuary [a]	<+1	14	<-1	3	**a**	**a**
Philippines						
Luzon Island						
Calauag Bay	2	20	2	-35	-75	-220
Lagonoy Gulf	0	3	7	195	75	730
Lingayen Gulf [b]	100	520	-50	-400	500	6000
Manila Bay	60	940	20	-700	-1130	-2000
Ragay Gulf	<+1	2	<+1	33	+	0
San Miguel Bay	2	10	-2	-20	0	110
Sorsogon Bay	10	45	35	200	-385	-4000
Subic Bay	1	35	-5	50	55	255
Visayan Islands						
Carigara Bay	15	105	0	-35	-35	0
Mindinao Island						
Davao Gulf	5	90	-5	-90	-30	365
Leyte Island						
Sogod Bay	1	5	-10	-230	-25	1460
Thailand						
Bandon Bay	2	10	10	-5	230	5420
Bangpahong River estuary	2	25			**a**	**a**
Chao Phraya River	2000	15000	1300	13000	**a**	**a**
Mae Klong River [a,c]	1400	63000	-250	-2400	1400	-25
Pakphanang River	425	3600	115	1600		
Prasae River [a,c]	95	800	20	35	-300	-2500
Tachin River [a]	2900	31400	260	10700	-5800	101000
Vietnam						
Hau River,	850	6630	85	2200	765	11700
Cau Hai Lagoon	70	980	-25	15	105	2260
Nha Trang Bay	10	170	70	-250	-1100	-5000

a exchange time too short to calculate reliable non-conservative fluxes

b calculations based on dry season only

c calculations based on dry season, upper estuary only

iii) Two new tools have been developed to assist in the assessment of material fluxes in estuarine systems, viz.

a) A rapid assessment method to determine effluent generation from various economic land-use activities (Appendix II). A manuscript for estimating these waste loads has been accepted by Marine Pollution Bulletin.

b) A methodology for estimating river discharge (Appendix III), where climatological information is available but where direct measurements in watersheds is limited or non-existent. The methodology has been tested in several site budget assessments in this report.

The Workshop was hosted by the Marine Science Institute, University of the Philippines. LOICZ is grateful for this support and the opportunity to collaborate in working to mutual goals, and is indebted to Prof. Ed Gomez, Director, MSI and staff for their contributions to the success of the Workshop. In particular, Drs Liana Talaue-McManus, Laura David, Maria Lourdes San Diego-McGlone and Ms Leah Asuncion put in much hard work as local organisers to ensure the smooth running of the Workshop. Ms Cynthia Pattiruhu, LOICZ IPO, has contributed greatly to the preparation of this report. LOICZ gratefully acknowledges the effort and work of the participants not only for their significant contributions to the Workshop goals, but also for their continued interaction beyond the meeting activities.

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

CHINA ESTUARINE SYSTEMS

2.1 Pearl River Estuary and Mirs Bay, South China

M.H. Wong and K.C. Cheung

Study area description

The Pearl River is the largest river system in South China, and the fourth largest in the country (Figure 2.1). The river is 2,218 km long with a catchment area of 450,000 km^2. It has three major tributaries that merge into the Pearl River delta i.e., West River, North River and East River. The Pearl River Delta region is broadly triangular in shape, with Guangzhou at its northen apex, Hong Kong in the south-east corner and Zhuhai in the south-west corner. The mean annual discharge of the Pearl River is 330x10^9 m^3, and the sediment load is 70x10^9 kg yr^{-1} (Kot and Hu 1995).

The Pearl River delta (22.57^{o}N, 113.59^{o}E) covers an area of 4,000 km^2, with 21 million inhabitants (Guangdong Statistical Bureau 1996), including Hong Kong (6.7 million) and Macau (0.5 million). The Pearl River delta has eight openings: Yamen, Hutiaomen, Jitimen, Modaomen, Hengmen, Hongqimen, Jiaomen and Humen, through which the Pearl River waters discharge into South China Sea. The latter four outlets are to the east and drain into the Pearl River estuary. Hong Kong is located at the eastern side of the estuary and Macau is on its western bank.

With a sub-tropical climate, the area has a long summer and a short winter, average annual temperature of 21-22^{o}C and total rainfall of 1,600-2,000 mm. Eighty per cent of the river's annual discharge occurs during the wet season (April to September). Typhoons are common to the region, and when the typhoons coincide with high water levels, flooding occurs, especially near the estuary. Winds are usually southerly in summer, opposite to the direction of stream flow, so the wind stirs up sand and silt in the shallow sea and brings back some of the sediments into the estuary. In winter, winds are northerly, blowing parallel to the direction of stream flow, which helps in carrying away the sediments.

The area can be regarded as an amphibious environment, favorable for both agricultural and aquacultural developments, and in fact the area has been named as “homeland for rice and fish”. However, there has been rapid socio-economic change including population growth, industrialisation and urbanisation in the region during the past two decades. Although the natural rate of population increase has not been high, immigration into the region contributes significantly to the overall population growth of the region. A large amount of domestic, industrial and agricultural sewage is discharged into the river system, and water quality has been a major concern. It has been estimated that up to 560 million tonnes of domestic wastes and 2 billion tonnes of industrial effluent are generated annually (Chen 1994). Agricultural activities also give rise to pollution from fertilizers and pesticides, and the use of chemical fertilizers has been increased by 40% between 1986 and 1989 (Neller and Lam 1994). Eutrophication and associated red tides have occurred frequently in the Pearl River estuarine zone in the past twenty years (Ho and Hodgkiss 1991). The most severe one occurred in 1998 due to a bloom of dinoflagellate *Gymnodinium milkimotoi* and a large number of maricultured fish were killed, the loss valued at over US$80 million (Dickman *et al*. 1998).

In this exercise, the nutrient budget of the Pearl River delta is studied. Mirs Bay, to the east of Hong Kong, is included for comparison. Mirs Bay (22.50^{o}N, 114.70^{o}E) is cleaner than and less influenced by the Pearl River. Major developments in the north of the bay include Shatoujiao town at the border and the Yantian Container Port at Shenzhen. Tolo Harbour is a nearly land-locked tidal estuary in the south-western part of Mirs Bay. It lies south-west/north-east and discharges into Mirs Bay. The harbour can be considered as a vertically fully mixed estuary for most of the time, apart from certain periods in the summer season when heavy rainfall may bring about significant stratification. Because of the land-locked feature, poor tidal flushing, especially in the inner regions, is expected.

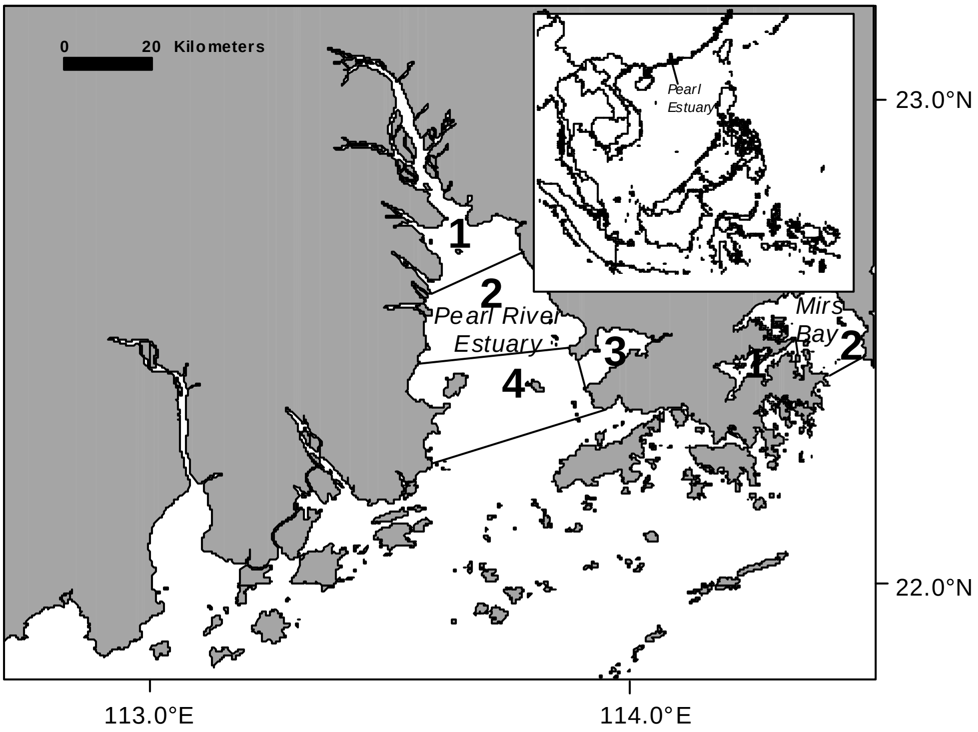

Figure 2.1. Pearl River estuary and Mirs Bay. Bars represent boundaries of the budgets.

Water and salt balance

At steady state, the box model describes salt flux. This and the succeeding equations are from Gordon *et al.* (1996).

$$V_{syst}\frac{dS_{syst}}{dt} = 0 = V_Q S_Q - V_R S_R + V_x(S_{ocn} - S_{syst}) \qquad (1)$$

In order to account for strong gradients in water composition for budgeting purposes, the Pearl River estuary and Mirs Bay were divided into 4 and 2 boxes, respectively. The boundaries used for budgeting boxes in this study are shown in Figure 2.2.

Two seasonal budgets for the Pearl River estuary were made because of the obvious difference due to river inflow into the estuary. The areas and volumes of each box are shown in Tables 2.1 and 2.2. The water composition data used for the budget calculations are summarised in Tables 2.3 and 2.4. The water and salt budgets are summarised in Figures 2.3 to 2.5. River water driving the residual flow primarily entered into Box 1 of Pearl River estuary. In this case, groundwater and sewage were ignored in this water budget. Net residual flows (V_R) at the estuary mouth were about 1,448x10^6 m^3day^{-1} and 362x10^6 m^3day^{-1}, in summer and winter respectively. Roughly 80% of the river's inflow occurs in the summer season (April-September). Mixing decreased rapidly down the axis of the Pearl River estuary in summer. The reverse was found in winter. The water residence time was 3 days in the summer and less than a day in the winter for the Pearl River estuary. More than a year residence time was calculated for Mirs Bay. The very rapid exchange time for the main stream of Pearl River estuary limits the calculation of reliable non-conservative fluxes of nutrients. The nutrient budgets obtained would barely describe physical transport of the nutrients into the ocean and may not necessarily reflect biotic processes.

Table 2.1. Dimensions of budget boxes for the Pearl River estuary (Chen *et al.* 1993; HKRO 1998).

Box	**Area**	**Depth**	**Volume**	**River inflow** (summer)	**River inflow** (winter)
	(10^6 m^2)	(m)	(10^6 m^3)	(10^6 m^3 day^{-1})	(10^6 m^{3}day^{-1})
1	220	7	1,540	1447	362
2	360	7	2,520	0	0
3	96	5	480	1	0.06
4	504	7	3,528	0	0

Table 2.2. Dimensions of budget boxes for Mirs Bay (HKEPD 1997a,b; HKRO 1998).

	Area	**Depth**	**Volume**	**River inflow**
Box	(10^6 m^2)	(m)	(10^6 m^3)	(10^6 m^3 yr^{-1})
1	52	12	624	18
2	294	12	4,410	60

Table 2.3. Water composition data for the Pearl River estuary (Chen *et al.* 1993; Lu 1993; Ho and Wang 1997; Hill *et al.* 1998).

	Summer			Winter		
Box	**Salinity** (psu)	**DIP** (mmol/m^3)	**DIN** (mmol/m^3)	**Salinity** (psu)	**DIP** (mmol/m^3)	**DIN** (mmol/m^3)
1	3.0	0.9	10.7	4.5	1.7	5.2
2	3.8	0.8	9.2	13.0	1.1	5.1
3	3.1	3.4	111	26.9	16.6	327
4	10.0	0.7	7.3	32.2	1.3	3.8

Table 2.4. Water composition data for Mirs Bay (HKEPD 1997a,b).

BOX	**Salinity**	**DIP (mmol/m^3)**	**DIN (mmol/m^3)**
1	29.8	0.8	10.0
2	31.2	0.4	5.1

Budgets of nonconservative materials

DIP and DIP balance

An equation analogous to Equation 1 is used to describe any dissolved material Y which has a source (+) or sink (-) in the system (denoted by *DY*, where Y is either DIP or DIN) (Gordon *et al.* 1996).

$$V_{syst}\frac{dY_{syst}}{dt} = 0 = V_Q Y_Q - V_R Y_R + V_x (Y_{ocn} - Y_{syst}) + \Delta Y \qquad (2)$$

Figures 2.6 to 2.11 summarise the DIP and DIN budgets for this system. The nutrient fluxes in two locations were outward. In all three cases, there were obvious gradients of DIN and DIP between the ocean and the studied systems due to the freshwater inputs. The order of residual fluxes of these materials in three cases was Pearl River estuary in summer > Pearl River estuary in winter > Mirs Bay.

The combination of residual flow and exchange flow between the estuary and the ocean resulted in higher nutrient export in winter than in summer.

In summer, there appeared to be a sink for DIP and DIN in the Pearl River estuary, with *DDIP* and *DDIN* being about -455x10^3 mol day^{-1} and -13,214x10^3 mol day^{-1} (Tables 2.5 and 2.6). By contrast, outward transport occurred in winter via both residual flow and mixing, in excess of the estimated inflow contributed by river. Thus, there appeared to be internal sources of DIP and DIN contribution in winter. This source might be sediment recycling processes and some local inputs of DIP with agricultural activities excluded from the budget. In Mirs Bay, there appeared to be a source of DIP and DIN.

Table 2.5. Nonconservative fluxes and stoichiometric calculations for the Pearl River estuary.

	Summer				*Wint Winter*			
	DDIP	***DDIN***	**(*p-r*)**	**(*nfix-denit*)**	***DDIP***	***DDIN***	**(*p-r*)**	**(*nfix-denit*)**
	(10^3 mol day^{-1})		(mmol m^{-2} day^{-1})		(10^3 mol day^{-1})		(mmol m^{-2} day^{-1})	
Total	-455	-13,214	+41	-5	+5,333	+16,745	-479	-58

Table 2.6. Nonconservative fluxes and stoichiometric calculations for Mirs Bay.

	DDIP	***DDIN***	***(p-r)***	***(nfix-denit)***
	(10^3 mol yr^{-1})		(mmol m^{-2} day^{-1})	
Total	+95	-5,303	-0.08	-0.05

Stoichiometric calculations of aspects of net system metabolism

Primary production in this system is assumed to be dominated by plankton, with a C:N:P ratio (C:N:P)$_{part}$ of about 106:16:1. This ratio is used to calculate net metabolism (*p*-*r*) from *DDIP* according to the relationship (Gordon *et al.* 1996):

$$-DDIP \text{ x } (C:P)_{part} = (p-r) \qquad (3)$$

The rate of nitrogen fixation minus denitrification (*nfix-denit*) can be also be calculated from *DDIP*, *DDIN*, and the N:P ratio of particulate material in the system (Gordon *et al.* 1996).

$$(nfix\text{-}denit) = DDIN - DDIP \text{ x } (N:P)_{part} \qquad (4)$$

The aspects of metabolism are estimated as shown in Tables 2.5 and 2.6. The Pearl River estuary in summer was a net producer of organic carbon based on the positive value of (*p*-*r*). As expected, there was a more significant production in the warm, light summer conditions. The reverse was found in winter in the Pearl River estuary as well as in Mirs Bay. However, it should be noted that the rates are extremely high for biotic processes. It is probable that the stoichiometric calculations are at best partially artifacts of the very high suspended load delivery of this system, although rapid rates of respiration (p-r) < 0 could represent high water organic load. The stoichiometric calculations also suggested that (*nfix-denit*) were negative for Pearl River estuary in both seasons, i.e., nitrogen loss through denitrification was higher than nitrogen fixation. Mirs Bay was also a net denitrifier: (*nfix-denit*) = -0.05 mmol m^{-2} day^{-1}.

The budgets showed considerable local variation in Hong Kong's eastern and western waters. The Pearl River estuary also showed a strong seasonal variation. Nutrient levels in Hong Kong's eastern waters were much lower than those in its western waters. Moreover, higher nutrient levels were recorded at the mouth of the Pearl River estuary due to the high net residual flow and exchange flow.

Based on these observations, the abundance of algae in Hong Kong's eastern waters should be lower than those in its western waters due to the lower nutrient levels in the eastern waters. However, there were a total of over 481 algal blooms reported for Hong Kong waters and less than 6% of these were from the Pearl River estuary from 1980 to 1997 (Dickman *et al.* 1998). According to the difference between the budgets of the Pearl River estuary and Mirs Bay, nutrients were probably not the limiting factor in the nutrient-enriched system. The water residence time and/or salinity of the estuary or the bay might be the limiting factor for eutrophication.

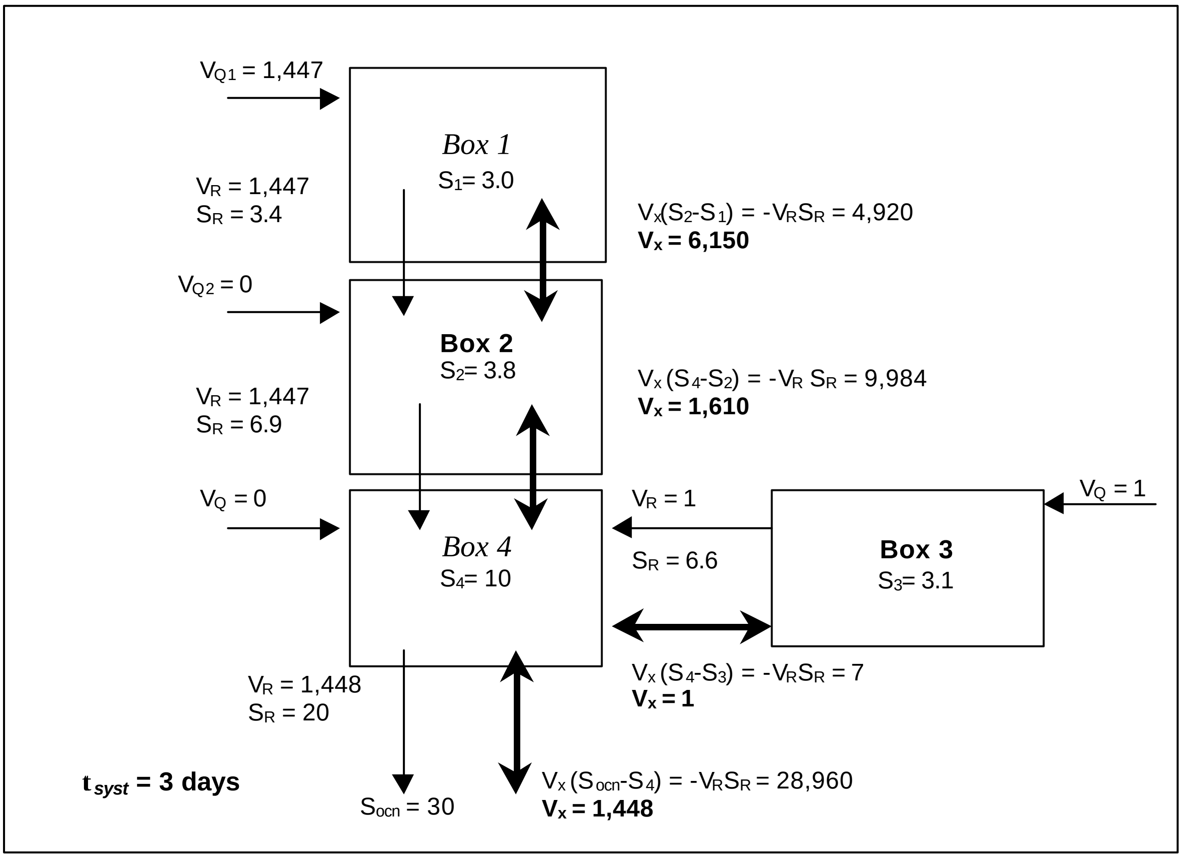

Figure 2.2. Water and salt budgets for the Pearl River estuary in summer. Water fluxes in 10^6 m^3 day^{-1}, salt fluxes in 10^6 psu-m^3 day^{-1} and salinity in psu.

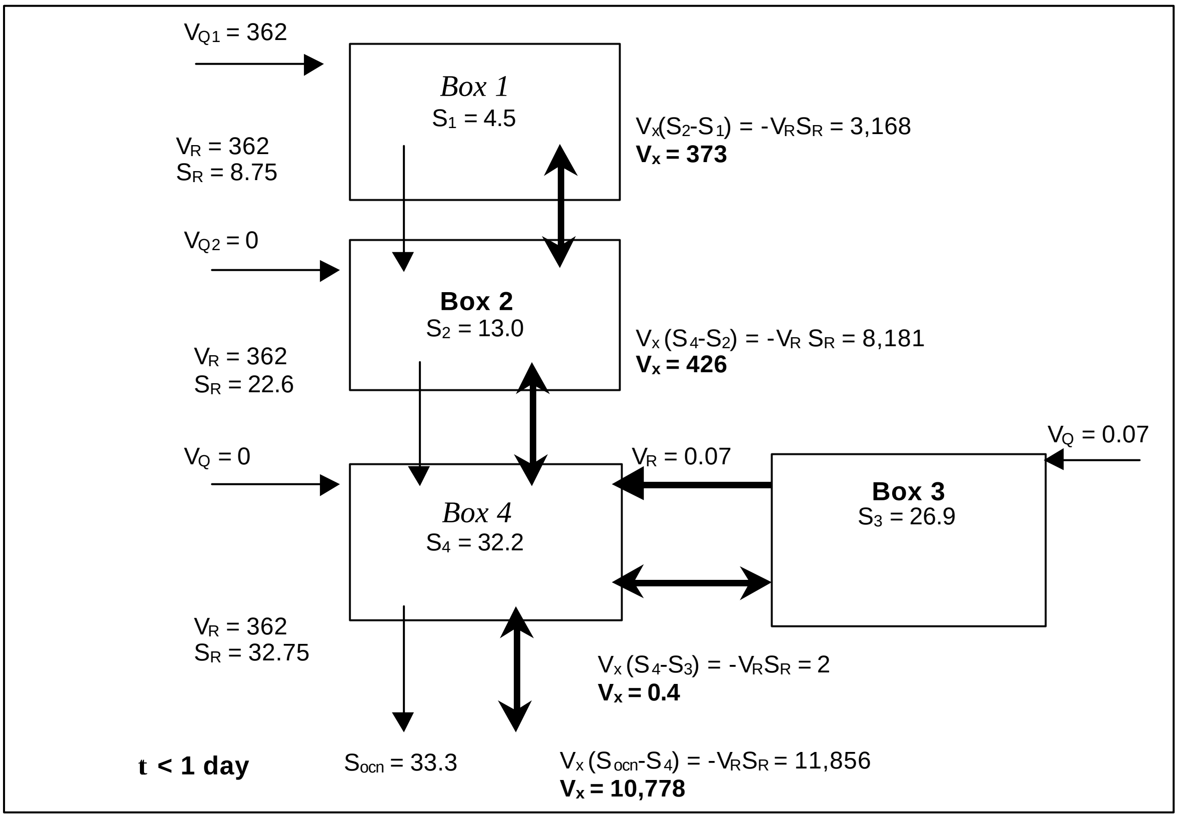

Figure 2.3. Water and salt budgets for the Pearl River estuary in winter. Water fluxes in 10^6 m^3 day^{-1}, salt fluxes in 10^6 psu-m^3 $day^{-1}$and salinity in psu.

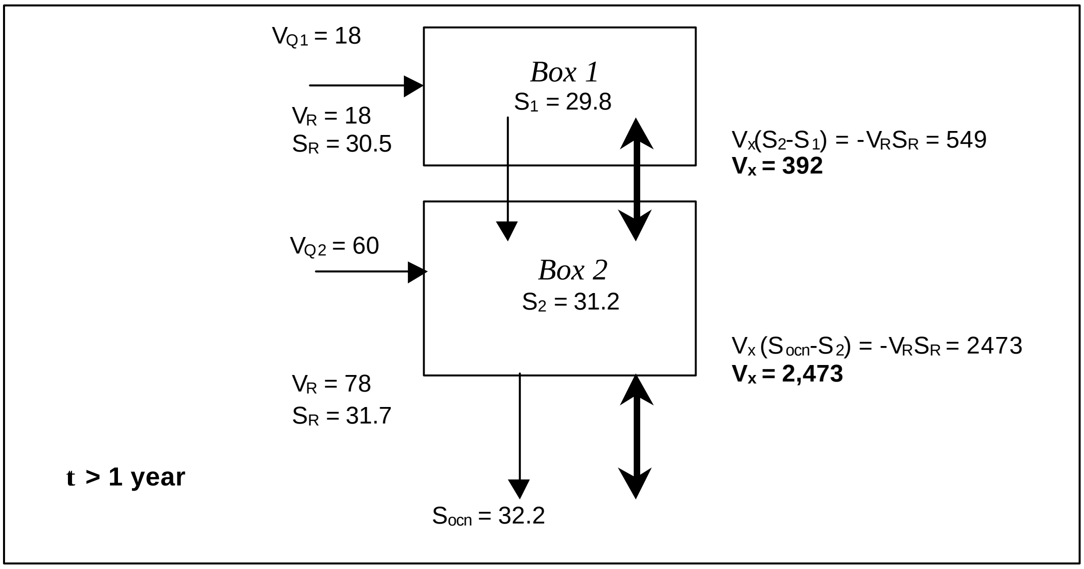

Figure 2.4. Water and salt budgets for Mirs Bay. Water fluxes in 10^6 m^3 yr^{-1}, salt fluxes in 10^6 psu-m^3 $yr^{-1}$and salinity in psu.

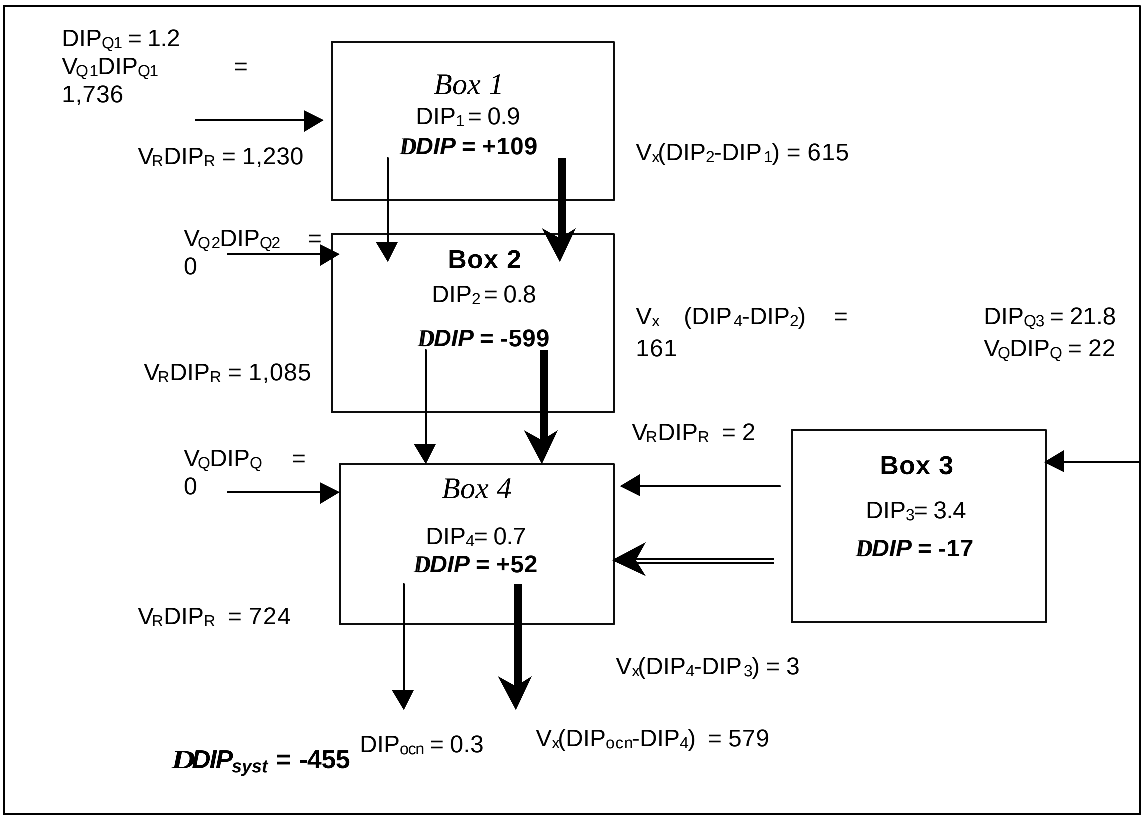

Figure 2.5. Dissolved inorganic phosphorus budget for the Pearl River estuary in summer. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

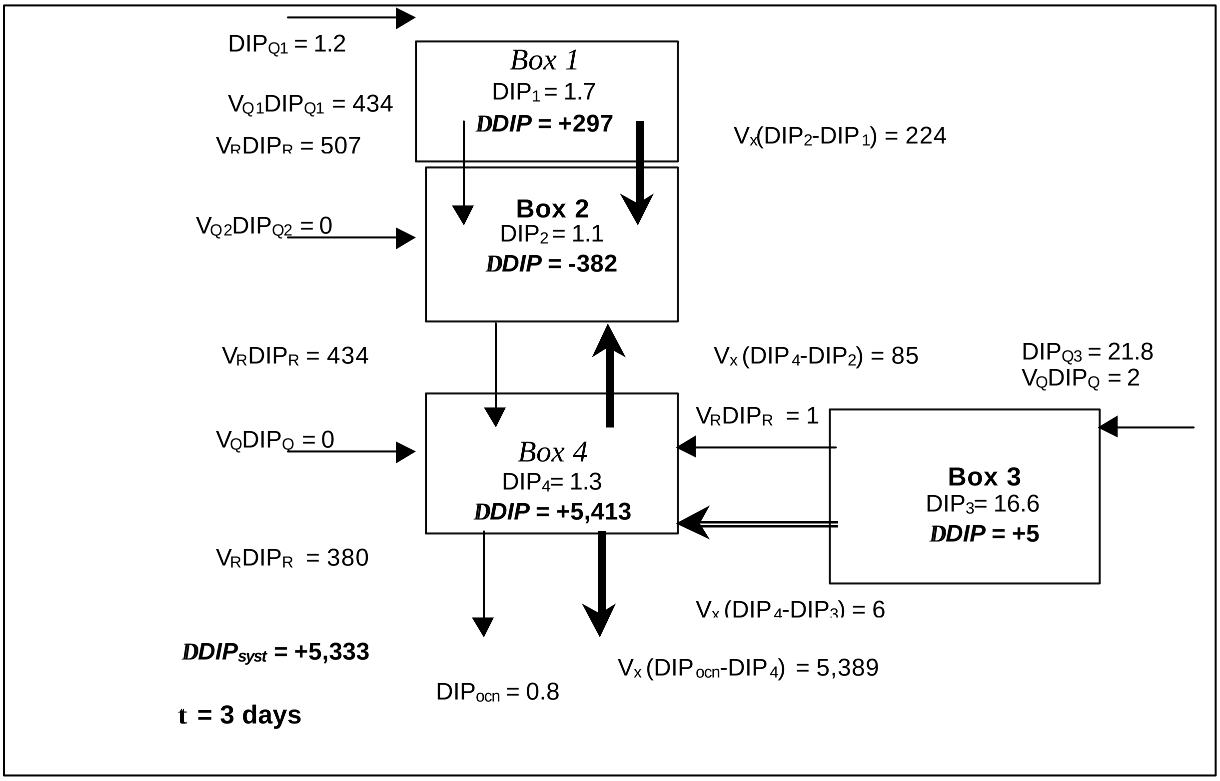

Figure 2.6. Dissolved inorganic phosphorus budget for Pearl River estuary in winter. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

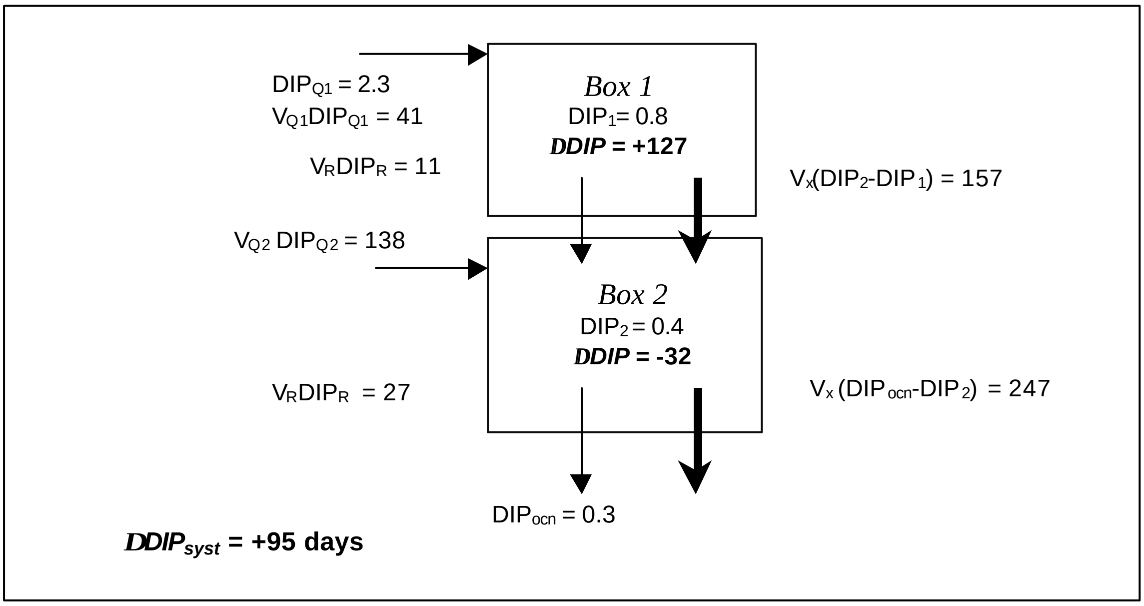

Figure 2.7. Dissolved inorganic phosphorus budget for Mirs Bay. Fluxes in 10^3 mol yr^{-1} and concentrations mmol m^{-3}.

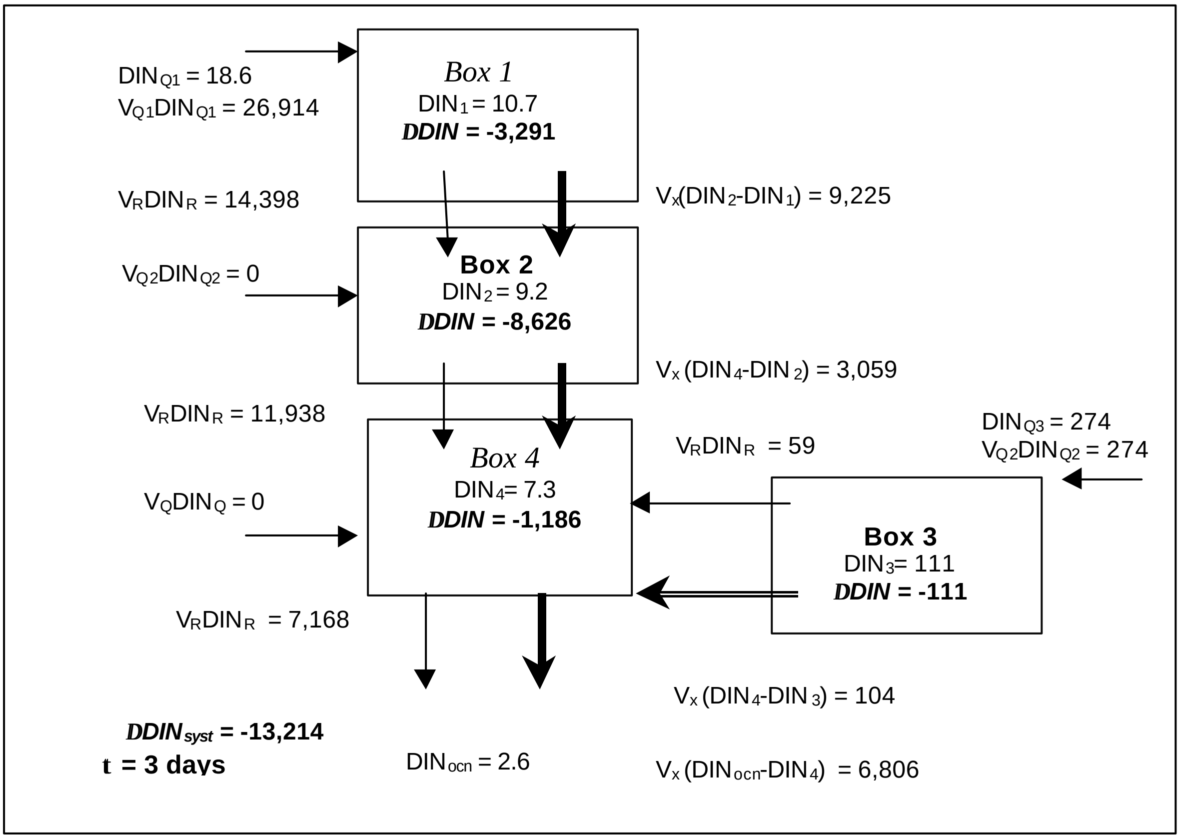

Figure 2.8. Dissolved inorganic nitrogen budget for the Pearl River estuary in summer. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

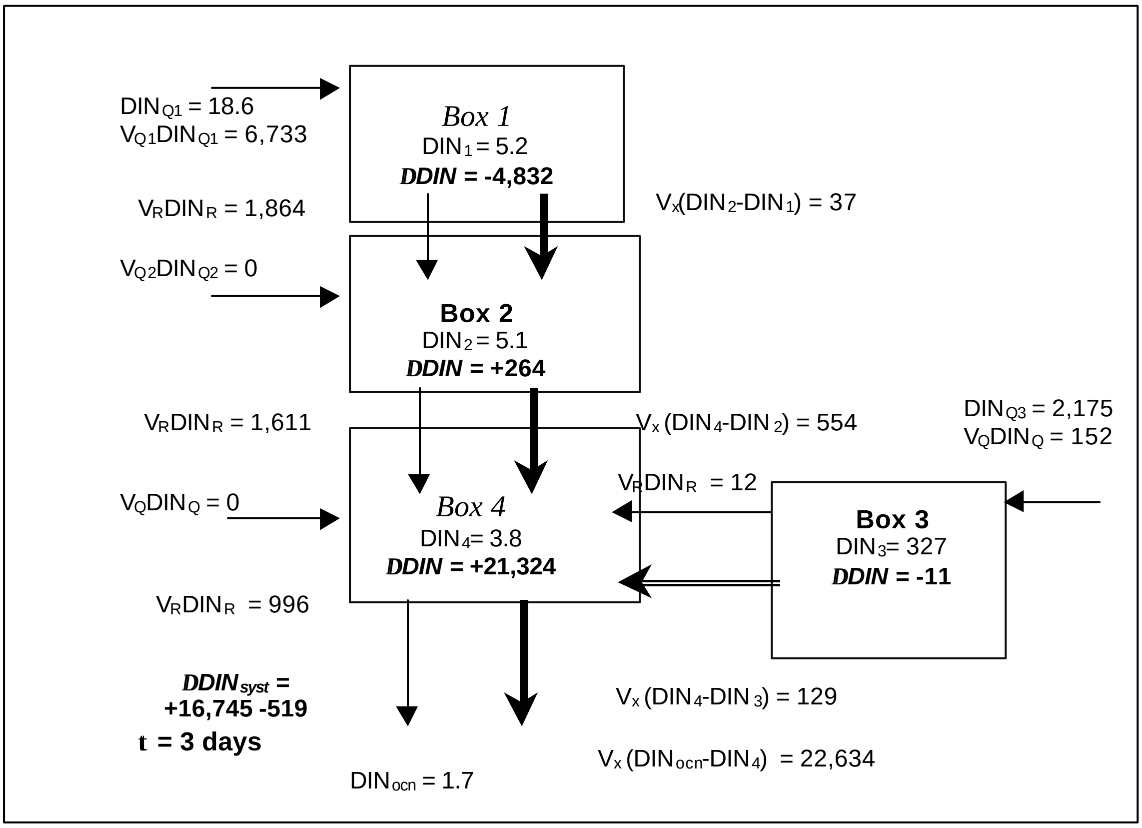

Figure 2.9. Dissolved inorganic nitrogen budget for Pearl River estuary in winter. Fluxes in 10^3 molday^{-1} and concentrations in mmol m^{-3}.

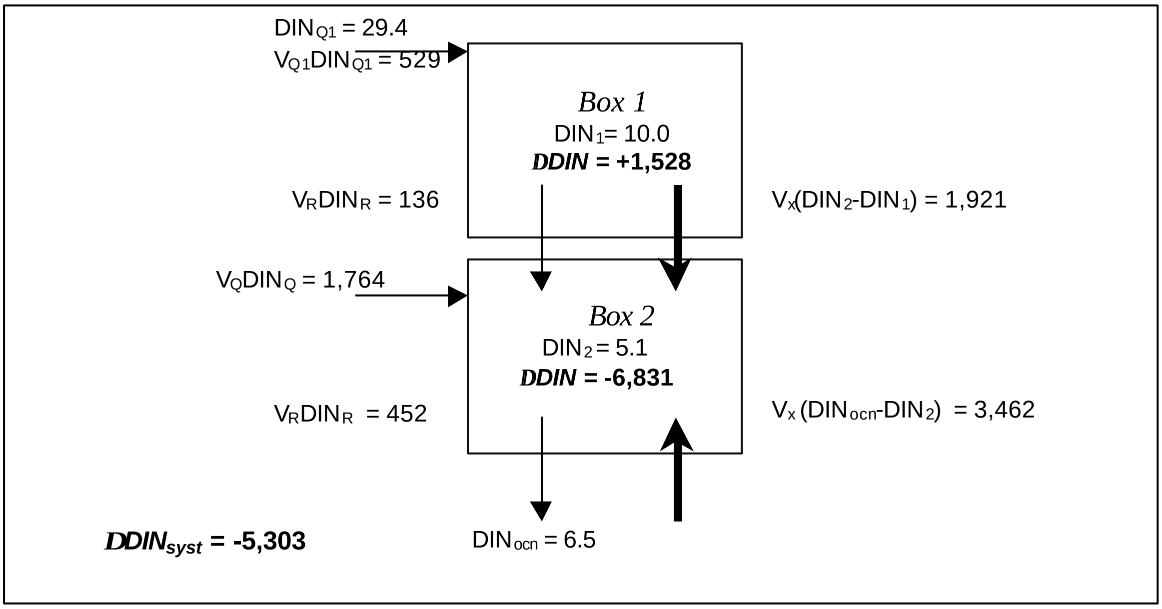

Figure 2.10. Dissolved inorganic nitrogen budget for Mirs Bay. Fluxes in 10^3 mol day^{-1} and concentrations mmol m^{-3}.

3. INDONESIA ESTUARINE SYSTEMS

3.1 Mamberamo River Estuary, Irian Jaya

M. Muchtar and A.G. Ilahude

Study area description

The Mamberamo River is in Irian Jaya, the Indonesian part of the West New Guinea Island, 2.0°S, 138.00°E. It is 650 km long, with a catchment of about 76,000 km^2. It discharges its turbid water into the narrow continental shelf and immediate, very steep continental slope of the Pacific Ocean north of the New Guinea Coast (see Figure 3.1).

The river originates from the mountainous area of the island at 3,000 m altitude, so that there is quite significant slope along the river's path to the ocean. A heavy load of suspended matter is carried through a deeply-scoured, long canyon that extends inland about 60 miles from the river mouth.

The mean depth at mid-estuary is 20 m, and the width of the river is about 2,500 m at the mouth and about 800 m at the river end of the estuary. The average net river flow into the estuary is about $130\mathrm{x}10^6$ m^{-3} yr^{-1}. Annual average rainfall is 3,050 mm.

The hydrological data are presented in Table 3.1. These data are from the observation in May 1999, during the ebb-tide in the estuary of the Mamberamo River. They are at present kept at Oceanography Division.

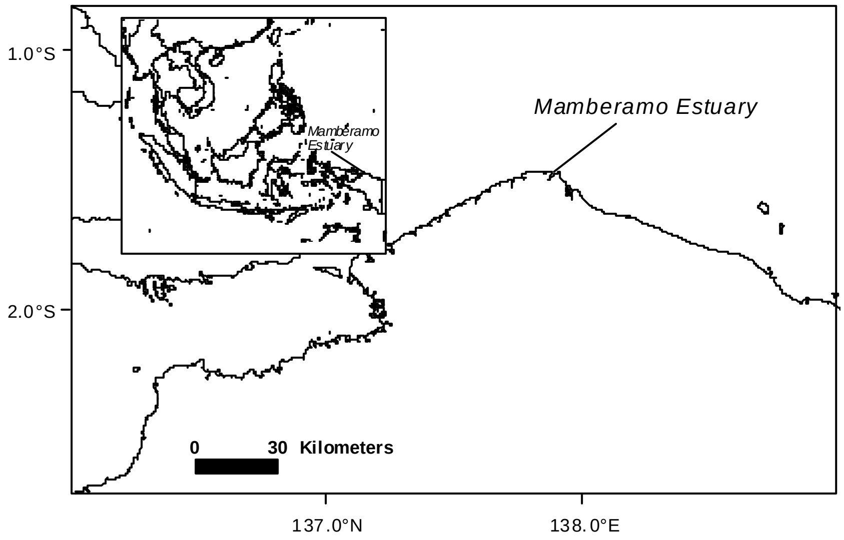

Figure 3.1. Location of Mamberano River estuary, Irian Jaya.

Water and salt balance

Figure 3.2 shows the water and salt budgets for Mamberamo River estuary. Using the data collected and applying the LOICZ Biogeochemical Modelling Guidelines (Gordon *et al.* 1996), water exchange time is estimated to be less than one day (4 hours).

Budgets of nonconservative materials

Because of the very rapid exchange time, it is not possible to calculate reliably the nonconservative fluxes of nutrients. Figures 3 and 4 show the estimated DIP and DIN fluxes of the system. There is insufficient data to derive a stoichiometric calculation at this stage.

Table 3.1. Hydrological data for the Mamberamo River estuary.

Observation site	**Salinity(psu)**	**DIP(mmol m^{-3})**	**DIN(mmol m^{-3})**
Boundary Box (river end)	0	0.8	1.5
Mid-estuary	10	0.5	1.5
Boundary Box (ocean end)	29.1	0.2	1.5

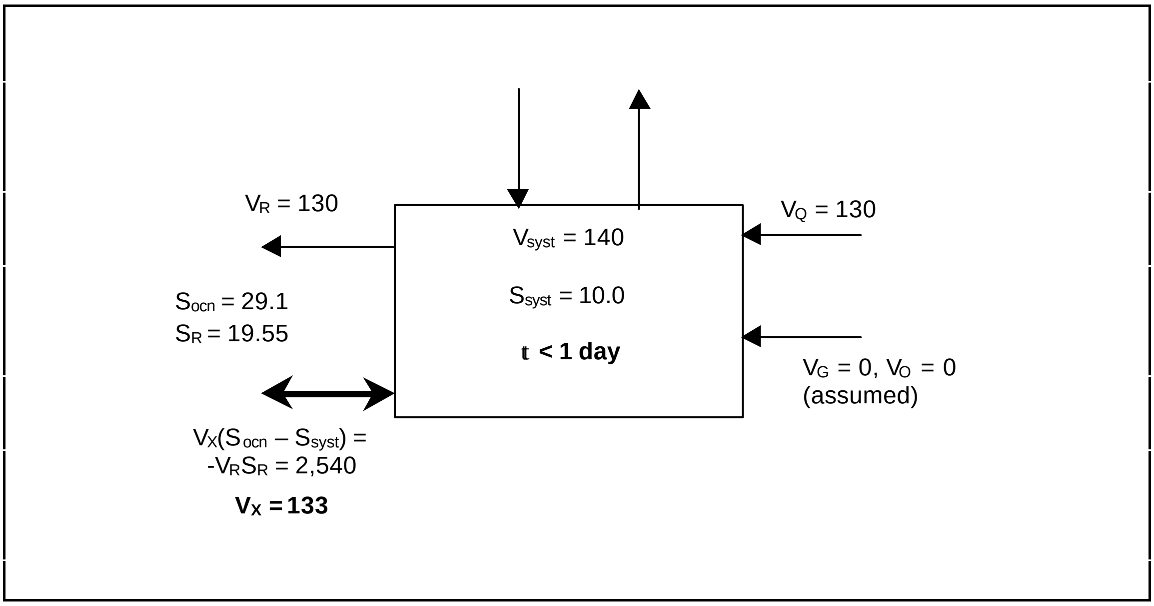

Figure 3.2. Water and salt budgets for the Mamberamo River estuary. Volume in 10^6 m^3, water fluxes in 10^6 m^3 yr^{-1}, salt fluxes in 10^6 psu-m^3 yr^{-1} and salinity in psu.

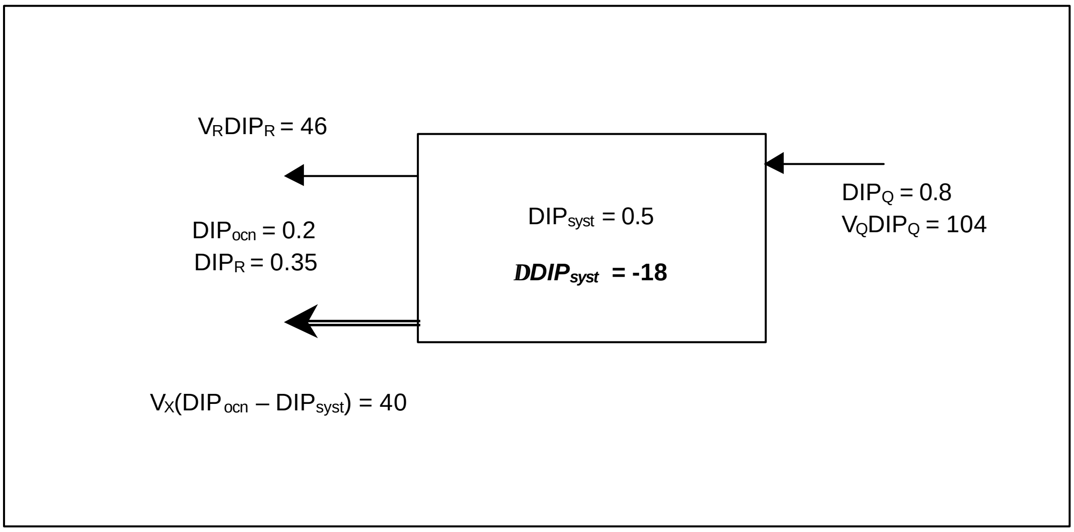

Figure 3.3. Dissolved inorganic phosphorus budget for the Mamberamo River estuary. Fluxes in 10^6 mol yr^{-1} and concentrations in mmol m^{-3}.

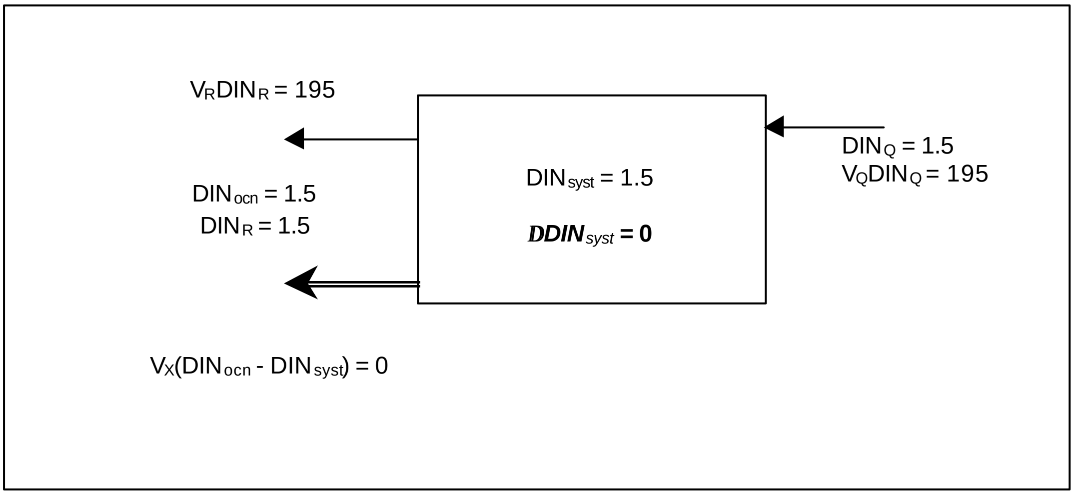

Figure 3.4. Dissolved inorganic nitrogen budget for the Mamberamo River estuary. Fluxes in 10^6 mol yr^{-1} and concentrations in mmol m^{-3}.

4. MALAYSIA ESTAURINE SYSTEMS

4.1 Kuala Terengganu River Estuary

Law Ah Theem

Study area description

Kuala Terengganu River estuary (5.32°-5.55°N, 102.95°-103.15°E) is situated on the east coast of peninsular Malaysia facing the South China Sea (figure 4.1). Generally, the Kuala Terengganu River estuary is relatively small and shallow. The total area of the estuary is approximately 8 km^2. Maximum depth recorded in this area was only 6 m and the average depth was about 4 m. Two river systems, the Nerus River and the Terengganu River, channel their water into this estuary.

The north-west monsoon rain has a great impact on the ecosystem and water budget of this area between October and January. The highest rainfall recorded in December 1998 was 155 mm day^{-1} with an average value of 21 mm day^{-1}. For the rest of the year, the average rainfall was between 0 to 6 mm day^{-1}. Highest evaporation rate in April 1998 was 8 mm day^{-1} with an average value of 6 mm day^{-1}.

The major waste waters discharged into this river and its estuary come from partially-treated domestic waste. The levels of nitrogen and phosphorus are generally low in the riverine system. However, substantial levels were found in the estuary along with the high level of fecal coliform bacterial count (Law *et al.* 1998). This revealed that there is gross sewage pollution in this estuary. Recent rapid development in Kuala Terengganu due to extensive crude oil production in the off-shore waters of this state, as well as the insufficient wastewater treatment systems, may have led to water quality deterioration in this river and its estuary.

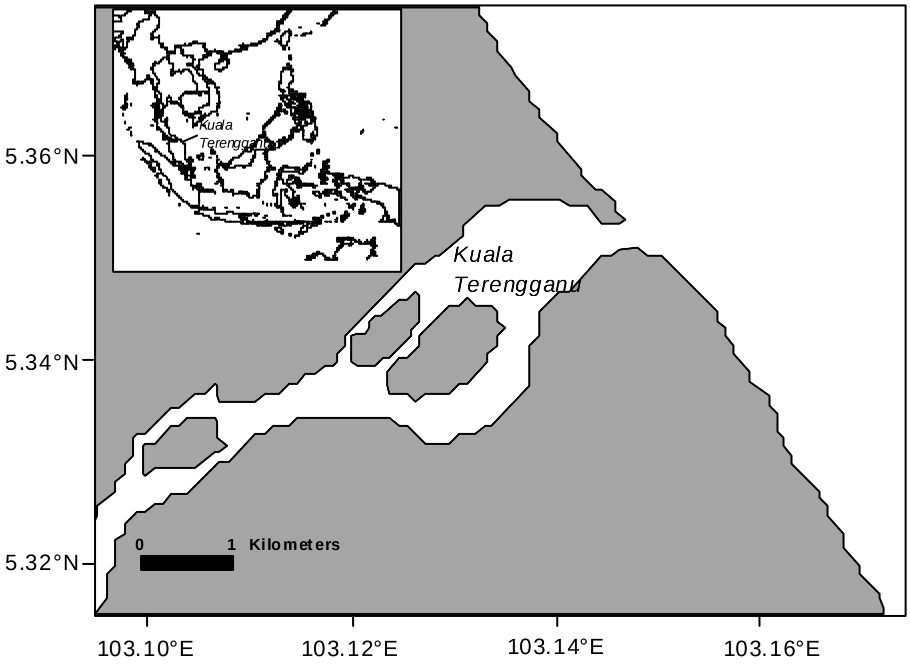

Figure 4.1. Location of Kuala Terengganu River estuary.

We have established sixteen sampling stations in this study, of which six are in the riverine water, six in the estuary and four along the coast in the vicinity of the estuary. The sampling stations were visited four times: in March, May and December 1998, and July 1999. Water flow rate was measured by a Flow-O-Meter (Flow-Mate Model 2000) at 1-metre intervals throughout the depth, and the depth-profile was measured by an echo sounder. The water samples were taken with a 5-litre horizontal Van Dorn water sampler. For each station, two water samples were taken to form a composite water sample for the analysis. Orthophosphate, nitrate, nitrite, and ammonium analyses followed the methods of Parsons *et al.* (1984). Analysis of BOD followed the Standard Methods (APHA l989). The nitrogen, phosphorus and BOD data were used for N and P budgets calculations. The rainfall and evaporation data were supplied by the Hydrology Division, Jabatan Pengaliran dan Saliran (JPS), Kuala Terengganu.

Methodology
The Kuala Terengganu River estuary was budgeted using the LOICZ Biogeochemical Modelling Guidelines (Gordon *et al.* 1996).

Waste loading into the system from residents staying around Kuala Terengganu River estuary was considered in this budget. The population of Terengganu was about 1 million in 1996 (**http://www.terengganu.gov.my/basic/070b-06a.htm**). We assume that about 5% of the waste derived from the residents is discharged into this system. The BOD (*Biological Oxygen Demand*) load to this system is taken as 20 kg yr^{-1} person^{-1} and the C:N:P ratio in the waste effluent is assumed to be approximately 43:13:1 (Smith, personal communication).

Water and salt balance
Figure 4.2 shows the water and salt budgets for Kuala Terengganu River estuary. The estuary is treated as a single system for the water and salt balance calculation. The system is very simple. The water has good mixing with a large amount of fresh water inflow. There is a substantial amount of sewage discharged into the system from the residents living near the estuary. Calculated annual water output from the estuary was 16,500x10^6 m^3**.** The V_R value obtained from the above water balance is surprisingly close to the value calculated from average water current speed in the estuary mouth multiplied by the cross section of the estuary mouth (Table 4.1). This indicated that other sources of water input in the system such as domestic water discharge and groundwater are insignificant in this area. Flushing time was calculated to be less than 1 day (7 hours).

Budgets of nonconservative materials
Due to extremely high flushing rate of this estuary, nutrient budgets probably cannot be considered reliable. Figures 4.3 and 4.4 presents the DIP and DIN budgets respectively, but these budgets are not considered further at this time.

Table 4.1. Kuala Terengganu River estuary freshwater inputs and outputs.

Station	Cross Section Area (m^2)	Flow Rate (m s^{-1})	Volume (m^3 s^{-1})	Volume (m^3 year^{-1})
Museum	**388**	**0.11**	**43**	**1.3 x 10^9**
Pengkalan Arang	**440**	**0.04**	**19**	**0.6 x 10^9**
Sg. Terengganu	**1259**	**0.37**	**462**	**14.6 x 10^9**
River Mouth	**987**	**0.53**	**526**	**16.5 x 10^9***

* Measured volume of water output per year from Kuala Terengganu estuary.

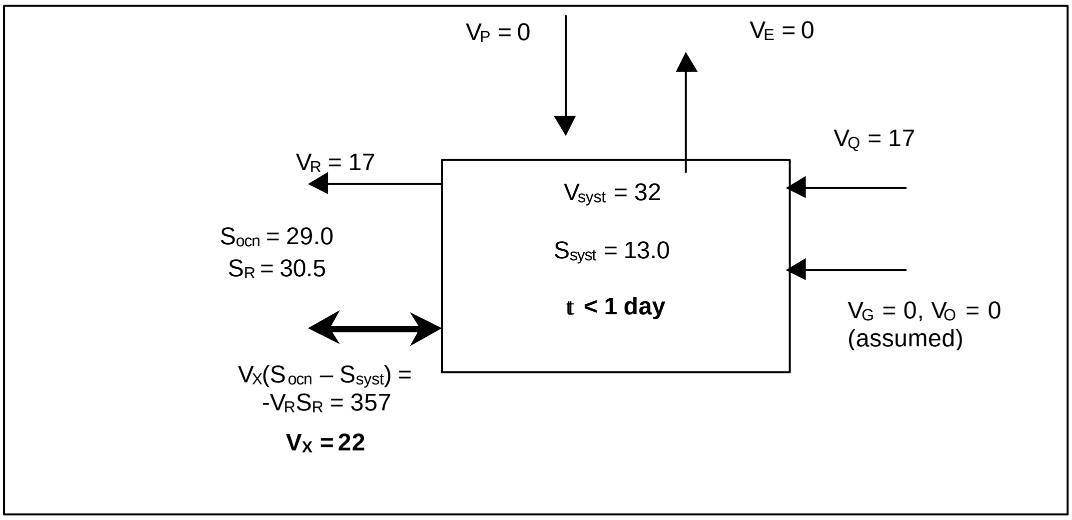

Figure 4.2. Water and salt budgets for Kuala Terengganu River estuary. Volume in 10^6 m^3, water fluxes in 10^9 m^3 yr^{-1}, salt fluxes in 10^9 psu-m^3 yr^{-1} and salinity in psu.

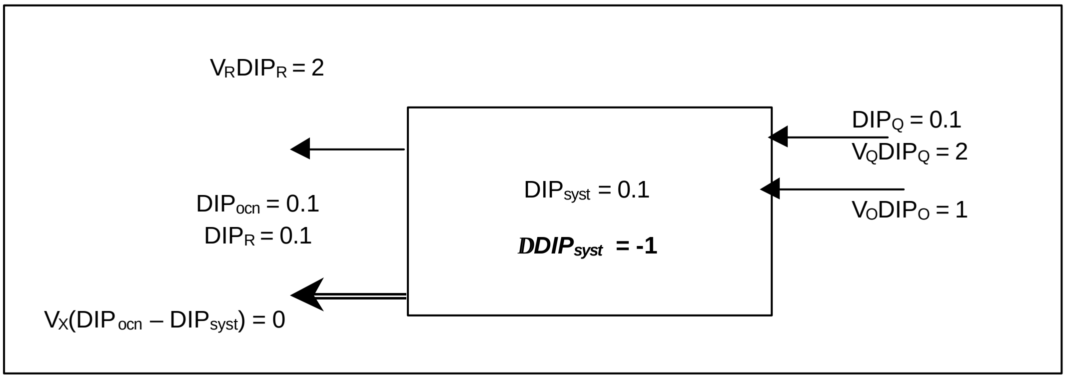

Figure 4.3. Dissolved inorganic phosphorus budget for Kuala Terengganu River estuary. Fluxes in 10^3 mol yr^{-1} and concentrations in mmol m^{-3}.

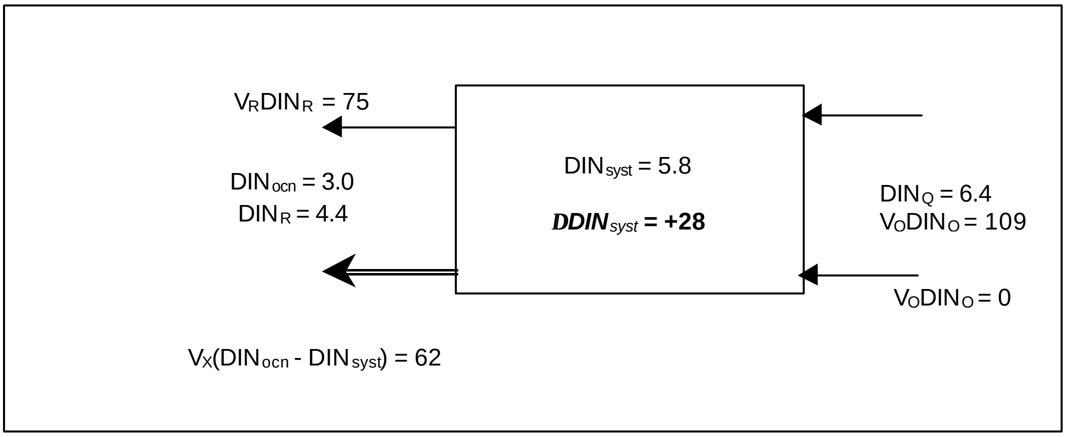

Figure 4.4. Dissolved inorganic nitrogen budget for Kuala Terengganu River estuary. Fluxes in 10^3 mol yr^{-1} and concentrations in mmol m^{-3}.

5. PHILIPPINES ESTUARINE SYSTEMS

5.1 Calauag Bay, Luzon Island

V. Dupra, S.V. Smith and G.S. Jacinto

Study area description

Calauag Bay is on Luzon island, 13.92°-14.22°N, 122.00°-122.33°E (Figure 5.1). The bay covers about 400 km^2, is 32 km long and 13 km wide. The average depth of the bay is 87 m, so the volume is approximately 35x10^9 m^3.

The Calauag River is the main drainage basin that empties into the bay. It is a relatively narrow (width ≈ 5 km, length ≈ 30 km) watershed that has a total drainage of 150 km^2. The river basin is located on the southern base of the bay and is in the vicinity of Calauag Town where a great proportion (72 %) of the 50,000 population living along the bay is concentrated (Bureau of Fisheries Resources (BFAR) 1993). Problems in the bay include overexploitation of marine resources and degradation of habitats and water quality. The expanding population (about 1.2 % average annual growth from 1980 to 1990) surrounding Calauag Bay has increased the pressure on the bay. This overexploitation has manifested itself in the declining fish catch from the bay (BFAR historical data).

Calauag Bay is a highly diverse ecosystem. The recorded number of fish species is 144 from 86 genera and 26 families (BFAR 1993). The bay is fringed on both sides with coral reefs, except on its southern base where it is deltaic mudflat. The eastern shore of the bay has extensive seagrass beds along the whole length of the reef flat. A taxonomic plant inventory indicates the presence of 46 species of seaweed and two species of seagrass. The long bay coastline is lined with varying dimensions of mangrove strips or patches.

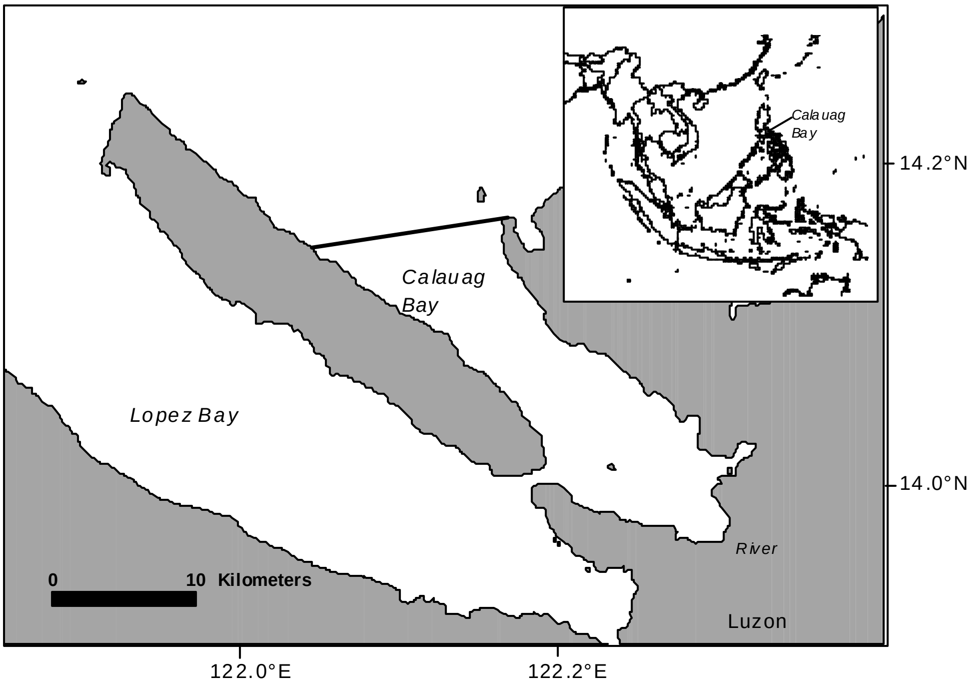

Figure 5.1. Calauag Bay. Solid line shows the boundary of the budgeted system.

The water column of the bay is stratified, the upper layer depth ranging from 10 to 15 m depending on the season. Salinity of the mixed upper layer varies seasonally by 1 psu and there seems to be no spatial variation of salinity within the bay. The concentration of nutrients (PO_4 and NO_3) in the mixed layer does not seem to vary significantly between seasons, and N:P ratios (2:1) are much less than the classic Redfield (16:1).

This study aims to quantify the fluxes of nitrogen and phosphorus in Calauag Bay and use the fluxes to understand the biogeochemical processes occurring in the system. The bay was budgeted as a two-layer model (designed for stratified systems) following the LOICZ Biochemical Modelling Guidelines (Gordon *et al*. 1996). The bay was treated as a horizontally mixed system because salinity data did not significantly vary spatially in all the sampling seasons. The three sampling seasons represented by wet, warm dry and cold dry seasons were conducted in May 1992, August 1992 and February 1993 respectively. For these stoichiometrically linked water-salt-nutrient budgets, only annual means of water flows and concentrations were considered. Oceanic values for salinity and nutrient concentrations were obtained from NOAA <http://ferret.wrc.noaa.gov/fbin/ climate_server >. Riverine nutrient concentrations for Lingayen Gulf (a relatively less perturbed bay) were used; this will be corrected for actual data when available. Sewage nutrient loads were also considered.

Water and salt balance

Figure 5.2 illustrates the two-layer water and salt budgets for Calauag Bay. The upper solid box and lower dashed box represent the upper and lower layers. The depth used for the upper mixed layer in this budget is 15 m (maximum depth for the upper mixed layer). Results of the freshwater balance indicate that there is a net annual freshwater input ($V_{R'}$) into the bay of 0.3×10^9 m^3. The net freshwater input is the balance of river runoff ($V_Q = 0.2 \times 10^9$ m^3 yr^{-1}), precipitation ($V_P = 0.9 \times 10^9$ m^3 yr^{-1}) and evaporation ($V_E = -0.8 \times 10^9$ m^3 yr^{-1}). The gauged river runoff reported by BFAR from the Calauag River was validated by the climatological model for calculating river discharge as described in this report (David, Appendix III). The two river runoff estimations did not vary much. Precipitation and evaporation data were obtained from the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA).

Annual average salinity of the upper layer system (S_{syst-s}), lower layer system (S_{syst-d}) and bottom oceanic water (S_{ocn-d}) are 33.6, 34.2 and 34.3 respectively. The two narrow inlets located near the southern sides of the bay were not considered; instead it was assumed that water exchange occurs only through the mouth of the bay. From the water and salt budgets, the relatively weak freshwater input resulted to a residual surface flow of 14.7×10^9 m^3 (V_{surf}) to compensate the net freshwater input ($V_{R'}$) and water entrained between the layers of the water column ($V_{D'}$). $V_{D'}$ is a consequence of water intrusion (V_D) from adjacent ocean bottom water to balance the residual water flux. A volume needed to mix (V_Z) between the layers was calculated as 3.0×10^9 m^3. The water exchange time (τ)is 122 days for the upper mixed layer of the bay and 598 days for the lower layer. The water exchange time for the whole bay is more than a year. The very long water exchange time is due to the great depth of the bay and may be due also to imprecise knowledge of the annual average salinity of the system. The annual average salinity of the upper water column is actually the annual average of 1-m surface samples and not the integrated average salinity of the 15-m water column. Adjustment of the annual average salinity for the upper layer would tend to increase the volume of bottom water intrusion and would mean a decrease of the water exchange time.

Budgets of nonconservative materials

DIP balance

Figure 3 summarises the two-layer DIP budget for Calauag Bay. Nonconservative processes in Calauag Bay yielded a net source for DIP (*DDIP* = $+1 \times 10^6$ mole P yr^{-1} or +0.006 mmole P m^{-2} day^{-1}). These values were simply the sum of the *DDIP*'s of upper and lower boxes. It is most reasonable to assume that the lost nutrients in the upper layer were deposited as particulate materials from primary production into the lower layer and were regenerated in the lower layer. Increase in the water fluxes would also change the magnitude of both the conservative and nonconservative nutrient fluxes and might alter the direction of the net nonconservative fluxes.

River nutrient concentrations used for these budgets were values from relatively less perturbed rivers of the Philippines (Lingayen Gulf rivers). Sewage nutrient loads were estimated from the 50,000 population around the bay including those living near the Calauag River. Sewage nutrient inputs coming from Calauag River population were reconsidered in the waste load since riverine nutrient loads were too low compared with the loads coming from the Calauag River population alone.

DIN balance

Figure 4 presents the two-layer DIN budget for Calauag Bay. In contrast to nonconservative DIP, the bay is a net sink for DIN (*DDIN* = -14x10^{6} mole N yr^{-1} or -0.1 mmole N m^{-2} day^{-1}). DIN budgets would change with the change of the water fluxes.

Stoichiometric calculations of aspects of net system metabolism

With the assumption that metabolic processes are primarily driven by phytoplankton (C:N:P = 106:16:1), the bay is slightly denitrifying: (*nfix-denit*) = -0.2 mmole N m^{-2} day^{-1}; and heterotrophic: (*p-r*) = -0.6 mmole C m^{-2} day^{-1}. Primary production in the bay was independently estimated as 178 mmole C m^{-2} day^{-1}, giving a p/r essentially equal to 1.00. It is also implied that both (*nfix-denit*) and (*p-r*) would vary with the change of water fluxes.

The fraction of the primary production deposited into the lower layer was calculated as *DDIP* (upper layer) x 106 C:P. It is equal to 4 mmole C m^{-2} day^{-1} and is about 2% of the total primary production. This deposited primary production supplies about 83% of the organic matter regenerated in the lower layer.

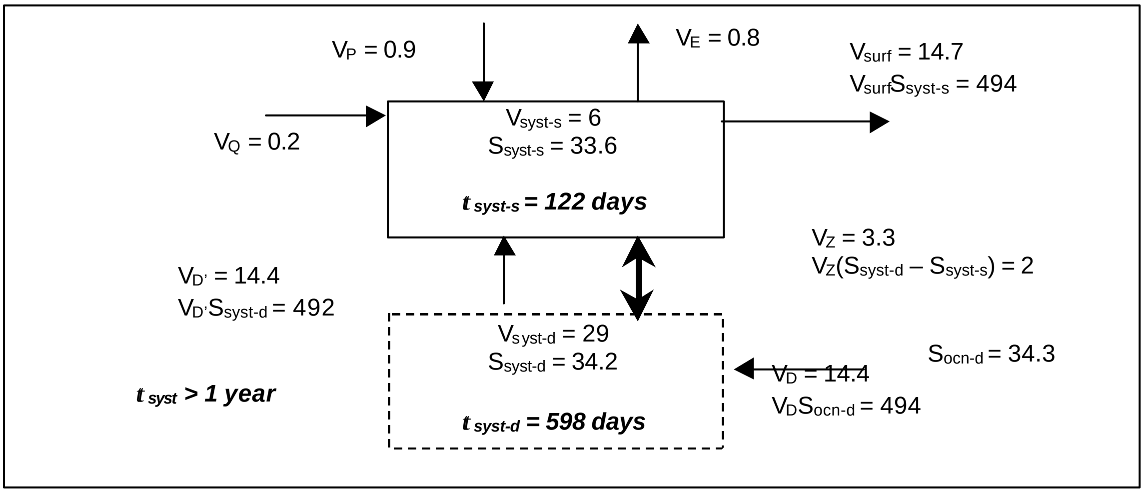

Figure 5.2. Two-layer water and salt budgets for Calauag Bay. The box outlined with dashed lines represents lower layer of the system. Volume in 10^{9} m^{3}, water fluxes in 10^{9} m^{3} yr^{-1}, salt fluxes in 10^{9} psu-m^{3} yr^{-1} and salinity in psu.

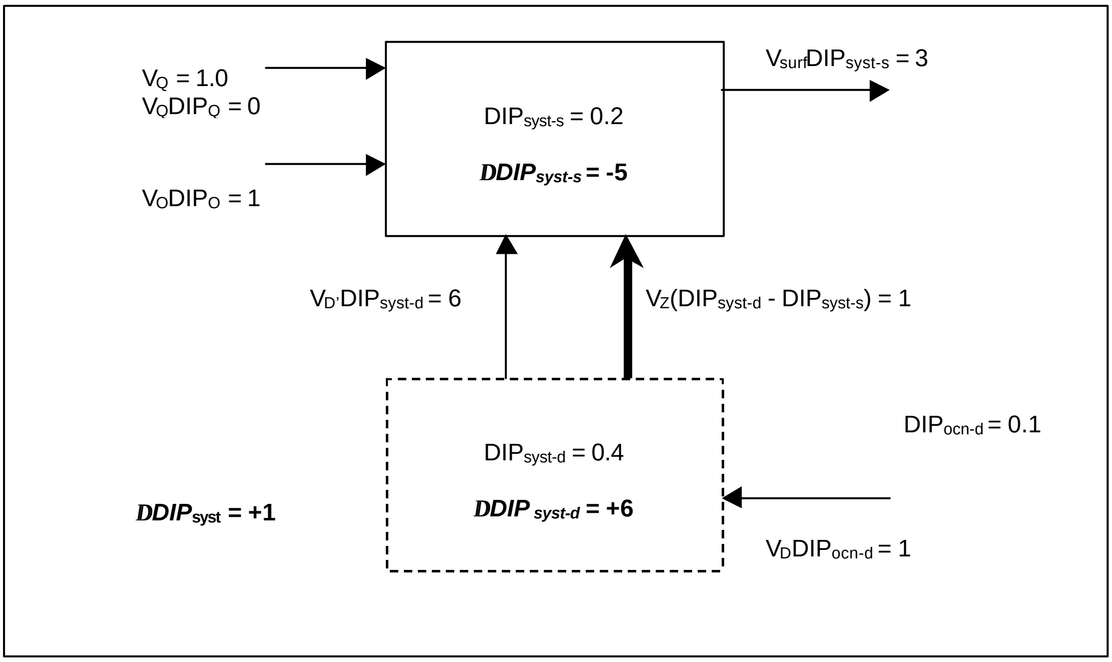

Figure 5.3. Two-layer dissolved inorganic phosphorus budget for Calauag Bay. The box outlined with dashed lines represents lower layer of the system. Fluxes in 10^6 mol yr^{-1} and concentrations in mmol m^{-3}.

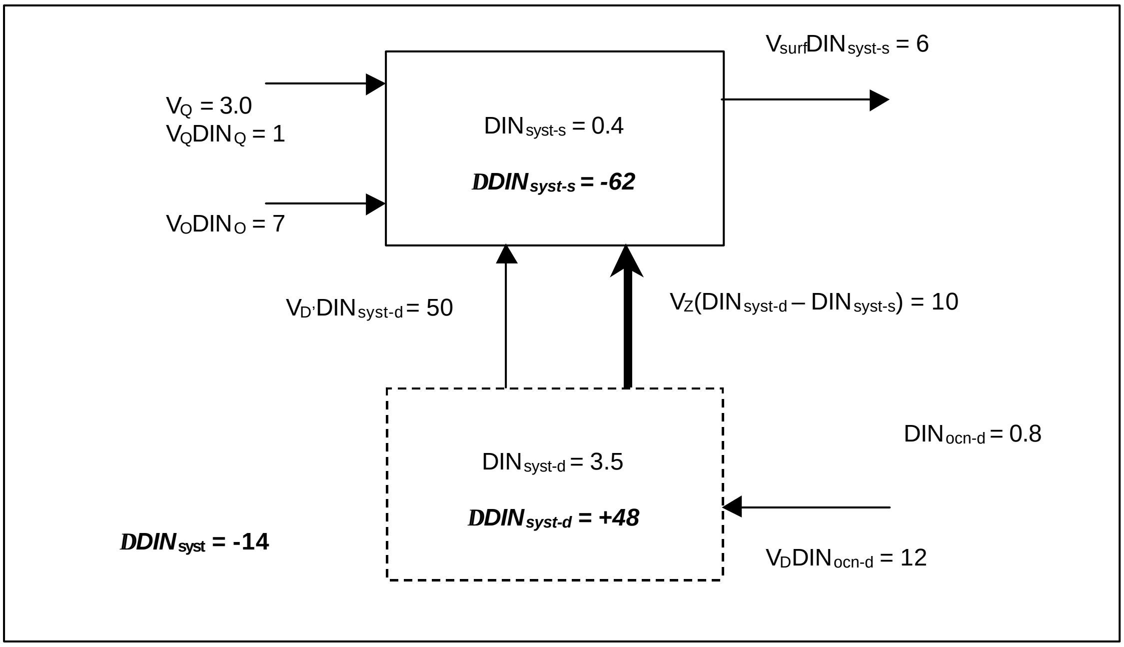

Figure 5.4. Two-layer dissolved inorganic nitrogen budget for Calauag Bay. The box outlined with dashed lines represents lower layer of the system. Fluxes in 10^6 mol yr^{-1} and concentrations in mmol m^{-3}.

5.2 Lagonoy Gulf, Luzon Island

V. Dupra, S.V. Smith, M.L. San Diego-McGlone and R.A. Valmonte-Santos

Study area description

Lagonoy Gulf is a relatively large embayment (total area ≈ 3,100 km^2) in the south-eastern of Luzon Island (13.25°-13.80°N, 123.50°-124.25°E) (Figure 5.5). The gulf is roughly rectangular in shape, about 80 km long and 30 km wide. The presence of Catanduanes Island results in two mouths of unequal widths, which open into the ocean in different directions. The gulf is very deep, with an average depth of 542 m and a permanent pycnocline at about 150 m depth which divides the gulf into two layers. The lower layer is oceanic in nature as a result of the wide connection to the open ocean.

Despite the wide connections with the western Pacific, the hydrographic characteristics of Lagonoy Gulf are strongly influenced by the Asian Monsoon System (Villanoy and Encisa 1995). The monsoons prevail from the south-west during June to October and from the north-east from November to February. As a consequence, the wet season in the eastern part of the Philippines occurs during the north-east monsoon, while in the western part it coincides with the south-west monsoon. The transition between the monsoons is generally characterized by weak easterly winds. High precipitation occurs during the months October to December (12 to 15 mm day^{-1}) and low precipitation occurs during the months February to April (3 to 4 mm day^{-1}). The influence of the Asian monsoon system is very evident in the surface layer (e.g., surface heating and freshwater runoff).

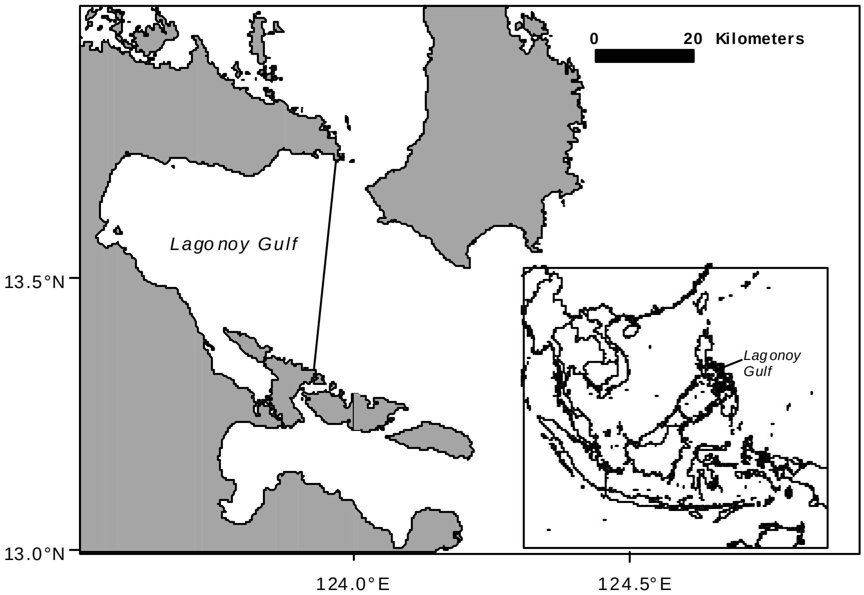

Figure 5.5. Lagonoy Gulf. Solid line shows the boundary of the budgeted system.

The primary objective of this paper is to estimate nonconservative nitrogen and phosphorus fluxes and infer the biogeochemical processes within the system through the derived fluxes. The gulf was budgeted as a two-layer stratified system following the LOICZ Biogeochemical Modelling Guidelines (Gordon *et al.* 1996). The budgeted area is the inner 1,500 km^2 shown in Figure 5.5 by the boundary line. Salinity and nutrient data used were annual means of measurements in January, April and July 1994 that coincide with the northeast monsoon, summer transition and southwest monsoon seasons, respectively (Valmonte-Santos *et al.* 1995).

Water and salt balance

Figure 5.6 shows the water and salt budgets. Net freshwater input residual flow ($V_{R'}$) from river discharge, precipitation and evaporation is approximately 5x10^9 m^3 yr^{-1}. From the water and salt budgets, the freshwater input into the gulf results in intrusion of oceanic water into the bottom layer equal to 74x10^9 m^3 yr^{-1} (V_D), water surface flow of 79x10^9 m^3 yr^{-1} (V_{surf}), water entrainment of 74x10^9 m^3 yr^{-1} ($V_{D'}$) and water mixing between the layers of 467x10^9 m^3 yr^{-1} (V_Z). Water exchange times were 150 days for the upper layer and more than a year for the bottom layer and for the gulf as a whole. The water exchange time is long because of the very deep water column.

Budgets of nonconservative materials

DIP and DIN balance

Figures 5.7 and 5.8 summarise the nutrient budgets for Lagonoy Gulf. Nutrient budgets estimate the gulf to be sources for both dissolved inorganic phosphorus (DIP) and dissolved inorganic nitrogen (DIN). Nonconservative nutrients *DDIP* and *DDIN* were calculated as +9x10^6 mole P yr^{-1} or +0.02 mmole P m^{-2} $day^{-1}$and +292x10^6 mole N yr^{-1} or +0.53 mmole N m^{-2} day^{-1}, respectively.

Stoichiometric calculations of aspects of net system metabolism

Stoichiometric analysis of nonconservative nutrients showed that the gulf is slightly net nitrogen fixing: (*nfix-denit*) = +0.2 mmole N m^{-2} day^{-1}, and heterotrophic: (*p-r*) = -2 mmole C m^{-2} day^{-1}. Primary production in the gulf, calculated independently using chlorophyll concentrations, is 44 mmole C m^{-2} day^{-1} (Brizuela *et al.* 1995), giving a p/r equal to 0.96. If assumed that the removed DIP at the upper layer was converted into phytoplankton, primary productivity is approximately equal to +19 mmole C m^{-2} day^{-1} (*DDIP* x 106). The production in the upper layer, as calculated by chlorophyll, is about 44. If the chlorophyll-based number for primary production is correct, then essentially 40% of the primary production sinks out of the upper water column.

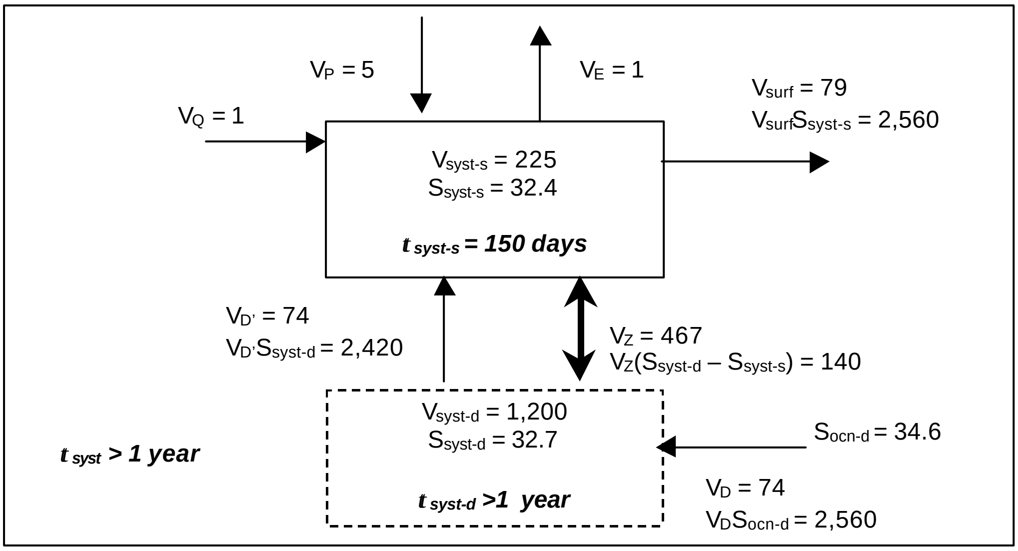

Figure 5.6. Two-layer water and salt budgets for Lagonoy Gulf. The box outlined with dashed lines represents lower layer of the system. Volume in 10^9 m^3, water fluxes in 10^9 m^3 yr^{-1}, salt fluxes in 10^9 psu-m^3 yr^{-1} and salinity in psu.

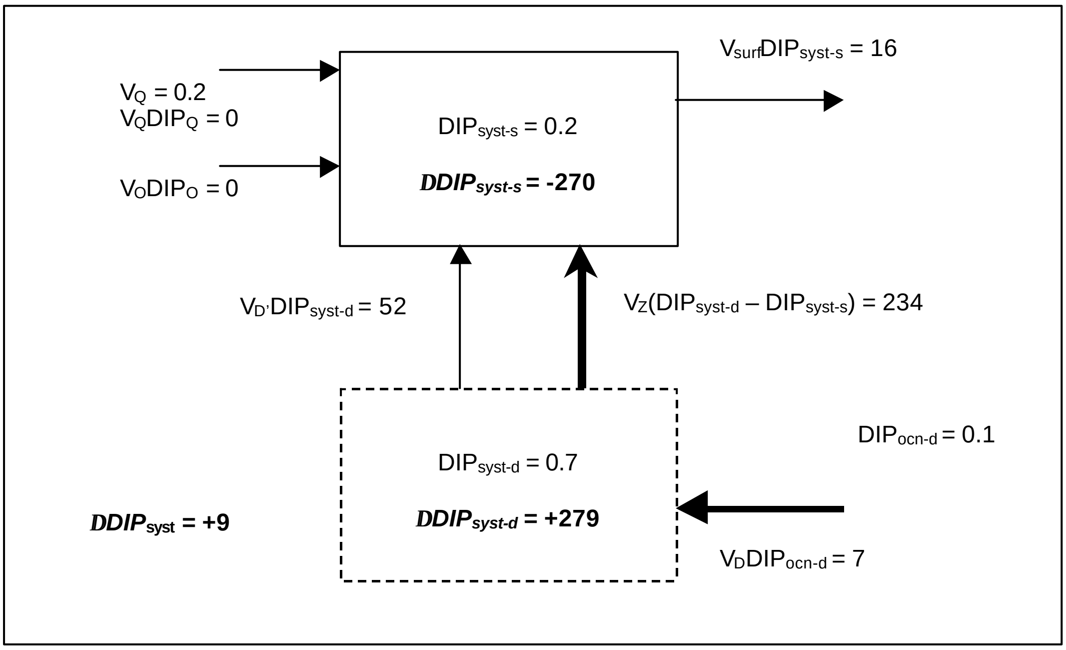

Figure 5.7. Two-layer dissolved inorganic phosphorus budget for Lagonoy Gulf. The box outlined with dashed lines represents lower layer of the system. Fluxes in 10^6 mol yr^{-1} and concentrations in mmol m^{-3}.

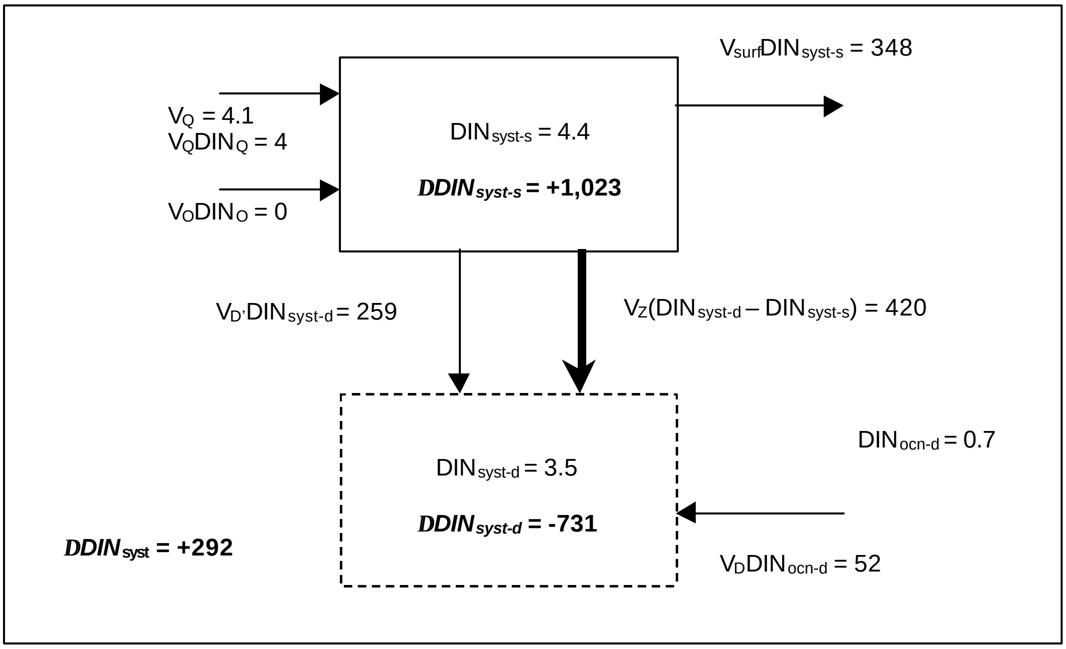

Figure 5.8. Two-layer dissolved inorganic nitrogen budget for Lagonoy Gulf. The box outlined with dashed lines represents lower layer of the system. Fluxes in 10^6 mol yr^{-1} and concentrations in mmol m^{-3}.

5.3 Lingayen Gulf, Luzon Island

M.L. San Diego-McGlone, V. Dupra, D. Padayao, J. Abalos and S.V. Smith

Study area description

Lingayen Gulf is situated in the north-western Philippines (16.02°-16.67°N, 119.89°-119.90°E) (figure 5.10). It is a large (2,100 km^2) embayment which wraps around 17 municipalities and one city in the provinces of Pangasinan and La Union. Its marine waters are biologically diverse, providing 1.5% of the Philippine fish supply in 1995 (Bureau of Fisheries and Aquatic Resources (BFAR) 1996). The area is also a popular tourist destination with the Hundred Islands National Park as its major attraction and the beaches lining the coast host visitors throughout the year.

The gulf has an average depth of 46 m and volume of 85x10^9 m^3. It has three major coastal types. The western section is dominated by fringing reefs surrounding two large islands (Santiago and Cabarruyan Is.) and several smaller ones. The southern section has a mainly muddy bottom and is where most of the river systems of the gulf are located. Agno River, the largest river contributing about 67% of the gulf's surface water discharge of 10x10^9 m^3 yr^{-1}, is in this section. Most of the other rivers (e.g., Naguilian/Bauang, Aringay) connect to Lingayen Gulf's eastern margin (lined mainly by sandy beaches) and constitute approximately 16% of the total surface water discharge. Altogether six major river systems drain into the gulf. Groundwater input into Lingayen Gulf is approximately 10% of the reported river discharge rate. Over 50% of the groundwater discharge comes from the western section of the gulf.

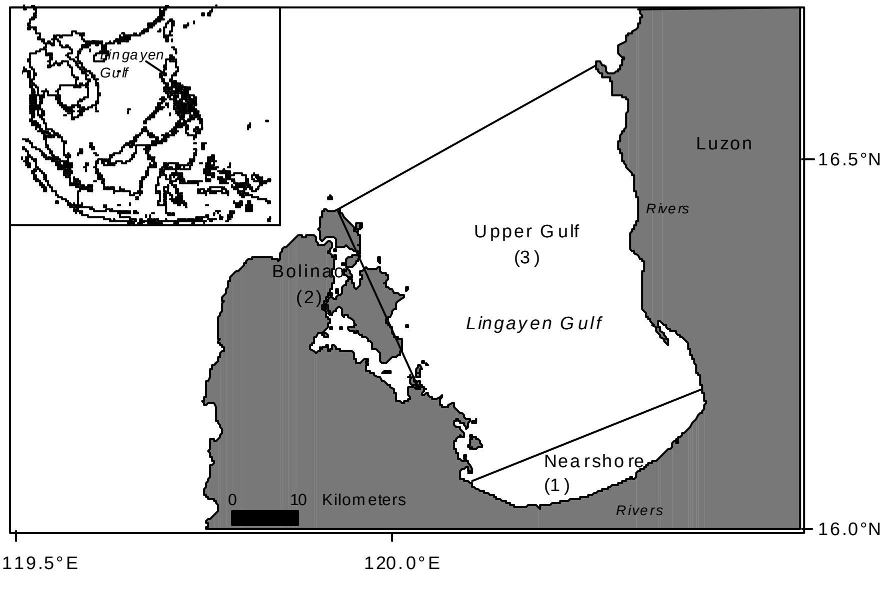

Figure 5.9. Map of Lingayen Gulf showing the boundaries of the budgets.

Due to economic growth of the provinces linked by Lingayen Gulf, the water quality of the gulf and that of the rivers that drain into it are deteriorating. In 1995, all the six major rivers in the gulf were classified by the Department of Environment and Natural Resources as fit only for uses such as fishery, industry, and agriculture and not suitable for contact recreation (e.g., bathing). The various economic activities (e.g., agriculture, domestic sewage, livestock) along its perimeter have also contributed waste loads of N and P into gulf waters. A discussion on estimating waste loads from these activities is given below.

Methodology

In general, the LOICZ Biogeochemical Modelling Guidelines (Gordon *et al.* 1996) were used to calculate the stoichiometrically linked water-salt-nutrients budgets. In these mass balance budgets, complete mixing of the water column is assumed and only dry season mean nutrient concentrations are considered.

Particular attention is paid to the issue of waste loading into Lingayen Gulf, since these are important inputs to the system. The waste loads of N and P were estimated from relevant economic activities in the gulf. The steps followed in doing waste load calculations from economic activities are given in a separate section in this report (Appendix II). Briefly, after identifying economic activities, total discharge of effluents were approximated using the rapid assessment method utilised by WHO (1993). Results are given in Table 5.1. From point of origin to the coastal waters, a 40% assimilation factor was applied, thereby implying that approximately 60% of the N and P from waste loads make it to the gulf. Literature (e.g., Howarth *et al.* 1996) has cited a higher assimilation rate (80%) of waste before entering coastal waters but this estimate may be too high for the gulf because most of the waste may be directly discharged into the water. Since the derived N and P in effluents are Total N and Total P, conversions were made to determine the inorganic fraction using the DIP/TP (0.5) and DIN/TN (0.27) ratios given in San Diego-McGlone, Smith and Nicholas (1999).

Lingayen Gulf was divided into three boxes: Nearshore box, Bolinao box, and Upper Gulf box (Figure 5.10). The Nearshore box is 10% of the total area of the Gulf, while the Bolinao and Upper Gulf boxes are 6% and 84% of the total area, respectively. The large river systems of the gulf are located in the Nearshore box, the major habitats (coral reef and seagrass beds) are located in the Bolinao box, and the open area of the gulf that directly interacts with the South China Sea is included in the Upper Gulf box.

Water and salt balance

Figure 5.10 represents the water and salt budgets. The water budget for each of the boxes in Lingayen Gulf is determined mainly by the average precipitation over the gulf area (V_P), the average evaporation (V_E), the average freshwater discharge from the rivers (V_Q) and the average groundwater discharge (V_G). River discharge for the Nearshore box was estimated to be $8x10^9$ m^3 yr^{-1} (National Wetlands Research Center (NWRC) Philippines 1976). In the Bolinao box, the river discharge was $0.2x10^9$ m^3 yr^{-1}, while in the Upper Gulf box the discharge is $2x10^9$ m^3 yr^{-1} (NWRC Philippines 1976). A mean annual pan evaporation of 2,060 mm was obtained from the local weather office (Philippine Atmospheric, Geophysical and Astronomical Services Administration, PAGASA) in San Manuel, Pangasinan. This rate was multiplied with the area in each box to get V_E. No pan correction factors were used. Mean annual precipitation (2,250 mm), based on 1965-1970 data from PAGASA stations in Dagupan City, Mabini (both in Pangasinan), and Tubao, La Union, when multiplied by the area of each box gave the V_P. Freshwater from groundwater (V_G) was estimated using Darcy's law (WOTRO 1998). Freshwater input from sewage is assumed to be 0. To balance inflow and outflow of water in each box, there must be a residual outflow (V_R) of $-8x10^9$ m^3 yr^{-1} from the Nearshore box to the Upper Gulf box, $-1x10^9$ m^3 yr^{-1} from the Bolinao box to the Upper Gulf box, and $-11x10^9$ m^3 yr^{-1} from the Upper Gulf box to the South China Sea.

The salinity outside the gulf (34.4 as an average value in the top 50 m) was taken from a hydrographic station in the South China Sea closest to the mouth of the gulf (San Diego-McGlone *et al.* 1995). Inside the boxes, average salinity values were obtained from the data set of WOTRO (1997, 1998). The residual fluxes of salt ($V_R S_R$) from the three boxes indicate advective export. Exchange of gulf water with ocean water must replace this exported salt by $V_{X1}(S_3\text{-}S_1) = +260x10^9$ psu-m^3 yr^{-1} from the Nearshore box to the Upper Gulf box, $V_{X2}(S_3\text{-}S_2) = +34x10^9$ psu-m^3 yr^{-1} from the Bolinao box to the Upper Gulf box, and $V_{X3}(S_{Ocn}\text{-}S_3) = +376x10^9$ psu-m^3 yr^{-1} from the Upper Gulf box to the South China Sea. The water exchange flow (V_X) is then determined to be $+87x10^9$ m^3 yr^{-1}, $68x10^9$ m^3 yr^{-1}, and $940x10^9$ m^3 yr^{-1} for the Nearshore box, Bolinao box, and Upper Gulf box, respectively. The total exchange time (flushing time) of the Upper Gulf box is longest at 27 days since the volume of this box is the largest. The flushing time of the Nearshore box is 12 days, while the Bolinao box is only 2 days. Flushing time for the whole gulf is 32 days.

Table 5.1. Effluents from economic activities in Lingayen Gulf (in 10^6 mole yr^{-1}).

Economic Activity	*Nitrogen*	*Phosphorus*
Household activities	1,754	202
- domestic sewage	1,595	91
- solid waste	159	11
- detergents	-	100
Urban Runoff	126	5
Agricultural Runoff	3,465	174
- crop fertilization	1,820	157
- cropland erosion	1,645	17
Livestock	29	2
- commercial piggery	25	2
- poultry	4	-
Aquaculture	22	2
Total	**5,396**	**385**

Budgets of nonconservative materials

DIP balance

Figure 5.11 illustrates the DIP budget for Lingayen Gulf. The DIP concentrations inside the boxes were taken from the data set of WOTRO (1997, 1998). These data represent dry season conditions in the gulf. The average PO_4 concentration for the Nearshore box is 0.4 mmol m^{-3}, 0.4 mmol m^{-3} for the Bolinao box, and 0.1 mmol m^{-3} for the Upper Gulf box. The average PO_4 concentration is 11 mmol m^{-3} in the rivers of the Nearshore box, 6 mmol m^{-3} for rivers in the Bolinao box, and 0.7 mmol m^{-3} of PO_4 for rivers in the Upper Gulf box (LGCAMC 1998). The oceanic PO_4 concentration is 0.0 mmol m^{-3} (San Diego-McGlone *et al.* 1995). Groundwater PO_4 concentration is 8 mmol m^{-3} in the Nearshore box, 0.4 mmol m^{-3} in the Bolinao box, and 2 mmol m^{-3} in the Upper Gulf box. These values are comparable to reported groundwater PO_4 concentration for similar systems (1-10 mmol m^{-3}: Lewis 1985; Tribble and Hunt 1996). Waste load of PO_4 ($V_O DIP_O$) in each box was determined from the waste load estimated for the entire gulf scaled down to the gulf's coastline found within the box. This assumes that most of this waste enters the gulf from along the coast and some from the rivers; waste carried by the rivers has been partially accounted for in the river flux ($V_Q DIP_Q$). Overall, waste load input dominates the DIP budget for the Bolinao and Upper Gulf boxes. For the Nearshore box, river input of DIP is higher than waste load. In order to balance the DIP contributed by the rivers, waste load and groundwater in the boxes with residual and exchange fluxes, nonconservative processes inside the boxes must fix or remove DIP. The large input of DIP from the rivers and from waste load in the Nearshore box relative to what goes out of this box has resulted in a net removal of DIP (i.e. *DDIP* is negative) in this box. The Bolinao box is also a net sink of DIP but the Nearshore box is a stronger net sink of DIP in the gulf. On the other hand, the Upper Gulf box is a net source of DIP.

DIN balance

Figure 5.12 illustrates the DIN budget for the gulf. DIN is defined as $\Sigma\ NO_3^- + NO_2^- + NH_4^+$. The DIN concentrations inside the boxes were taken from the data set of WOTRO (1997, 1998) and these data represent dry season conditions in the Gulf. The average DIN concentration is 1.7 mmol m^{-3} for the Nearshore box, 3.9 mmol m^{-3} for the Bolinao box, and 0.8 mmol m^{-3} for the Upper Gulf box. The average DIN concentration is 16 mmol m^{-3} for the rivers in the Nearshore box, , 22 mmol m^{-3} for the rivers in the Bolinao box, and 4 mmol m^{-3} of DIN for rivers in the Upper Gulf box (LGCAMC 1998). The oceanic DIN concentration is 0.5 mmol m^{-3} (San Diego-McGlone *et al.* 1995). Groundwater DIN concentration is 53 mmol m^{-3} for the Nearshore box, 55 mmol m^{-3} for the Bolinao box, and 71 mmol m^{-3} for the Upper Gulf box. These values are comparable to reported groundwater DIN concentration for similar systems (37-72 mmol m^{-3}: Lewis 1985; Tribble and Hunt 1996).

Waste load of DIN ($V_O DIN_O$) in the boxes was estimated using similar methods as for ($V_O DIP_O$). Again, the balance for DIN is strongly dominated by waste discharge in all the boxes. Budgeting results show that the three boxes are net sinks of DIN (*DDIN* is negative).

Stoichiometric calculations of aspects of net system metabolism

As outlined by Gordon *et al.* (1996)**,** net ecosystem metabolism (*p-r*) can be calculated from *DDIP*. The basic formulation is as follows, where $(C:P)_{part}$ represents the C:P ratio of organic matter which is reacting in the system.

$$(p\text{-}r) = -DDIP \cdot (\mathrm{C:P})_{\mathrm{part}} \qquad (1)$$

Because *DDIP* is negative in the Nearshore box, the qualitative conclusion to be drawn from Eq. (1) is that the system is net autotrophic (i.e., (*p-r*) is positive). This implies that the DIP delivered by the rivers and from waste load is fixed in the Nearshore box as organic P in the dissolved form or trapped in the sediments. Net (*p-r*) is also positive in the Bolinao box suggesting that this box is autotrophic, albeit not as strongly as the Nearshore box. In the Upper Gulf box, the (*p-r*) is negative, indicating net heterotrophy thus implying that an external source of organic material is needed to support decomposition in this box. This source material that is exported to the Upper Gulf box is the organic P fixed in both the Nearshore box and the Bolinao box. The small *DDIP* flux and correspondingly the low (*p-r*) for the Upper Gulf box suggests that the system is very nearly in balance metabolically. This means that waste materials delivered to the Gulf are broken down within the system, an indication of the efficiency of the Gulf in recycling organic material.

The stoichiometric approach given by Gordon *et al.* (1996) can also be used to estimate (*nfix-denit*), the difference between nitrogen fixation and denitrification. The general formulation (based on the inorganic nutrient budgets, in the absence of dissolved organic nutrient data):

$$(nfix\text{-}denit) = DDIN_{obs} - DDIN_{exp} = DDIN_{obs} - DDIP \times (N{:}P)_{part} \qquad (2)$$

where $DDIN_{obs}$ is the observed value for *DDIN*, and $DDIN_{exp}$ is that value expected by the reaction of organic matter of a known N:P ratio $(N{:}P)_{part}$. Because the N:P ratio of both planktonic and waste-derived organic matter lies near 16:1, the ambiguity associated with the source organic matter does not exist. The $DDIN_{obs}$ for all three boxes indicate that these are sinks for DIN. However the amount of DIN fixed with DIP in the Nearshore box and Bolinao box ($DDIN_{exp}$) via autotrophic processes exceed the net DIN calculated from the balance of inflow and outflow in these boxes. Hence in these boxes, N fixation is in excess of denitrification. In the Upper Gulf box, which was estimated to be net heterotrophic from (*p-r*), the DIN released and that due to $DDIN_{obs}$ resulted in a negative (*nfix-denit*), indicating net denitrification. The N fixed in the Bolinao box and Nearshore box is most probably exported as organic N into the Upper Gulf box and this could be the material that fuels denitrification in the Upper Gulf box.

In the Bolinao box, (*nfix-denit*) is estimated to be 2 mol N m^{-2} yr^{-1} in excess of denitrification. Nitrogen fixation is known to provide most of the nitrogen requirement in coral reefs (e.g., Larkum *et al.* 1988; Shashar *et al.* 1994) and seagrass beds (e.g., Hanisak 1983). The 200 km^2 of coral cover in the Bolinao area (McManus *et al.* 1992) and approximately 10 km^2 of seagrass beds (WOTRO 1996) within the Gulf may account for the predominance of nitrogen fixation over denitrification in this box.

A summary of nonconservative fluxes for the nutrients in Lingayen Gulf (based on the mean flux estimates) is given in Table 5.2.

Table 5.2. Summary of nonconservative fluxes in the three boxes of Lingayen Gulf.

Process (Area, Vol.)	**Nearshore Box** (210 km^2, 3.2 km^3)		**Bolinao Box** (126 km^2,0.3 km^3)		**Upper Gulf Box** (1,764 km^2,81 km^3)		**Whole System** (2,100 km^2,84.5 km^3)	
	10^6 mol yr^{-1}	mol m^{-2} yr^{-1}	10^6mol yr^{-1}	mol m^{-2} yr^{-1}	10^6mol yr^{-1}	mol m^{-2} yr^{-1}	10^6mol yr^{-1}	mol m^{-2} yr^{-1}
DDIP	-97	-0.46	-27	-0.21	+10	+0.01	-114	-0.05
DDIN	-313	-1.5	-180	-1.4	-310	-0.2	-803	-0.4
(*p-r*)	+10,282	+49	+2,862	+23	-1,060	-1	+12,084	+6
(*nfix-denit*)	+1,239	+5.9	+252	+2.0	-470	-0.3	+1,021	+0.5

Some ecological implications

One major concern in Lingayen Gulf is the growing number of human activities that input waste materials into Gulf waters. The validity of this concern can be seen in the dominance of the P and N budgets by waste loading. If the system were indeed autotrophic with inorganic nutrients primarily coming from decomposed organic wastes utilised to sustain production in the area, then of interest would be the carrying capacity of the Gulf under these conditions. With present loads of organic waste, only 30% of 5mg L^{-1} of dissolved oxygen (minimum level set by the Department of Environment and Natural Resources) is utilised for respiration. Since the distribution and average of nutrient concentrations as well as the N:P ratio in the Gulf have not varied much over the years, this is an indication of the Gulf's current assimilative capacity. Thus any added load which will bring the dissolved oxygen concentrations to levels less than 2 mg L^{-1} (limit for fish to survive) will compromise existing conditions.

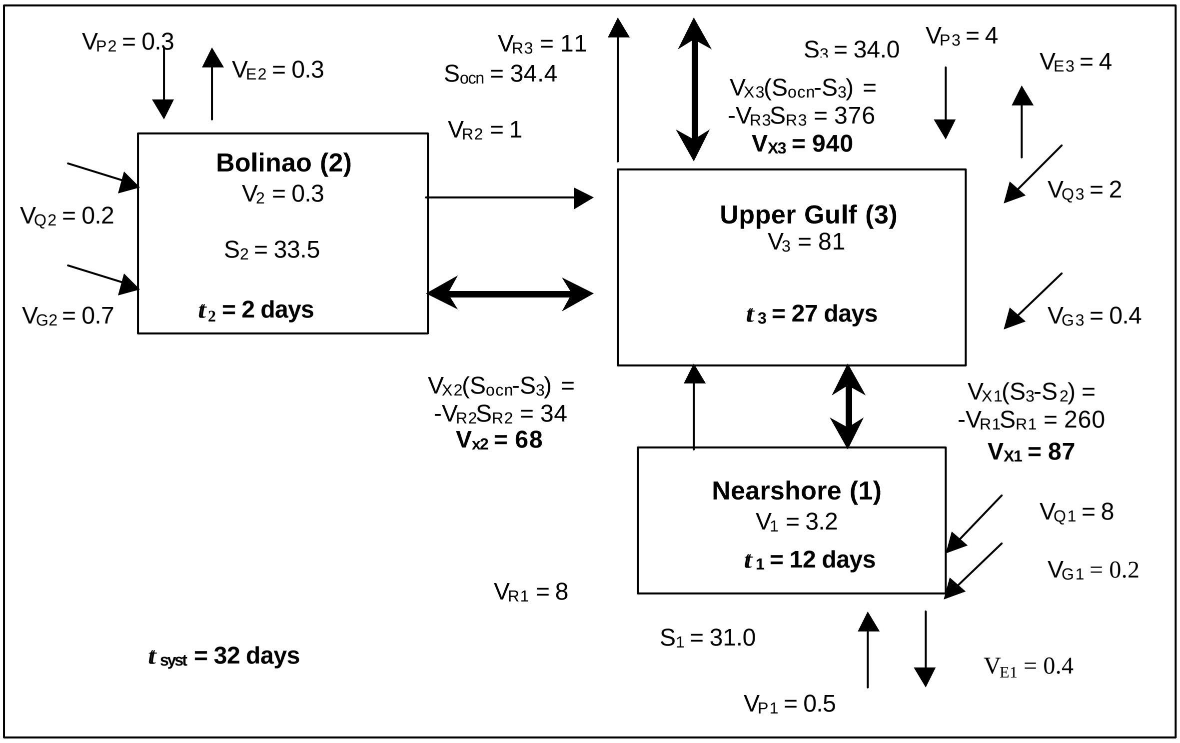

Figure 5.10. Water and salt budgets for Lingayen Gulf. Volume in 10^9 m^3, water fluxes in 10^9 m^{-3} yr^{-1}, salt fluxes in 10^9 psu-m^3 yr^{-1} and salinity in psu.

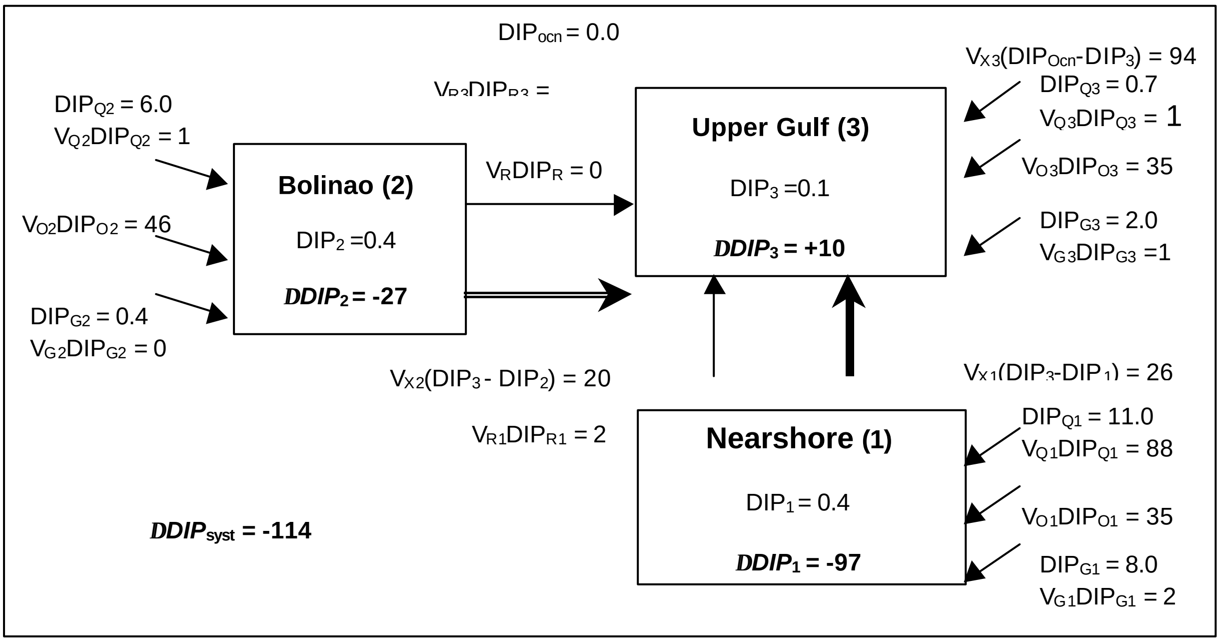

Figure 5.11. Dissolved inorganic phosphorus budget for Lingayen Gulf. Fluxes in 10^6 mol yr^{-1} and concentrations in mmol m^{-3}.

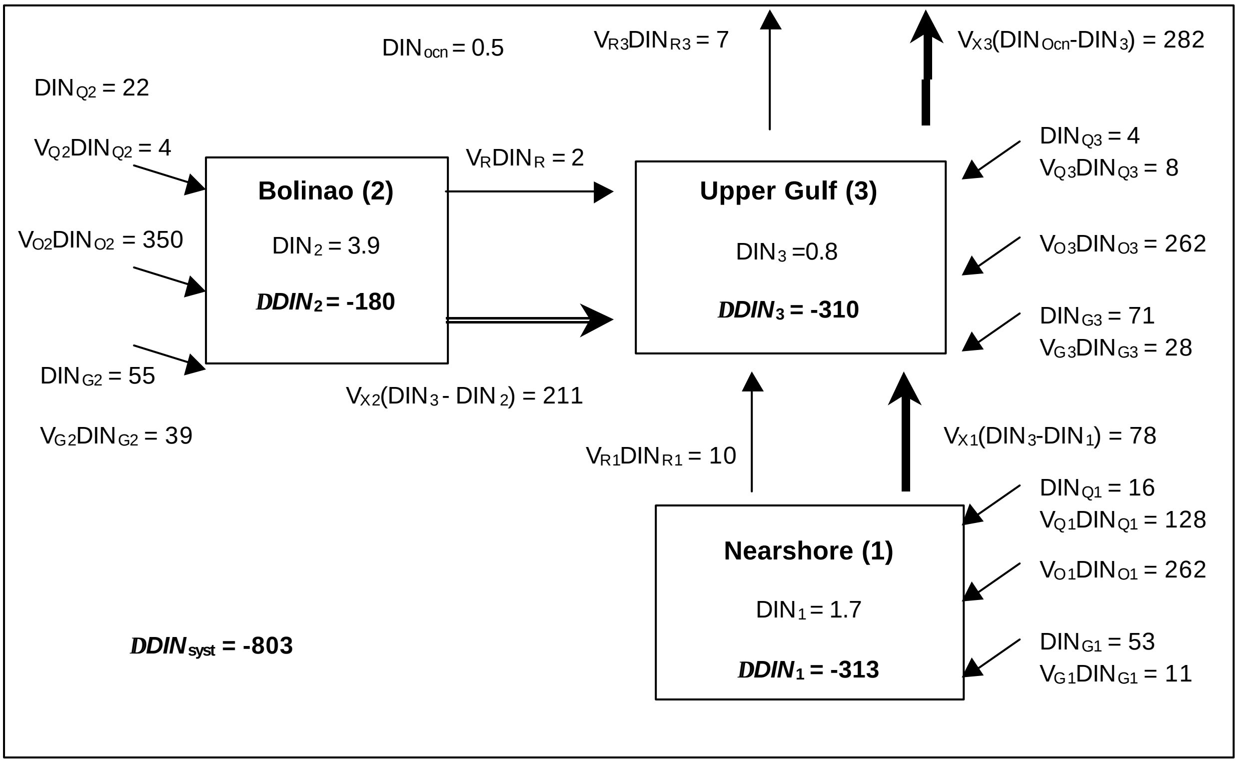

Figure 5.12. Dissolved inorganic nitrogen budget for Lingayen Gulf. Fluxes in 10^6 mol yr^{-1} and concentrations in mmol m^{-3}.

5.4 Manila Bay, Luzon Island

G. S.Jacinto, M. L. San Diego-McGlone, I. B. Velasquez and S. V. Smith

Study area description

Manila Bay is situated on the western coast of Luzon Island (14.23°-14.87°N, 120.53°-121.03°E) (Figure 5.13). The bay is bounded by the provinces of Cavite in the south, Metro Manila and Rizal in the east, Bulacan and Pampanga in the north, and Bataan in the west and north-west. The bay has an area of approximately 1,700 km^2, a length of 60 km, and widths varying from 22 km at the mouth to 60 km at the widest section. The average depth is 17 m (volume = $30x10^9$ m^3). It receives drainage from nearly 17,000 km^2 of watershed composed of 26 catchment areas.

The Pasig River Basin (9,000 km^2) and the Pampanga River Basin (3,900 km^2) make up more than 75% of the watershed of Manila Bay. The Pampanga River contributes approximately 49% of the net freshwater influx into the bay, while the Pasig River contributes about 21%. The other river systems make up 26% of the freshwater source and the remaining 4% come from precipitation onto the bay.

The population of the cities and municipalities within the catchment areas is estimated at 16 million people (approximately 27% of the population of the country), with 8 million people inhabiting the Pasig River watershed. About 70% of the organic pollution load into the Pasig River comes from domestic wastewater since the existing sewerage system in Metro Manila serves only 10% of the population (EMB-DENR/UNEP 1991). Some of the population is served by septic tanks, but it is estimated that approximately 3 million people in the area discharge their wastes directly and through sewer pipes that empty untreated sewage into Manila Bay.

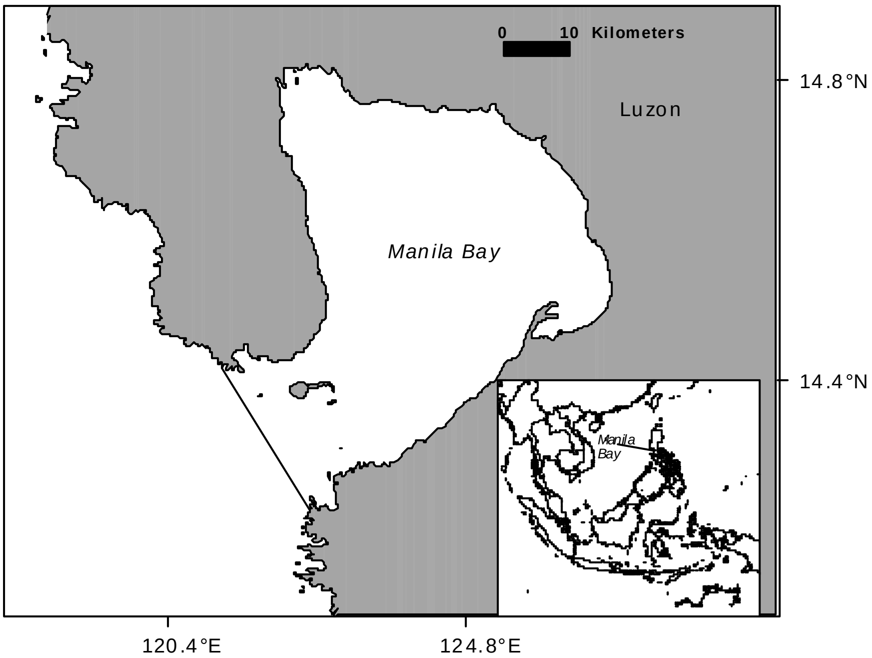

Figure 5.13. Map and location of Manila Bay.

Methodology

The LOICZ Biogeochemical Modelling Guidelines (Gordon *et al.* 1996) were used to calculate the stoichiometrically-linked water-salt-nutrient budgets. In these mass balance budgets, complete mixing of the water column is assumed and only dry season mean estimates are considered.

Manila Bay was divided into a two-layer system, an upper and a lower box. The upper box covers the top 10 m of the water column and the lower box is from 10 m to the bottom.

Waste loading

Particular attention is paid to the issue of waste loading into the bay because of the importance of this input to the system. In many systems, including this one, organic matter and nutrient loading from domestic, agricultural, or industrial wastes are important yet poorly-identified contributions to the biogeochemical budgets. The waste loading for Manila Bay is not known directly, so this section presents indirect estimates of organic and inorganic C, N and P loading associated with these wastes. Effluent from human wastes is assumed to dominate discharge into this system. Thus waste loading was estimated from population size. The steps followed in doing waste load calculations from demography are given in a separate section in this LOICZ Workshop report.

A brief explanation of how the estimates were made is given here. Effluent from human wastes has some typical characteristics. COD (the total oxidation demand of such wastes) is typically about 2.6 times the BOD (San Diego-McGlone, Smith and Nicholas 1999), and this can be converted from mass of oxygen consumed to mass of organic carbon by the mass ratio of carbon to oxygen, which is 12:32 (= 0.375). The product of 2.6 times 0.375 is 0.98 (close to 1), and this product represents an estimate of the conversion factor from BOD to organic C (both expressed in mass units). To estimate sewage input, an effluent load factor of 20 kg person^{-1} yr^{-1} of BOD is assumed (World Health Organisation 1993). From the above conversion factors, this is equivalent to a per capita organic carbon loading of 20 kg yr^{-1} (about 1,700 moles C person^{-1} yr^{-1}).

The next conversion is from organic C loading to total N and P loading. Domestic human and animal agriculture effluent has a typical TOC:TN:TP molar ratio of approximately 40:12:1 (San Diego-McGlone, Smith and Nicholas 1999). The ratios of inorganic to total N and total P in organic waste material are 0.4 and 0.5, respectively (San Diego-McGlone, Smith and Nicholas 1999).

In Manila Bay, it is assumed that 50% of the catchment area population more or less directly inputs into the system. Some discharge directly into the river systems, and their inputs should be handled in the budget. It is estimated that about 3 million people discharge their wastes directly and through sewers that empty into the Bay; this is accounted for in the waste load approximations.

Water and salt balance

Figure 5.14 illustrates the steady state water and salt budgets for Manila Bay. The water budget in the upper box of Manila Bay is influenced mainly by freshwater runoff (V_Q = 24x10^9 m^3 yr^{-1}) (EMB-DENR/UNEP 1991), precipitation (V_P = 3x10^9 m^3 yr^{-1}) (Philippine Atmospheric, Geophysical and Astronomical Services Administration, PAGASA), evaporation (V_E = 2x10^9 m^3 yr^{-1}) (PAGASA), the deep water input (V_D = 333x10 m^3 yr^{-1}) and vertical mixing (V_Z = 466x10^9 m^3 yr^{-1}). To balance all the inflows and outflows of water, there must be an outflow (V_{surf}) of 358x10^9 m^3 yr^{-1} from the bay.

The salinity data outside the mouth of the bay (average of top 50 m) was obtained from a NOAA database (http:// ferret.wrc.noaa.gov/fbin/climate_server). This salinity value is 34.4 psu. The average salinity in the upper box is 32.0 psu while the lower box salinity is 33.0 psu (Velasquez *et al.* 1997). The salt balance is maintained by deepwater input of oceanic salinity and vertical mixing between surface and deep. This flux is estimated to be 11,455x10^9 psu-m^3 yr^{-1}. The total exchange time (flushing time) of bay waters, calculated from the volume of the bay divided by the sum of ($|V_R|$ + V_D), is 0.08 yr, or approximately 31 days.

Budgets of nonconservative materials

DIP balance

Figure 5.15 summarises the steady state DIP budget for Manila Bay. The average phosphate concentration in the upper and lower boxes of Manila Bay is 0.5 µM (Velasquez *et al.* 1997), outside the Bay it is 0.1 µM (http:// ferret.wrc.noaa.gov/fbin/climate_server), and the rivers contribute 3.0 µM of PO_4 (EMB-DENR/UNEP 1991). In order to balance the phosphate contributed by the rivers

($V_Q DIP_Q$ = 45x10^6 mol yr^{-1}), direct sewage discharge ($V_O DIP_O$ = 61x10^6 mol yr^{-1}) and vertical entrainment ($V_D DIP_{syst\text{-}d}$ = 167x10^6 mol yr^{-1}) with residual outflow ($V_{surf} DIP_{syst\text{-}s}$ =179x10^6 mol yr^{-1}), non-conservative processes must fix -94x10^6 mol yr^{-1} of dissolved inorganic P (*DDIP*) inside the upper box of the Bay. In the lower box, the balance between deep-water input and vertical mixing is satisfied when there is removal of DIP from this box. The net *DDIP* between the upper and lower boxes is a positive term implying net loss or removal of DIP from the whole system.

DIN balance
Figure 5.16 summarises the steady state DIN budget for Manila Bay. Dissolved inorganic nitrogen (DIN) is defined as $\Sigma NO_3+NO_2+NH_3$. The average DIN concentration inside the upper box of Manila Bay is 1.1 µM and in the lower box it is 4.2 µM (Velasquez *et al.* 1997). Outside the bay, DIN is 0.5 µM (http://ferret.wrc.noaa.gov/fbin/climate_ server) and DIN from the rivers is 60 µM (EMB-DENR/UNEP 1991). Structuring the DIN budget like the DIP budget yields an internal nutrient removal of about -3,950x10^6 mol yr^{-1} ($DDIN_{syst\text{-}s}$) in the upper box and internal nutrient production of +2,677x10^6 mol yr^{-1} ($DDIN_{syst\text{-}d}$) in the lower box. The net *DDIN* of -1,273x10^6 mol yr^{-1} indicates net removal of DIN for the whole system.

Stoichiometric calculations of aspects of net system metabolism
The nutrient budgets can be used according to procedures laid out by Gordon *et al.* (1996) in order to estimate (*p-r*) and (*nfix-denit*). Net ecosystem metabolism (*p-r*) is estimated from *DDIP* and the C:P ratio of reacting particulate material, according to the relationship:

$$(p\text{-}r) = -\,DDIP \cdot (\mathrm{C{:}P})_{\mathrm{part}} \qquad (1)$$

In the upper box, *DDIP* is negative indicating that the system is net autotrophic (*p-r*) = +6 mol C m^{-2} yr^{-1}. In the lower box, *DDIP* is positive indicating net heterotrophy (*p-r*) = -8 mol C m^{-2} yr^{-1}). It is most likely that the organic matter fixed in the upper box supplies the material needed to support decomposition (net heterotrophy) in the lower box. Additional material for the lower box is supplied from the sediments in the bay. The net (*p-r*) for the bay is -2 mol C m^{-2} yr^{-1}.

The difference between nitrogen fixation and denitrification (*nfix-denit*) is estimated from the difference between the observed value for *DDIN* and that value expected from simple of organic matter. That is,

$$(nfix\text{-}denit) = DDIN_{obs} - DDIN_{exp} = DDIN_{obs} - DDIP \times (N{:}P)_{part} \qquad (2)$$

The $DDIN_{obs}$ for the upper and lower boxes indicate that the upper box is a sink of DIN and that the lower box is a source of DIN. In the upper box, part of the DIN is fixed in autotrophy ($DDIN_{exp}$) but the net flux still shows that this box is denitrifying (*nfix-denit* = -1.44 mol N m^{-2} yr^{-1}). In the lower box, the amount of DIN produced by decomposition ($DDIN_{exp}$) is lower than that removed within this box, hence (*nfix-denit*) is positive (0.31 mol N m^{-2} yr^{-1}). The bay appears to be a net denitrifying system, at a rapid but believable rate: $(nfix\text{-}denit)_{\mathrm{syst}}$ is -1.13 mol N m^{-2} yr^{-1} (e.g., Seitzinger 1988).

A summary of the nonconservative fluxes for nitrogen and phosphorus in Manila Bay is given in Table 5.3.

Table 5.3. Summary of nonconservative fluxes for the upper box, lower box and the whole system of Manila Bay

Process	Upper box		Lower box		Whole system	
	10^3 mol yr^{-1}	mol m^{-2} yr^{-1}	10^3 mol yr^{-1}	mol m^{-2} yr^{-1}	10^3 mol yr^{-1}	mol m^{-2} yr^{-1}
DDIP	-94	-0.06	+134	+0.08	+40	+0.02
DDIN	-3,950	-2.3	+2,677	+1.6	-1,273	0.7
(*p-r*)	+9,964	+6	-14,204	-8	-4,240	-2
(*nfix-denit*)	-2,446	-1.44	+533	+0.31	-1,913	-1.13

Acknowledgments: *The authors gratefully acknowledge the assistance of Ms. C.I. Narcise and N. Cuaresma; and the ASEAN-CANADA CPMS II Programme and the Philippine Council for Aquatic and Marine Research and Development (PCAMRD) for providing the funds for the project.*

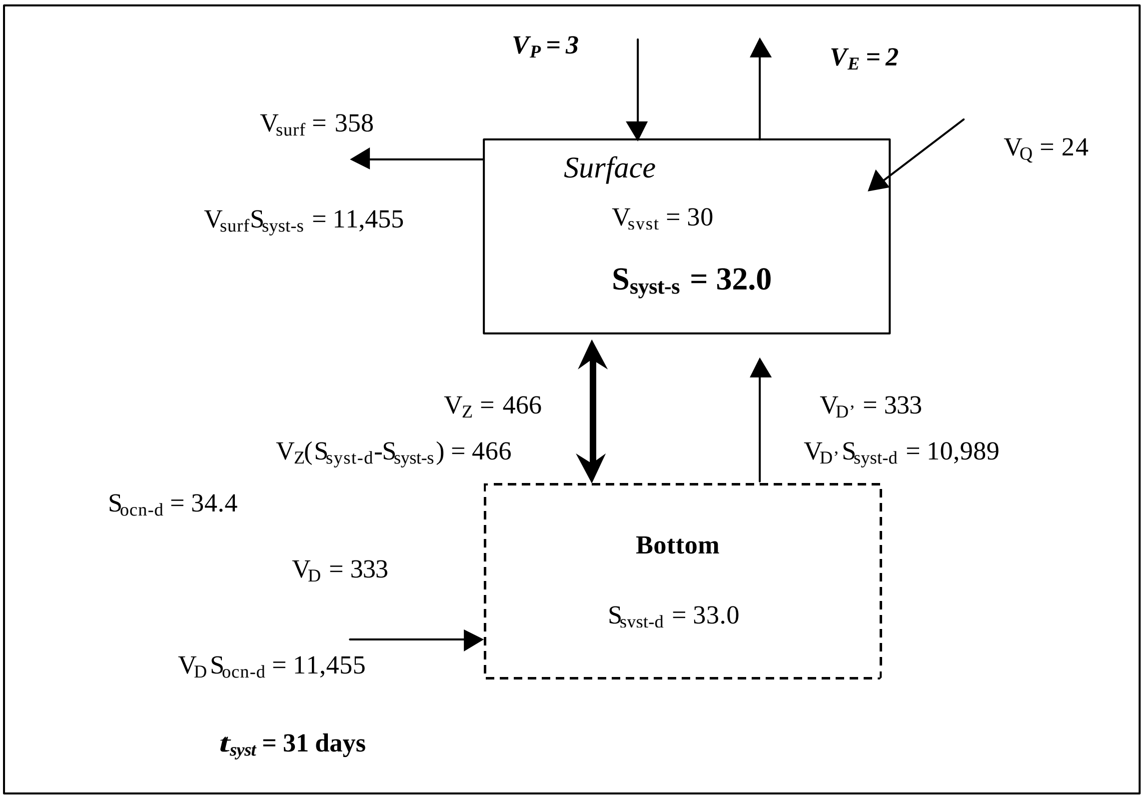

Figure 5.14. Water and salt budgets for Manila Bay. Volume in 10^9 m^3, water fluxes in 10^9 m^3 yr^{-1}, salt fluxes in 10^9 psu-m^3 yr^{-1} and salinity in psu.

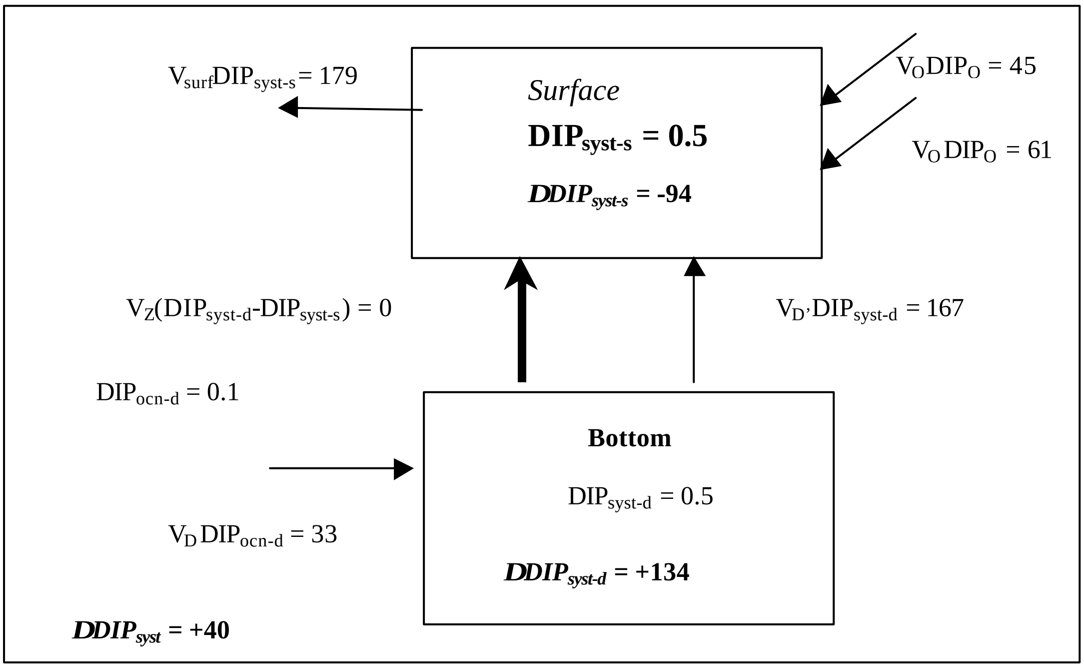

Figure 5.15. Dissolved inorganic phosphorus budget for Manila Bay. Fluxes in 10^6 mol yr^{-1} and concentrations in mmol m^{-3}.

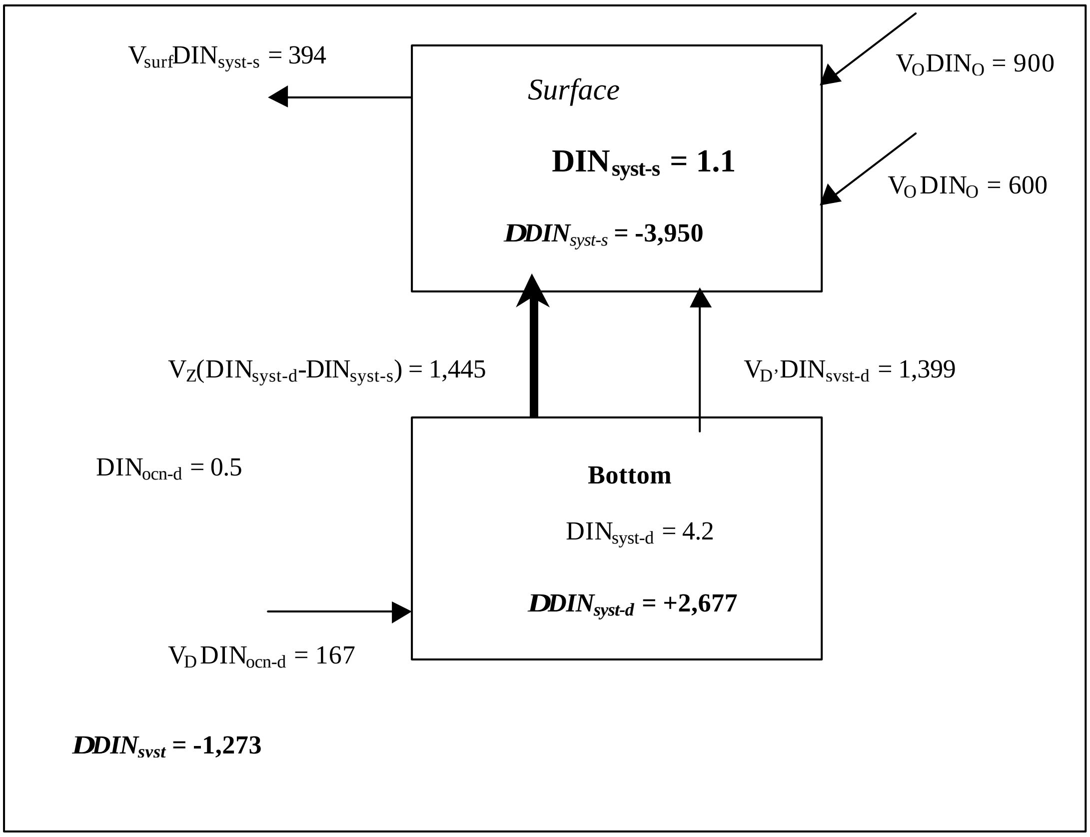

Figure 5.16. Dissolved inorganic nitrogen budget for Manila Bay. Fluxes in 10^6 mol yr^{-1} and concentrations in mmol m^{-3}.

5.5 Ragay Gulf, Luzon Island

V. Dupra and S.V. Smith

Study area description

Ragay Gulf is located in the south-eastern part of Luzon Island (13.00°-14.00°N, 122.25°-123.40°E) (Figure 5.17). The gulf is a relatively large triangular embayment with a total area of 3,600 km^2 and with average depth of 179 m. At the mouth of the gulf is Burias Island, which effectively divides the mouth into two. The eastern half forms the northern boundary of Burias Pass that extends southwards for about 50 km without any significant change in depth. The western part opens into Sibuyan Sea. At depths greater than about 120 m, the gulf is separated from the ocean by a shallow sill (approximately 120 m), which extends from the northern tip of Burias Island to the southeastern tip of the Bondoc Peninsula. The presence of the sill across the gulf mouth plays a major role in the hydrographic properties and the circulation patterns in the gulf. Water in the gulf below the sill depth is supplied by sill overflow from the adjacent open sea. The vertically homogenous temperature and salinity properties of the gulf waters below the sill depth are defined by the properties of the water outside the gulf at the level of sill depth. In contrast, the temperature and salinity characteristics of the top 150 m exhibit strong seasonal variability, which is influenced by the monsoons.

There are eight major rivers surrounding Ragay Gulf, with a total river drainage area of 1,083 km^2. Average annual rainfall is 2,593 mm, annual rainfall in 1994 was 2,680 mm. Based on the water quality observations conducted by the Bureau of Fisheries and Aquatic Resources (BFAR) (1994), the gulf may be considered as relatively undisturbed water body in spite of anthropogenic-linked perturbations in some parts (BFAR 1994).

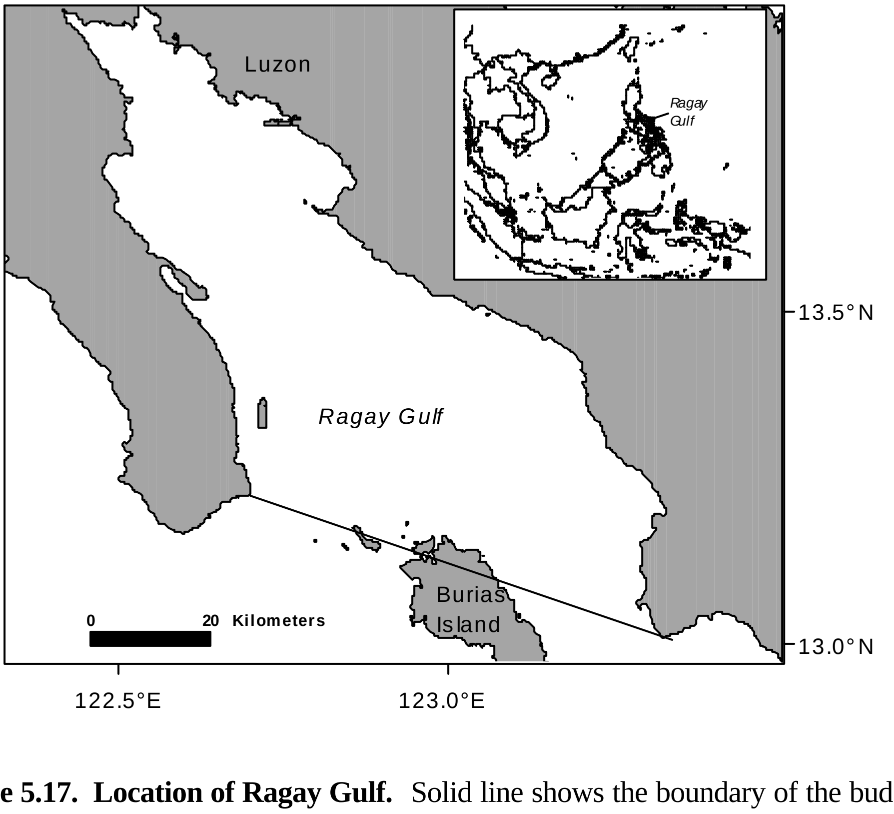

Figure 5.17. Location of Ragay Gulf. Solid line shows the boundary of the budget.

The gulf was budgeted following the LOICZ Biogeochemical Modelling Guidelines (Gordon *et al.* 1996) to assess the net system metabolic processes of the gulf. Data collected in 1994 by BFAR were used.

Water and salt balance

Figure 5.18 presents the two-layer water and salt budget for Ragay Gulf. River runoff gauged from the eight rivers surrounding the bay was 2x10^9 m^3 yr^{-1} (V_Q). The calculated river runoff applying the method described by David, Appendix **X** was closed to the gauged river runoff. Precipitation (V_P) was 10x10^9 m^3 yr^{-1} and evaporation (V_E) was calculated to be 80% of the total precipitation. Assuming that other freshwater fluxes were insignificant, the net freshwater input (residual flow, $V_{R'}$) was 2x10^9 m^3 yr^{-1}. Volume of water intrusion (V_D) calculated from the residual flow and salinity difference was 457x10^9 m^3 yr^{-1}. From the salt balance, volume of mixing (V_Z) was calculated to be 225x10^9 m^3 yr^{-1}. Water exchange time for the gulf was calculated to be more than 1 year. Because of the very large volume of the gulf, the water exchange time is expected to be long. The unique feature of the gulf, the presence of sill, is manifested in this budget by the fast water exchange of the bottom layer (Figure 2).

Budgets of nonconservative materials

DIP and DIN balance

Figure 5.19 and 5.20 illustrate the DIP and DIN budgets for Ragay Gulf. Assuming that nutrient loads into the gulf were delivered via rivers and that other inputs were insignificant, the budgets show that the gulf almost balances the uptake and release of DIP: *DDIP* = +1x10^6 mol P yr^{-1} (0.00 mmol P m^{-2} day^{-1}); and is slightly net releasing DIN: *DDIN* = +115x10^6 mol N yr^{-1} (0.09 mmol N m^{-2} day^{-1}).

Stoichiometric calculations of aspects of net system metabolism

The system seems to balance production and respiration and behaves as slightly fixing nitrogen. The budget is consistent with the conclusion derived from the BFAR report that the land-derived nutrients still seem to be within the assimilative capacity of the gulf. However, it is important to note that the budgeted area is large and that the impact of waste loads may be more apparent when budgets are done on smaller regions of the gulf.

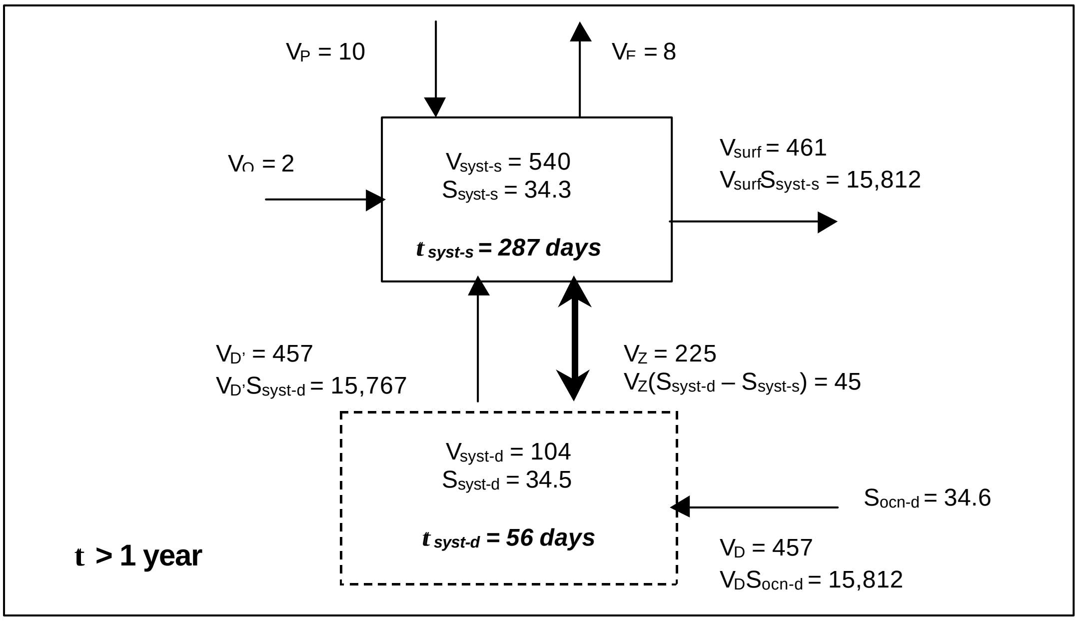

Figure 5.18. Two-layer water and salt budgets for Ragay Gulf. The box outlined with dashed lines represents the lower layer of the system. Volume in 10^9 m^3, water fluxes in 10^9 m^3 yr^{-1}, salt fluxes in 10^9 psu-m^3 yr^{-1} and salinity in psu.

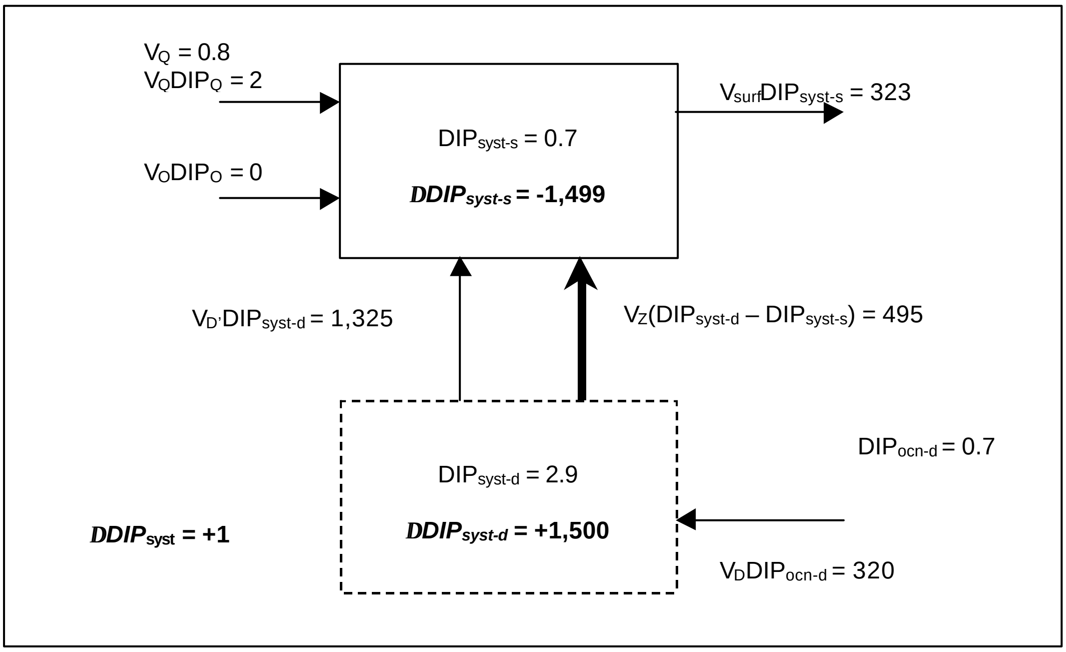

Figure 5.19. Two-layer dissolved inorganic phosphorus budget for Ragay Gulf. The box outlined with dashed lines represents the lower layer of the system. Fluxes in 10^6 mol yr^{-1} and concentrations in mmol m^{-3}.

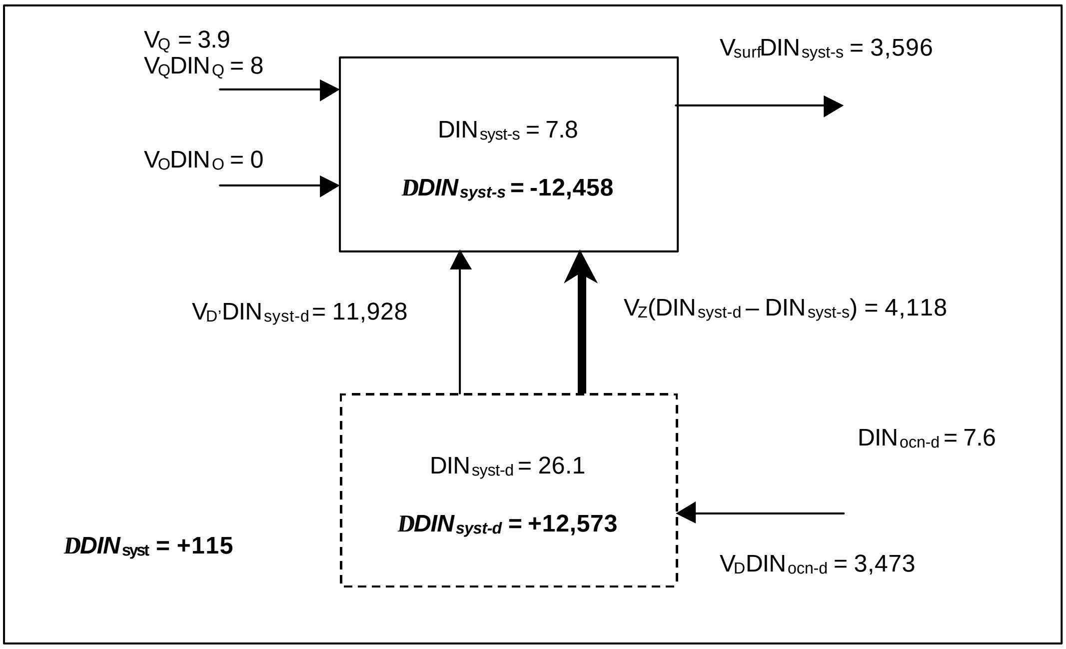

Figure 5.20. Two-layer dissolved inorganic nitrogen budget for Ragay Gulf. The box outlined with dashed lines represents the lower layer of the system. Fluxes in 10^6 mol yr^{-1} and concentrations in mmol m^{-3}.

5.6 San Miguel Bay, Luzon island

V. Dupra, S.V. Smith, M.L. San Diego-McGlone, D.J.R. Mendoza and C.L. Villanoy

Study area description

San Miguel Bay is a large shallow embayment on the Pacific coast of Luzon Island (13.72°-14.15°N, 123.00°-123.33°E) (Figure 5.21). San Miguel Bay has an area of about 1,000 km^2. The recorded average depth of the bay at the beginning of the 19th century was 9 m but this has been reduced to 7 m because of sediment deposition. Sediment deposition was estimated as 2 cm yr^{-1} assuming a constant deposition rate between 1907 and 1980; however a large amount of the deposition may have come from deforestation and destructive farming activities (e.g., slash-and-burn agriculture) in the last decade (Mines *et al.* 1982).

The bay is a tropical estuary with the Bicol River as the end-member with the largest freshwater input. Freshwater inflow from rivers into the bay was estimated to be 2.87×10^9 m^3 yr^{-1}, 96 % of which stems from Bicol River (Anon. 1972). The Bicol River flows through deforested areas but also through several cities, the major one of which is Naga City with approximately 100,000 inhabitants. This should add to the material transported by the river waters, notably in terms of domestic sewage.

A major feature along the Pacific coasts of the Philippines is the occurrence, in conjunction with the north-east monsoon, of extremely strong winds. Annual rainfall and evaporation were estimated as 3.4 m and 0.7 m, respectively. The shallow depths, tidal currents and strong winds of the bay make it vertically well-mixed despite the large net freshwater input.

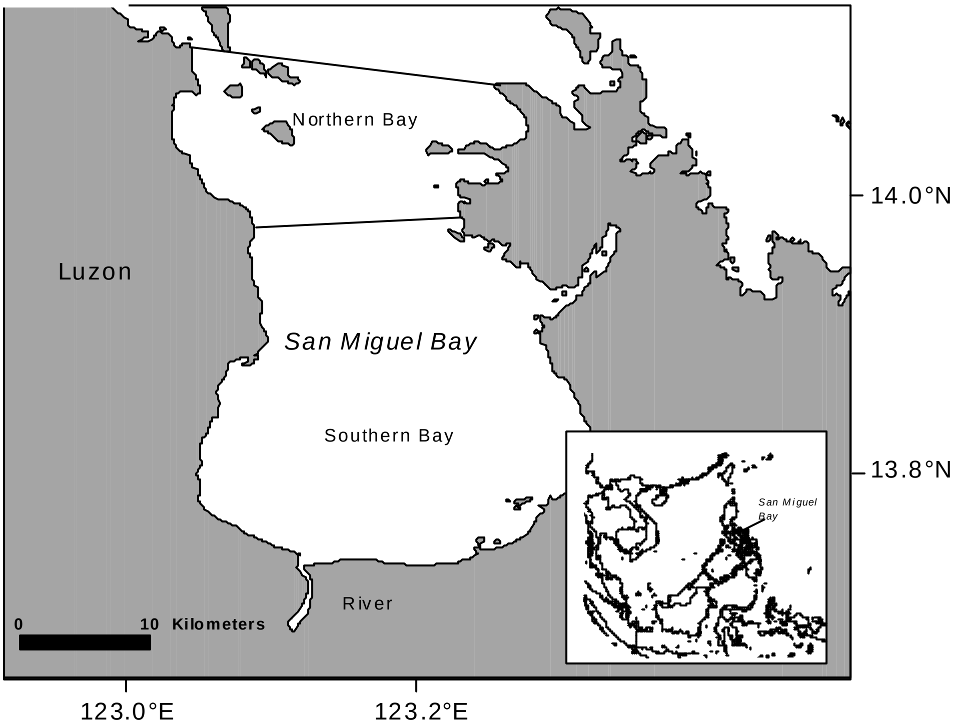

Figure 5.21. San Miguel Bay. Bars represent boundaries for the budgets.

This paper aims to estimate nonconservative fluxes of nitrogen and phosphorus for San Miguel Bay and to infer from these fluxes the biogeochemical processes occurring in the system. The main bay was divided into southern and northern sectors based on depths (Figure 1) and the Bicol River as the end box flowing into the bay. The components were then budgeted as systems in series according to the LOICZ Biogeochemical Modelling Guidelines (Gordon *et al.* 1996). The bay was divided to resolve processes between the directly riverine-influenced southern sector and that of less exposed northern sector. The river box is considered to derive the water fluxes between the river box and the adjacent southern sector. This approach may be used in systems with poorly defined riverine nutrient loads and where nutrients data are only available near the river mouth.

The salinity values used were measured in April and June 1993 by Villanoy *et al.* (1994), when freshwater input was low. Salinity data during high freshwater discharge were limited to the inner bay due to unfavorable weather conditions (strong winds brought by the north-east monsoon). The southern bay is shallower and more estuarine than the northern bay. Nutrient concentrations used were averaged from data measured for four different sampling months between 1992 and 1993, with 20 sampling stations (Mendoza *et al.* 1994, Parts I and II).

<u>*Water and salt balance*</u>
Figure 5.22 illustrates the water and salt budgets for San Miguel Bay. The boxes represent the southern and northern sectors of the bay and the river box. Freshwater inputs were primarily from river discharges (V_Q). Other freshwater fluxes were assumed insignificant. V_{R1} and V_{X1} present the water exchange between the river box and the southern bay. Surface flow of southern sector (V_{R2}) is simply equal $V_{R!}$ while surface flow for the northern sector (V_{R3}) is the total of V_{Q3} and V_{R2}, which is actually the total freshwater input of the whole Bay.

Surface flow (V_{R3} = 6 x 10^9 $m^3 yr^{-1}$) and mixing of waters to the adjacent ocean (V_{X3} = 1,030x10^9 m^3 yr^{-1}) resulted in a water exchange time (ι) in the bay of 6 days. Mines *et al.* (1982) and Villanoy *et al.* (1994) obtained similar values (4.8 and 5.8 days respectively). Water exchange time (τ) calculated for the southern and northern bay sectors are 2 and 3 days respectively.

<u>*DIP and DIP balance*</u>
Figures 5.23 and 5.24 summarise phosphorus and nitrogen budgets for San Miguel Bay. The river box was considered as an intermediate to the whole process and given less importance for nonconservative fluxes, so the fluxes of DIP and DIN were only calculated for the southern and northern sectors of the bay.

It was assumed in this budget, based on topography and population distribution, that all nutrient loads into the bay were delivered through the Bicol River. Because of the fast water exchange rate it is most prudent to infer fluxes for the system as a whole rather than for the separate boxes. The bay may be a slight net sink for both dissolved inorganic phosphorus (DIP) and dissolved inorganic nitrogen (DIN). *DDIP* = -2x10^6 mole P yr^{-1} or -0.005 mmole P m^{-2} day^{-1} and *DDIN* = -20x10^6 mole N yr^{-1} or -0.05 mmole N m^{-2} day^{-1}. However the signal is hard to see because of the rapid exchange. Despite the fact that the DIP loads come mainly from the river box there is no apparent spatial gradient of DIP concentrations.

Stoichiometric calculations of aspects of net system metabolism
From stoichiometric analysis, the bay in general has (*nfix-denit*) essentially equal to 0 mmole N m^{-2} day^{-1} and (*p-r*) equal to +0.3 mmole C m^{-2} day^{-1}, within the ability to be resolved because of the rapid exchange.

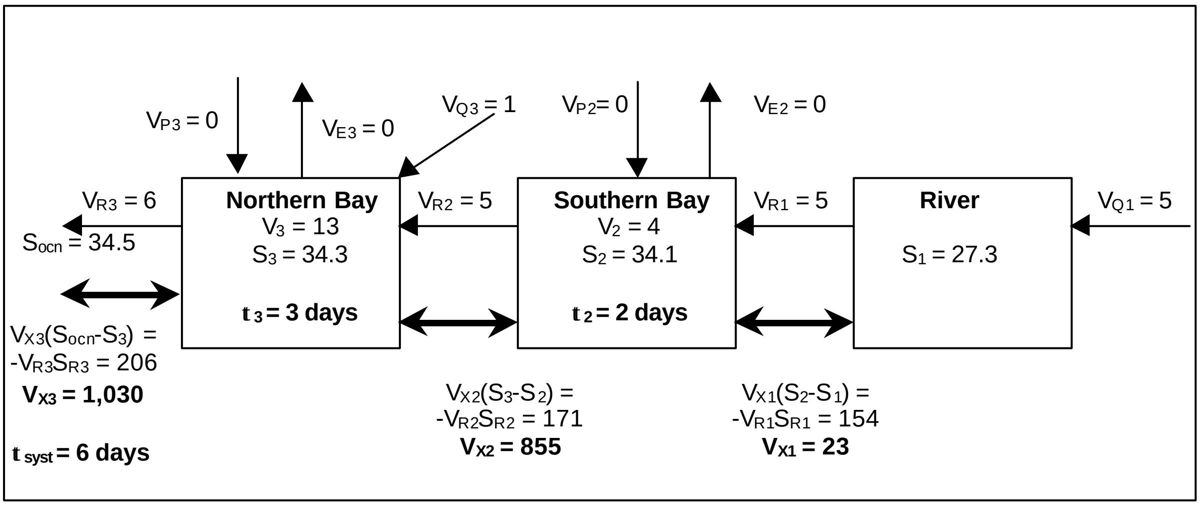

Figure 5.22. Water and salt budgets for San Miguel Bay. Volume in 10^9 m^3, water fluxes in 10^9 m^3 yr^{-1}, salt fluxes in 10^9 psu-m^3 yr^{-1} and salinity in psu.

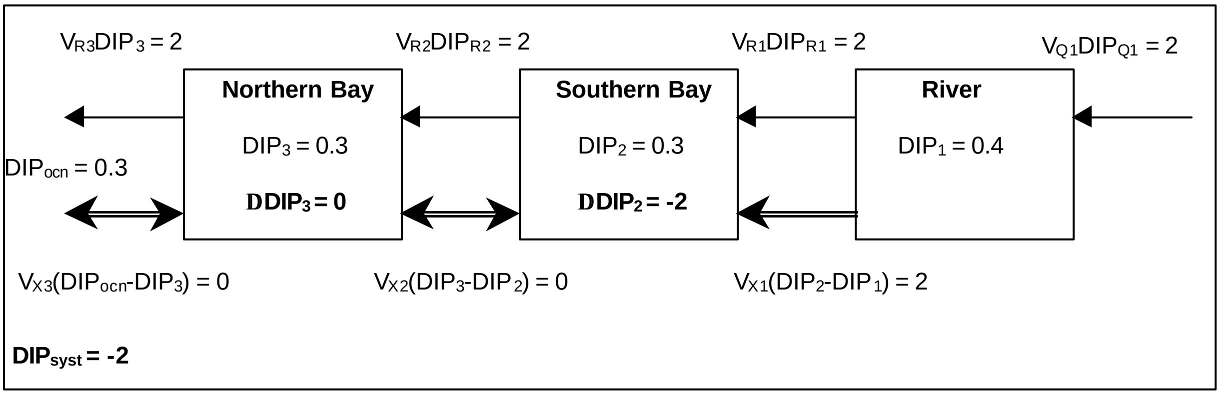

Figure 5.23. Dissolved inorganic phosphorus budget for San Miguel Bay. Fluxes in 10^6 mol yr^{-1} and concentrations in mmol m^{-3}.

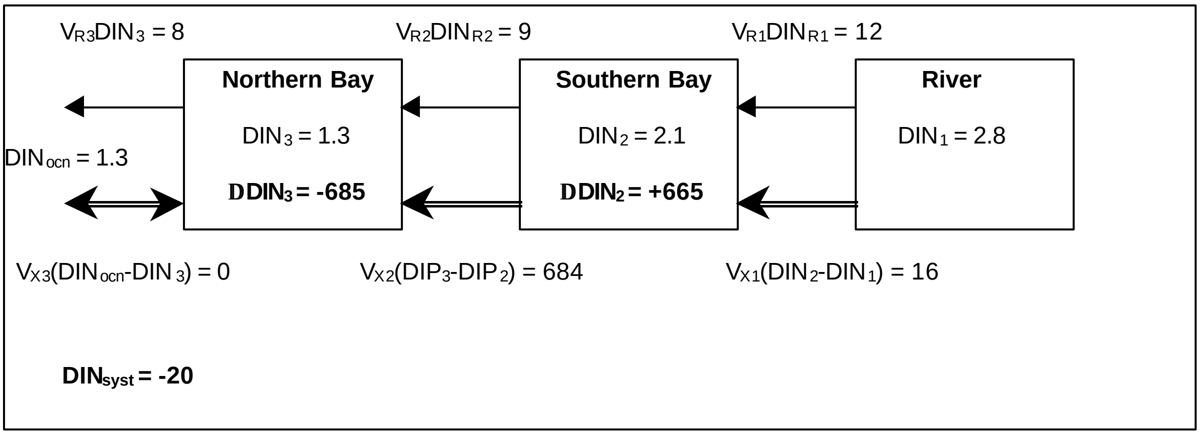

Figure 5.24. Dissolved inorganic nitrogen budget for San Miguel Bay. Fluxes in 10^6 mol yr^{-1} and concentrations in mmol m^{-3}.

5.7 Sorsogon Bay, Luzon Island

V. Dupra, S.V. Smith and D.J.R. Mendoza

Study area description

Sorsogon Bay is situated on the south-eastern coast of Luzon Island (12.80°-13.00°N, 123.73°-124.05°E) (Figure 5.25). The bay is relatively large (area ≈ 300 km^2) and shallow (average depth ≈ 5 m). It has a narrow mouth, approximately 2.5 km at its narrowest point. The bottom slopes down (2-3 m) from the shallow eastern end towards the mouth and is deepest (>30 m) at the channel, which forms the mouth of the Bay. Beyond the mouth, the bottom slopes down towards the open ocean rather steeply.

The prevailing winds over the region are dominated by the Asian Monsoon System, which blows from the north-east from November to March and from the south-west from June to October. The transition between the monsoons is characterized by the weak easterly breezes of the North Pacific trade winds. Periods of high rainfall in the region occur with the north-east monsoon, while intermittent high intensity rainfall during the south-west monsoon is associated with the occurrence of tropical cyclones, which are common during this period. The Bay is strongly influenced by freshwater discharge from rivers around it, resulting in large horizontal and temporal salinity variation. The shallow depth of the bay, which induces mixing, results in an almost homogenous water column. There appear to be two major sources of freshwater that result in a swing of the salinity gradient between eastern and western parts due to shifts in the amount of freshwater discharged from the major rivers (Villainy and Ranola 1995), which include the Dulanagan, the Pili and the Cadacan rivers.

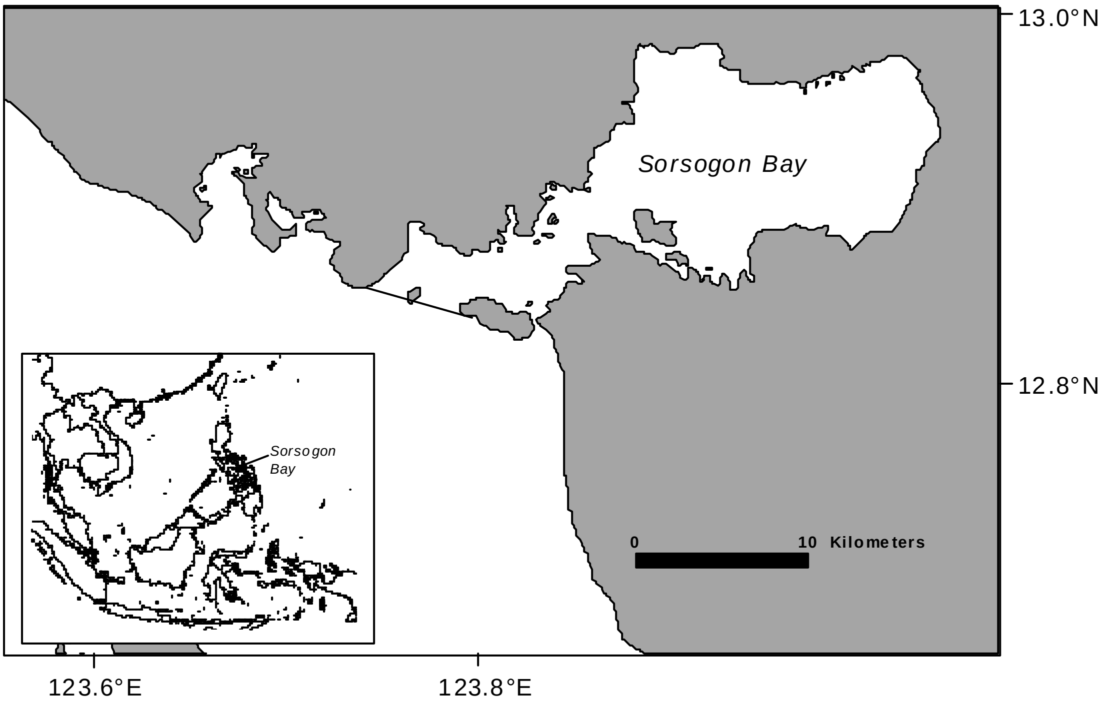

Figure 5.25. Sorsogon Bay. The solid line at the mouth of the bay shows the boundary of the budgeted system.

Major issues regarding pollution in Sorsogon Bay include effects of widespread use of fertilizer and pesticides for both agriculture and aquaculture, discharge of raw domestic wastes due to the lack of sewage system and adequate sanitary facilities, and effluents from industries. Siltation is also a problem in the bay; sediment deposition was estimated as 5.3 cm yr^{-1} (Mendoza *et al.* 1995).

The primary objective of this paper is to estimate the nonconservative fluxes of nitrogen and phosphorus and infer from these fluxes the biogeochemical processes occurring in the system. The bay was budgeted as single box that is both horizontally and vertically well-mixed following the LOICZ Biogeochemical Modelling Guidelines (Gordon *et al.* 1996). The complex horizontal salinity gradient within the bay was not considered in this budget; only the water exchange through the narrow mouth was taken into account. Hydrographic data used were annual averages of measurements in April, August and November 1994 and January 1995.

Water and salt budgets

Figure 5.26 shows the water and salt budgets. The net freshwater input from the river inflow, precipitation and evaporation is 1×10^9 m^3 yr^{-1} (V_R). This requires a mixing volume (V_X) of approximately 11×10^9 m^3 yr^{-1} to maintain the salt at steady-state. The exchange time (ι) of the water in the bay is about 61 days.

DIP and DIN balance

Figures 5.27 and 5.28 summarise the phosphorus and nitrogen budgets for Sorsogon Bay. Sorsogon Bay is a source for both dissolved inorganic phosphorus (DIP) and dissolved inorganic nitrogen (DIN). *DDIP* = $+11\times10^6$ mole P yr^{-1} or +0.10 mmole P m^{-2} day^{-1} and *DDIN* = $+60\times10^6$ mole N yr^{-1} or +0.55 mmole N m^{-2} day^{-1}. This budget assumed that all nutrient inputs from sewage, agriculture and aquaculture were drained into the bay through the rivers thus incorporated in the riverine input.

Stoichiometric calculations of aspects of net system metabolism

Stoichiometric analysis of non-conservative nutrient fluxes reveals that the bay is net denitrifying: (*nfix-denit*) = -1.06 mmole N m^{-2} day^{-1}; and net heterotrophic: (*p-r*) = -11 mmole C m^{-2} day^{-1}. The bay is highly productive: direct measurement of primary production was 153 mmole C m^{-2} day^{-1} (Mendoza 1995) giving a p/r ratio of 0.93.

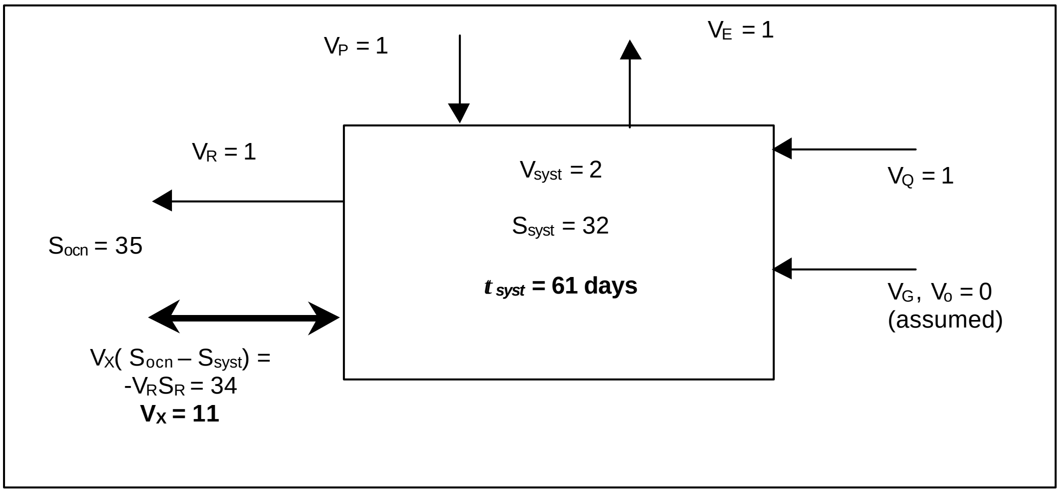

Figure 5.26. Water and salt budgets for Sorsogon Bay. Volume in 10^9 m^3, water fluxes in 10^9 m^3 yr^{-1}, salt fluxes in 10^9 psu-m^3 yr^{-1} and salinity in psu.

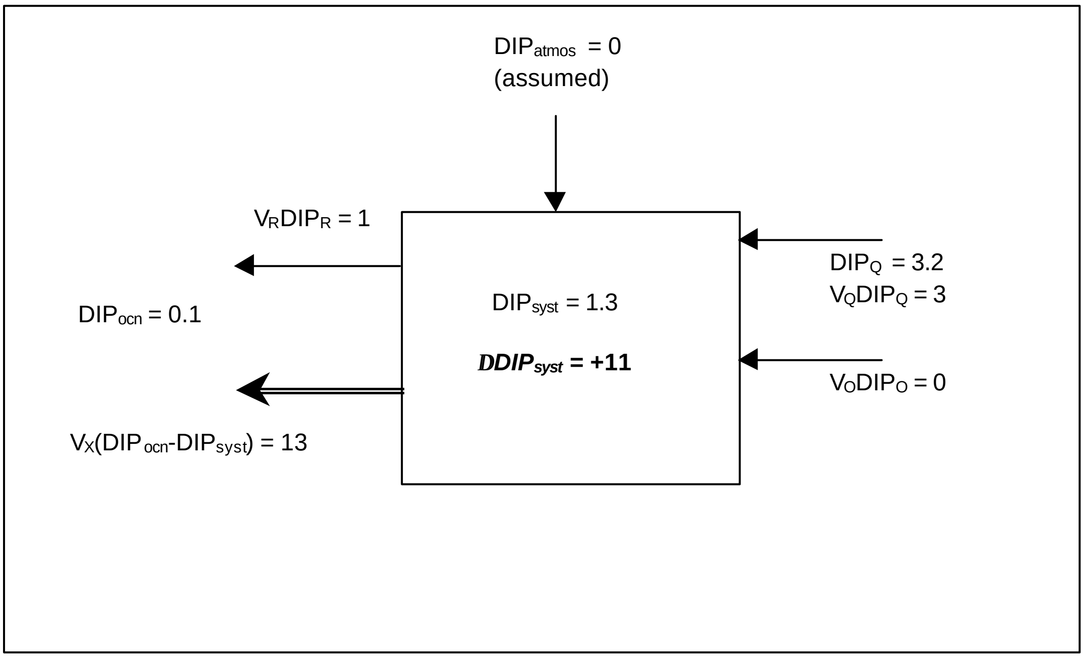

Figure 5.27. Dissolved inorganic phosphorus budget for Sorsogon Bay. Fluxes in 10^6 mol yr^{-1} and concentrations in mmol m^{-3}.

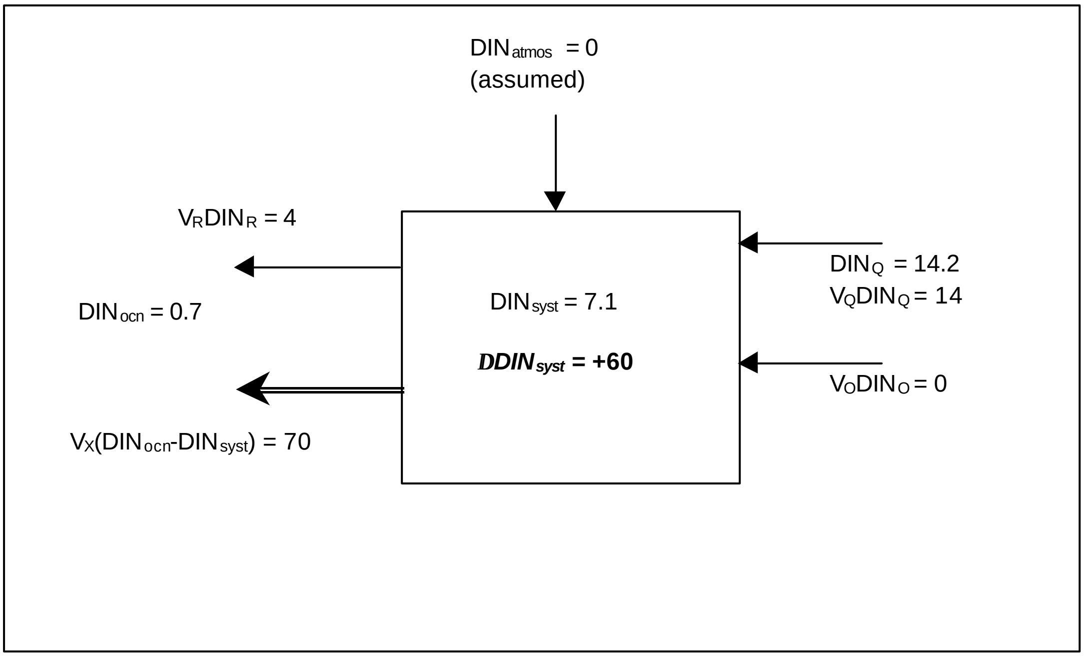

Figure 5.28. Dissolved inorganic nitrogen budget for Sorsogon Bay. Fluxes in 10^6 mol yr^{-1} and concentrations in mmol m^{-3}.

5.8 Subic Bay, Luzon Island

Laura T. David and Eileen L. Peñaflor

<u>Study area description</u>

Subic Bay is on the western coast of Luzon Island in the Philippines at 14.75°-14.83°N, 120.15°-120.28°E, 25 km north-east of Manila Bay (Figure 5.29). The bay covers 324 km^2 with a maximum width of 12 km, a maximum length of 20 km and a mean depth of 20 m. Tides from the South China Sea are mixed, semi-diurnal with a mean range of 1.9 m. Local climate is characterised by two pronounced seasons: a dry season from November to April and a wet season from March to October.

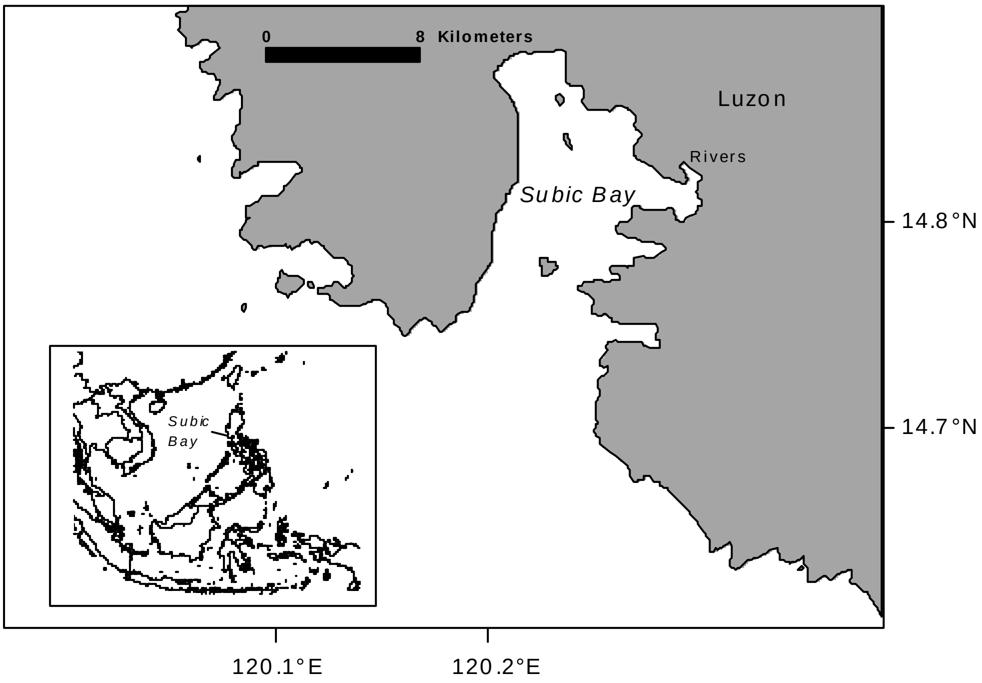

Figure 5.29. Location and map of Subic Bay.

<u>Water and salt balance</u>

Multiple rivers and rivulets provide a substantial amount of freshwater input to the bay. The seven most significant ones have a total watershed area of 361 km^2 with a mean discharge of 870×10^6 m^3 yr^{-1} and a maximum of $3{,}813 \times 10^6$ m^3 yr^{-1} as determined by q_R (m^3 yr^{-1}). The calculation of q_R is based on a simple climatological model (Schreiber 1904), using the 42-year monthly rainfall (r in mm) and air temperature (T in K) measured at Cubi Point in Subic Bay (the US Naval Oceanography Command Facility). The model is given by the following equations:

$$q_R = A_x (\Delta f/r)(r/(2.74\, D_i * 10^6))$$

$$\Delta f/r = \exp(-e^0/r)$$

$$e^0 = 1.0 * 10^9 \exp(-4.62 * 10^3/T)$$

where A_x (km^2) is the total watershed area; D_i is the number of days in the i^{th} month; e_0 (mm) is the calculated potential evapotranspiration, and Δf (mm) is the monthly runoff (Schreiber 1904; Sellers 1965; Holland 1978; Kjerfve 1990). As a means of verifying the model results we compared the runoff model as applied to a sample drought year (1968) and a sample flood year (1978) when we have data of river discharge for one of the rivers, the Agusuhin River (Woodward-Clyde 1999). The calculations yielded a mean discharge of $500x10^6$ m^3 yr^{-1} and $1,520x10^6$ m^3 yr^{-1} for the drought and flood years respectively.

The average annual precipitation is measured to be 3,580 mm at Cubi resulting in a direct rainfall average of $1,160x10^6$ m^3 yr^{-1} for the entire bay. Therefore most of the freshwater input into the bay is by precipitation. Evaporation rates are taken from the regional average of 2,100 mm giving an annual water loss of $680x10^6$ m^3 yr^{-1} from the bay surface.

Groundwater input (m^3 s^{-1}) along the coast was approximated using an equation derived from Darcy's Law (Shaw 1994):

$Q_{approx} = -K\ [(h_2 - h_1)/d]\ L\ W$

where K is the hydraulic conductivity given to be $3x10^{-4}$ m s^{-1} for the mainly alluvium/beach deposit upper aquifer of Subic Bay (Woodward-Clyde 1999). This upper aquifer extends to -22m (translating to the lowest hydraulic head, h_1) with the average distance of a line through h_1 and h_2 perpendicular to the coastline given as d (10 km), the length of the coastline as L (64 km), and the width of flow as W (7 m) (Woodward-Clyde 1999). This gives a calculated groundwater input for Subic Bay of $9x10^6$ m^3 yr^{-1}. Thus the mean total approximated freshwater contribution from groundwater to Subic Bay is 1% of the mean total river input. As a means of verifying this estimate we compared this groundwater model result with independent calculations for groundwater input for the drought (1968) and flood (1978) years. These independent calculations were done by Woodward-Clyde (1999) for the watershed of the Agusuhin River (15.4 km^2) using the following equations:

Groundwater Base Flow = 10% Groundwater End Storage

Groundwater End Storage = Initial Storage + Recharge – Pumping

Recharge = 10% * (Precipitation – Actual Evapotranspiration)

Extrapolating their calculations for the entire Subic Bay watershed yields a groundwater discharge of $3x10^6$ m^3 yr^{-1} and $10x10^6$ m^3 yr^{-1} for the drought and flood years respectively. Table 5.4 summarises the freshwater flux in Subic Bay.

Ocean salinity is taken to be 34 psu, while the bay mean salinity is 27 psu and groundwater salinity is 6 psu. Actual salinities for the drought and flood years were not available. Estimates were made using a volume-salinity ratio.

$S_{syst} = [(V_{syst} - V_{Q*})\ S_{ocn} + V_G\ S_G] / V_{syst}$

$V_{Q*} = V_Q + V_G + V_P - V_E$

This yielded a salinity of 31 psu and 20 psu for the drought and flood years, respectively.

Figure 5.30 summarises the mean water and salt budgets. The freshwater inputs minus the evaporative output results in a net freshwater $1,360x0^6$ m^3 yr^{-1} that is used for further calculations. Residual outflow ($V_R = -V_{Q*}$) of the mean is amount of water from the lagoon removes $41,480x10^6$ psu m^3 yr^{-1} of salt. Mixing between the ocean and lagoon water (V_X) to balance the loss of salt due to residual flow is estimated to be $5,917x10^6$ m^3 yr^{-1}. Note that due to the fact that the groundwater has a salinity of 6 psu the V_X is estimated using the following equation:

$V_X = (V_G S_G - V_R S_R) / (S_{ocn} - S_{syst})$

Water exchange rate ($\tau = V_{syst}/(\ |V_R| + V_X)$ rate is calculated to be about 11 months.

Budgets of nonconservative materials

The mass balance equations for the nonconservative materials explicitly identifies the different freshwater sources. River and groundwater contributions were taken from Agusuhin River and associated watersheds, and are assumed to be similar for all the rivers (Woodward-Clyde 1999). Ocean concentration came from the work done by McGlone *et al.* (1999). The biogeochemical flux is identified as ΔY, such that

$$DY = -V_R Y_R - V_X Y_{ocn} - V_Q Y_Q - V_P Y_P - V_G Y_G$$

DIP balance

Groundwater concentrations were estimated to be near 0, since in general, DIP flux in groundwater flowing through carbonate terrain is known to be low. In any case, groundwater inflow is small. Calculated ΔDIP is $-2{,}084 \times 10^3$ mol yr^{-1}. There is an effective net DIP flux from the ocean into the bay. Likewise, all the river inputs appear to be trapped within the system (Figure 5.31).

DIN balance

Only nitrate concentrations were available for calculations. Groundwater concentrations were taken from the Agusuhin River Watershed (Woodward-Clyde 1999). There is net nonconservative DIN flux ($+15{,}848 \times 10^3$ mol yr^{-1}) out of the bay. This input is probably overestimated because of very low value for oceanic DIN. However, increasing the net oceanic flux of DIN to be half of the system DIN (i.e. 2 mmol m^{-3}) would still lead to an estimate of a substantial DIN sink in the system (figure 5.32).

Stoichiometric calculations of aspects of net system metabolism

Using the *DDIN* and *DDIP* estimates to calculate nitrogen fixation minus denitrification we have (*nfix-denit*) =*DDIN* –16**DDIP* = $+49 \times 10^6$ mol N yr^{-1} which is equivalent to +0.15 mol N m^{-2} yr^{-1} for the entire lagoon. This suggests that the system is fixing nitrogen. If ocean influx of DIN were increased, the estimate of (*nfix-denit*) would approach 0.

The net ecosystem metabolism is calculated as (*p-r*) = -106**DDIP* = $+221 \times 10^6$ mol C yr^{-1}, which is equivalent to +0.7 mol C m^{-2} yr^{-1} for the entire lagoon. This implies that the lagoon is net autotrophic.

Seasonality

The large dependence of the freshwater input into the bay on the amount of direct precipitation, as well as the availability of the data, prompted calculation of the budget during different precipitation regimes. In general, the drought and flood budgets mirrored that of the mean budget with DIP flux from the ocean to the lagoon, and with the bay fixing nitrogen. As expected, the calculated water exchange rate is progressively faster from drought to flood regime. It is interesting to note that the calculations for the water exchange rate suggest that on the average the bay behaves like the flood regime but for calculation of the nonconservative nutrient fluxes the bay is more similar to the drought regime. Therefore, for a system such as Subic Bay where direct precipitation is the major contributor to the freshwater budget, calculation of mean water exchange rate must be done using data from a year with relatively high rainfall in the absence of long-term data set. On the other hand, calculation for nonconservative fluxes, and stoichiometric calculations, might best be done using data from a relatively dry year or dry months.

Table 5.5 summarises the water and salt budgets for the three precipitation regimes while Table 5.6 summarises the phosphate and nitrate budgets. During all three regimes the system is fixing nitrogen. Calculation of the net ecosystem metabolism implies that the lagoon remains to be net autotrophic. Table 5.7 summarises the stoichiometric calculations of aspects of net system metabolism.

Table 5.4. Statistics for freshwater flux in Subic Bay.

	Mean	Drought	Flood
Annual Rainfall (mm)	3,580	2,150	5,400
Mean Freshwater Runoff (10^6 m^3 yr^{-1})	870	500	1,520
Groundwater Input (10^6 m^3 yr^{-1})	10	0	10

Table 5.5. Salt and water budgets for the different precipitation regimes.

	Mean	Drought	Flood
	(1948-1989)	(1968)	(1978)
V_Q (10^6 m^3 yr^{-1})	870	500	1,520
V_P (10^6 m^3 yr^{-1})	1,160	700	1,750
V_G (10^6 m^3 yr^{-1})	10	0	10
V_E (10^6 m^3 yr^{-1})	-680	-680	-680
S_{syst} (10^6 psu m^3 yr^{-1})	27	31	20
S_{ocn} (10^6 psu m^3 yr^{-1})	34	34	34
S_R (10^6 psu m^3 yr^{-1})	30.5	32.5	27
V_R (10^6 m^3 yr^{-1})	-1,360	-520	-2,600
V_X (10^6 m^3 yr^{-1})	5,917	5,633	5,010
τ (days)	325	384	311

Table 5.6. Nonconservative materials budgets for the different precipitation regimes.

	Mean	Drought	Flood
	(1948-1989)	(1968)	(1978)
V_QDIP_Q (10^3 mol yr^{-1})	+261	+150	+456
V_RDIP_R (10^3 mol yr^{-1})	-544	-208	-1,040
$V_X(DIP_{ocn}-DIP_{syst})$ (10^3 mol yr^{-1})	+2,367	+2,253	+2,004
DDIP (10^3mol yr^{-1})	-2,084	-2,195	-1,420
V_QDIN_Q (10^3 mol yr^{-1})	+10,440	+6,000	+18,240
V_GDIN_G (10^3 mol yr^{-1})	+100	0	+100
V_RDIN_R (10^3 mol yr^{-1})	-2,720	-1,040	-5,200
$V_X(DIN_{ocn}-DIN_{syst})$ (10^3 mol yr^{-1})	-23,668	-22,532	-20,040
DDIN (10^3 mol yr^{-1})	+15,848	+17,572	+6,900

Table 5.7. Calculated stoichiometry of fluxes based on seasonal data.

Processes	Mean(1948-1989)		Drought (1968)		(1978)	
	10^6 mol yr^{-1}	mmol m^{-2} yr^{-1}	10^6 mol yr^{-1}	mmol m^{-2} yr^{-1}	10^6 mol yr^{-1}	mmol m^{-2} yr^{-1}
(*nfix-denit*)	+49	+0.15	+53	+0.16	+30	+0.09
(*p-r*)	+221	+0.69	+233	+0.72	+151	+0.47

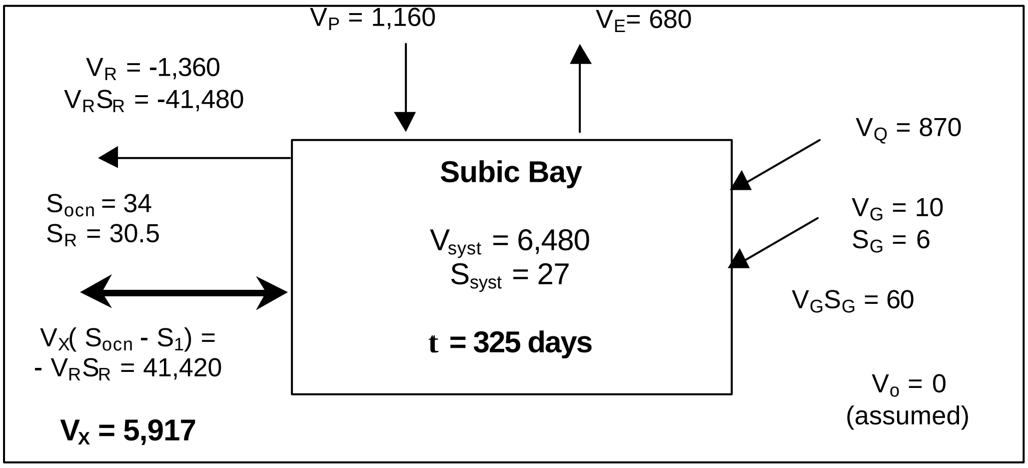

Figure .5.30. Water and salt budgets for Subic Bay. Volume in 10^6 m^3, water fluxes in 10^6 m^3 yr^{-1}, salt fluxes in10^6 psu-m^3 yr^{-1} and salinity in psu.

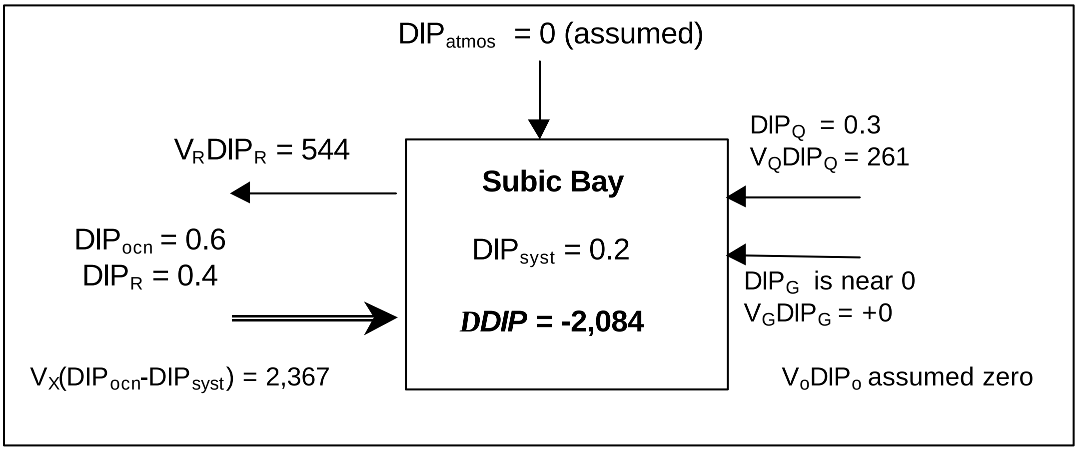

Figure 5.31. Dissolved inorganic phosphorus budget for Subic Bay. Fluxes in 10^3 mol yr^{-1} and concentrations in mmol m^{-3}.

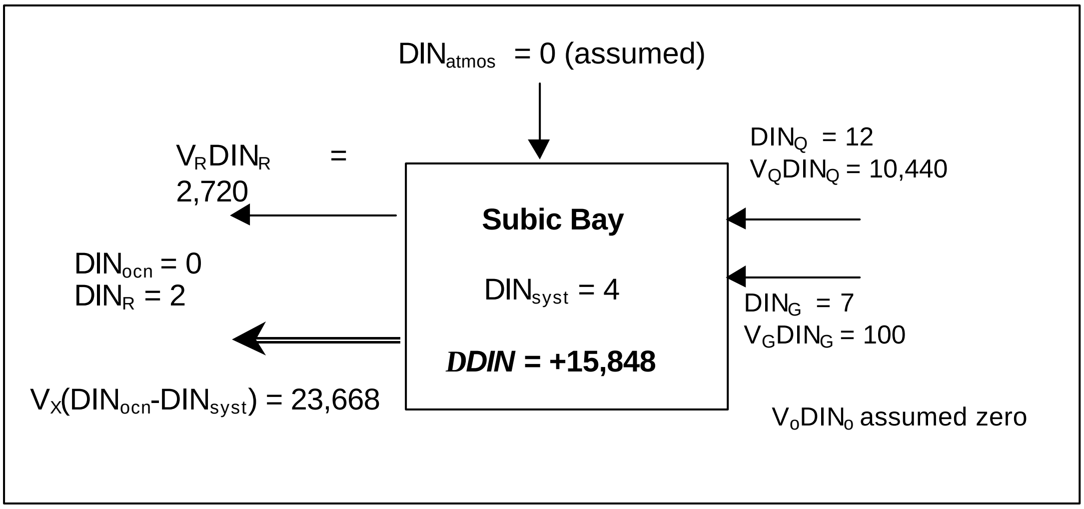

Figure 5.32. Dissolved inorganic nitrogen budget for Subic Bay. Fluxes in 10^3 mol yr^{-1} and concentrations in mmol m^{-3}.

5.9 Carigara Bay, Visayan Islands

V. Dupra, S.V. Smith, M.L. San Diego-McGlone and R.A. Valmonte-Santos

Note: This single box budget will be later modified to systems in series budget. The systems in series budget will include waters north of Carigara Bay.

Study area description

Carigara Bay is situated in the Visayan Islands, the Philippines (11.30°-11.42°N, 124.53°-124.83°E) (Figure 5.33). The bay is a broad (width ≈ 27 km), relatively large (area ≈ 500 km^2) and shallow (depth ≈40 m) crescent-shaped embayment (Calumpong *et al.* 1994). It is bounded on both its northern rims by steep hills, with a shallow floodplain along its southern coast. Five major river systems drain into the Bay, and there are also several small tributaries within the floodplain area. The five rivers are the Naugisan, Carigara, Canomantag, Himanglos and Sapiniton rivers. These rivers run through fairly heavily populated areas (ca. 130 000 population). There are five municipalities with coastal jurisdiction: Capoocan, Carigara, Barugo, San Miguel and Babatngon. Land-use status of the municipalities within the watersheds of the five rivers flowing into the Carigara Bay are categorised as Alienable and Disposable (47%), Forest (26%), Timberland (16%), and Reservation (10%).

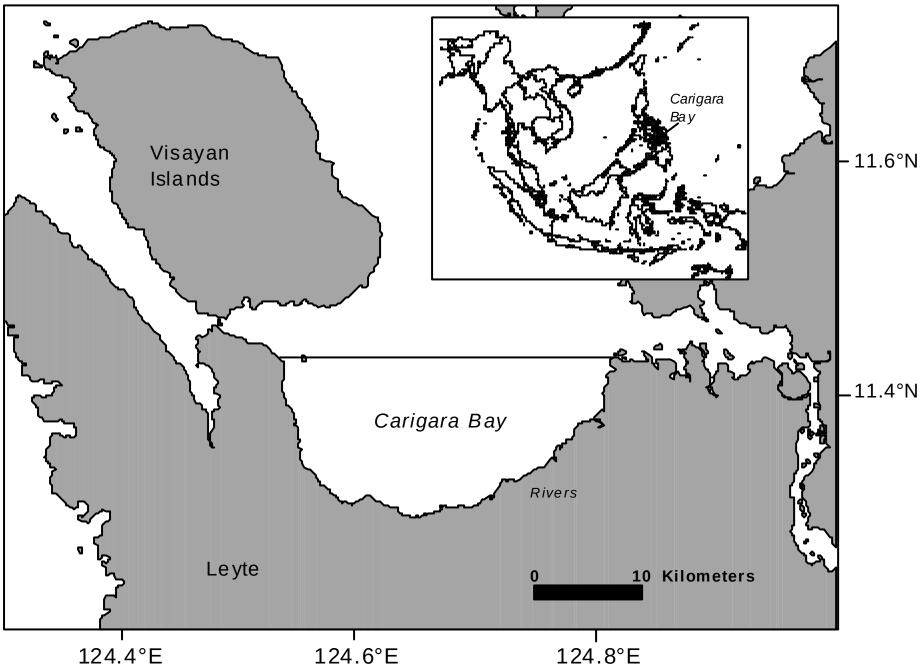

Figure 5.33. Location of Carigara Bay. The solid line represents the boundary of the budgeted systems.

There are three distinct seasons affecting weather patterns in Carigara Bay: a dry season which coincides with the south-west monsoon from January to May, a rainy season which coincides with the north-east monsoon from June to September and a storm or transitional season from October to December (Calumpong *et al.* 1994; Valmonte-Santos *et al.* 1996).

Carigara Bay is heavily stressed and damaged as a result of the increasing population pressure and economic depression. The inhabitants of the region, having few options, continue to exploit the resources. Several major problems have been identified within the bay: overfishing and the use of destructive fishing method, siltation from poor land use practices and loss of marine habitats.

This study aims to estimate nitrogen and phosphorus nonconservative fluxes and infer from these fluxes the biogeochemical processes occurring in the system. Carigara Bay was budgeted applying the

LOICZ Biogeochemical Budget Modelling Guidelines (Gordon *et al.* 1996) as a single box model with horizontally and vertically mixed water. This involved the use of water-salt-nutrient linked budgets. Data used were mostly from a survey of Carigara Bay during the rainy season of September 1996 and the dry season of March 1996 (Valmonte-Santos *et al.* 1996). Average salinity and nutrient concentrations for the two sampling periods were calculated to represent annual values. Nutrient concentrations for rivers and the adjacent ocean used in this budget were measurements from Valmonte-Santos *et al.* (1996). Nutrient loads from sewage were estimated from the 130,000 population and considered in this budget. Conversions of 9.5 mole P per person per year and 140 mole N per person per year were used (San Diego-McGlone Appendix II, this report).

<u>Water and salt balance</u>

Figure 5.34 shows the steady-state water and salt budgets for Carigara Bay. The net freshwater input was calculated from precipitation (V_P = 1x10^9 m^3 yr^{-1}), evaporation (V_E = 1x10^9 m^3 yr^{-1}) and river discharges (V_Q = 6x10^9 m^3 yr^{-1}); other freshwater sources were assumed insignificant. Precipitation and evaporation rates were from Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA). River discharges coming from the five rivers were from Calumpong *et al.* (1994). The presence of many rivers emptying into the bay makes the rivers the dominant sources for freshwater. The net freshwater input, which is equal to the residual flow, is 6x10^9 m^3 yr^{-1} (V_R). The residual flow needs water to mix between the bay and adjacent ocean equal to 63x10^9 m^3 yr^{-1} (V_X) to balance salt flux. The water exchange between the bay and adjacent oceanic water is 106 days.

<u>Budgets of nonconservative materials</u>

DIP balance

Figure 5.35 presents the dissolved inorganic phosphorus (DIP) budget for Carigara Bay. Processes in the system seem to balance the release and uptake of DIP, *DDIP* = 0. From sewage nutrient loads, inorganic phosphorus (V_ODIP_O) was estimated by multiplying the conversion factors of 9.5 mole P $person^{-1}$ yr^{-1} by the 130,000 population living along the bay. Sewage conversion factors were estimated from a load of 20 kg BOD $person^{-1}$ yr^{-1}. Inorganic phosphorus load, V_ODIP_O = 1.2x10^6 mole yr^{-1} was calculated.

DIN balance

Figure 5.36 illustrates the dissolved inorganic nitrogen (DIN) budget. The bay seems to be a net sink for nitrogen, *DDIN* = -17x10^6 mole N yr^{-1} or -0.09 mmole N m^{-2} day^{-1}. From sewage nutrient loads, inorganic nitrogen (V_ODIN_O) was estimated using the conversion 140 mole N $person^{-1}$ yr^{-1}. Inorganic nitrogen load, V_ODIN_O = 18x10^6 mole yr^{-1} was estimated.

Nutrients for river discharges were not measured at zero salinity so that the actual nutrient loads were underestimated. DIN considered for these budgets were only NO_2^- and NO_3^-. Disregarding ammonia (NH_4^+) further intensifies underestimation of DIN input in the river loads. On the other hand, nutrient loads may be overestimated by the sewage inputs that actually become incorporated into the river loads. This could be resolved with measurements of river nutrient concentrations upstream.

Nonconservative fluxes of nutrients derived for the bay were low and within the above-mentioned uncertainties. The problem of the loads and the rapid exchange of water between the embayment and adjacent water necessitate a systems-in-series model, which involves extension of the budget towards the north.

Stoichiometric calculations of aspects of net system metabolism

From stoichiometric analysis of the nonconservative nutrients, the system is very slightly denitrifying: (*nfix-denit*) = -0.1 mmole N m^{-2} day^{-1}. Production and respiration were balanced, (*p-r*) = 0. Primary production derived from chlorophyll values ranged from 2 to 8 mmole C m^{-2} day^{-1}.

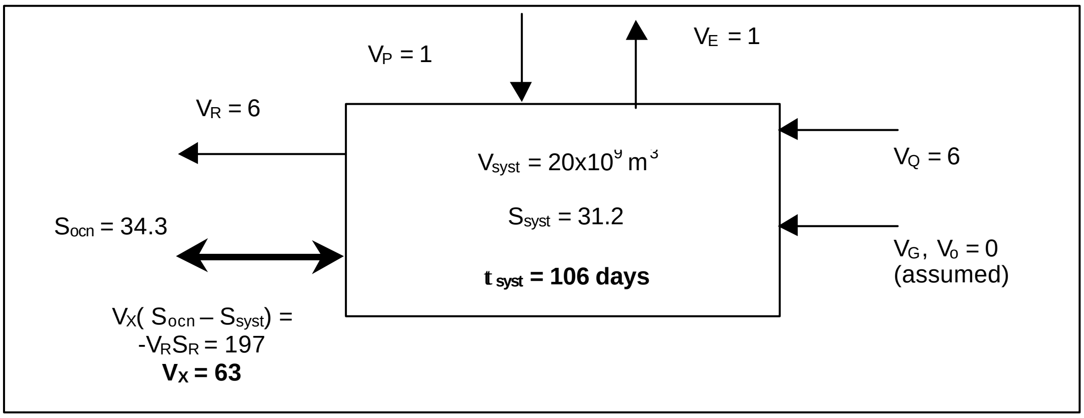

Figure 5.34. Water and salt budgets for Carigara Bay. Water fluxes in 10^9 m^3 yr^{-1} and salinity in psu.

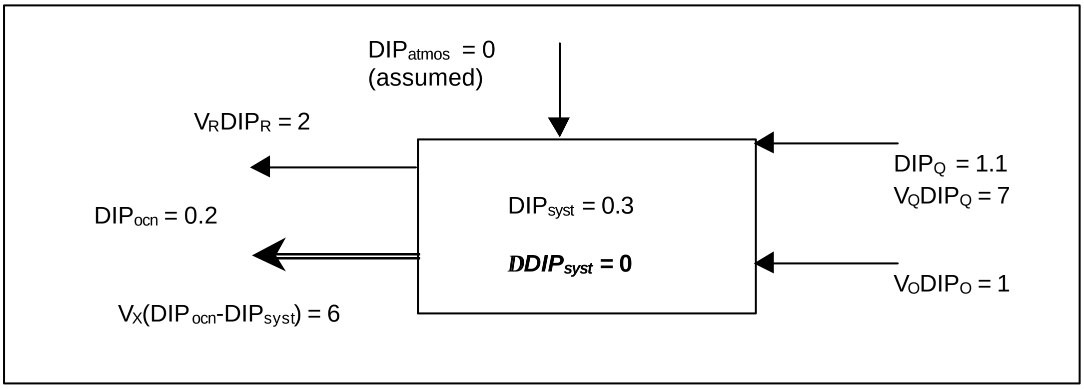

Figure 5.35. Dissolved inorganic phosphorus budget for Carigara Bay. Fluxes in 10^6 mol yr^{-1} and concentrations in mmol m^{-3}.

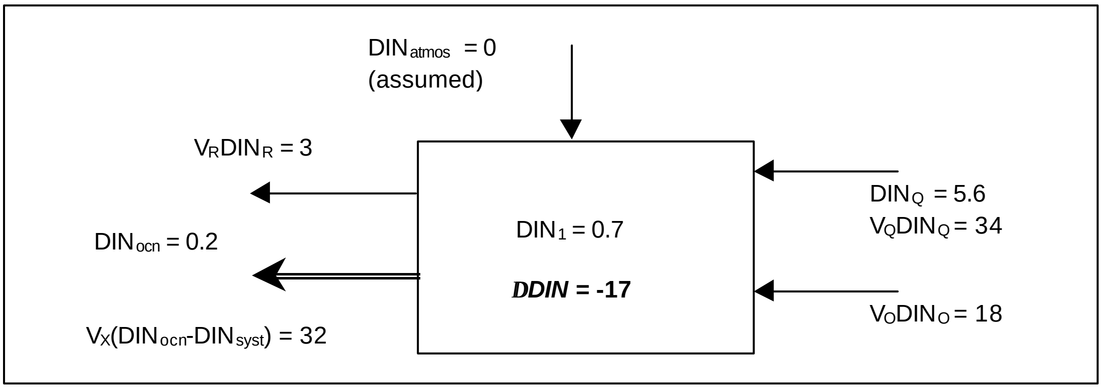

Figure 5.36. Dissolved inorganic nitrogen budget for Carigara Bay. Fluxes in 10^6 mol yr^{-1} and concentrations in mmol m^{-3}.

5.10 Davao Gulf, Mindanao Island

V. Dupra and S.V. Smith

Study area description

Davao Gulf is located in the south-eastern part of Mindanao Island, the Philippines (6.12°-7.36°N, 125.37°-126.20°E) (Figure 5.37). The gulf has an area of 6,600 km^2 and a coastline of approximately 500 km. The average depth of the gulf is 17 m, volume approximately 112x10^9 m^3. The high mountain ranges of Sarangani Province in the west and south-west, the mountain ranges of Mt. Apo (the highest Philippine peak) in the north and north-west portion of the region, and the mountain ranges of Davao del Norte and Oriental in the eastern side, surround the gulf. Within the gulf are the islands of Samal and Talikud.

The total catchment area of Davao Gulf is about 5,100 km^2. The total catchment area is derived from various watershed areas of Sarangani, Davao del Norte and Davao Oriental provinces and Davao City. This is about 78 % of the gulf's water area. The total population of the three provinces including Davao City is ca. 4,000,000 (in 1995). The gulf has about 33 major rivers and creeks making the inner part of the gulf estuarine in character. The Davao region has an annual rainfall of 1.8 m that is evenly distributed through the year (Philippine Atmospheric, Geophysical and Astronomical Services Administration, PAGASA). The average annual temperature is 27°C, the mean humidity 82%. The north-east monsoon occurs from October to May, the south-west monsoon from June to September. The region is generally free from typhoons.

The surface soils are mostly of clay and loam types. Activities around the gulf include farming and mining of minerals. These activities inevitably introduce chemicals to maximize production that ultimately reached the gulf, in addition to sediment load.

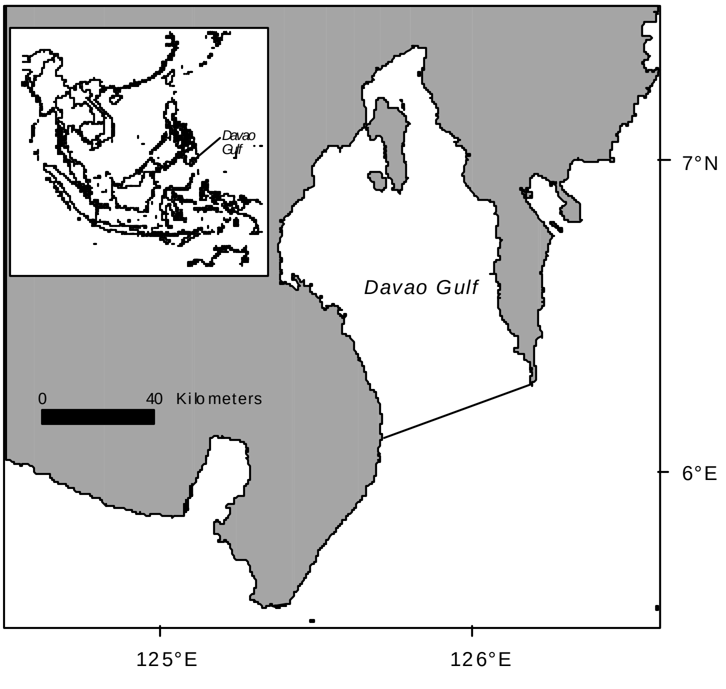

Figure 5.37. Davao Gulf. Solid line shows the boundary of the budgeted system.

This paper aims to estimate nonconservative nitrogen and phosphorus fluxes and to infer from these fluxes the biogeochemical processes occurring in the system. The gulf was budgeted following the LOICZ Biogeochemical Modelling guidelines (Gordon *et al.* 1996). The gulf was treated as single box model despite of its large area because of insufficient data to resolve spatial variations of nutrient concentrations. Data from 32 sampling stations within the gulf and 10 river stations measured in August 1995 were considered. Oceanic salinity and nutrient concentrations were extracted from NOAA <**http://ferret.wrc.noaa.gov/fbin/climate_server** >. Sewage nutrient loads from the population around the gulf were also considered in this budget. Calculations for sewage inorganic phosphorus and nitrogen were based on San Diego-McGlone (Appendix II this report).

Water and salt balance

Figure 5.38 shows the steady-state water and salt budgets for Davao Gulf. River runoff (V_Q) was $3\mathrm{x}10^9$ m^3 yr^{-1} calculated using the climatological model for calculating river discharge as described in this report (David, Appendix III this report). A river runoff of $12\mathrm{x}10^9$ m^3 yr^{-1} was estimated (Bureau of Fisheries and Aquatic Resources (BFAR) 1995) from the 18 major rivers. This value seems far too high, as it implies that the net rainfall (rainfall - evapotranspiration) across the watershed was about 2.4 m yr^{-1}, yet the rainfall across the gulf itself (before adjustment for evaporation) was only 1.8 m. The estimated runoff was used, because it seems very likely that there is a serious overestimation in gauged runoff in the BFAR report. The error on the gauged runoff could be an effect of tidal oscillation on the gauging stations if some of those stations are within the tidal portions of the rivers. Precipitation (V_P = $12\mathrm{x}10^9$ m^3 yr^{-1}) and evaporation (V_E = $10\mathrm{x}10^9$ m^3 yr^{-1}) were calculated from data provided from PAGASA. Other freshwater sources were assumed zero.

Residual flow is $5\mathrm{x}10^9\mathrm{m}^3$ yr^{-1} (V_R). This flow resulted from the freshwater input to conserve the volume of the gulf. Residual flow is derived from the total of all freshwater fluxes. Mixing exchange is about $38\mathrm{x}10^9$ m^3 yr^{-1} (V_X) to balance residual salt flux. Water exchange time (t) between the gulf and adjacent oceanic water is more than a year. The long water exchange time may be a result of the low salinity of the system since data were averaged from nearshore measurements. If the actual salinity of the system is higher than we have estimated, then V_X would be higher and water exchange time would be shorter.

Budgets of nonconservative materials

DIP and DIN balance

Figures 5.39 and 5.40 summarise the dissolved inorganic phosphorus (DIP) and dissolved inorganic nitrogen (DIN) budgets respectively. Using the available data, nutrient budgets show that the gulf is a net sink for both DIP and DIN, presented by ΔDIP = $-31\mathrm{x}10^6$ mole P yr^{-1} or -0.01 mmole P m^{-2} day^{-1} and ΔDIN = $-572\mathrm{x}10^6$ mole P yr^{-1} or -0.24 mmole N m^{-2} day^{-1}, respectively.

The nutrient concentrations available in BFAR report (1995) of Davao Gulf (1995) were concentrated close to the coast. Additional measurements far from the shore would decrease the nutrient concentrations of the system, this would drive the non-conservative DIP and DIN more negative. On the other hand, increase of V_X would mean a larger export of nutrients to the adjacent ocean which would drive the processes of the nonconservative flux to positive.

Nutrient loads into the bay were also poorly defined. River nutrient concentrations were measured at salinity range from 0 to 22 psu, which might underestimate river nutrient fluxes. Other important nutrient sources (e.g., agricultural loads) were not considered. Addressing these issues including spatial and vertical sectioning of the gulf would improve the budget.

Stoichiometric calculations of aspects of net system metabolism

Stoichiometric analysis of the nonconservative nutrients estimates the gulf as denitrifying: (*nfix-denit*) = -0.08 mmole N m^{-2} day^{-1}; and autotrophic: (*p-r*) = +1 mmole C m^{-2} day^{-1}. Independent measurement of primary production of the gulf is 15 mole C m^{-2} yr^{-1}, giving a p/r ratio of 1.07.

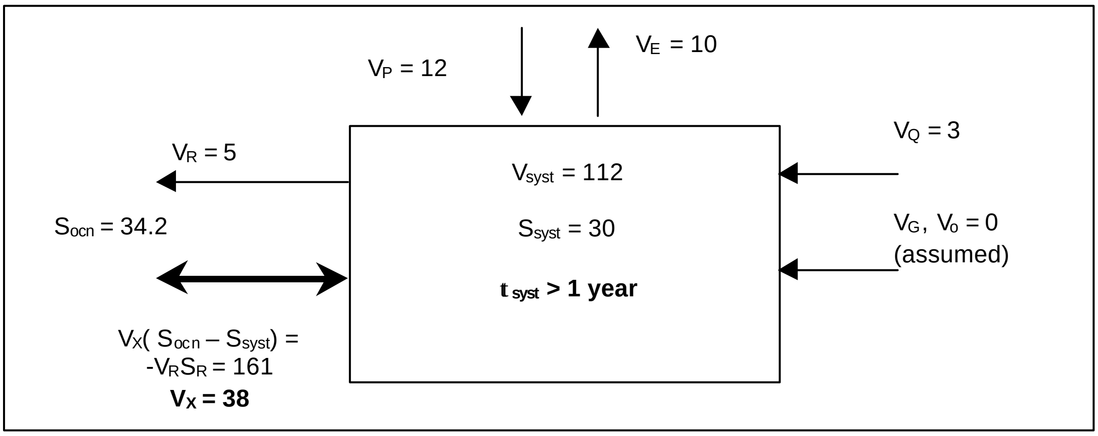

Figure 5.38. Water and salt budgets for Davao Gulf. Volume in 10^9 m^3, water fluxes in 10^9 m^3 yr^{-1}, salt fluxes in 10^9 psu-m^3 yr^{-1} and salinity in psu.

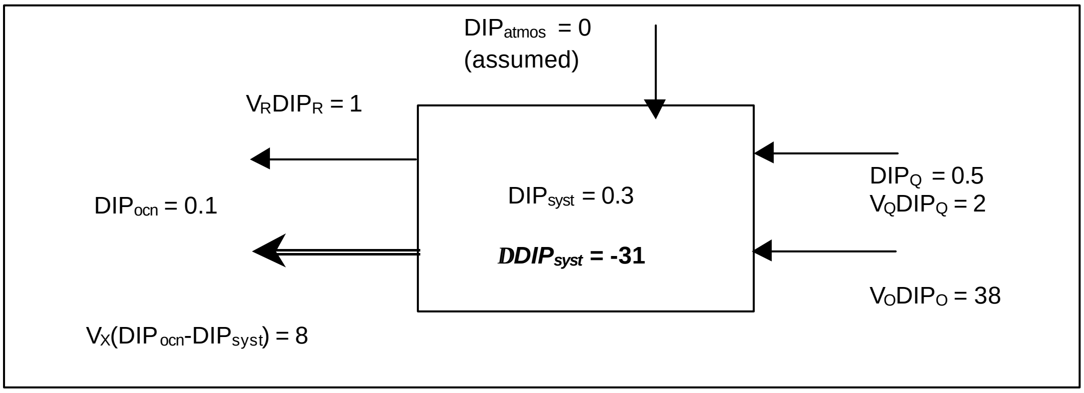

Figure 5.39. Dissolved inorganic phosphorus budget for Davao Gulf. Fluxes in 10^6 mol yr^{-1} and concentrations in mmol m^{-3}.

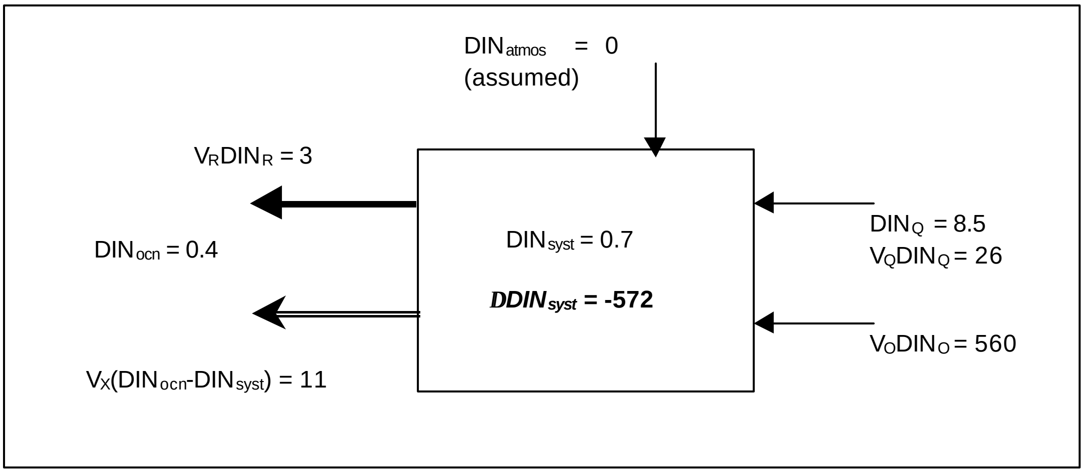

Figure 5.40. Dissolved inorganic nitrogen budget for Davao Gulf. Fluxes in 10^6 mol yr^{-1} and concentrations in mmol m^{-3}.

5.11 Sogod Bay, Leyte Island

V. Dupra and S.V. Smith

Study area description

Sogod Bay, on the southern coast of Leyte Island (10.00°-10.15°N, 125.00°-125.25°E), is a narrow, deep bay that contains about 130 km of coastline, with a total area of 1,500 km^2 (Figure 5.41). The average depth is approximately 700 m. It is characterized by steeply-sloping nearshore areas and topography marked by rolling hills and steep mountains. This slope continues into the water, providing the bay with a very small coastal shelf and a deep narrow channel.

There are nine major rivers and many smaller channels that empty into the bay. Most of the major rivers are located near the vertex of the bay. These nine rivers are estimated to discharge about 1x10^9 m^3 volume of water. The annual rainfall averages 2,000 mm. There is no pronounced dry season in the region, so that rainfall is more or less evenly distributed through the year, but with more rain between July and December. This period is also marked by frequent storms and typhoons.

Sogod Bay, like most of the Philippine bays, is threatened by population expansion, the lack of waste management and poor land-use practices. The total population living around the bay is 114,000 people as of a 1995 survey.

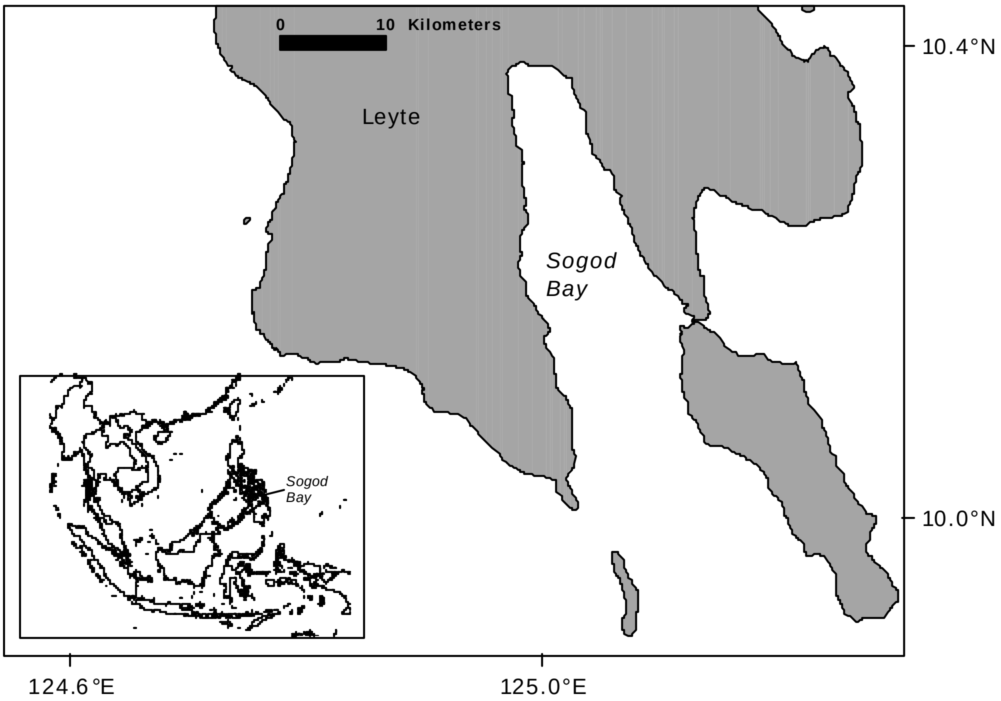

Figure 5.41. Location of Sogod Bay.

Water and salt balance

Figure 5.42 illustrates the two-layer water and salt budgets for Sogod Bay, based on the LOICZ Biogeochemical Modelling Guidelines (Gordon *et al.* 1996). The net residual flow (V_R) from river runoff, precipitation and evaporation was estimated to be 2x10^9 m^3 yr^{-1}. Using residual flow and salinity data of the upper and lower water column for both the bay and the adjacent ocean, oceanic bottom water intrusion (V_D), volume of water entrained between the system layers ($V_{D'}$) and volume mixing (V_Z) between the layers were estimated to be 170, 170 and 0x10^9 m^3 yr^{-1}, respectively. The computed water exchange time for the upper layer was 159 days. Because the system is very deep, water exchange time computed from the budget was more than a year.

Budgets of nonconservative materials

DIP and DIN balance

Figures 5.43 and 5.44 present the dissolved inorganic phosphorus (DIP) and dissolved inorganic nitrogen (DIN) budgets. Computed waste load coming from the population was insignificant compared to river discharge thus it was ignored in this budget. The system is a net sink for both DIP and DIN: *DDIP* = $-19\text{x}10^6$ mol yr^{-1} or -0.03 mmol C m^{-2} day^{-1} and *DDIN* = $-345\text{x}10^6$ mol yr^{-1} or -0.63 mmol C m^{-2} day^{-1}.

Stoichiometric calculations of aspects of net system metabolism

Stoichiometric analysis shows that the system is net autotrophic: (p-r) = $+2{,}014\text{x}10^6$ mol C yr^{-1} or +4 mmol C m^{-2} day^{-1}. The bay is slightly net denitrifying: (nfix-denit) = $-41\text{x}10^6$ mol N yr^{-1} or -0.07 mmol C m^{-2} day^{-1}.

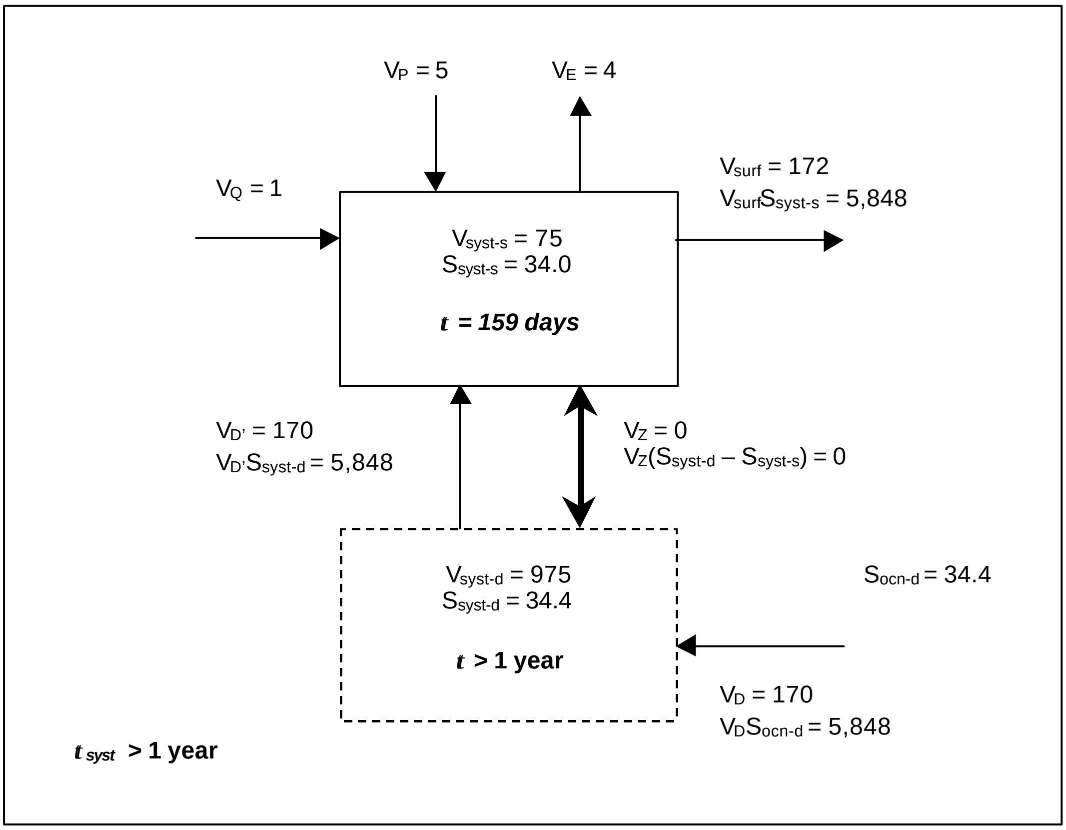

Figure 5.42. Two-layer water and salt budgets for Sogod Bay. The box outlined with dashed lines represents the lower layer of the system. Volume in 10^9 m^3, water fluxes in 10^9 m^3 yr^{-1}, salt fluxes in 10^9 psu-m^3 yr^{-1} and salinity in psu.

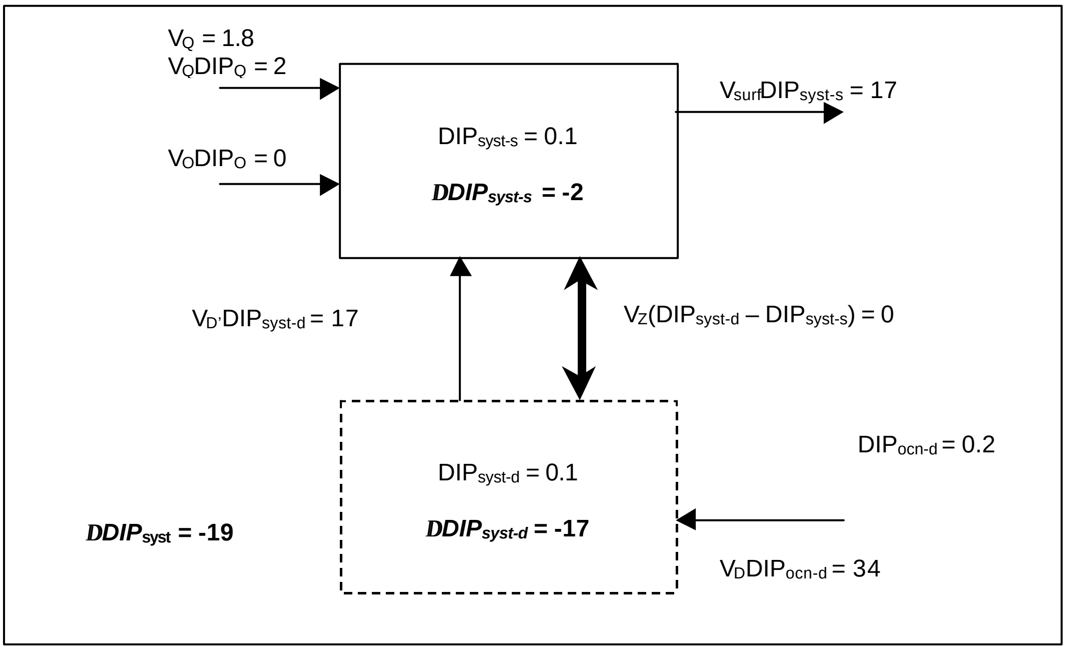

Figure 5.43. Two-layer dissolved inorganic phosphorus budget for Sogod Bay. The box outlined with dashed lines represents the lower layer of the system. Fluxes in 10^6 mol yr^{-1} and concentrations in mmol m^{-3}.

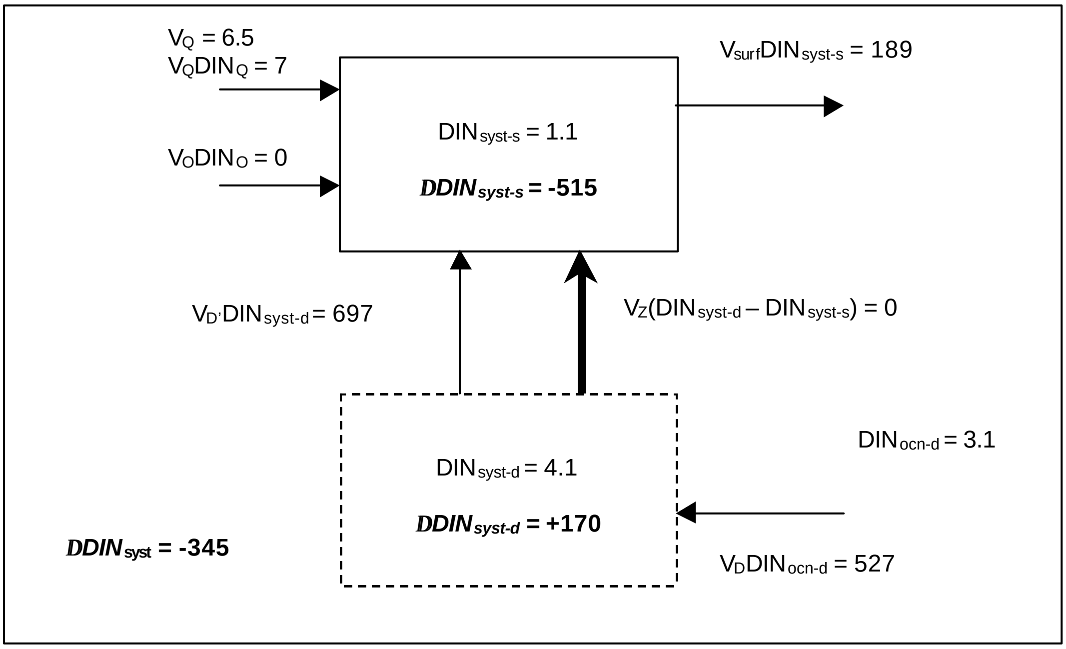

Figure 5.44. Two-layer dissolved inorganic nitrogen budget for Sogod Bay. The box outlined with dashed lines represents the lower layer of the system. Fluxes in 10^6 mol yr^{-1} , and concentrations in mmol m^{-3}.

6. THAILAND ESTUARINE SYSTEMS

6.1 Bandon Bay

Gullaya Wattayakorn

Study area description

Bandon Bay (9.20°N and 99.67°E) is located in Surat Thani Province, southern Thailand. The watershed of the bay is 12,220 km^2, of which an important part consists of agricultural lands and aquaculture. The population living within the watershed numbers approximately 830,000 with fisheries, aquaculture and tourism as their main activities. In the coastal area, there are several socio-economic activities such as fisheries, oyster culture and shrimp farming that represent an income for the people living in the area. Mangroves (*Rhizophora* spp, *Sonneratia alba*, *Xylocarpus* spp, *Avicennia alba* and *Bruguiera* spp.) cover the shores of the bay and the upland area.

Tide in Bandon Bay is diurnal, with the average tidal range of 1 metre. The inner bay, from Chaiya District to Kanchanadit District (Figure 6.1), covers an area of 480 km^2 with 80 km of coastline. The coastal area has a gradual slope and the water is shallow. A large band of mudflats, resulting from high sedimentation in the bay area, extends along the coast to about 2 km from the shore. Water depths vary from below 1 m to 5 m near the mouth of the bay, with a mean depth of 3 m, with respect to mean sea level. The volume of the bay is estimated to be 1,440x10^6 m^3.

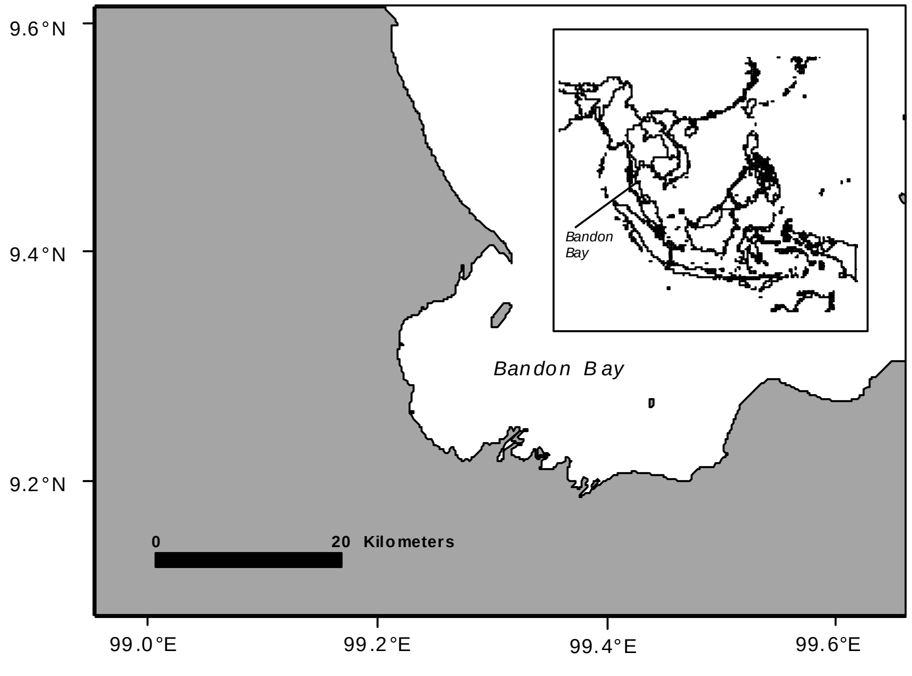

Figure 6.1. Location and map of Bandon Bay.

The climate is intermediate between equatorial and tropical monsoon types and is characterized by constant high temperature and high rainfall without extremes of heat, with average rainfall and evaporation of 4 mm day^{-1}. Mean relative humidity is 81% (range from 61-95%). Mean monthly temperature ranges from 26°C, usually in the wettest month, to 32°C, usually in April. Meteorological data for Bandon Bay in 1997 and 1998 is based on the data compiled from the Surat Thani weather station. The wet season starts in May and lasts until December; during this season monthly rainfall ranges from 77 mm to 412 mm. The highest amount of rainfall was in August. Lower rainfall, 50 mm, and a higher evaporation rate characterises the dry season, from January to April. Annual rainfall for 1997 was 1,500 mm, which is less than the mean annual rainfall for 1951-1996 (1,690 mm).

Most of the surface freshwater discharge into Bandon Bay is from the Tapi-Phumduang River watershed. The Phumduang River basin covers an area of 6,125 km^2 and the Tapi River Basin covers about 5,460 km^2. These two rivers join about 15 km west of Surat Thani, forming an extended delta as they discharge into the Gulf of Thailand. Annual runoff in Tapi and Phumduang rivers normally amounts to more than 10 billion m^3. The hydrological characteristics of the Tapi and Phumduang rivers in 1997 are summarised in Table 6.1. The ratio of the maximum and minimum discharges appears to be high, which implies that monthly discharges fluctuate according to seasonal precipitation.

Table 6.1. Hydrological characteristics of Tapi and Phumduang rivers in 1997.

River	**Drainage Area (km^2)**	**Discharge (m^3 sec^{-1})**			**Ratio Maximum/ minimum**	**Annual Runoff (10^6 m^3)**
		Mean	**Minimum**	**Maximum**		
Tapi	5,200	135.4	14.4	803.9	56	4280
Phumduang	3,012	120.9	14.5	1253.4	86	3830

Source: Royal Irrigation Department

The water quality of the Tapi River is greatly affected by human activities and land usage in the fairly densely populated Surat Thani province. The present population of Muang and Phun Phin Districts is about 215,780. Furthermore, about twenty large factories, mainly food-related industries, petroleum and oil depots and a distillery plant, are located along the river. Further upstream, a rockfill dam with clay core (Chiew Larn Multipurpose Dam), 94 metres high, was constructed across the Klong Saeng River, a tributary of the Phumduang River. The dam helps to ensure adequate water supply for irrigable area downstream, alleviation of flooding in southern provinces and salinity control in the Tapi River.

Average salinity in the bay range from 21.7 psu in the dry season to 17.4 psu in the wet season. In the sea, salinity ranges from 32.3 psu in the dry season to 29.0 psu in the wet season. Salinity of freshwater from Tapi-Phumduang rivers and rainfall are assumed to be 0 psu.

Three surveys have been carried out so far for data for C, N and P budgets in Bandon Bay. Data in April were collected to represent the dry season and October to characterise the wet season within the study area.

Water and salt balance

Salt and water budgets for April 1997 are illustrated in Figure 6.2. Similar procedures were applied for October 1997 and April 1998, as summarised in Table 6.3. Freshwater flow (V_Q) was estimated by adding the flows of the Tapi and Phumduang rivers. Since only part of the watershed area draining into Bandon Bay is gauged, the total freshwater input to the bay was estimated using the ratio of measured to the rest of the watershed area. The Tapi-Phumduang River basin has problems with saline intrusion into the groundwater, so groundwater inflows (V_G) can be considered to be zero. Other inflows like sewage (V_O) are not available and are assumed to be zero.

Data in Table 6.2 were used to calculate the water balance for each season according to equation (3) of Gordon *et al.* (1996). Residual volume (V_R), the process responsible for adding and removing water, can then be estimated (Table 6.3). The system shows substantial net residual outflow of water, as expected from the freshwater inputs to the system, higher during the wet season than during the dry season. The salt balance of the system and the exchange or mixing volume (V_X) between the Gulf of Thailand and Bandon Bay can then be estimated according to equation (8) of Gordon *et al.* (1996).

Table 6.2. Runoff (V_Q), precipitation (P), and evaporation (E) data for Bandon Bay, April 1997 - April 1998.

Date	V_Q (10^6 m^3 day^{-1})	**P** (mm day^{-1})	**E** (mm day^{-1})
26-28 Apr 1997	6	4	4
21-23 Oct 1997	58	0	4
26-28 Apr 1998	26	0	5

The exchange time of water in the bay can be calculated as the total volume of the bay divided by the sum of V_X , mixing between bay and ocean, plus the absolute value of residual flow $|V_R|$. It can be seen that the water exchange rate in Bandon Bay is faster in the wet season (9 days) than in the dry season (17 to 80 days). Apparently, tides seem to be the main force driving water exchange with the adjacent Gulf of Thailand during the dry season, particularly in 1997.

Table 6.3. Water circulation, residual flow (V_R), water exchange rates(V_X) and water exchange time as calculated from the water and salt budgets for Bandon Bay. The subscript "Q" indicates river; "P" is precipitation and "E" is evaporation.

Date	V_Q (10^6 m^3 day^{-1})	V_P (10^6 m^3 day^{-1})	V_E * (10^6 m^3 day^{-1})	V_R * (10^6 m^3 day^{-1})	V_X (10^6 m^3 day^{-1})	**Water exchange time**, days
Apr-97	6	2	-2	-6	12	80
Oct-97	58	0	-2	-56	112	9
Apr-98	26	0	-3	-23	64	17

* minus sign for V_E and V_R indicates an output from the system

Budgets of nonconservative materials

Table 6.4 gives the nutrient waste loads calculated from BOD values, and Table 6.5 shows the chemical composition of Bandon Bay, the Tapi River and the adjacent sea. The non-conservative fluxes of C, N and P in Bandon Bay were calculated from data in Tables 6.4 and 6.5 using a simple box model following Gordon *et al.* (1996), and are presented in Table 6.6.

DIP balance

Dissolved inorganic phosphorus (DIP) values ranged from 0 to -16x10^3 mol day^{-1} (0 to -0.03 mmol m^{-2} day^{-1}) in Bandon Bay. This indicates that the system is a slight net sink for DIP especially in the wet season. If phosphate desorption from sediments does not contribute significantly to *DDIP*, then this DIP sink probably results from primary producer uptake.

Dissolved organic phosphorus (DOP) was also removed from the water column in both seasons. Overall, the system is a net sink for dissolved phosphorus (DIP + DOP) for both seasons but much more so in the wet season.

Table 6.4. Nutrient loads calculated from BOD values for Bandon Bay. BOD data were from Pollution Control Department, 1998.

Nutrients	**Apr 1997**	**Oct 1997**	**Apr 1998**
BOD, 10^3 mol day^{-1}	75	85	78
DIO DIP, 10^3 mol day^{-1}	2	2	2
DOP, 10^3 mol day^{-1}	2	2	2
NH_4^+, 10^3 mol day^{-1}	7	8	7
NO_3^-, 10^3 mol day^{-1}	5	5	5
DIN, 10^3 mol day^{-1}	12	13	12
DOC, 10^3 mol day^{-1}	128	145	133

DIN balance

In the dry season, there is a release of NH_4^+ and uptake of NO_3^- with a net release of dissolve inorganic nitrogen (DIN). This appears to represent net respiration of organic matter in the dry season.

DIN was taken up in the wet season which is consistent with DIP + DOP uptake, while NH_4^+ release reflects nitrogen recycling. Some nitrogen and phosphorus were, of course, lost by being bound into refractory organic matter in the sediments (adsorption to particles).

DON was also removed from the water column in both seasons. Overall, the system is a net sink of dissolved nitrogen (DIN + DON) for both seasons and this is also more strongly demonstrated in the wet season.

Table 6.5. Average chemical composition of Bandon Bay, Tapi River and adjacent Gulf of Thailand water samples.

	April 1997			**October 1997**			**April 1998**		
	River	**Bay**	**Sea**	**River**	**Bay**	**Sea**	**River**	**Bay**	**Sea**
Salinity, psu	0	19.5	32.3	0	17.4	29.0	0	21.7	31.2
DIP, µM	0.3	0.6	0.5	0.4	0.3	0.4	0.6	0.5	0.4
DOP, µM	0.5	0.3	0.2	0.5	0.2	0.2	0.1	0.1	0.1
NH_4, µM	5.5	7.5	2.8	7.3	5.2	2.2	9.4	5.9	2.3
NO_3, µM	5.4	2.7	1.6	5.6	1.7	0.4	3.4	1.4	0.4
DIN, µM	10.9	10.2	4.4	12.9	6.9	2.6	12.8	7.3	2.7
DON, µM	31.6	29.4	32.3	12.4	8.7	11.9	29.3	27.5	26.9
TA, meq	1.2	1.2	1.9	1.0	1.6	2.2	1.7	2.3	2.7
DIC, mM	0.5	0.6	2.1	0.1	0.2	1.7	1.2	2.1	2.5
DOC, mM	0.2	0.7	0.4	0.8	0.5	0.3	0.8	0.6	0.2

Table 6.6. Non-conservative carbon, nitrogen and phosphorus fluxes for Bandon Bay.

	April 1997		*October 1997*		*April 1998*	
	10^3 mol day^{-1}	mmol m^{-2} day^{-1}	10^3 mol day^{-1}	mmol m^{-2} day^{-1}	10^3 mol day^{-1}	mmol m^{-2} day^{-1}
DDIP	0	0	-16	-0.03	-2	0
DDOP	-2	0	-20	-0.04	-3	-0.01
DNH_4	+47	+0.10	+112	+0.23	+73	+0.15
DNO_3	-11	-0.02	-125	-0.26	-8	-0.02
DDIN	+37	+0.08	-13	-0.03	+64	+0.13
DDON	-40	-0.08	-500	-1.04	-98	-0.20
DTA	-6*	-10	-19*	-40	-12*	-30
DDIC	-13**	-30	-121**	-250	-4**	-10
DDOC	+6**	+10	-2**	-4	+4**	+30

* fluxes in 10^6 meq day^{-1}
** fluxes in 10^6 mol day^{-1}

Stoichiometric calculations of aspects of net system metabolism

The net nitrogen fixation minus denitrification (*nfix-denit*) of the system can be calculated as the difference between observed (*DDIN* + *DDON*) and expected (*DDIN* + *DDON*). The preliminary result on the average C:N:P ratio of reactive organic matter in the Tapi River was 324:27:1. The budgetary estimates yield an estimated (*nfix-denit*) equivalent to about +0.11 to +0.21 mmol m^{-2} day^{-1} in the dry season and 0.96 mmol m^{-2} day^{-1} in the wet season. Hence, Bandon Bay is a coastal system where nitrogen fixation exceeds denitrification in both seasons (Table 6.7).

The calculation of the net ecosystem metabolism, which is, the difference between organic carbon production (*p*) and respiration (*r*) within the system (*p-r*), based on the particulate C:P ratio (324:1), indicate that Bandon Bay is a slightly net autotrophic system in the dry season: (*p-r*) = +1 to +3 mmol m^{-2} day^{-1} ;and greatly autotrophic in the wet season: (*p-r*) = +24 mmol m^{-2} day^{-1}. This assumes that lost DIP and DOP were both eventually consumed by primary producers. Simultaneously, Piumsomboon and Paphavasit (1998) measured phytoplankton biomass as chlorophyll_a and estimated the phytoplankton production for Bandon Bay to be 105, 218 and 191 mg C m^{-3} day^{-1} (or 25, 52 and 45 mmol C m^{-2} day^{-1}) for April 1997, October 1997 and April 1998 respectively. The respiration rate and *p:r* ratio in Bandon Bay can then be estimated (Table 6.8). The system consumes the produced organic matter about 93 to 96% in the dry season and 24% in the wet season.

Table 6.7. Stoichiometric calculations of aspect of net system metabolism for Bandon Bay.

	April 1997	*October 1997*	*April 1998*
	mmol m^{-2} day^{-1}	mmol m^{-2} day^{-1}	mmol m^{-2} day^{-1}
(*p-r*)[1]	0	+11	+1
(*nfix-denit*)[2]	+0.08	+0.87	+0.25

[1] based on particle C:P of 324
[2] based on particle N:P of 27

Table 6.8. Primary production, estimated respiration and photosynthesis/respiration ratio in Bandon Bay.

Date	Primary production (mmol C m^{-2} day^{-1})	$(p\text{-}r)_{estimated}$	$r_{estimated}$ (mmol C m^{-2} d^{-1})	$p{:}r$
Apr 1997	2	0	25	1.00
Oct 1997	52	+11	41	1.27
Apr 1998	45	+1	44	1.02

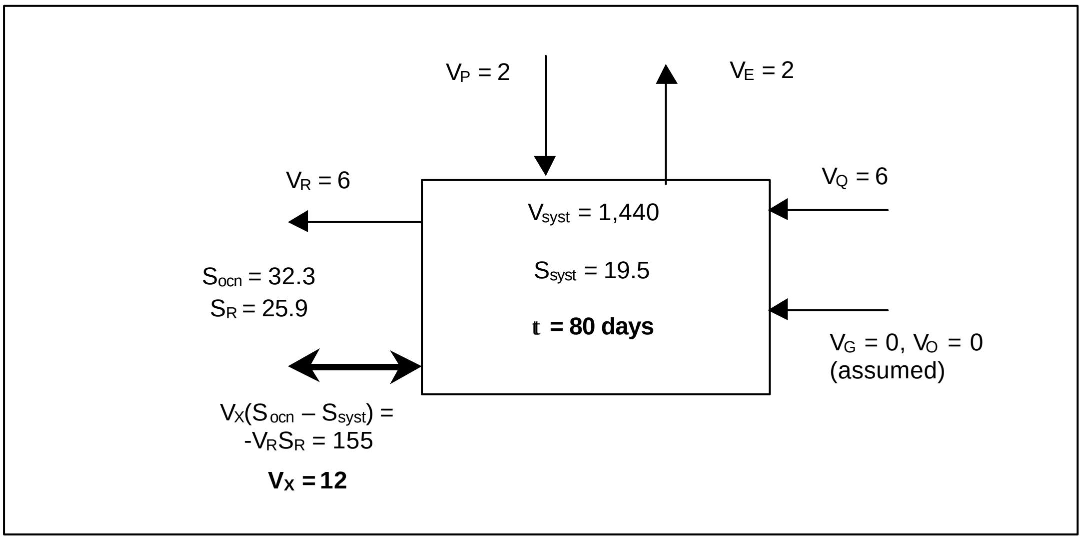

Figure 6.2. Water and salt budgets for Bandon Bay in April 1997. Volume in 10^6 m^3, water fluxes in 10^6 m^3 day^{-1}, salt fluxes in 10^6 psu-m^3 day^{-1} and salinity in psu.

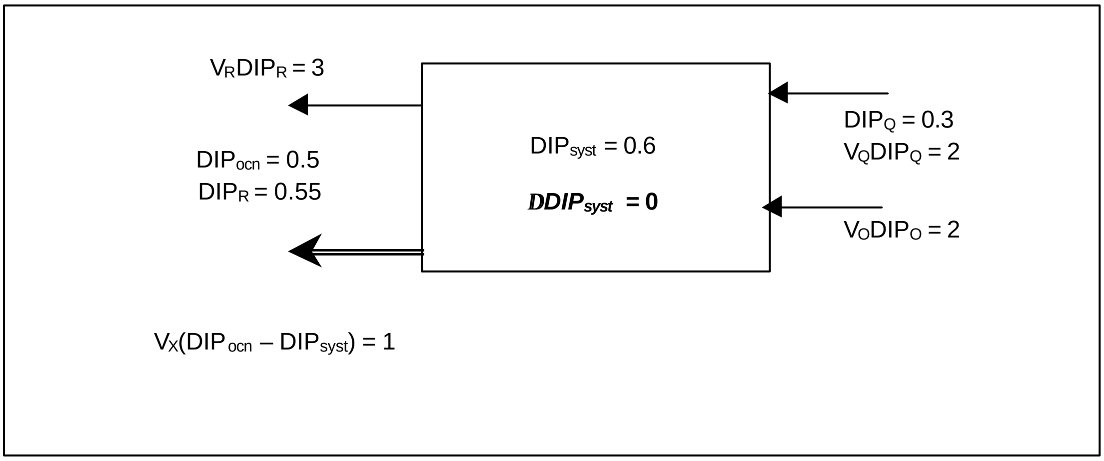

Figure 6.3. Dissolved inorganic phosphorus budget for Bandon Bay in April 1997. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

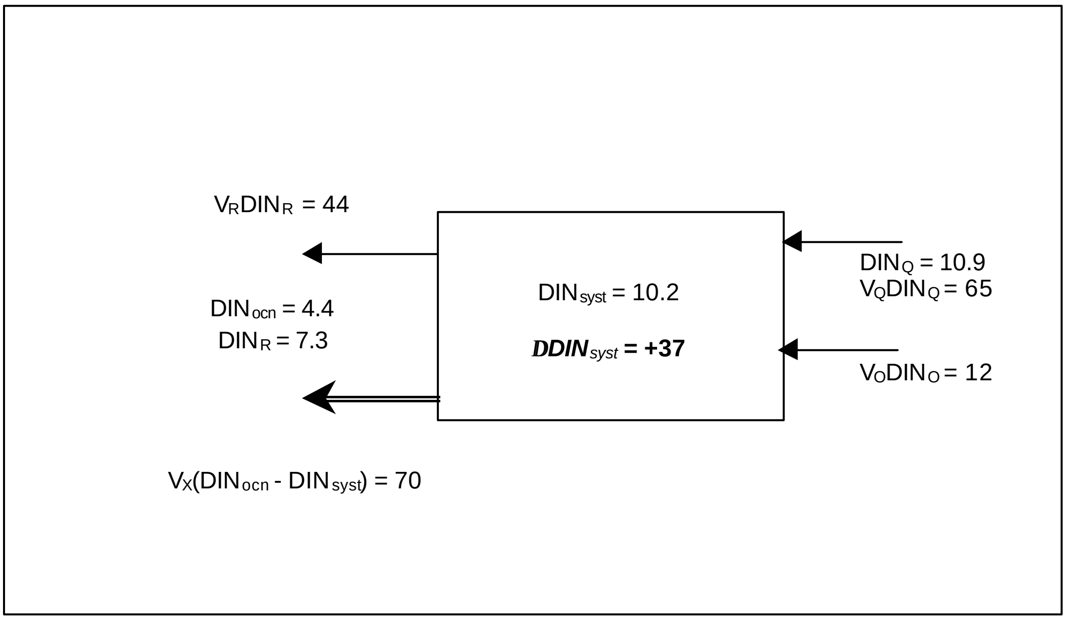

Figure 6.4. Dissolved inorganic nitrogen budget for Bandon Bay in April 1997. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

6.2 Bangpakong River Estuary

Gullaya Wattayakorn

Study area description

The Bangpakong River basin covers an area of about 8,700 km^2, located between 13.00°-14.50° N, 101.00°-102.00° E (Figure 6.5). The main contributing rivers, the Prachinburi and Nakorn Nayok, originate in hilly ranges in excess of 900 m elevation and these join to form the Bangpakong River, which is 122 km long. The main rivers are joined by a number of significant tributaries, in particular the Khlong Phra Sathung and Maenam Hanuman. Below the confluence the river crosses the broad alluvial plains as it flows south to discharge into the Gulf of Thailand (13.4° N, 101.9° E). A channel with an undulating but predominantly flat slope characterises the lower reaches of the river. The channel is typically meandering with low banks affected by tidal height variations at the mouth and the frequent flooding over the floodplain. The depth of the river ranges from 6 to 12 m and the width from 80 to 450 m. Annual rainfall varies from 990 to 1,500 mm, with the maximum average in September and the minimum average in January. Temperatures are usually highest in March or April and lowest between November and January. The highest monthly evaporation, 175 mm, is observed in March and April, the lowest normally in September, at 115 mm. A period of low flows from December to May and high flows from June to November, with peak flow in September, characterise the hydrology of the river. Wet season flow amounts to 80-90% of the total annual flow. The 10-year return period flood volume is between 4,000 and 5,000 m^3 (Pollution Control Department 1998).

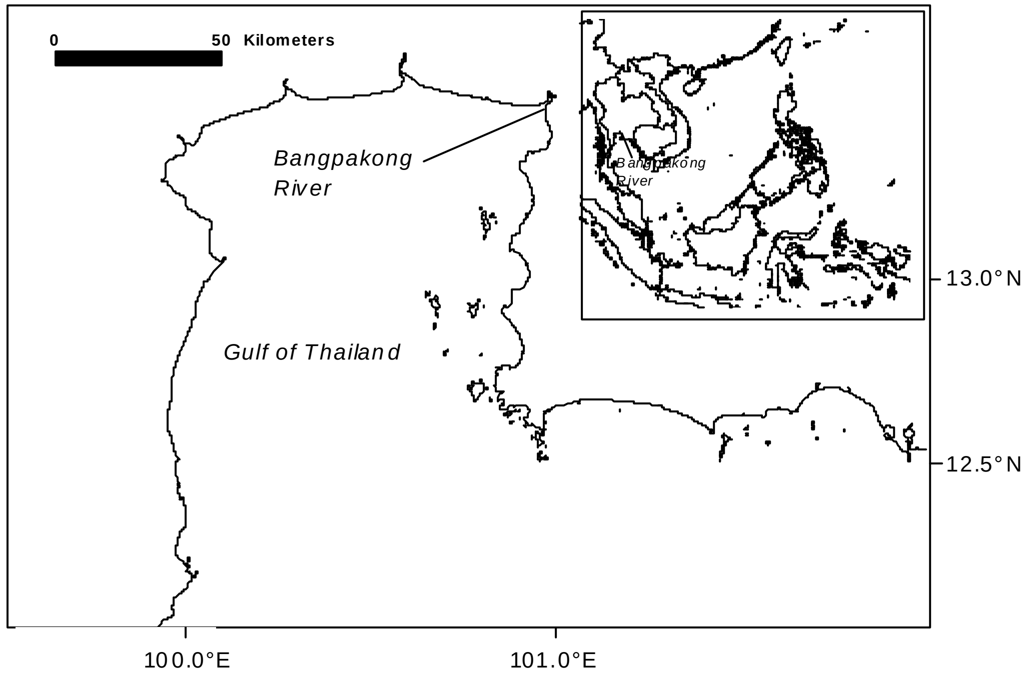

Figure 6.5. Location of Bangpakong River estuary, Thailand.

The aquatic ecosystem of the basin is controlled by the extreme estuarine nature of the Bangpakong River, in which salinities of 2-5 psu are not uncommon 110 km upstream of the mouth at the peak of the dry season. The rivers upstream of the confluence of the Prachinburi and Nakorn Nayok are principally fresh throughout the year. *Chlorophyta* species dominate the phytoplankton of the freshwater sections, while brackish and marine *Chrysophyta* are more typical of the estuarine sections. The zooplankton is dominated by marine/estuarine copepods in the lower reaches with arthropod and mollusk larvae and fish fry also present. Submerged macrophytes are limited by the high suspended solids concentrations restricting light penetration. Emergent macrophytes are found in the shallows along the banks where current speeds are reduced. Free floating macrophytes, in particular water hyacinth, can be seen floating in small rafts down the river or aggregating to form large mats in backwaters.

The principal crop grown in the basin is rice. The Bangpakong River basin has an average annual rainfall of 1,590 mm and both wet and dry paddies suffer from shortage of water so that supplemental irrigation is required even in the wet season. There are brackish water shrimp and freshwater finfish farms along the lower reaches of the Bangpakong River. The water is extracted from the river by pumping directly into ponds or common distribution canals.

Approximately 1.2 million people live within the river basin. Pollutants discharged into the river are from point and non-point sources. Major point sources of pollutants to the Bangpakong River include domestic and industrial waste discharges as well as some agricultural point sources such as pig, duck, fish and other farms. Food processing is the major industry in the area. Most factories are small and distributed in residential areas. Generally, wastewater from industrial plants is discharged into receiving waters after partial treatment or often no treatment at all. Non-point sources include agricultural areas (paddy fields), and orchards, which constitute the main land uses in the basin.

Tidal intrusion, and associated estuarine conditions, extend 122 km upstream during low stream-flow conditions (dry season) and to about 60 km during high stream-flow conditions (wet season). The physical dimensions of the estuary are shown in Table 6.9. For the purposes of budget analysis, the estuary is assumed to be a well-mixed system. Nutrient data were obtained from studies conducted by the Pollution Control Department and the Department of Fisheries in 1993. Organic loads into the estuary were estimated using data from previous studies (Pollution Control Department 1997), assuming 50% BOD assimilation rates. Total N and P inflows were obtained by conversion of BOD loading using the stoichiometric relationships of C:N:P ratios in organic waste materials (San Diego-McGlone, Smith and Nicholas 1999).

Table 6.9. Physical dimensions of the Bangpakong River estuary.

Compartment	**Mean length** (km)	**Mean width** (m)	**Surface area** (10^6 m^2)	**Mean depth** (m)	**Volume** (10^6 m^3)
Upper estuary	52	180	9.4	10	94
Lower estuary	18	300	21.0	10	210

Water and salt balance

Figures 6.6 and 6.7 give the water and salt budgets for the Bangpakong River estuary in the dry (March 1993) and wet (August 1993) seasons respectively. The calculations assumed an inflow salinity of 0 psu. Runoff is based on the measurements recorded by the Royal Irrigation Department. It is estimated to be $8x10^6$ m^3 day^{-1} in the dry season, and $27x10^6$ m^3 day^{-1} in the wet season. Groundwater flow is assumed to be zero. Rainfall is estimated to be 73,000 (dry) – 365,000 (wet) m^3 day^{-1} and evaporation estimated at 137,000 (wet) – 158,000 (dry) m^3 day^{-1}, but these atmospheric inputs are regarded as insignificant to the water budget when compared with freshwater inflow. Although the water volume of waste is small relative to freshwater input, dissolved P and N are highly concentrated in the discharge so that nutrient flux from this source is significant relative to freshwater nutrient source.

Utilising to the LOICZ Biogeochemical Modelling Guidelines (Gordon *et al.* 1996) and with a two-box system for the dry season, the water exchange time of the upper estuary is calculated to be 5 days and that for the lower estuary is 4 days in the dry season. The water exchange time for the entire estuary in the dry season is 6 days. In the wet season, the estuary extends only 60 km, one box is used, and the exchange time is calculated to be 5 days.

Budgets of nonconservative materials

Figures 6.8 to 6.15 illustrate the nutrient budgets for the Bangpakong River estuary and Table 6.10 summarises the stoichiometric calculations.

Nonconservative nutrient fluxes were too high to be explained by metabolic processes. These high fluxes may be due to both the fast water exchange rate for the river estuary and the poorly defined waste load. It is beyond the capability of the budget procedure to discriminate biotic metabolism in systems that have rapid water exchange rate and are heavily loaded with nutrients.

Table 6.10. Stoichiometric calculations of aspect of net system metabolism for Bangpakong River estuary.

	March 1993 (dry) mmol m^{-2} day^{-1}			**August 1993 (wet) mmol m^{-2} day^{-1}**
	Upper estuary	**Lower estuary**	**Whole estuary**	**Upper estuary**
(*p-r*)[1]	-214	-2,433	-1,614	-555
(*nfix-denit*)[1]	+166	-331	-177	-125
(*p-r*)[2]	+91	-1,033	-685	-236
(*nfix-denit*)[2]	+120	-124	-40	-78

[1] based on C:P of 106:1; and N:P of 16:1 (plankton-dominated system)

[2] based on C:P of 45:1; and N:P of 7:1 (terrestrial organic detritus dominated system)

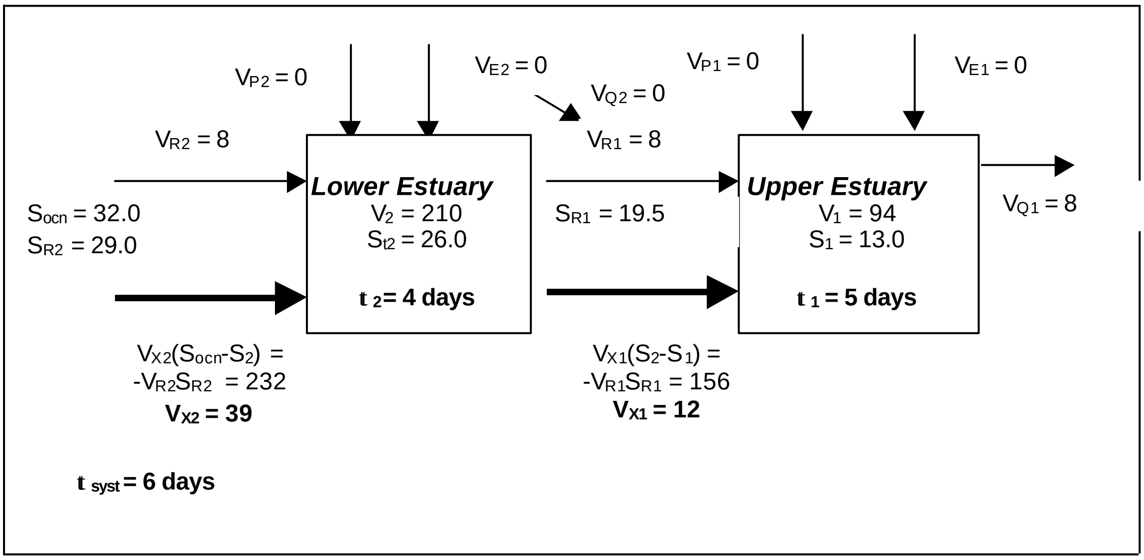

Figure 6.6. Water and salt budgets for Bangpakong River estuary in the dry season. Volume in 10^6 m^3, water fluxes in 10^6 m^3 day^{-1}, salt fluxes in 10^6 psu-m^3 day^{-1} and salinity in psu.

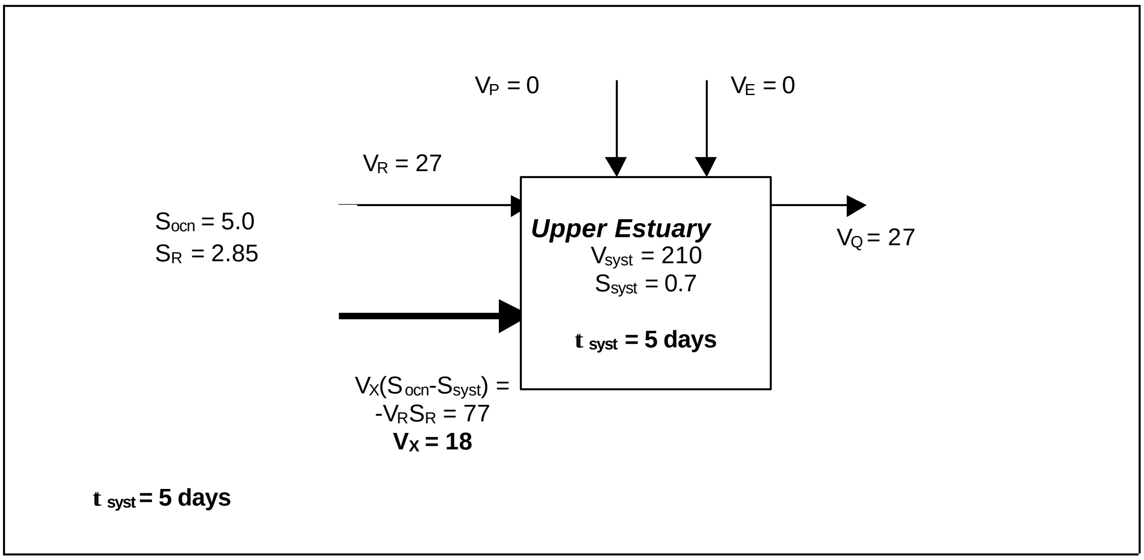

Figure 6.7. Water and salt budgets for Bangpakong River estuary in the wet season. Volume in 10^6 m^3, water fluxes in 10^6 m^3 day^{-1}, salt fluxes in 10^6 psu-m^3 day^{-1} and salinity in psu.

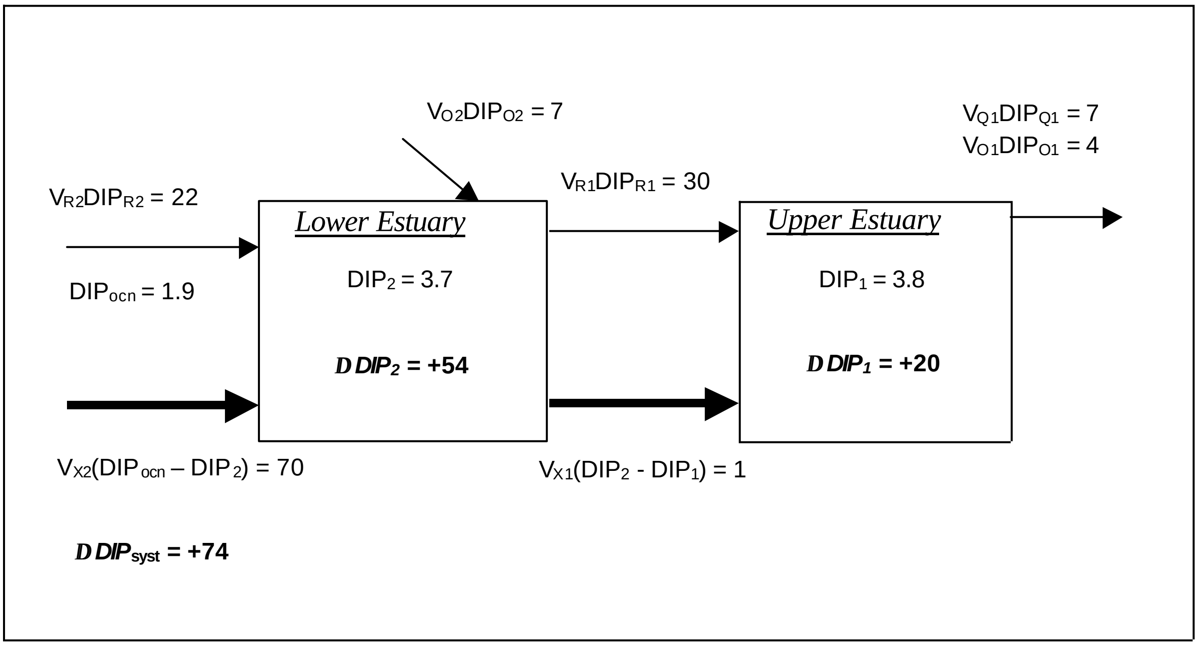

Figure 6.8. Dissolved inorganic phosphorus budget for the Bangpakong River estuary in the dry season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

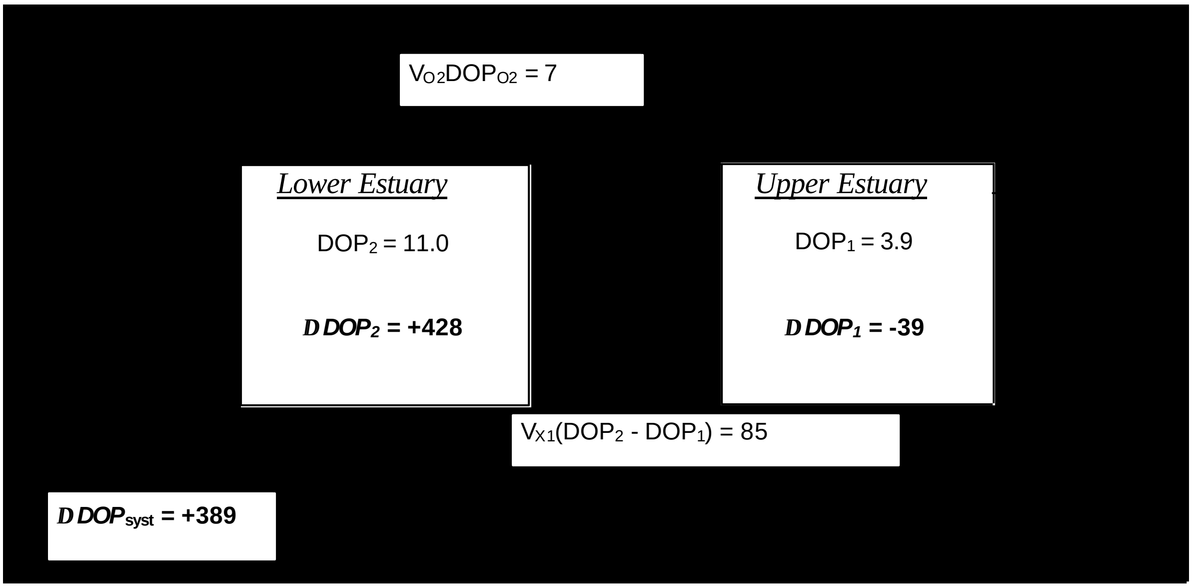

Figure 6.9. Dissolved organic phosphorus budget for the Bangpakong River estuary in the dry season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

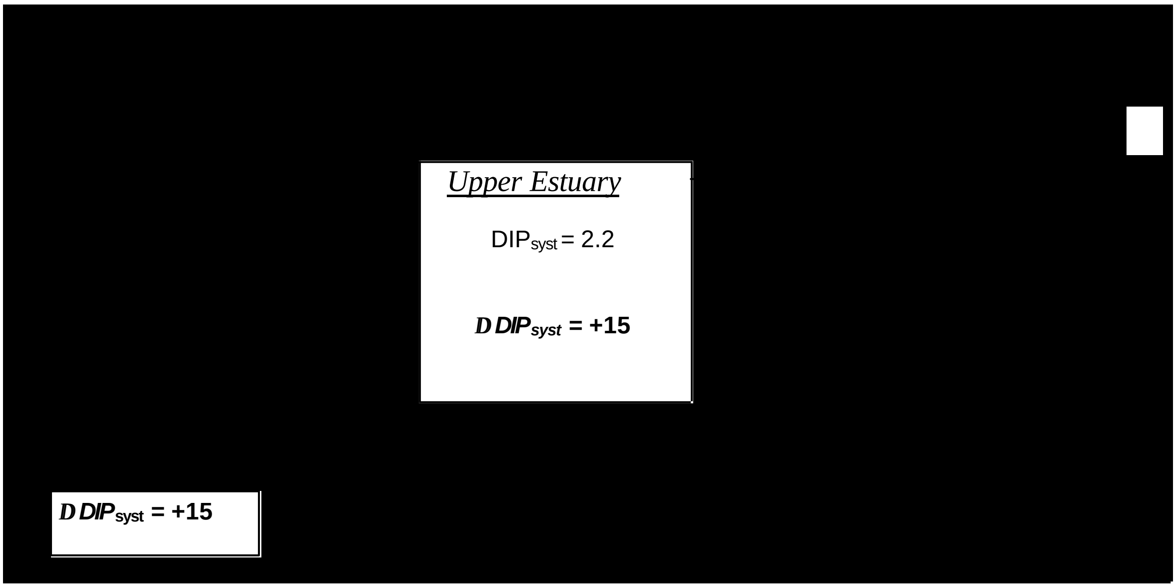

Figure 6.10. Dissolved inorganic phosphorus budget for Bangpakong River estuary in the wet season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

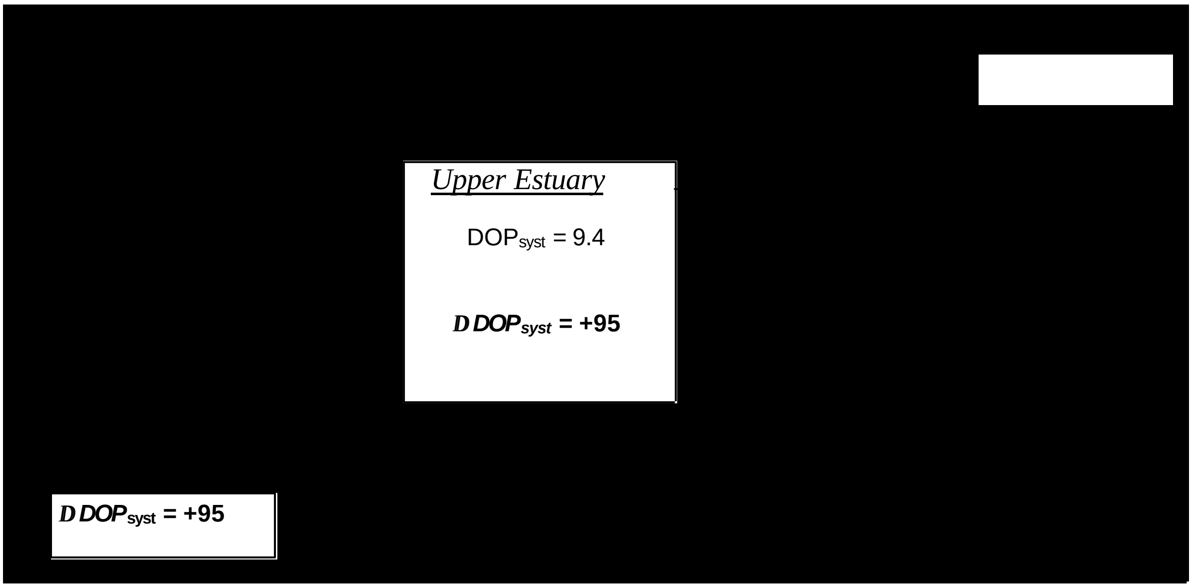

Figure 6.11. Dissolved organic phosphorus budget for Bangpakong River estuary in the wet season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

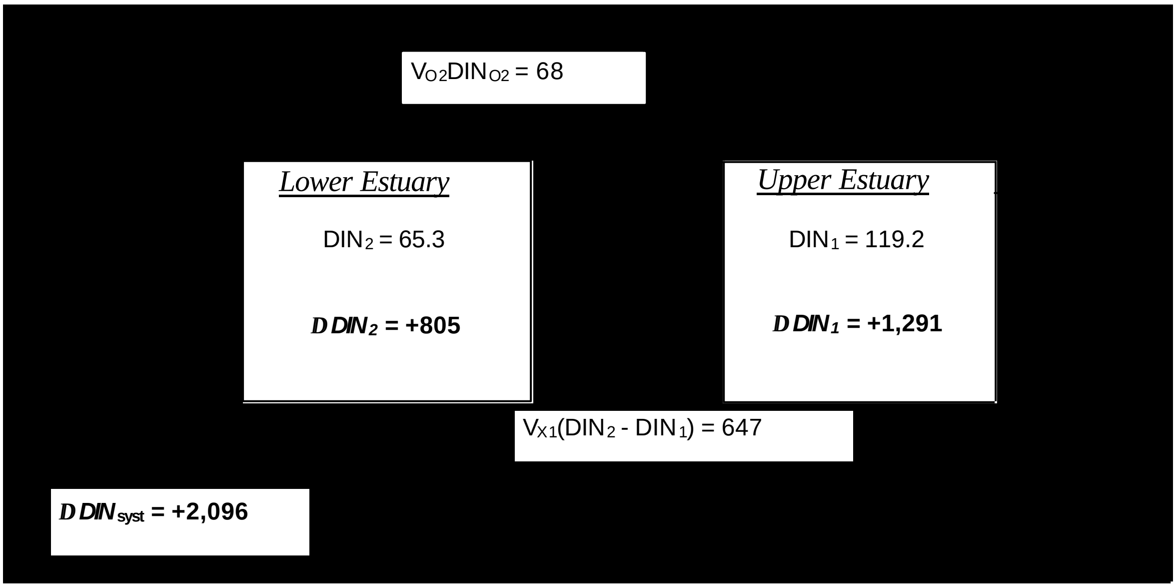

Figure 6.12. Dissolved inorganic nitrogen budget for Bangpakong River estuary in the dry season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

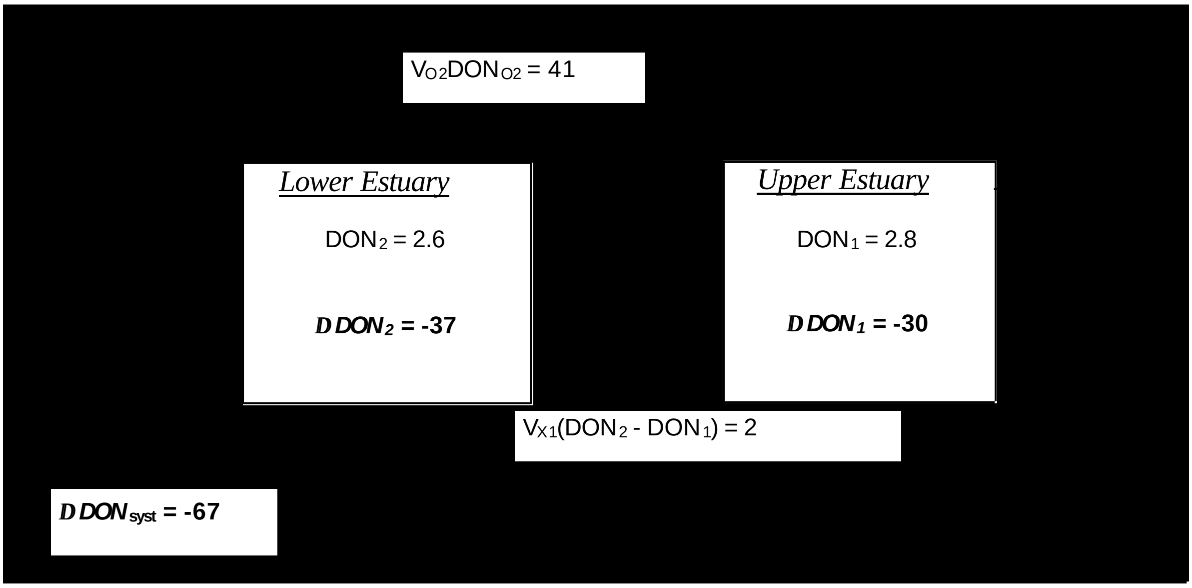

Figure 6.13. Dissolved organic nitrogen budget for Bangpakong River estuary in the dry season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

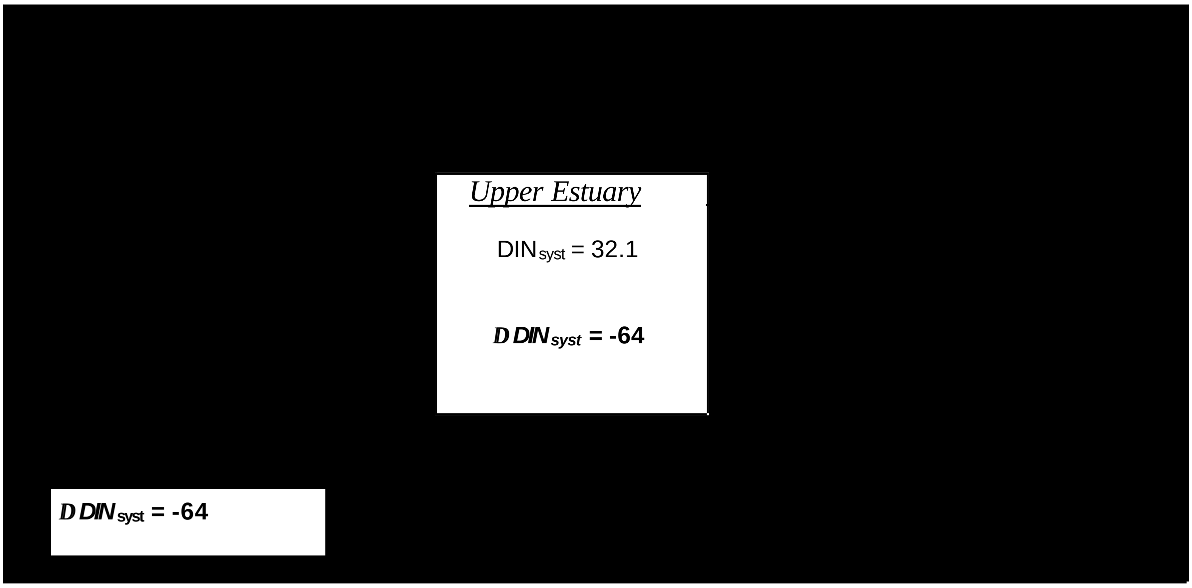

Figure 6.14. Dissolved inorganic nitrogen budget for Bangpakong River estuary in the wet season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

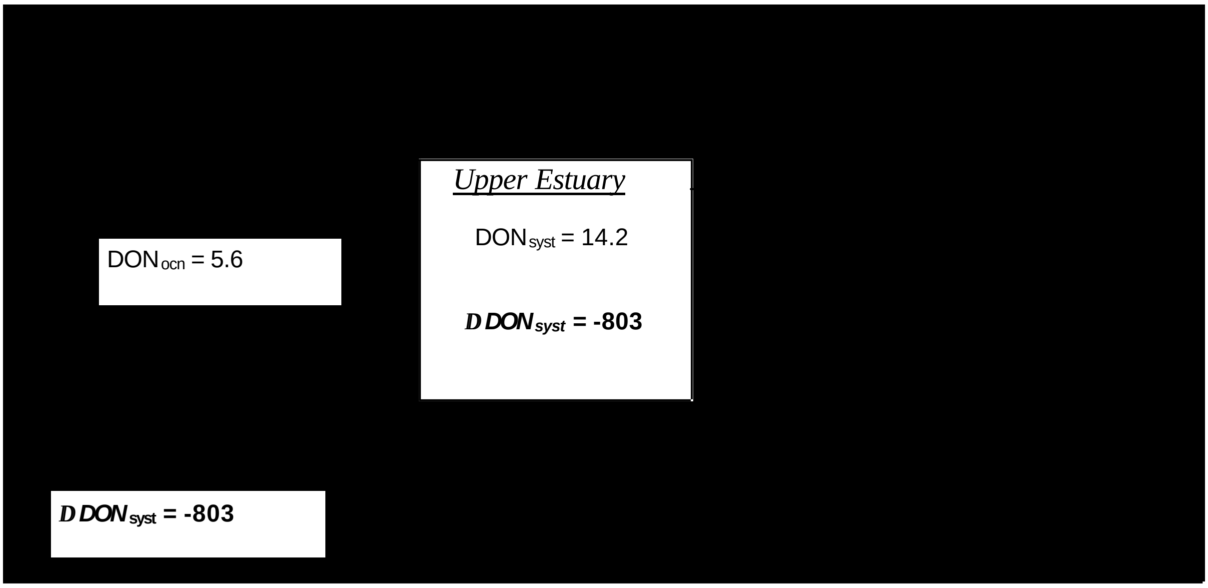

Figure 6.15. Dissolved organic nitrogen budget for Bangpakong River estuary in the wet season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

6.3 Chao Phraya River Estuary

Gullaya Wattayakorn

Study area description

The Chao Phraya Basin covers an area of about 162,600 km^2, on the Lower Central Plain, which occupies the central part of Thailand (14°-20°N, 98°-101°E), with 980 km of river length in the north-south direction (Figure 6.16). The elevation of the plain ranges from 25 m above the mean sea level at Nakorn Sawan in the north to less than 4 metres at Ayutthaya, and to about 2 metres in the vicinity of Bangkok. Soils in the flood plain deposits are mostly sandy clay and are formed throughout the northern half of the plain. The basin has been used for paddy fields and is a major rice production region for the country. The annual rainfall varies from 1,200 to 1,600 mm in the upper basin, and is about 1,200 mm in the north and west bank areas of the lower basin. Temperatures are usually high in March or April and low between November and January. The temperature difference between the highest and the lowest within a year is about 4°-7° C.

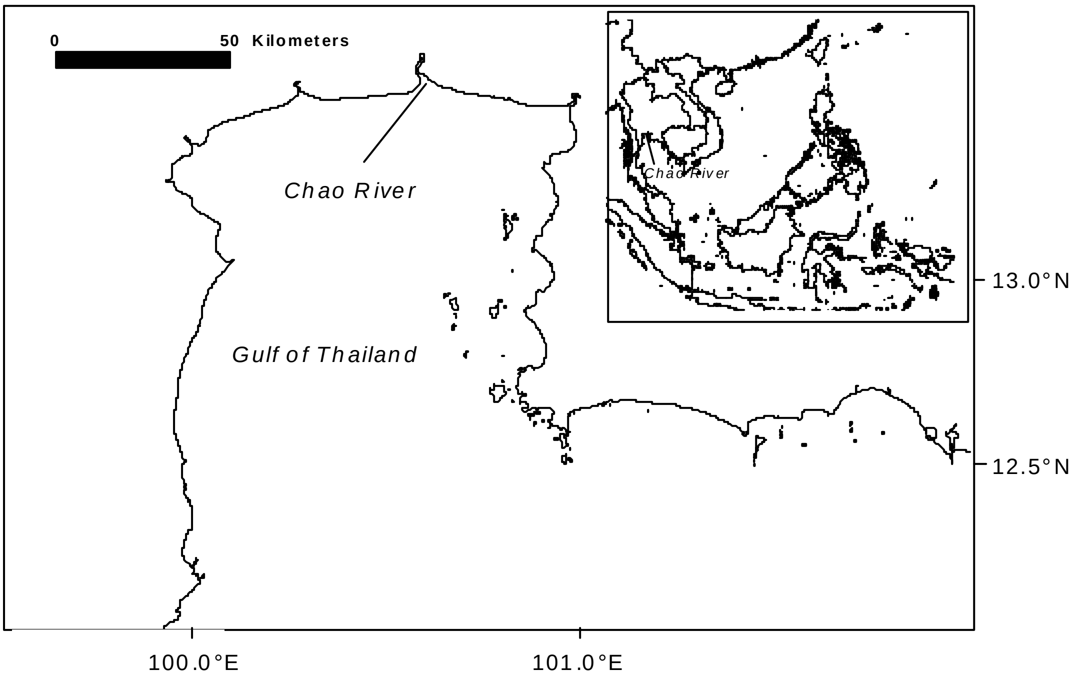

Figure 6.16. Location of Chao Phraya River estuary, Thailand.

The Chao Phraya River (13.58°-15.67° N, 100.10°-101.00° E) is 375 km long, and flows from Nakonsawan Province to the Gulf of Thailand in Samut Prakarn Province. The river basin is about 19,390 km^2. The population living in the basin is approximately 8 million. The depth of the river ranges from 5 to 20 m and the width ranges from 200 to 1,200 m. The river traverses several large cities and the major agricultural region of the country, hence this river receives large amounts of wastes along its path. Pollutants discharged into the river are from point and non-point sources. Major point sources of pollutants to the Chao Phraya River basin include domestic and industrial waste discharges as well as some agricultural point sources such as pig, duck, fish and other farms. Only two urban centres, Bangkok and Uthai Thani have operating sewage treatment systems. Although some industrial sites have some form of wastewater treatment systems, most tend to dispose of raw effluent to the nearest waterways, usually a street drain or smaller stream. Non-point sources include agricultural areas (paddy fields), and orchards, which constitute the main land uses in the basin.

The river is dammed and used to irrigate the agricultural land, so the discharge is strongly regulated. Water is released from the Chao Phraya Dam to the lower basin is for the purposes of salinity control, irrigation, navigation, industry and domestic consumption. However, the discharge hydrographic of the Chao Phraya River still exhibits a periodic variation with a cycle of one year. The hydrological cycle starts in April when the discharge is typically at its minimum. From May to August the discharge gradually increases, while from August to October the increase is more rapid, peaking in October. The discharge then decreases fairly rapidly during November and December, with the rate of decrease then slowing until minimum flow conditions are again experienced in April. During the low flow periods from January to April the discharge typically ranges from 50 to 200 m^3 sec^{-1}. Tidal intrusion extends to Angthong (175 km) during low stream flow conditions and to about 75 km upstream during high stream flow conditions. At a freshwater discharge rate of 4,000 m^3 sec^{-1}, common during the wet season, tidal fluctuations are not observed upstream of Pak Kret. However, salinity effects from the sea are only noticeable downstream of Nontaburi, about 60 km from the river mouth.

The estuarine section of the Chao Phraya (approximately 70 km from the river mouth) can be divided into two portions, the upper estuary and the lower estuary. Physical dimensions of the estuary are shown in Table 6.11. For the purposes of the budgetary analysis, the estuary is assumed to be a well-mixed system. Organic loads into the estuary were estimated using data from previous studies (Pollution Control Department 1997). Total N and P waste loads were obtained by conversion of BOD loading using the stoichiometric relationships of C:N:P ratios in organic waste materials (San Diego-McGlone, Smith and Nicholas 1999).

Table 6.11. Physical dimensions of the Chao Phraya River estuary.

Compartment	**Mean length** (km)	**Mean width** (m)	**Surface area** (10^6 m^2)	**Mean depth** (m)	**Volume** (10^6 m^3)
Upper estuary	52	450	23.4	10	234
Lower estuary	18	800	14.4	10	144

Water and salt balance

Figures 6.17 and 6.18 present the water and salt budgets for the Chao Phraya River estuary in the dry (April) and wet (August) seasons of 1996 respectively. The calculations assumed an upstream river inflow salinity of zero psu. River runoff is based on the average daily measurements of the flow of all the diverting water gates, as recorded by the Royal Irrigation Department. River runoff (V_Q) is estimated to be $10x10^6$ m^3 day^{-1} in the dry season, and $22x10^6$ m^3 day^{-1} in the wet season. Groundwater flow is assumed to be zero. Rainfall (V_P) is estimated to be $60x10^3$ m^3 day^{-1} in dry season and $220x10^3$ m^3 day^{-1} in the wet season. Evaporation (V_E) is estimated to be $130x10^3$ m^3 day^{-1} in the dry season and $100x10^3$ m^3 day^{-1} in the wet season. However, net precipitation and evaporation are regarded as insignificant to the water budget when compared with the river runoff. Although the volume of waste is small relative to river freshwater input, dissolved P and N are highly concentrated in this waste discharge so that nutrient flux from this source is significant to the nutrient budget.

Following the LOICZ Biogeochemical Modelling Guidelines (Gordon *et al.* 1996), the water exchange time of the upper estuary is calculated to be 10 days in the dry season and 6 days in the wet season. For the lower estuary, the exchange time is shorter, two days in the dry season and one day in the wet season. The water exchange time for the entire estuary is five days in the dry season and four days in the wet season.

Budgets of nonconservative materials

DIP balance

Figures 6.19 and 6.21 display the dissolved inorganic phosphorus (DIP) budget, and Figures 6.20 and 6.22 show the dissolved organic phosphorus budget (DOP) for the Chao Phraya River estuary in the dry and wet seasons. The wet season budgets have a greater magnitude of nutrient fluxes, with much larger quantities of nutrients carried in with river runoff than in the dry season.

The upper estuary appears to be a sink and the lower estuary a source for both DIP and DOP in all seasons. However, the entire system in general seems to be a net sink of dissolved phosphorus (DIP + DOP) in the dry season and a net source in the wet season.

N balance

A similar balance is estimated for DIN and DON (Figures 6.23 to 6.27): the upper estuary is a net sink and the lower estuary is net source for DIN and DON in both the dry and wet seasons. The whole system behaves as a net source of dissolved nitrogen except in the dry season for DON which makes the system a sink of dissolved nitrogen in the dry season.

Stoichiometric calculations of aspects of net system metabolism

Table 6.12 shows the results for stoichiometric analysis of the nonconservative nutrients, but the values are extremely high for biotic processes thus cannot be interpreted for system metabolism. The system seems overwhelmed with the huge nutrient loads, and “slight” errors in these loads may be introducing unacceptable errors in the nonconservative flux estimates.

Table 6.12. Stoichiometric calculations of aspect of net system metabolism for Chao Phraya River estuary.

	April 1996 (dry) mmol m^{-2} day^{-1}			**August 1996 (wet) mmol m^{-2} day^{-1}**		
	Upper estuary	**Lower estuary**	**Whole estuary**	**Upper estuary**	**Lower estuary**	**Whole estuary**
(*p-r*)[1]	+195	-280	+14	+276	-2,237	-681
(*nfix-denit*)[1]	+11	+24	+16	+10	-122	-50
(*p-r*)[2]	+83	-119	+6	+117	-950	-289
(*nfix-denit*)[2]	-31	+47	+7	-33	+76	+8

[1] based on C:P of 106:1; and N:P of 16:1 (plankton-dominated system)

[2] based on C:P of 45:1; and N:P of 7:1 (terrestrial organic detritus dominated system)

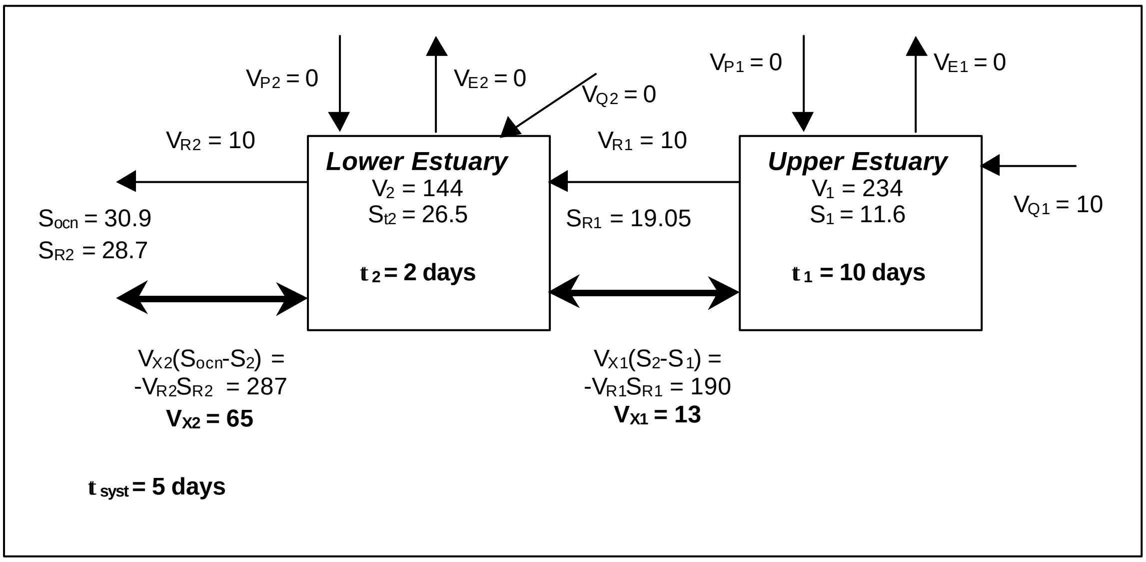

Figure 6.17. Water and salt budgets for Chao Phraya River estuary in the dry season. Volume in 10^6 m^3, water fluxes in 10^6 m^3 day^{-1}, salt fluxes in 10^6 psu-m^3 day^{-1} and salinity in psu.

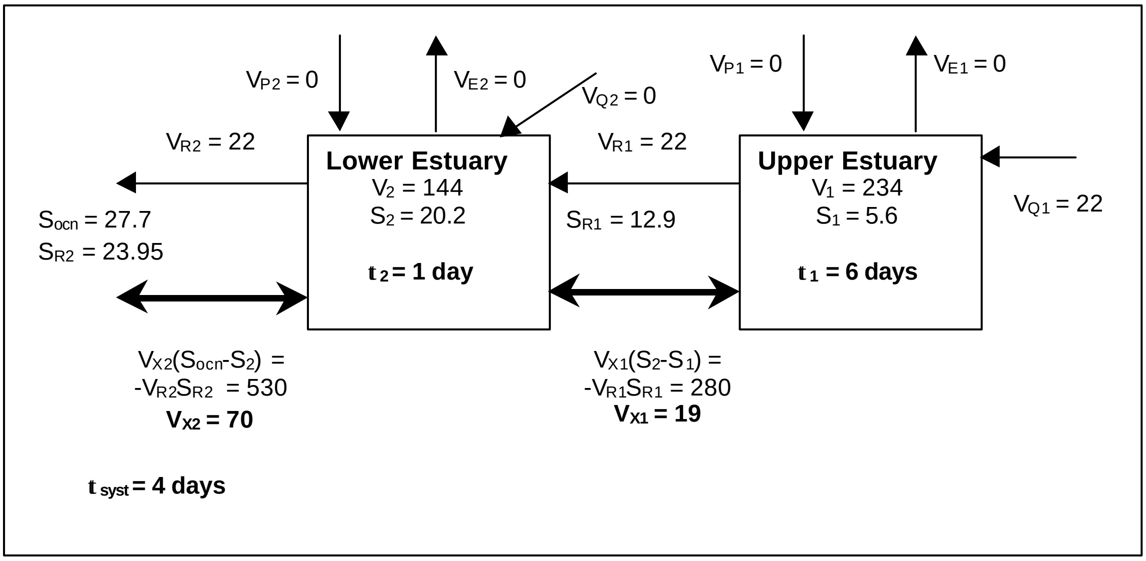

Figure 6.18. Water and salt budgets for Chao Phraya River estuary in the wet season. Volume in 10^6 m^3, water fluxes in 10^6 m^3 day^{-1}, salt fluxes in 10^6 psu-m^3 day^{-1} and salinity in psu.

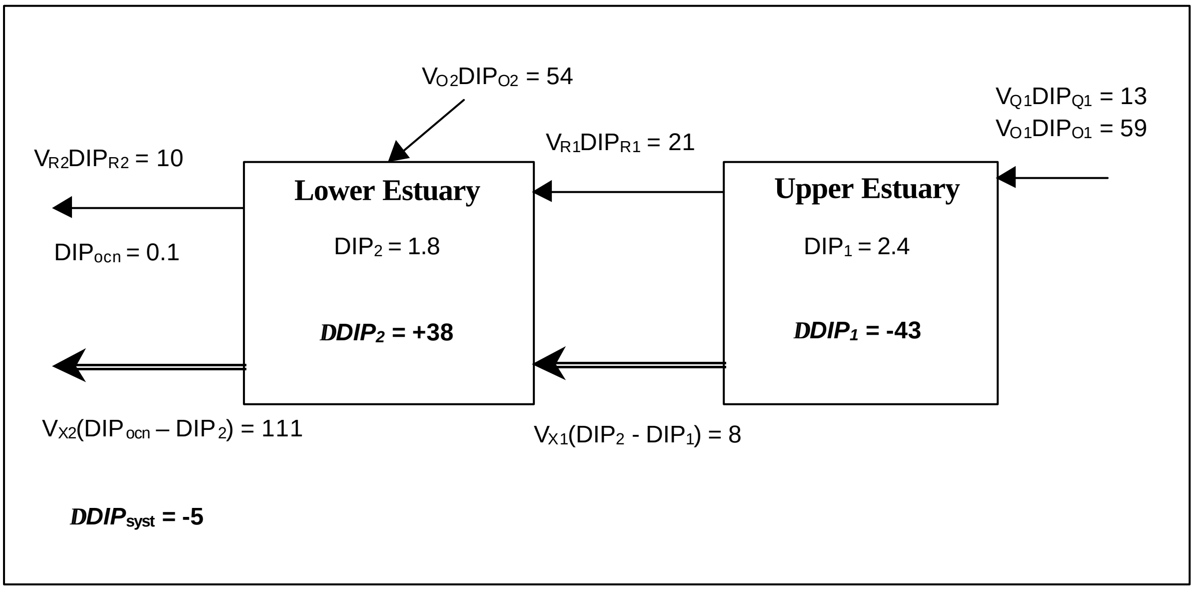

Figure 6.19. Dissolved inorganic phophorus budget for Chao Phraya River estuary in the dry season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

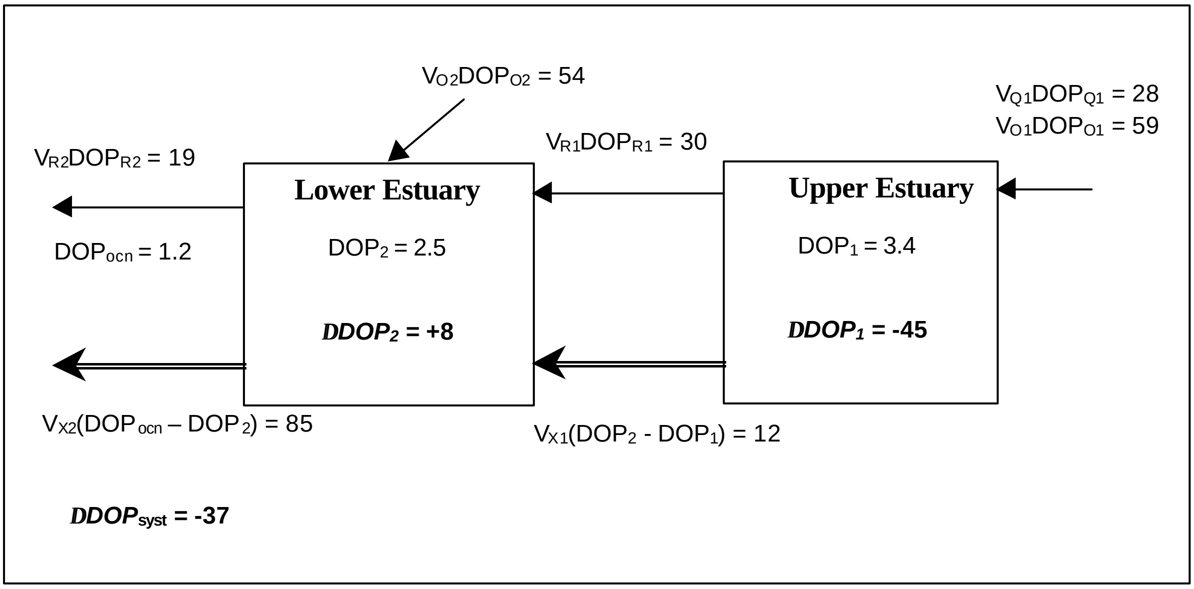

Figure 6.20. Dissolved organic phosphorus budget for Chao Phraya River estuary in the dry season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

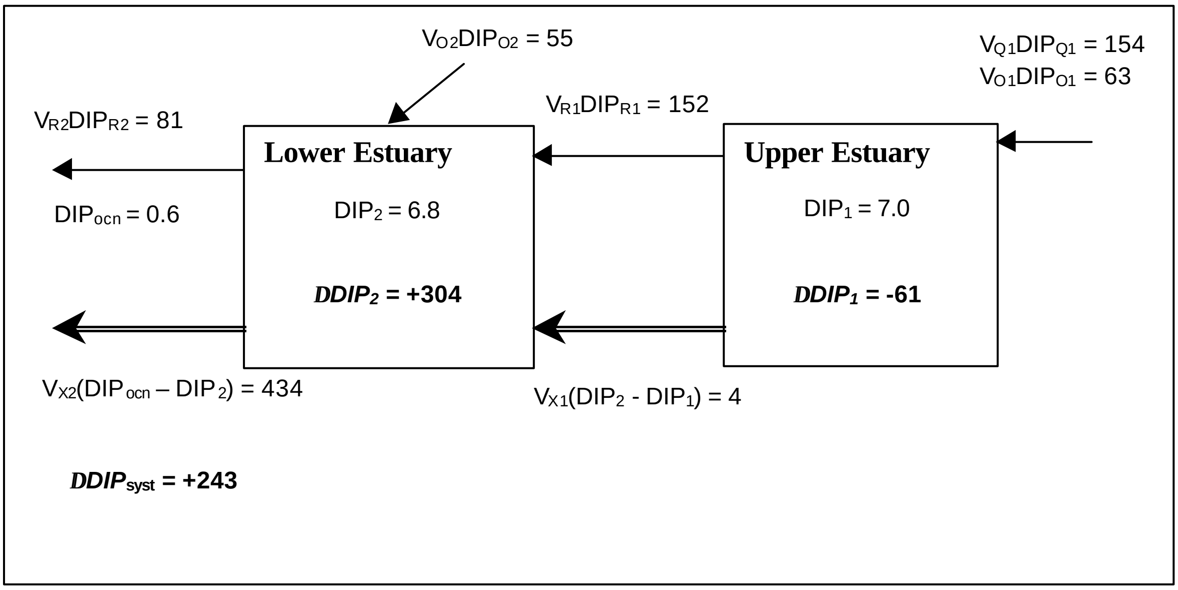

Figure 6.21. Dissolved inorganic phosphorus budget for Chao Phraya River estuary in the wet season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

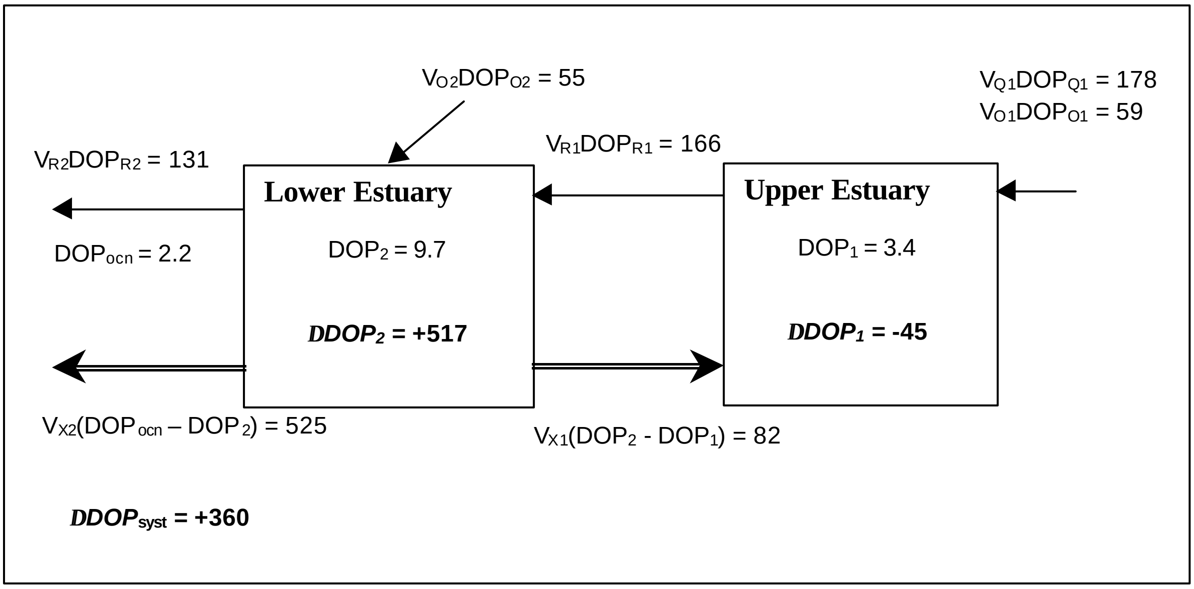

Figure 6.22. Dissolved organic phosphorus budget for Chao Phraya River estuary in the wet season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

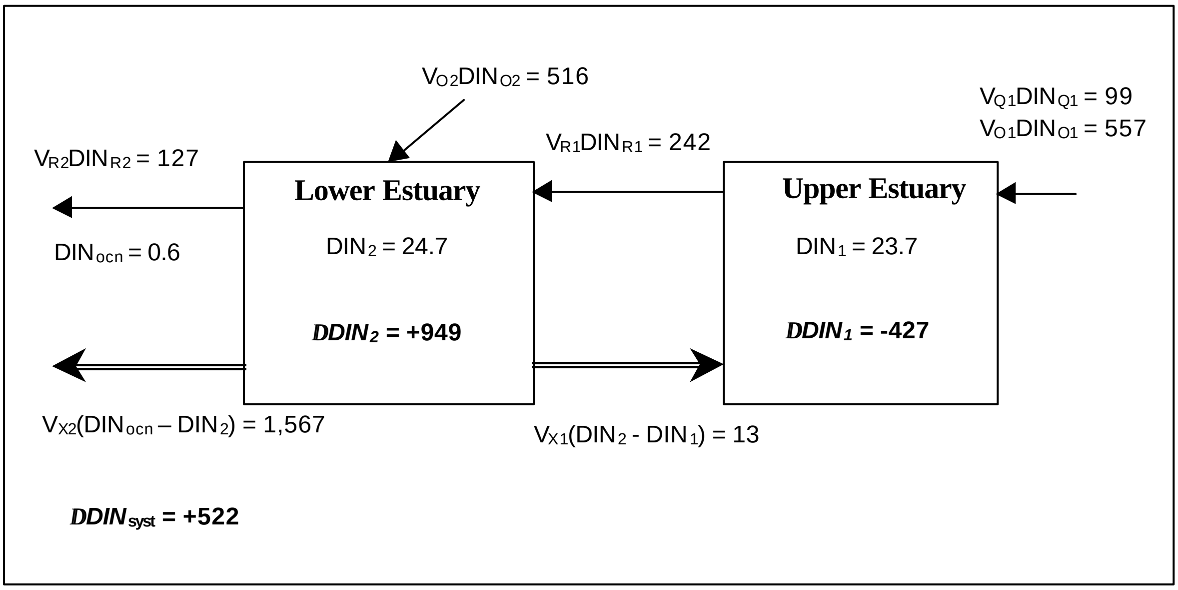

Figure 6.23. Dissolved inorganic nitrogen budget for Chao Phraya River estuary in the dry season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

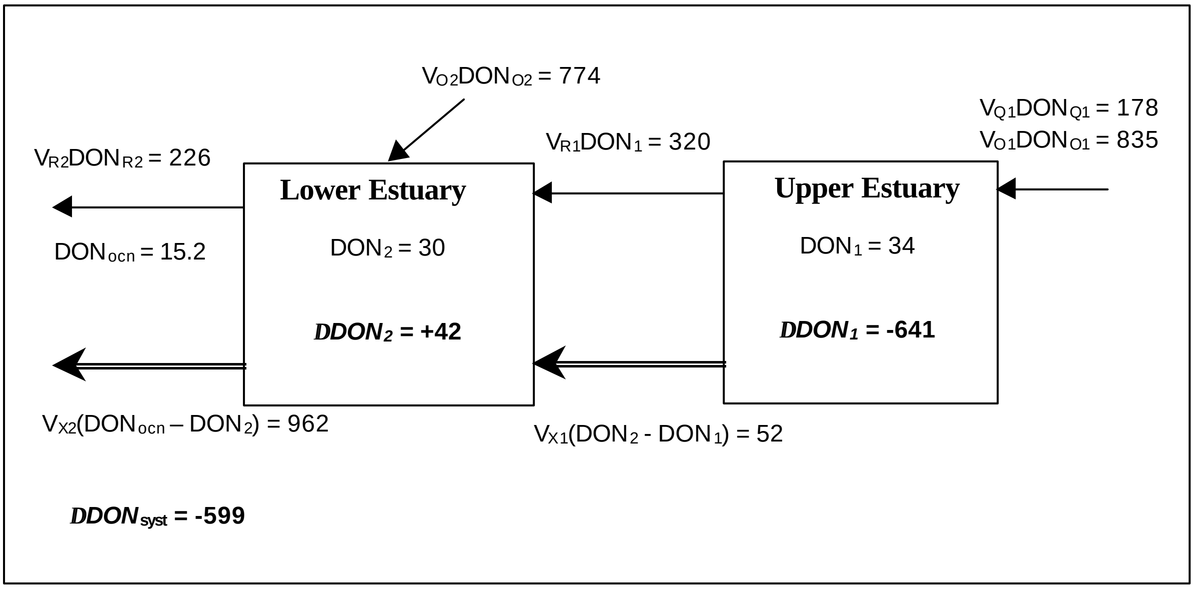

Figure 6.24. Dissolved organic nitrogen budget for Chao Phraya River estuary in the dry season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

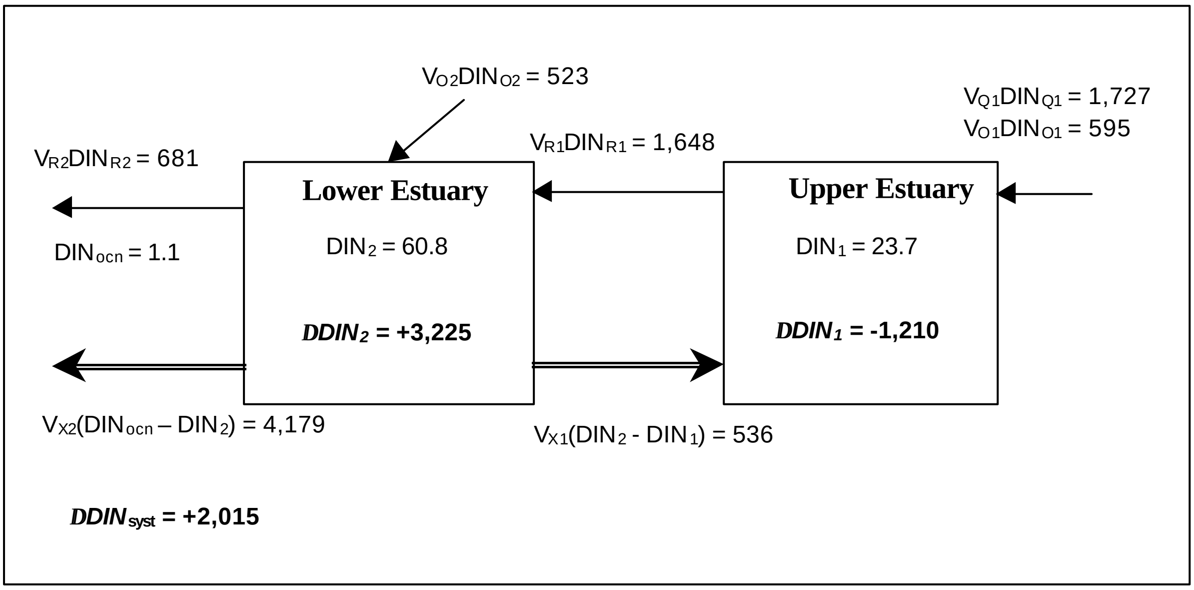

Figure 6.25. Dissolved inorganic nitrogen budget for Chao Phraya River estuary in the wet season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

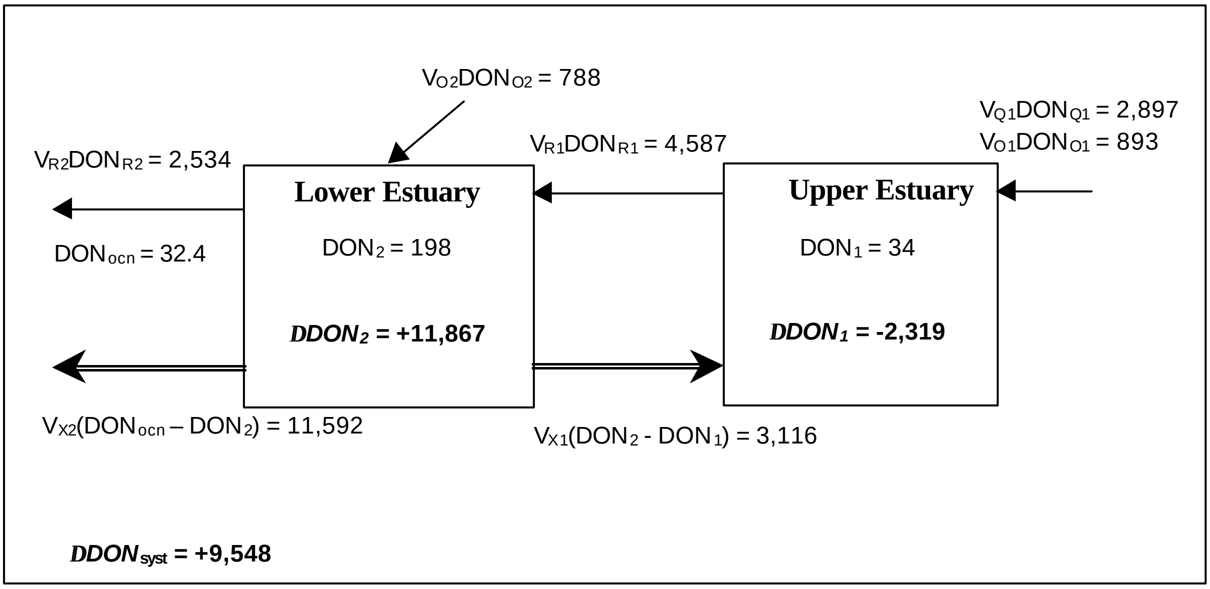

Figure 6.26. Dissolved organic nitrogen budget for Chao Phraya River estuary in the wet season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

6.4 Mae Klong River

Ajcharaporn Piumsomboon

Study area description

The Mae Klong River lies on the western part of the Upper Gulf of Thailand (13.33°-14.00°N, 99.50°-100.09°E) (Figure 6.27). The river, 138 km long, starts from the confluence of Kwai Noi and Kwai Yai rivers in Kanchanburi Province. It flows through Ratchaburi Province and Samut Songkhram Province into the Gulf of Thailand. The slope of the river is about 1:5000 between Kanchanaburi and Tamaka sub-district (in Kanchanburi Province) and 1:7250 from Tamaka to the river mouth (Phantumvanit 1976). The channel cross-section is a wide U-shape with typical flow velocity of 0.3 to 0.4 m sec^{-1}.

The weather conditions in the area can be divided into two seasons, the wet season from May to October, and the dry season from November to April. However, the river receives heavy freshwater loading during November to January each year due to the release from Vachiralongkorn Dam upstream of contaminated wastes (Pollution Control Dept 1997). Meteorological data indicate two peaks of heavy rainfall in the area of Mae Klong River, in May and October each year. Evaporation measured in Kanchanaburi is higher than rainfall except between August and November (Thailand Environment Foundation 1997).

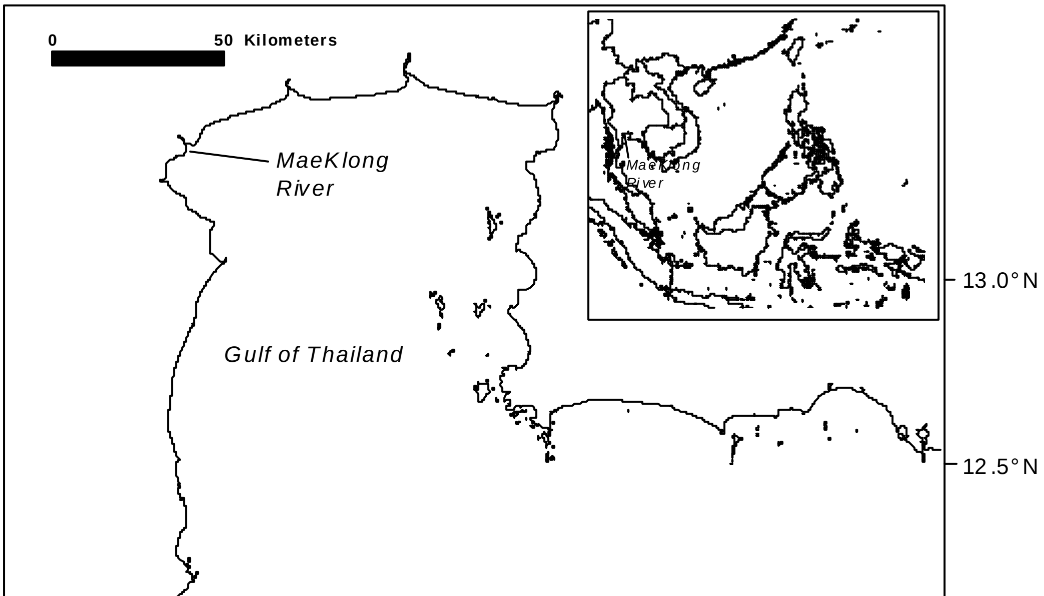

Figure 6.27. Location of Mae Klong River, Thailand.

The river discharge is 35-100 m^3 sec^{-1} from January to May. The value increases to 150-950 m^3 sec^{-1} for the period June to December, with the peak discharge in August or September (Thailand Environment Foundation 1997). The tidal range varies from 1-2 m at neap tides to 2-3 m at spring tides. Tidal intrusion extends 28 km upstream in the dry season and less than 8 km from the river mouth in the wet season (Hungspreugs *et al.* 1987). More recent data recorded tidal influence ranges of 40 km to 69 km upstream from the river mouth for high and low stream flow conditions, respectively (Thailand Environment Foundation 1997). The total catchment of the river and its tributaries occupies an area of 4,200 km^2 in six provinces, with a population of 1.2 million people in

1996. The projected population growth rates in the three provinces are between 0.6 to 0.8 % per year (Thailand Environment Foundation 1997).

The Mae Klong basin can be divided into two sub-basins. The lower sub-basin, under the influence of seawater intrusion, extends from the Mae Klong River mouth in Samut Songkhram Province to Sirilak Bridge in Ratchaburi Province. This sub-basin is about 45 km long, with a highly populated area near the coast. Patches of mangrove and broad mudflats occupy the coastline of Samut Songkhram Province, supporting mussel and clam cultivation. The main activities in the coastal area include aquaculture, salt ponds, and fisheries, particularly razor clam harvesting. Fish, shellfish and jellyfish are important fishery products from the area. Agriculture and food industries account for only a small proportion of land use. The upper sub-basin extends 95 km, from Photharam district, Ratchaburi Province to Maung district in Kanchanaburi Province. Most of the land use in this sub-basin consists of pig and duck farming, agriculture, pulp and paper production and sugar refining (Hungspreugs *et al.* 1987; Thailand Environment Foundation 1997).

Water and salt balance

Budget models were formulated using the 1996 water discharge and meteorological data adopted from the Royal Irrigation Department (1996) and the Meteorological Department. Water quality data used in the models are from two different sources. Freshwater and river mouth measurements derive from Pollution Control Department (personal communication) while another set of river mouth data and seawater quality is extracted from Boutong (1997). Unfortunately, water samplings were conducted at the subsurface layer thus giving the length of seawater intrusion to 15 km and 5 km upstream in the dry season and wet seasons respectively. In order to correct this disadvantage, the interpolation of bottom salinity was derived using the relationship between surface and bottom salinity reported by Piyakarnchana *et al.*(1979). The tidal intrusion limits of 26 km (lower Klong Damnoensaduek, Ratchaburi) in the dry season and of 10 km (Maung district, Samut Songkhram) in the wet season were used for budget calculations. All salinity values used in the models are average values of measured surface and interpolated bottom salinity. Furthermore, the budgets were calculated for both dry and wet seasons due to the differences in the meteorological nature as well as the amounts of freshwater runoff into the basin.

A two-box model was introduced for the budgets in the dry season. The lower estuary is 10,000 m long by long, 205 m wide and 9 m deep (Area = 3 km^2; V = 30x10^6 m^3). Discharges measured by the Royal Irrigation Office at Ban Wang Khanai (13.94°N, 99.65°E) downstream from the Vachiralongkorn Diversion Dam were used as the source of freshwater into the system. Groundwater as well as water from other sources is assumed to be zero. The amount of rainfall and evaporation can also be negligible in comparison to the freshwater discharge as shown in Table 6.13.

Table 6.13. Amount of freshwater discharge, rainfall and evaporation in Mae Klong River Basin in 1996.

Period	**Locality**	**FW Discharge (10^3 m^3 day^{-1})**	**Rainfall (10^3 m^3 day^{-1})**	**Evaporation (10^3 m^3 day^{-1})**
Dry Season April 1996	Upper Estuary	12,000	7	19
	Lower Estuary		9	22
Wet Season August 1996	Estuary	34,000	12	17

Figures 6.28 and 6.29 represent the water and salt budgets for the Mae Klong River in wet and dry seasons. The result indicates the influence of freshwater runoff from Vachiralongkorn Diversion Dam to the coastal zone causing the residual water flow toward the sea throughout the year. The amount of freshwater runoff is much larger during the rainy season than in the dry season. However, the heavy

rainfall upstream in the mountain area of the Mae Klong tributaries during the months of October to January each year may cause large amounts of freshwater discharge to the estuarine system and the coastal zone. This situation, observed in January 1996, affects the structure of pelagic communities in the mangrove swamp located on the southern coast of the river mouth as mentioned by Piumsomboon *et al.* (1997).

The system is driven only by freshwater input from Mae Klong River. Saltwater intrusion dominates the lower sub-basin to 26 km upstream. The exchange flows were calculated using the salinity gradients between the mudflat area adjacent to the river mouth and the river basin system. The estimated flushing time is 2 days for the upper estuary in the dry season and less than 1 day for both the lower estuary in the dry season and whole system during the wet season of 1996.

The very rapid water flushing limits the calculation of reliable nutrient budgets for the lower estuary in the dry season and the whole system in the wet season. Nutrient budgets for the upper estuary in the dry season are presented in this paper.

Budgets of nonconservative materials

DIP budget

Figure 6.30 presents the DIP budget for the upper estuary of the Mae Klong River in the dry season. Except for the concentrations of phosphate in seawater and in the estuarine water at the station near the river mouth, phosphorus in the river as well as from other parts of the estuary was reported as total phosphorus. Conversion of total phosphorus to phosphate was based on San Diego-McGlone, Smith and Nicholas (1999). Other sources of DIP into the system are from BOD loading from various types of waste. BOD loading from urban, domestic and industrial activities, aquaculture and livestock in each province was converted to TP and NH_4 (San Diego McGlone *et al.* 1999). Only the BOD from urban runoff is considered in this budget. The model shows that the upper estuary behaves as a sink of phosphorus in the dry season: *DDIP* = -2,000 mol day^{-1} (-0.7 mmole m^{-2} day^{-1}.

DIN budget

The amount of DIN in the model accounts mainly for the concentrations of nitrate plus nitrite and ammonium nitrogen (if available). Nitrogen waste was incorporated into the model in the same fashion as in the DIP model. Figure 6.31 illustrates the net sink of nitrogen of the upper estuary during the dry season.

Stoichiometric calculations of aspects of net system metabolism

From the budgets of nonconservative materials, nitrogen and phosphorus, the stoichiometric calculations of net system metabolism are presented in Table 6.14. The rates however are high for biotic processes. This may be due to both the fast water exchange rate for the river estuary and the poorly defined waste load.

Table 6.14. Estimated rates of non-conservative DIN and DIP fluxes and net system metabolism for the upper estuary in the dry season of Mae Klong River.

	Upper Estuary (dry season)	
	10^3 mol day^{-1}	mmol m^{-2} day^{-1}
DDIP	-2	-0.7
DDIN	-20	-6.7
(*nfix-denit*)	+12	+4
(*p-r*)	+212	+71

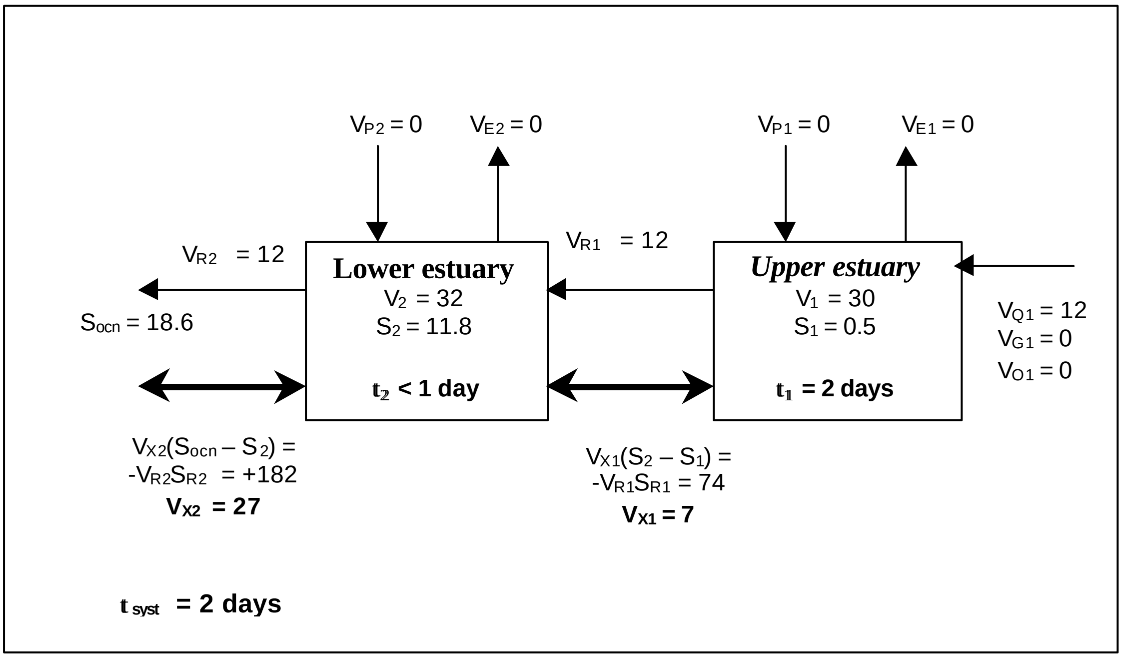

Figure 6.28. Salt and water budgets for the Mae Klong River estuary in the dry season. Volume in 10^6 m^3, water fluxes in 10^6 m^3 day^{-1}, salt fluxes in 10^6 psu-m^3 day^{-1} and salinity in psu.

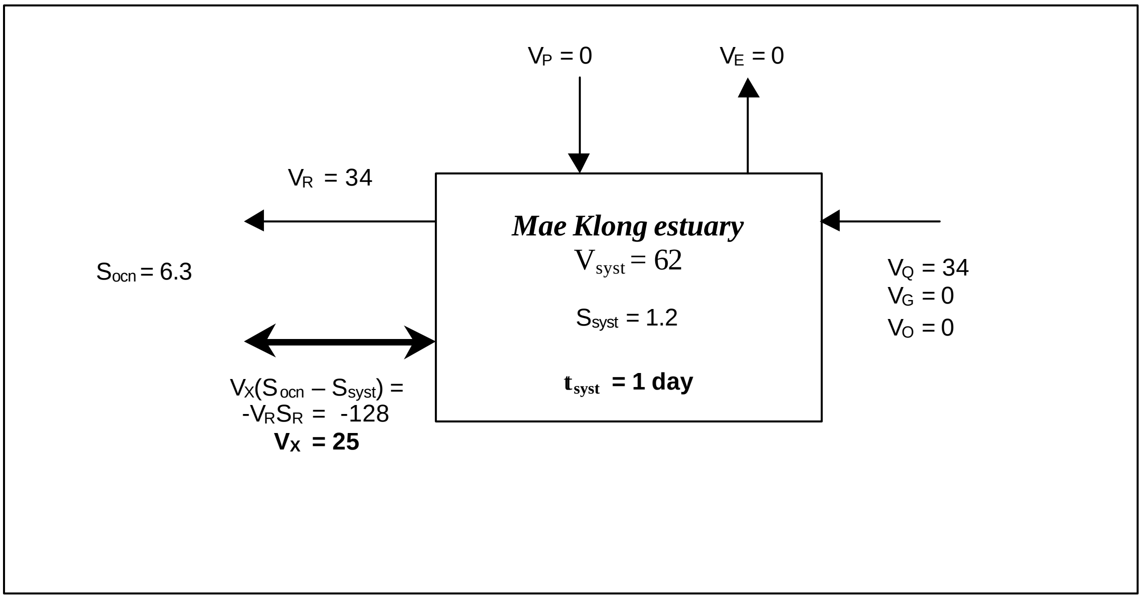

Figure 6.29. Salt and water budgets for the Mae Klong River estuary in the wet season. Volume in 10^6 m^3, water fluxes in 10^6 m^3 day^{-1}, salt fluxes in 10^6 psu-m^3 day^{-1} and salinity in psu.

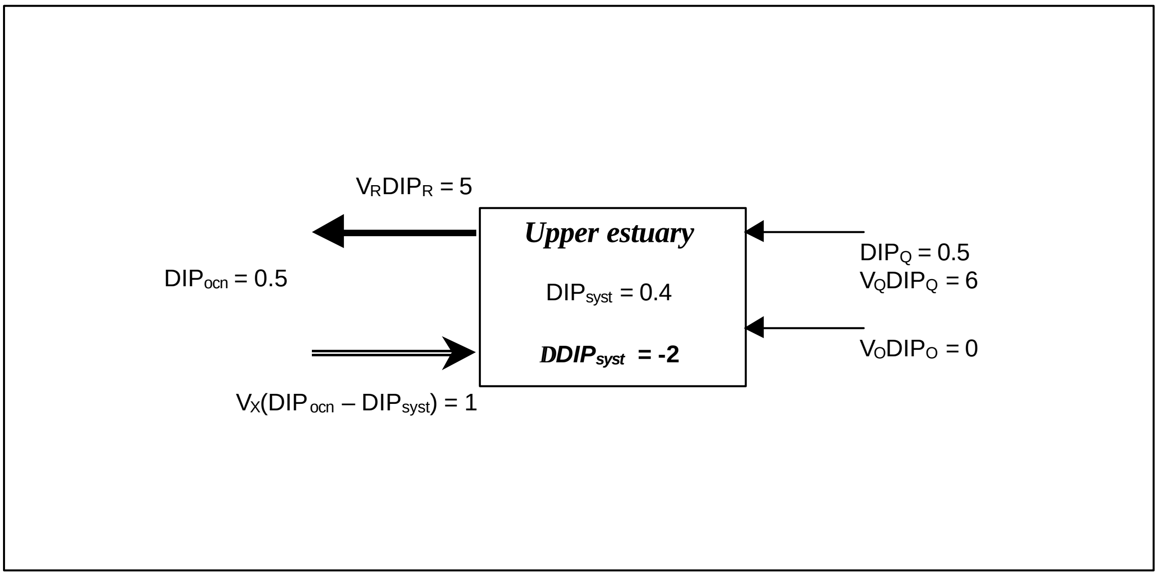

Figure 6.30. Dissolved inorganic phosphorus budget for the upper estuary of the Mae Klong River in the dry season. Fluxes in 10^3 mole day^{-1} and concentrations mmol m^{-3}.

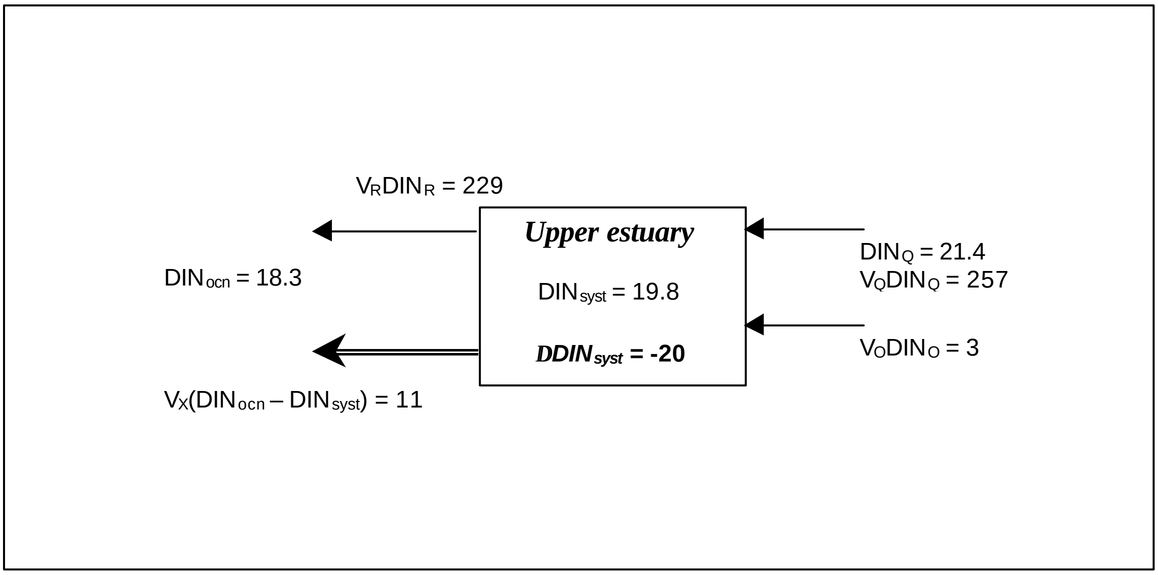

Figure 6.31. Dissolved inorganic nitrogen budget for the upper estuary of the Mae Klong River in the dry season. Fluxes in 10^3 mole day^{-1} and concentrations mmol m^{-3}.

6.5 Pakphanang River

Suphaphorn Rakkhiaw

Study area description

The Pakphanang River (8.37°N, 100.18°E) is in the south of Thailand (Figure 6.32). The river is about 150 km long, to the mouth at Pakphanang Harbour. The upper reach has a steep slope, while the lower reach has moderate slope and water level is at mean sea level. In the dry season (January to May), there is seawater intrusion into the Pakphanang River. In very dry years, seawater will intrude into the Pakphanang River up to Amphoe (district) Chian Yai. The Pakphanang River has a depth of 7-10 m in the upper reach (40-90 km from the ocean). The upper river reach has DO higher than 5 mg L^{-1} because the steep slope results in high flow velocity. In the lower reach (0-40 km from the ocean), DO decreases due to wastewater from various sources discharging into the Pakphanang River such as from Amphoe Cha-uat (16 km), and from non-point source (rural communities, agricultural area and pig farms) at 24 km (Pollution Control Department 1998).

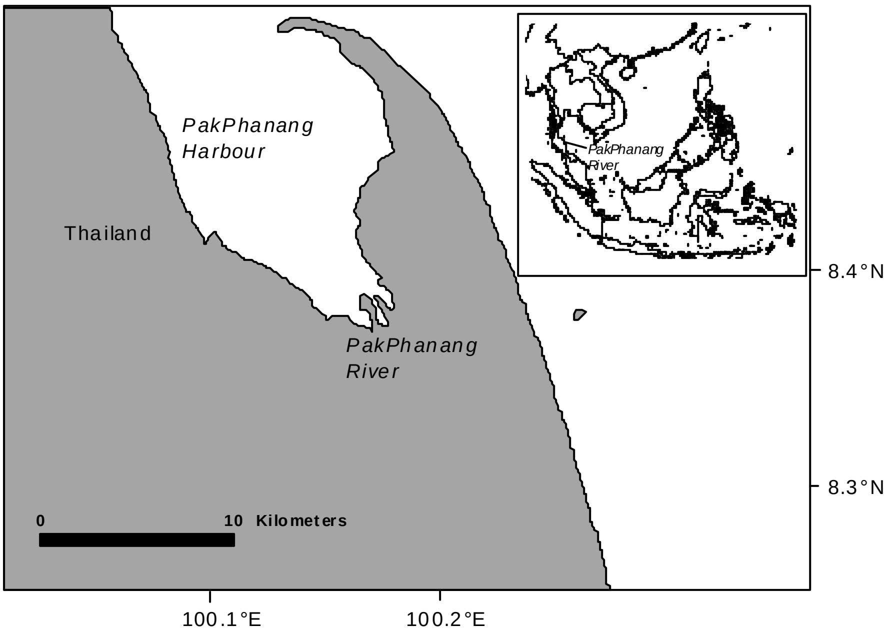

Figure 6.32. The Pakphanang River flows into the southern end of Pakphanang Harbour.

The budget presented here in based on data collected between November 1996 (representing the wet season) and April 1997 (representing the dry season) (Predalumpaburt *et al.*, 1999.) In the wet season, total size of system (Pakphanang River estuary) is 8×10^6 m^2, the mean depth about 6m, volume 47×10^6 m^3, rainfall 22 mm day^{-1}, evaporation 3 mm day^{-1} and runoff 2×10^6 m^3 day^{-1}. In the dry season, the system covers 8×10^6 m^2, the mean depth is about 6 m, the volume 47×10^6 m^3, rainfall 9 mm day^{-1}, evaporation 5 mm day^{-1} and runoff 1×10^6 m^3 day^{-1}. The fluxes of water, salt, DIP and DIN were calculated using a simple box model following Gordon *et al.* (1996).

Water and salt budgets

Figures 6.33 and 6.34 summarise the water and salt budgets for Pakphanang River for the wet and dry seasons respectively. In the wet season, the residual water flow (V_R) out of this system was about 2×10^6 m^3 day^{-1}. The salinity of freshwater inflow was assumed as 0 psu. Oceanic salinity was estimated as 12.0 psu and average system salinity was 4.0 psu. Wet season water exchange time was 12 days. In the dry season, the residual flow (V_R) out of system about 1×10^6 m^3 day^{-1}. Oceanic salinity and average system salinity were about 21.0 psu and 11.0 psu, respectively. Dry season water exchange time was calculated to be 16 days.

Budgets of nonconservative materials

DIP balance

Figures 6.35 and 6.36 summarise the dissolved inorganic phosphorus (DIP) budgets for Pakphanang River for the wet and dry seasons respectively. The system was a net phosphorus source for both seasons: *DDIP* = +1,000 mol day^{-1} or +0.1 mmol m^{-2} day^{-1} for the wet season, and *DDIP* = +3,000 mol day^{-1} or +0.4 mmol m^{-2} day^{-1} for the dry season. The positive *DDIP* values apparently indicate that there was net release of DIP within the system. This is probably not a correct conclusion because there is an undefined amount of waste discharge into the system. In order to estimate the nonconservative fluxes it will be necessary to establish an estimate of this waste load.

DIN balance

Figures 6.37 and 6.38 summarise the dissolved inorganic nitrogen (DIN) budgets for Pakphanang River for the wet and dry seasons respectively. There was a positive nonconservative flux of DIN within this system for both seasons: *DDIN* = +33,000 mol d^{-1} (+4 mmol m^{-2} day^{-1}) for the wet season and *DDIN* = +37,000 mol d^{-1} (+5 mmol m^{-2} day^{-1}) for the dry season. However, the result is not conclusive because of the absence of waste load.

Stoichiometric calculation of aspects of net system metabolism

It is not possible to assess the nonconservative fluxes and their stoichiometry at this time until waste load is considered in the budget.

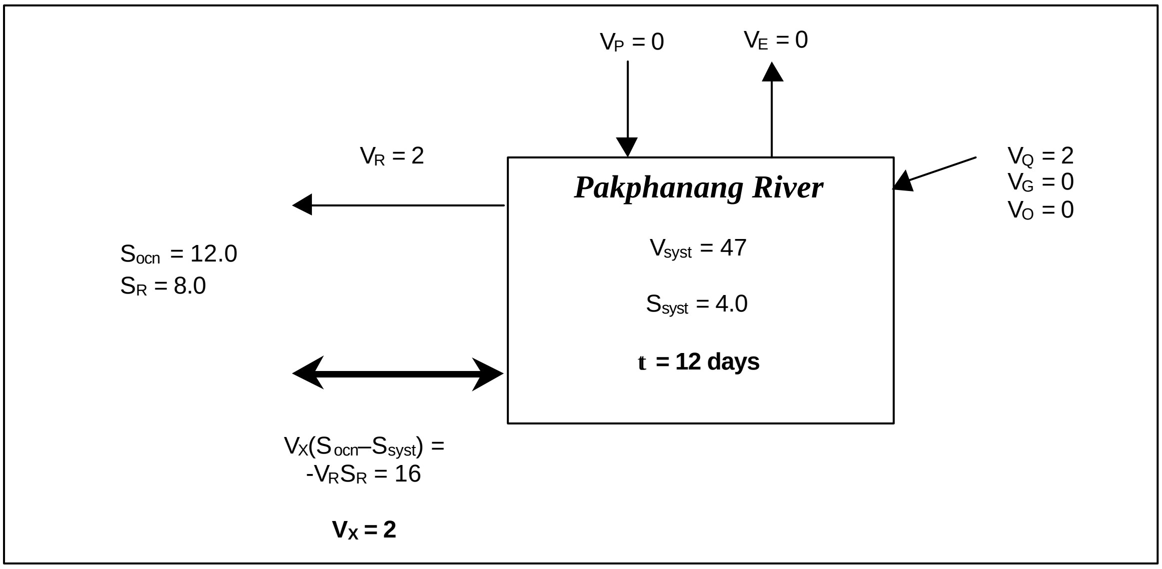

Figure 6.33. Water and salt budgets for the Pakphanang River in the wet season (November 1996). Volume in 10^6 m^3, water fluxes in 10^6 m^3 day^{-1}, salt fluxes in 10^6 psu-m^3 day^{-1} and salinity in psu.

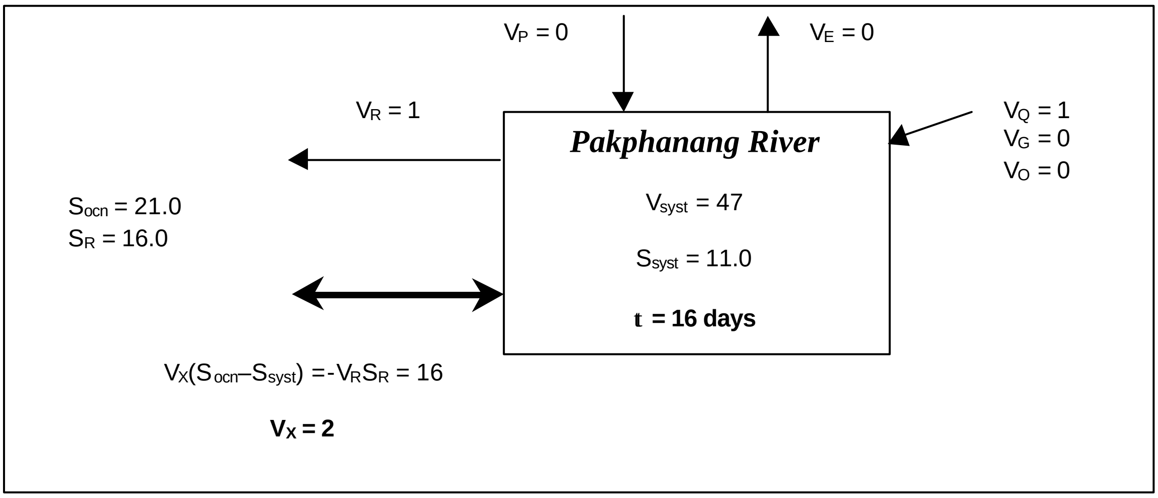

Figure 6.34. Water and salt budgets for the Pakphanang River in the dry season (April 1997). Volume in 10^6 m^3, water fluxes in 10^6 m^3 day^{-1}, salt fluxes in 10^6 psu-m^3 day^{-1} and salinity in psu.

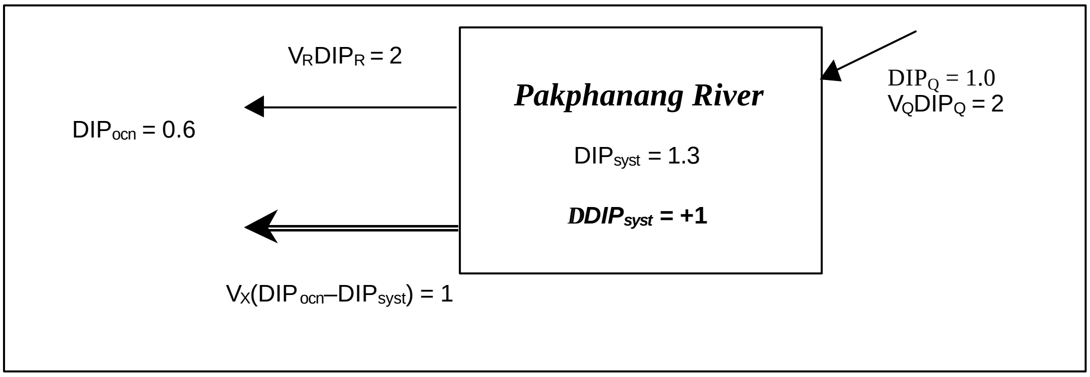

Figure 6.35. Dissolved inorganic phosphorus budget for the Pakphanang River in the wet season (November 1996). Fluxes in 10^3 mole day^{-1} and concentrations in mmol m^{-3}.

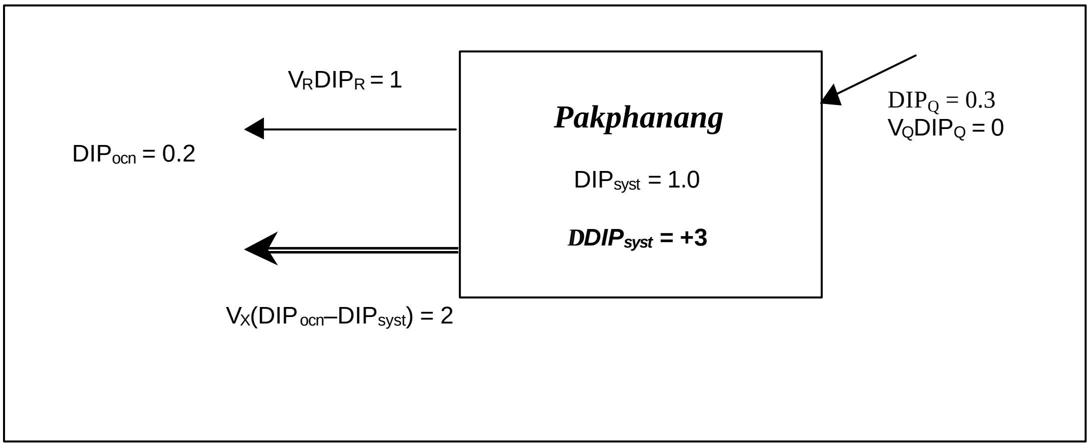

Figure 6.36. Dissolved inorganic phosphorus budget for the Pakphanang River in the dry season (April 1997). Fluxes in 10^3 mole day^{-1} and concentrations in mmol m^{-3}.

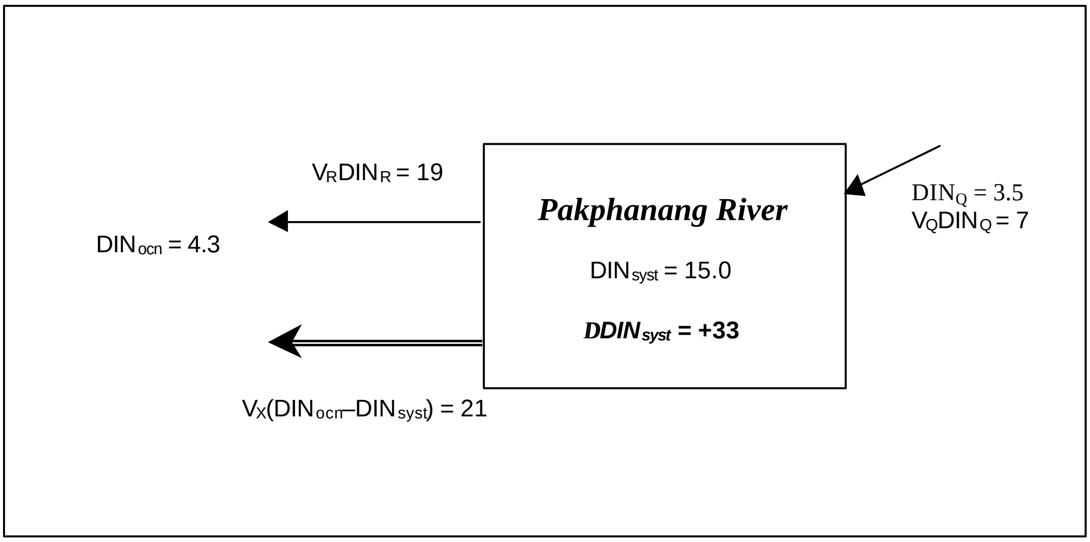

Figure 6.37. Dissolved inorganic nitrogen budget for the Pakphanang River in the wet season (November 1996). Fluxes in 10^3 mole day^{-1} and concentrations in mmol m^{-3}.

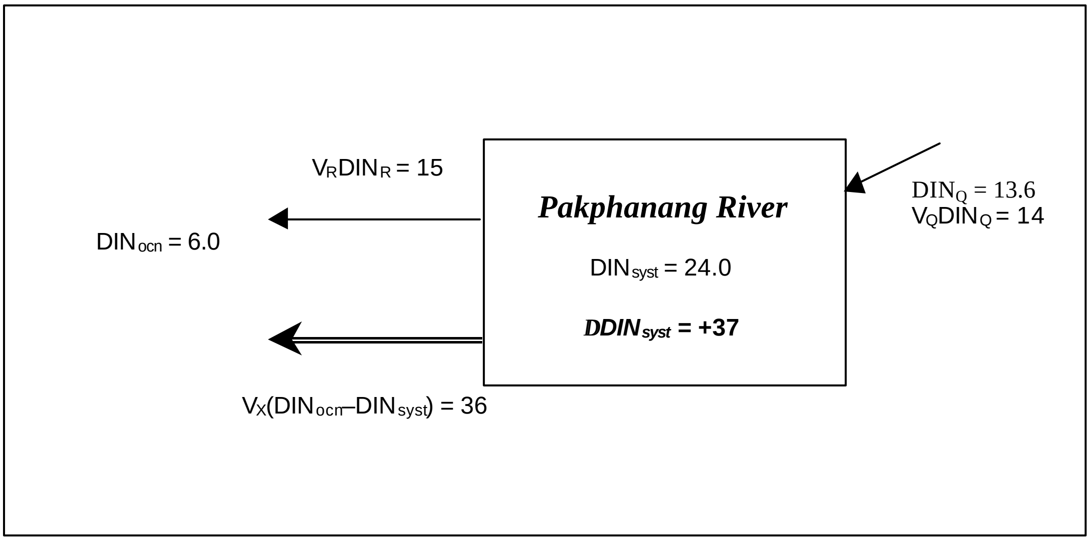

Figure 6.38. Dissolved inorganic nitrogen budget for the Pakphanang River in the dry season (April 1997). Fluxes in 10^3 mole day^{-1} and concentrations in mmol m^{-3}.

6.6 Prasae River

Suwanna Panutrakul

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

The Prasae River is situated between latitude 12.55°-13.19°N, and longitude 101.41°-101.83°E on the eastern coast of the Gulf of Thailand, about 260 km east of Bangkok. It has a length of 36 km and a catchment area of about 2,100 km^2. Klong Prasae and Klong Phao are the major tributaries of the river (Figure 6.39). They originate from Mount Chamao, located between Chon Buri, Chachernsao and Rayong Provinces, then flow through Klaeng District and drain to the Gulf of Thailand.

The area has a monsoon climate with the south-west monsoon from May to October and the north-east monsoon from November to April. The land-use pattern in the upper part of the watershed is mainly mixed crops (18%), orchard and rubber plantation (47 %), while the lower watershed has paddy fields, mixed crops and shrimp farming. There is a mangrove forest, about 0.9 % of the whole watershed area, located at the river mouth. There is one municipality and three sub-municipalities.

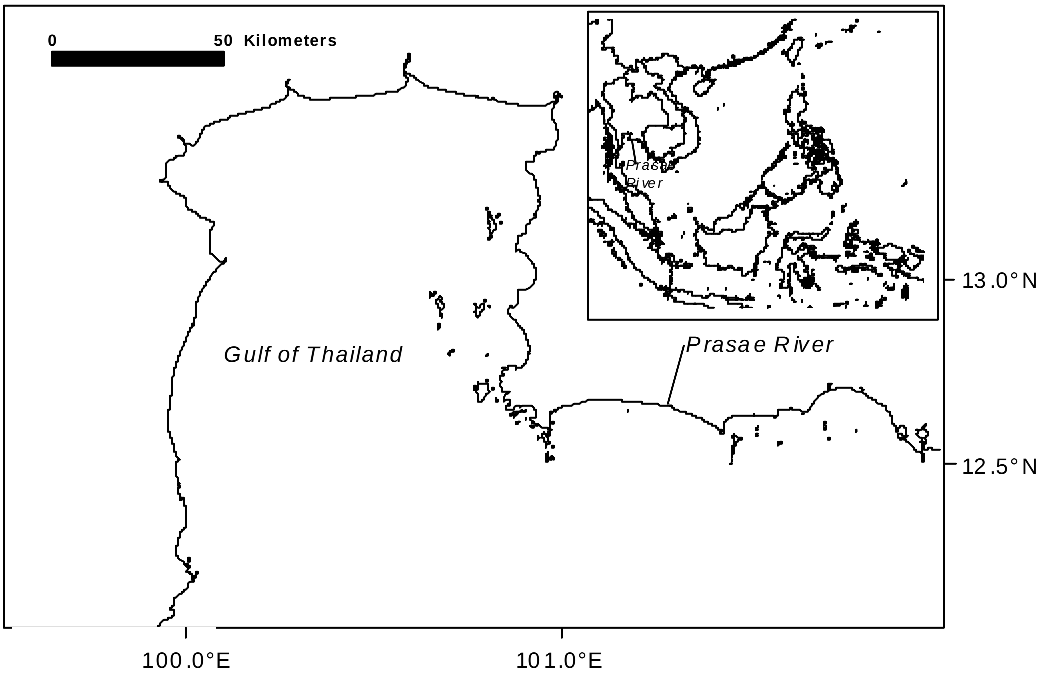

Figure 6.39. The Prasae River, on the eastern coast of the Gulf of Thailand.

The length of Prasae River estuary is estimated using salinity values in the dry season in which salt was found intruding up to Klong Sapandam about 20 km upstream. Hence a length of 25 km, from river mouth to the border between Klaeng and WangChan districts, is used as the estuary compartment length. The salinity content in wet and dry seasons in the estuary differs greatly. In the wet season, salinity at the river mouth is 4 psu and at Klong Sapandam it is close to zero, whereas in dry season salinity at the river mouth is 30 psu and at Klong Sapandam is 15 psu. Therefore, a one-box model was chosen for the wet season in which the length of the box equals the length of the estuary, 25 km. Mean width and depth of the whole estuary are 15 m and 3 m. A two-box model is necessary for the dry season. The first box is located from the border between Klaeng and WangChan districts to about 13 km down the river. Mean width and depth of this box are 10 m and 2 m. The second box covers an area from the river mouth to 12 km up the river with mean width 20 m and mean depth 4 m.

Data used in this calculation are from a UNEP study (Thongra-ar *et al.* 1995) and environmental monitoring of the Rayong and Prasae rivers in 1996. Since the evaporation rate in Rayong Province is not available at the moment, the evaporation rate in Krabinburi province, northeast of Rayong was used instead. Inputs from groundwater and other sources of water are not yet known, hence they have been omitted.

Water and salt budgets

Water and salt budgets of the Prasae River estuary in wet and dry seasons have been calculated using the LOICZ Biogeochemical Modelling Guidelines (Gordon *et al.* 1996) and are illustrated in Figures 6.40 and 6.41. In the wet season, discharge from upstream (V_Q) is as high as 5,000x10^3 m^3 day^{-1}. The water fluxes from precipitation (V_P) and evaporation (V_E) over the river are negligible, 4x10^3 and 1x10^3 m^3 day^{-1}, compared with the upstream discharge. Hence, upstream discharge is the major term controlling the water budget of the estuary. In the dry season, upstream discharge to upper estuary box is reduced to 51x10^3 m^3 day^{-1}. Evaporation volume in both upper and lower estuaries is higher than precipitation in this season. However, the evaporation volumes in both boxes are also small compared to the discharge. The amount of water from upper estuary discharges to lower estuary is 5x10^3 m^3 day^{-1}. Inputs of water to the lower estuary comes not only from discharge from the upper estuary but also discharge from Klong Phao (V_{Q2} = 23x10^3 m^3 day^{-1}) and a small amount from precipitation (V_P = 0.2x10^3 m^3 day^{-1}). Hence, the residual flow from the lower estuary to the ocean is 72x10^3 m^3 day^{-1}.

In the wet season, salinity of the estuary water is very low at 2 psu while salinity of the sea is 32 psu. The salt budget indicates that the mixing volume between the estuary and the sea is 3,000x10^3 m^3 day^{-1} (V_X). This mixing water carries 85,000x10^3 psu-m^3 day^{-1} of salt from the ocean to the estuary. Residence time of water in the wet season is very short, less than one day. In the dry season, the salinity of water in the upper estuary is 15 psu while in lower estuary the salinity is 32 psu. The seawater salinity slightly rises from 32 psu in the wet season to 33 psu in the dry season. The only source of salt tothe upper estuary comes from influx of salt from mixing water between upper and lower estuaries. The volume of mixing water between the two estuaries is 69x10^3 m^3 day^{-1}, in which it carries about 1,175x10^3 psu-m^3 day^{-1} of mixing salt flux. The mixing volume between the ocean and lower estuary is 2,340x10^3 m^3 day^{-1}. The residence time of water in dry season shows that water spends a longer time in the estuary especially in the upper part, 3 days, than in wet season. A residence time of 9 hours is found in the lower estuary. The flushing time for the whole system during the dry season is less than one day.

The whole estuary is too rapidly flushing in the wet season to be used for non-conservative nutrient budgeting. The same problem applies to the lower estuary even during the dry season. Therefore the nutrient budgets are estimated only for the upper estuary during the dry season.

Budgets of non-conservative materials

DIP budget

Figure 6.42 presents the dissolved inorganic phosphorus (DIP) budget for the upper estuary in the dry season. Nutrients budgets for the wet season and the lower estuary were not calculated due to high flushing rate. In the dry season, an amount of 36 mol day^{-1} of DIP is added to the upper estuary via upstream discharge. The DIP is removed from the upper estuary through residual outflow to lower estuary, 25 mol day^{-1}, and mixing water, 28 mol day^{-1}. This is balanced by *DDIP* of +17 mol day^{-1} (+0.06 mmol m^{-2} d^{-1}), which means that the upper estuary is releasing DIP in the dry season.

DIN budget

Figures 6.43 presents the dissolved nitrogen (DIN) budget for the upper estuary in the dry season. Nitrate is the only DIN concern in this calculations; ammonia is not included in this calculation due to incomplete information. The upper estuary receives 306 mol day^{-1} of DIN from upstream discharge. The budget shows that the upper estuary is a net release of DIN, *DDIN* = +40 mol day^{-1}(+0.1 mmol m^{-2} d^{-1}).

Stoichiometric calculations of aspects of net system metabolism

The (*p-r*) is estimated to be approximately -7 mmol C m^{-2} day^{-1} and (*nfix-denit*) of -0.85 mmol N m^{-2} day^{-1} for the upper estuary in the dry season (Table 6.15).

Table 6.15. Summary of nonconservative fluxes of the upper estuary in the dry season of the Prasae River, Thailand.

	Upper Estuary (dry season)	
	10^{-3} mol d^{-1}	mmol m^{-2} d^{-1}
DDIP	+17	+0.06
DDIN	+40	+0.1
(*nfix-denit*)	-232	-0.85
(*p-r*)	-1,802	-7

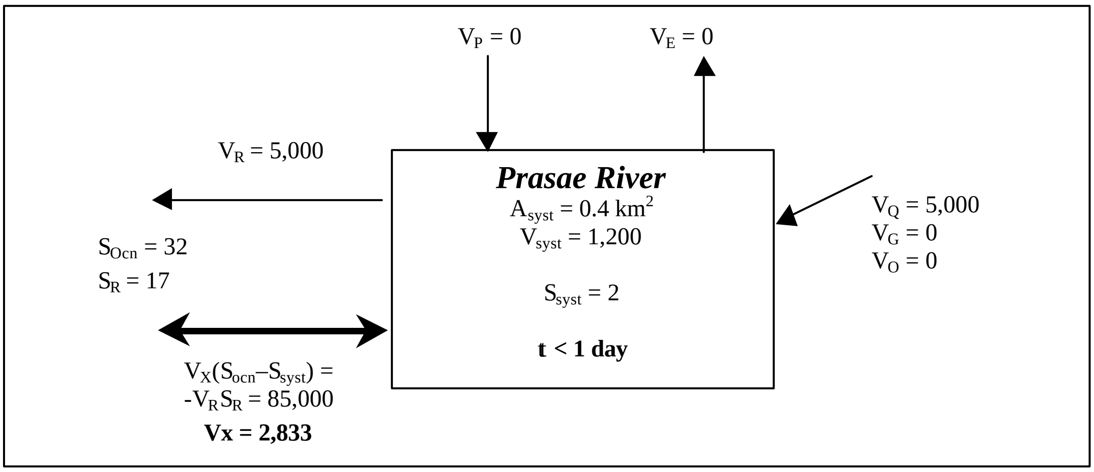

Figure 6.40. Water and salt budgets for the Prasae River in the wet season. Volume in 10^3 m^3, water fluxes in10^3 m^3 day^{-1}, salt fluxes in 10^3 psu-m^3 day^{-1} and salinity in psu.

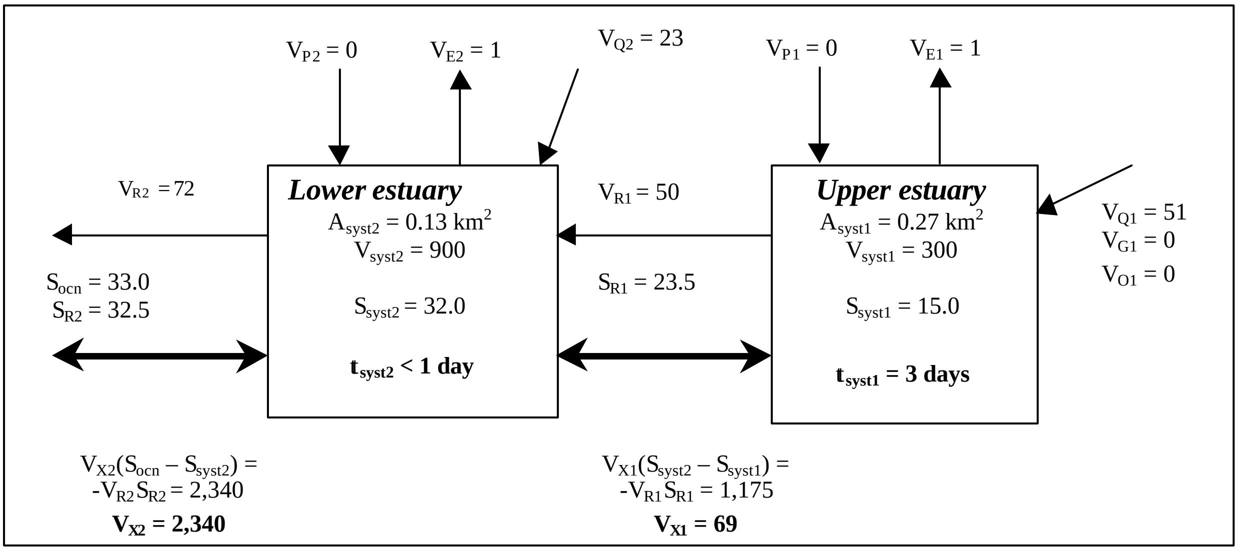

Figure 6.41. Water and salt budgets for the Prasae River in the dry season. Volume in 10^3 m^3, water fluxes in10^3 m^3 day^{-1}, salt fluxes in 10^3 psu-m^3 day^{-1} and salinity in psu.

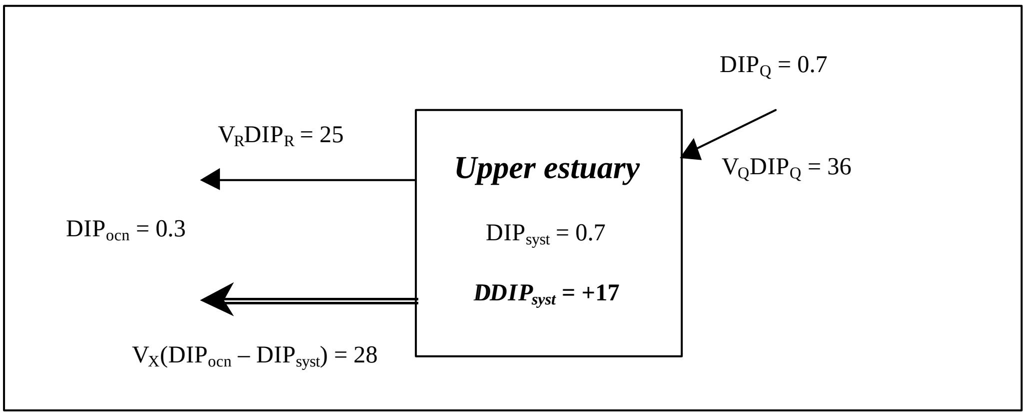

Figure 6.42. Dissolved inorganic phosphorus budget for the upper estuary of the Prasae River in the dry season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

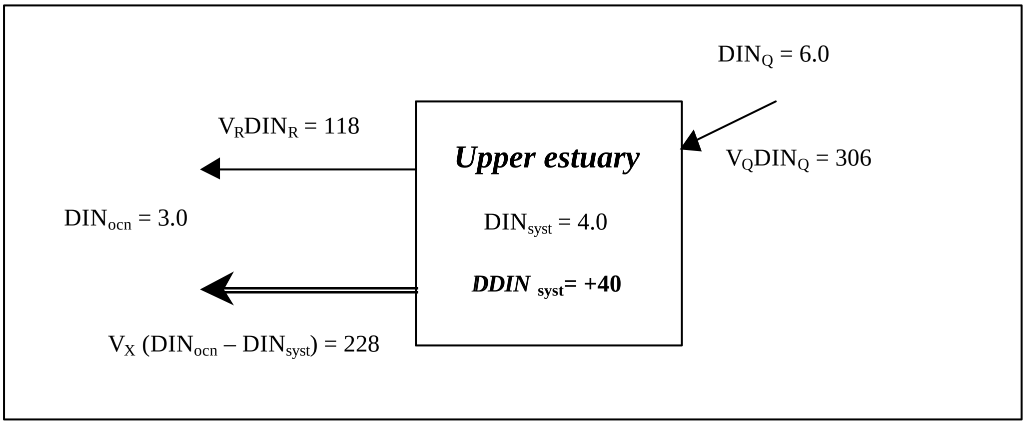

Figure 6.43. Dissolved inorganic nitrogen budget for the upper estuary of the Prasae River in the dry season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

6.7 Tachin River Estuary

Gullaya Wattayakorn

Study area description

The Tachin River (13.50°-15.50°N, 99.00°-100.50°E) is an effluent branch of the Chao Phraya River, in the central plain of Thailand (Figure 6.44). The Tachin River basin covers an area of approximately 11,000 km^2, contains a population of about 2 million, and is the second most important watershed in the central plain. The main channel of the Tachin River is defined as the 320 km stretch flowing from the Chao Phraya River (in the north) to the Gulf of Thailand (in the south). The depth of the river ranges from 3 to 12 m and the width ranges from 100 to 600 m. Annual rainfall varies from 1,030 to 1,200 mm, with the maximum average in September, at 276 to 232 mm and the minimum average in January, at 7 to 10 mm. The temperatures are usually highest in March or April and lower between November and January. The highest monthly evaporation is observed in March and April, being 250 mm, whereas the lowest evaporation is normally in November, at 130 mm.

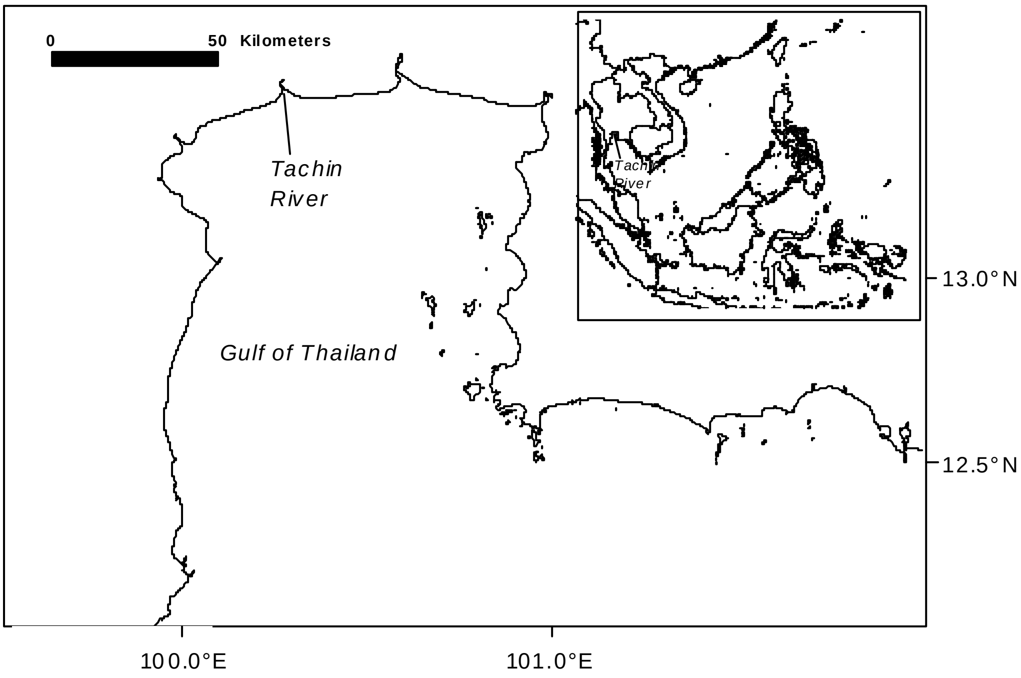

Figure 6.44. Location of the Tachin River estuary, Thailand.

The Tachin River basin is an irrigated area that connects with other rivers on both west and east sides through man-made channels. The major water uses along the middle and upper parts of the river are for agriculture. In the lower section, river water is mainly used for industry and transportation. The river is heavily regulated in order to mitigate the effects of flooding during the wet season, and also to provide a sufficient store of water to release to downstream reaches during the dry season for irrigation, water supply and salinity intrusion prevention. River flow fluctuates seasonally and annually depending on the amount of rainfall in the Chao Phraya basin, so it is regulated by four water gates (Pholthep, Taboad, Samchuk and Phophraya) upstream. The uppermost regulator, called Pholthep, supplies water to the Tachin River. The 10-year (1985 to 95) average freshwater inflow at the upper regulator was 32 $m^3 sec^{-1}$. The 10-year average monthly maximum and minimum flows of the river were 173 $m^3 sec^{-1}$ in September 1992 and 11 $m^3 sec^{-1}$ in April 1990, respectively. A zero value can often be recorded during the dry period from February to May (Pollution Control Department 1995). The average flow velocity of the Tachin River is low at approximately 0.2 $m^3 sec^{-1}$.

The Tachin River is heavily polluted, with water quality degradation only marginally less severe than the Chao Phraya River. Discharges of point sources occur throughout the year so the impact on water quality is most severe during the dry season when stream flows are low. Non-point sources of pollution derive from diffuse sources including surface runoff from farm land and numerous but scattered individual sources within an area, such as piggeries in the lower Tachin catchment, duck farms and aquaculture. Piggeries produce and discharge more BOD, ammonia and faecal coliform than domestic, industrial or other agricultural wastes. Typically, these pollutants enter the waterways through leaching or as runoff. Therefore they are more likely to be significant during the wet season when rainfall from most of the catchment contributes to stream flow.

The estuarine section of the Tachin River (approximately 80 km from the river mouth) can be divided into two portions: the upper estuary and the lower estuary. Physical dimensions of the estuary are shown in Table 6.16. For the purposes of the budgetary analysis, the estuary is assumed to be a well-mixed system. There are significant discharges of treated and untreated sewage and industrial effluents along the Tachin River estuary. Organic loads into the estuary were estimated using data from previous studies (Pollution Control Department 1997). Total N and P inflows were obtained by conversion of BOD loading using the stoichiometric relationships of C:N:P ratios in organic waste materials (San Diego-McGlone, Smith and Nicholas 1999).

Table 6.16. Physical dimensions of the Tachin River estuary.

Compartment	**Mean length** (km)	**Mean width** (m)	**Surface area** (10^6 m^2)	**Mean depth** (m)	**Volume** (10^6 m^3)
Upper estuary	64	200	12.8	8	102
Lower estuary	16	400	6.4	6	38

<u>*Water and salt balance*</u>

The water and salt budgets for each season are shown in Figures 6.45 and 6.46. The calculations for March (dry) and September (wet) 1997 assumed an inflow salinity of 0 psu. Runoff is based on daily measurements of the flow of all the diverting water gates as recorded by the Royal Irrigation Department. Freshwater inflows to the estuary are estimated to be 6×10^6 m^3 day^{-1} and 13×10^6 m^3 day^{-1} for the dry and wet seasons respectively. Groundwater flow is assumed to be zero. Rainfall is estimated to be in the range 30,000 to 95,000 m^3 day^{-1} and evaporation is 65,000 to 75,000 m^3 day^{-1}. Freshwater runoff was the dominant term in the freshwater budget, whereas evaporation almost balanced the estimates of rainfall and can be assumed as to be insignificant to the water budget. The water volume of sewage and industrial effluents is small relative to freshwater input and was assumed negligible.

Using the LOICZ Biogeochemical Modelling Guidelines (Gordon *et al.* 1996), the water exchange time of the upper estuary was 5 days in the wet season and 8 days in the dry season. For the lower estuary, the exchange time is about 1 day for both seasons. The total freshwater exchange time of the Tachin estuary is about 3 days in both wet and dry conditions.

Phosphorus balance

Figures 6.47 to 6.50 display the dissolved phosphorus fluxes for the Tachin estuary in the dry and wet seasons. The estuary in general was a net sink of dissolved phosphorus (DIP + DOP) in both the dry and wet seasons. However, DIP was released both for the upper and lower estuary in the wet season though was dominated by the large DOP sink in the same season. There was also a release of DIP in the upper estuary in the dry season. The system (except for the lower estuary) releases DIP in the dry season and consistently takes up DOP.

Nitrogen balance

A similar balance is estimated for dissolved nitrogen flux (Figures 6.51 to 6.54). The estuary was also a net sink for dissolved nitrogen (DIN + DON) in both seasons. Like DOP, DON was consistently taken up.

Stoichiometric calculations of aspects of net system metabolism

Results are extremely high for biotic processes (Table 6.17). It seems likely that this reflects the effects of very large and very poorly defined rates of nutrient loading to the system.

Table 6.17. Stoichiometric calculations of aspect of net system metabolism for the Tachin River estuary.

	March 1997 (dry)			**September 1997 (wet)**		
	mmol m^{-2} day^{-1}			mmol m^{-2} day^{-1}		
	Upper estuary	Lower estuary	Whole estuary	Upper estuary	Lower estuary	Whole estuary
(*p*-*r*)[1]	-124	+14	+5	-75	-364	-171
(*nfix*-*denit*)[1]	-10	+24	+1	-11	-339	-120
(*p*-*r*)[2]	-53	+76	+23	-32	-155	-73
(*nfix*-*denit*)[2]	+1	-11	-3	-4	-308	-105

[1] based on C:P of 106:1; and N:P of 16:1 (plankton-dominated system)

[2] based on C:P of 45:1; and N:P of 7:1 (terrestrial organic detritus dominated system)

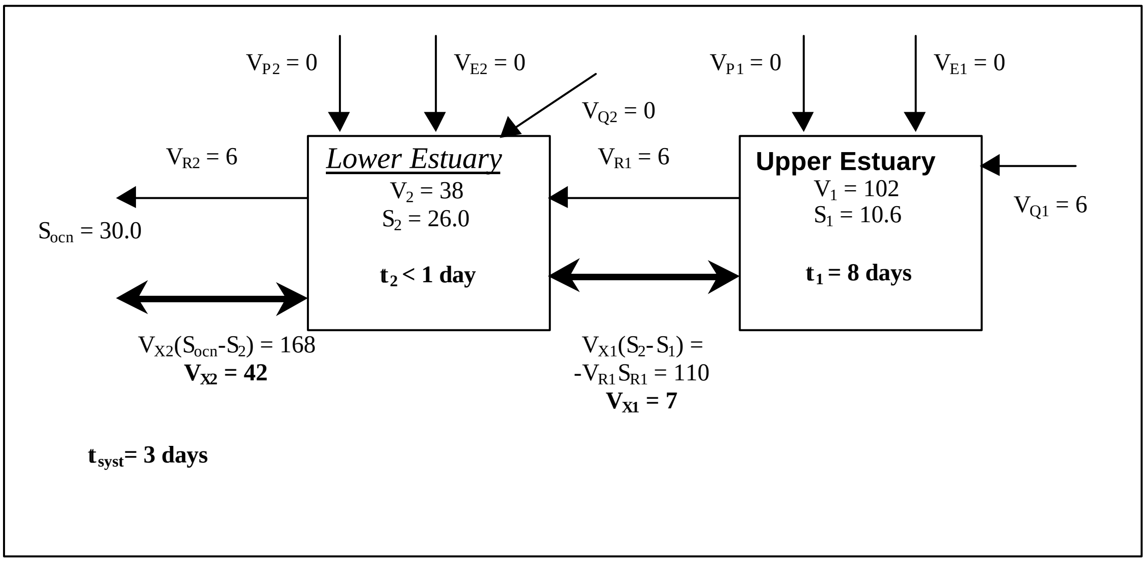

Figure 6.45. Water and salt budgets for the Tachin River estuary in the dry season. Water fluxes in 10^6 m^3 day^{-1}, salt fluxes in 10^6 psu m^3 day^{-1} and salinity in psu.

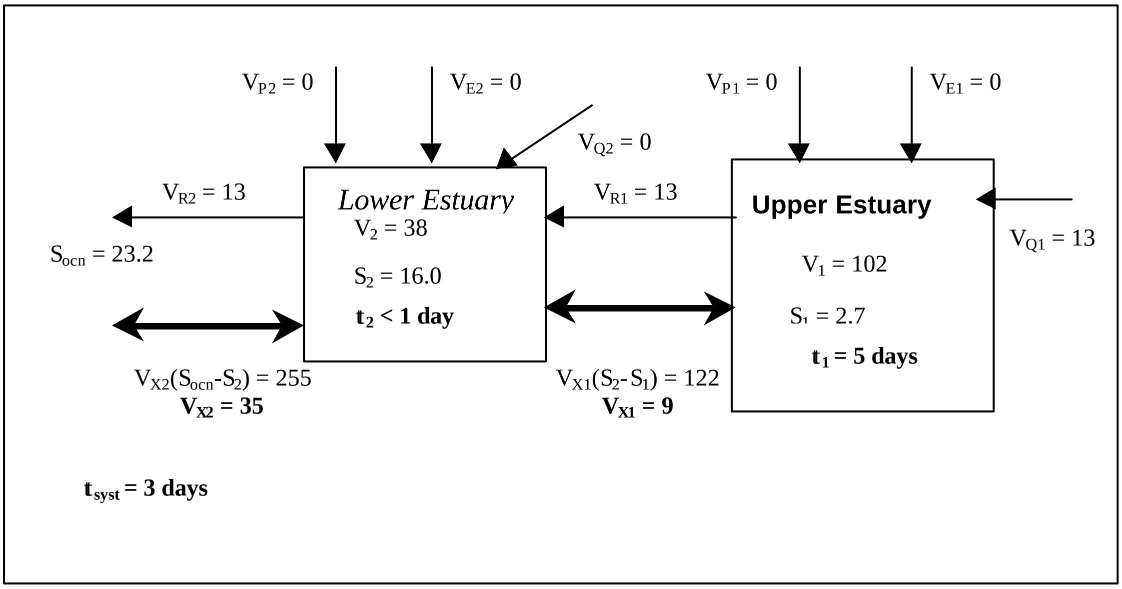

Figure 6.46. Water and salt budgets for Tachin River estuary in the wet season. Water fluxes in 10^6 m^3 day^{-1}, salt fluxes in 10^6 psu m^3 day^{-1} and salinity in psu.

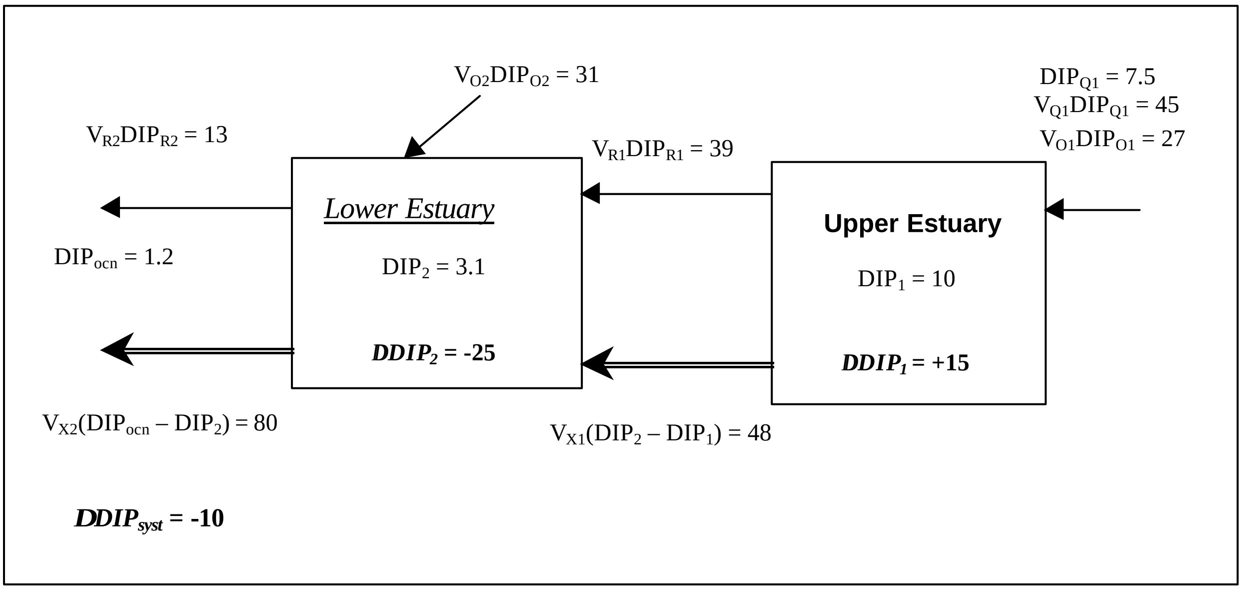

Figure 6.47. Dissolved inorganic phophorus budget for the Tachin River estuary in the dry season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

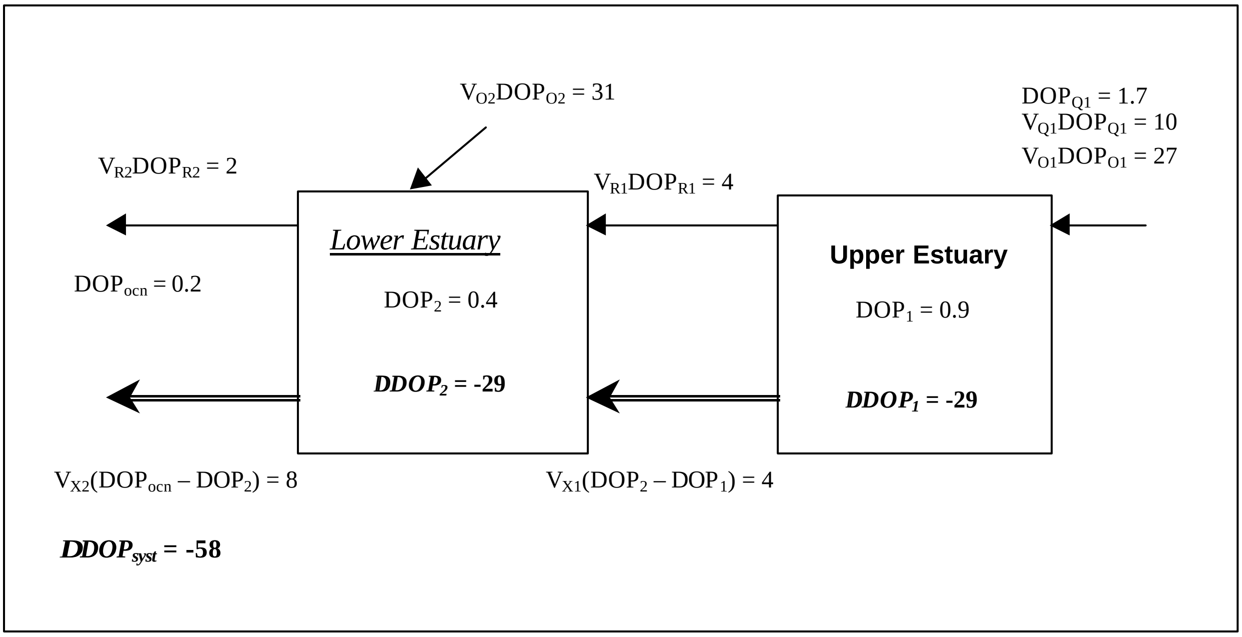

Figure 6.48. Dissolved organic phophorus budget for the Tachin River estuary in the dry season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

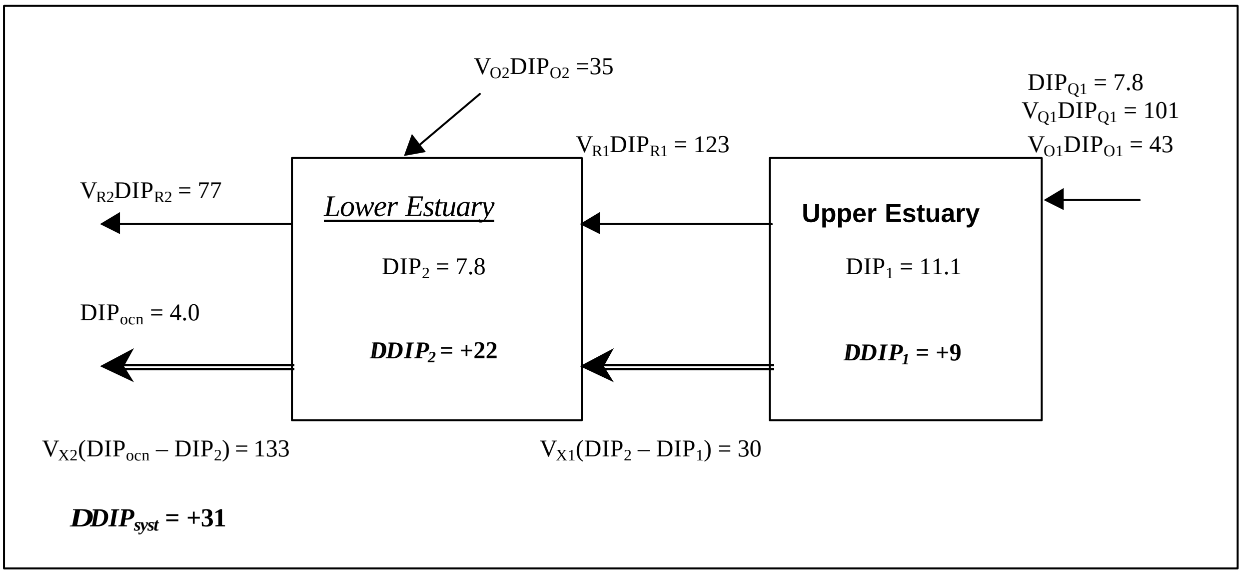

Figure 6.49 Dissolved inorganic phophorus budget for the Tachin River estuary in the wet season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

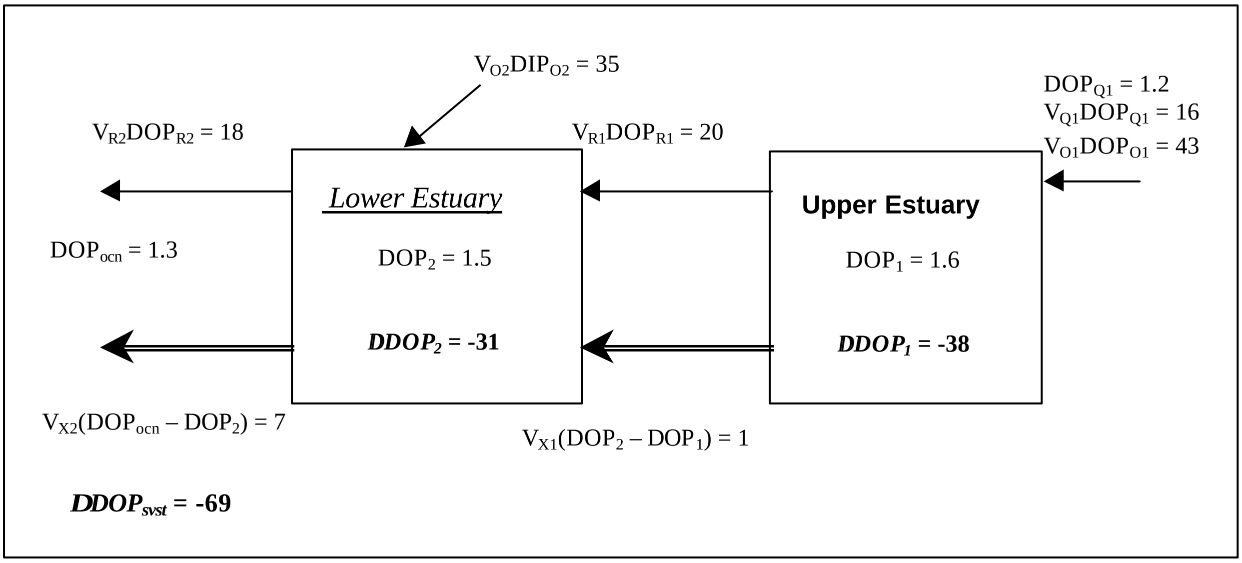

Figure 6.50. Dissolved organic phophorus budget for the Tachin River estuary in the wet season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

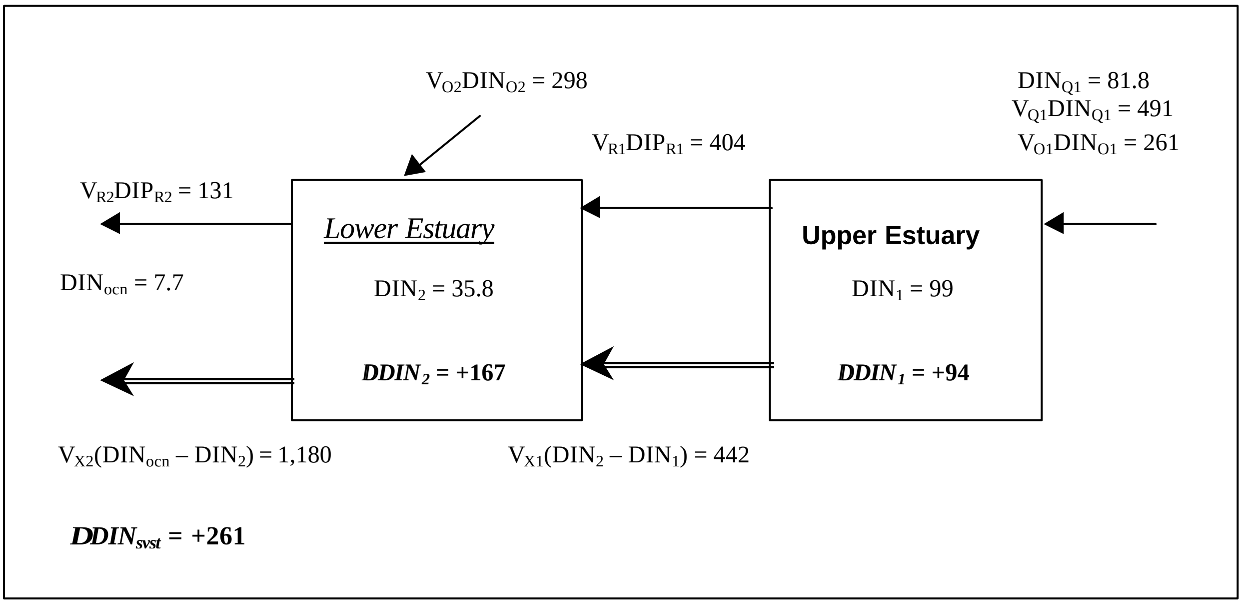

Figure 6.51. Dissolved inorganic nitrogen budget for the Tachin River estuary in the dry season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

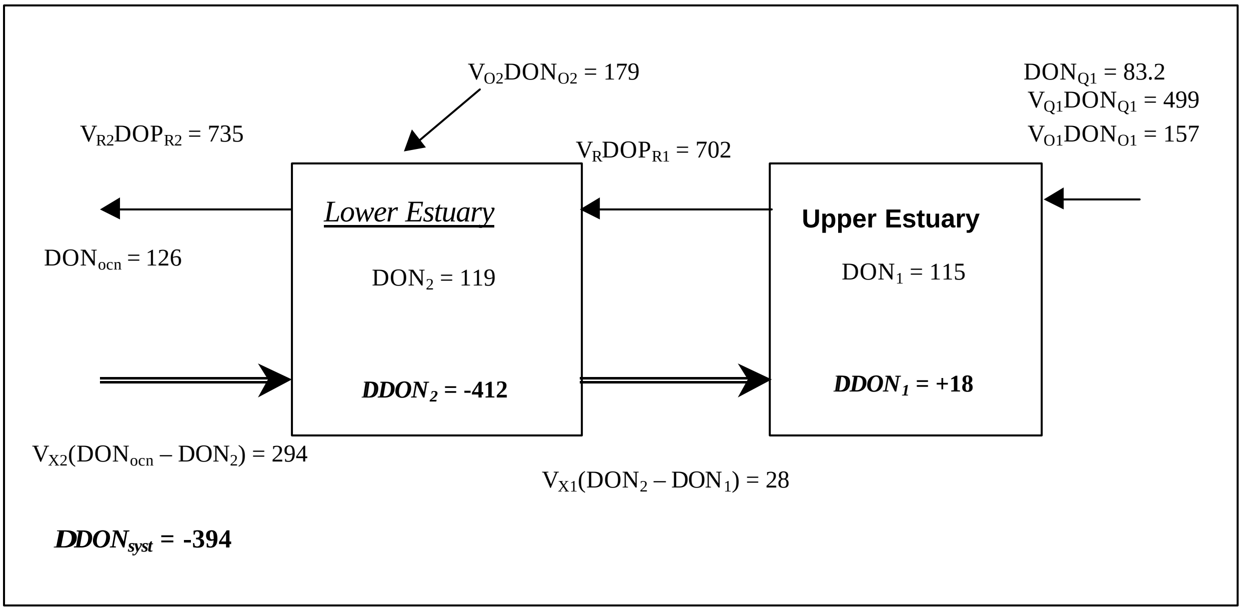

Figure 6.52. Dissolved organic nitrogen budget for the Tachin River estuary in the dry season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

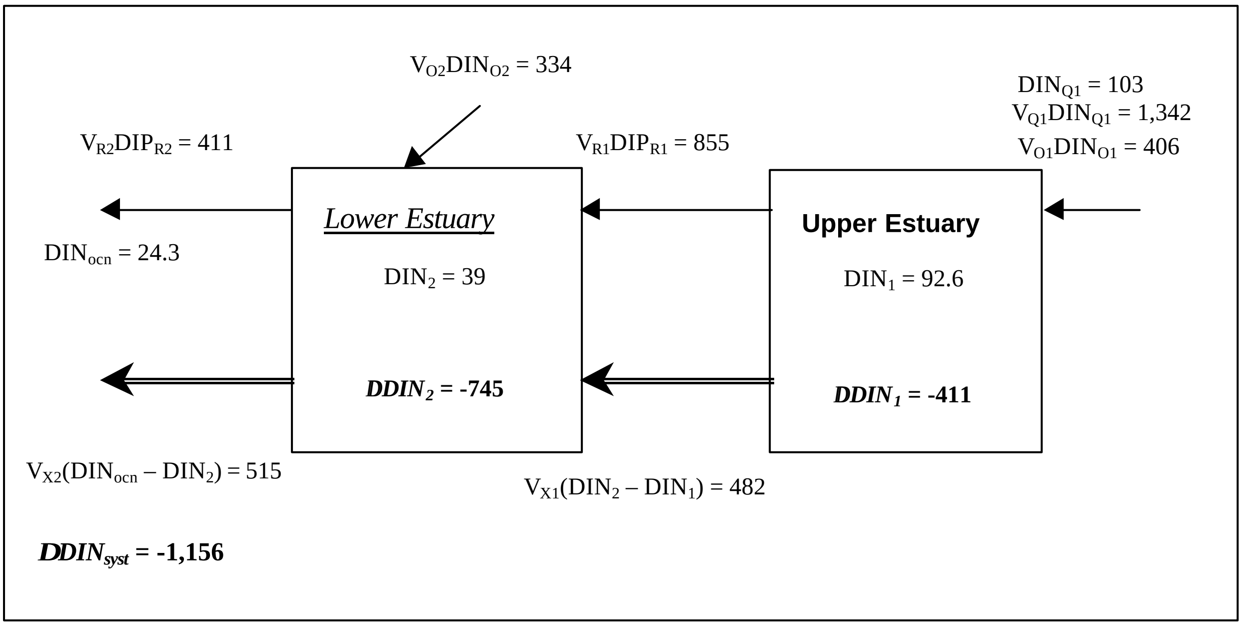

Figure 6.53. Dissolved inorganic nitrogen budget for the Tachin River estuary in the wet season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

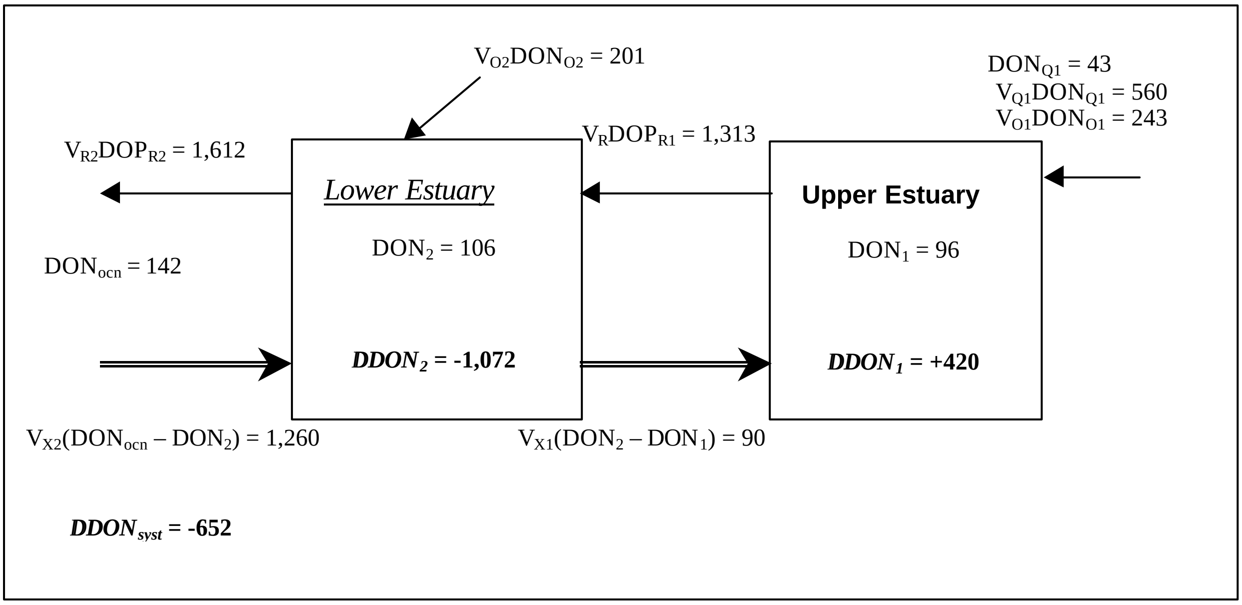

Figure 6.54. Dissolved organic nitrogen budget for the Tachin River estuary in the wet season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

7. VIETNAM ESTUARINE SYSTEMS

7.1 Cau Hai Lagoon

Le Thi Huong

Study area description

Cau Hai Lagoon is located in the coastal zone of Thua Thien Hue Province in the centre of Vietnam, 16.23°-16.50°N, 107.50°-107.97°E (Figure 7.1). The total lagoon area is about 102 km^2 with an average depth about 1.5 m (Cu 1995).

The hydrochemical characteristics of the lagoon show seasonal variability. The temperature maximum reaches 28°C during the dry season and 26°C during the rainy season. Dissolved oxygen values range from 4.8 to 6.8 mg L^{-1} (Vietnam Institute for Water Research 1998). Annual average precipitation is about 2,800 mm (with 158 rain days) and annual average evaporation is 1,000 mm. Normally, the rainy season stretches from August to January each year and the dry season from February to July. The lagoon area has the highest precipitation rate for central Vietnam. Salinity in the lagoon with season (Huan 1997).

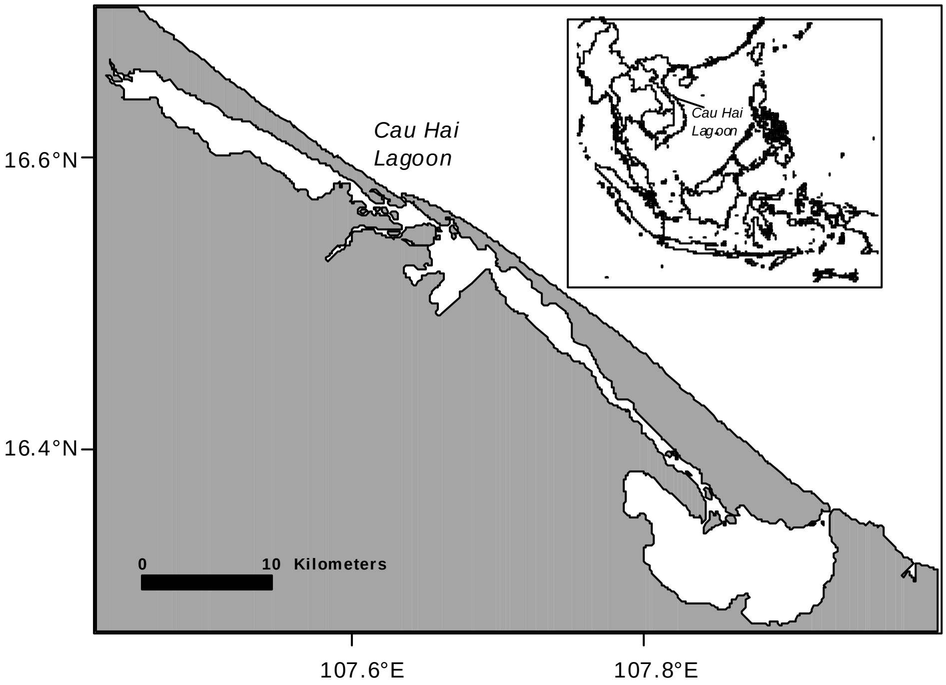

Figure 7.1. Location of Cau Hai Lagoon.

Water and salt balance

The water volume entering a system must equal water volume storage within the system minus the water volume flowing out of the system. Inflows include runoff (V_Q), direct precipitation (V_P), groundwater (V_G) and other water (V_O). Removals include evaporation (V_E).

Water storage may be represented by the change in system of interest with time (dV/dt). It is often assumed that dV/dt = 0.

$$DV/dt = V_Q+V_P+V_G+Vo+V_E+V_R \qquad (1)$$

We may calculate the water balance in the lagoon as follows:

$$V_Q+V_P+V_E+V_R= 0 \quad (2)$$

$$V_R= - V_Q- V_P+V_E \quad (3)$$

Following the LOICZ Biogeochemical Modelling Guidelines (Gordon *et al.* 1996), the water and salt budgets for Cau Hai Lagoon for the wet and dry seasons were calculated (Figures 7.2 and 7.3 respectively). Seasonal variations are apparent on the river water discharge, precipitation and evaporation fluxes, and salinity of the system. River discharge (V_Q) is 6x10^6 m^3 day^{-1} in the wet season and 2x10^6 m^3 day^{-1} in the dry season. From the data in Table 7.1 for freshwater fluxes, residual flow (V_R) and volume mixing (V_X) were estimated as 9x10^6 m^3 day^{-1} and 7x10^6 m^3 day^{-1} in the wet season, and 1x10^6 m^3 day^{-1} and 2x10^6 m^3 day^{-1} in the dry season. Water exchange times were calculated to be 10 days in the wet season and 51 days in the dry season. Annual average water exchange time is about 30 days.

Table 7.1: The water volume of inputs and outputs in Cau Hai Lagoon system (Cu 1995; Huan 1997)

Source	**Season**	**V** (10^{3}m^3/day)
Precipitation (V_P)	Rainy	2856
	Dry	255
Evaporation (V_E)	Rainy	- 230
	Dry	- 730
Runoff (V_Q)	Rainy	6380
	Dry	2173
Ground, water (V_G)	Rainy	0
	Dry	0
Other water (V_O)	Rainy	0
	Dry	0

Budgets of nonconservative materials

DIP balance

The nonconservative flux of dissolved inorganic phosphorus (DIP) in Cau Hai Lagoon for rainy and dry seasons is calculated using the data from Table 7.2 and results are illustrated in Figures 7.4 and 7.5. Assuming all nutrient loads were accounted and delivered by the river runoff, the system seems to be a slight sink for DIP for both seasons; *DDIP* is -7x10^3 mol day^{-1} (-0.07 mmol m^{-2} day^{-1}) in the wet season, and *DDIP* is –5x10^3 mol day^{-1} (-0.05 mmol m^{-2} day^{-1}) in the dry season.

DIN balance

The nonconservative flux of dissolved inorganic nitrogen (DIN) in Cau Hai Lagoon for rainy and dry seasons is calculated using the data from Table 7.2 and results are illustrated in Figures 7.6 and 7.7. The system seems to be a source in the wet season and a sink in the dry season for DIN; *DDIN* is +69x10^3 mol day^{-1} (+0.7 mmol m^{-2} day^{-1}) in the wet season, and -87x10^3 mol day^{-1} (-0.9 mmol m^{-2} day^{-1}) in the dry season.

Table 7.2: The dissolved inorganic inputs and outputs in Cau Hai Lagoon system (Vietnam Institute for Water Research 1998; Huan 1997)

Source	**Season**	**DIP (mmol/m^3)**	**DIN (mmol/m^3)**
Precipitation (V_P)	Rainy	0	0
	Dry	0	0
Evaporation (V_E)	Rainy	0	0
	Dry	0	0
Runoff (V_Q)	Rainy	4.97	73.52
	Dry	6.54	108.03
Ground and Other (V_G, Vo)	Rainy	0	0
	Dry	0	0
Ocean	Rainy	1.61	9.64
	Dry	1.94	11
System	Rainy	2.26	46.4
	Dry	4.56	58.2

Stoichiometric calculation 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: ΔDIN_{obs}-ΔDIN_{exp} (ΔDIN_{exp} is DIP multiplied by the N:P ratio of 16:1, for plankton: (*nfix-denit*) = ΔDIN_{obs} - $(N : P)_{part}$ x ΔDIP)

In the rainy season*:*

(*nfix-denit*) = 56931.10^3 - 16 x (- 9398.10^3) = 66345x10^{3}mmol/day (+ 0.65mmol N/m^2/day)

In the dry season:

(*nfix-denit*) = -39732.10^3 – 16 x (-1128.10^3) = -21684x10^{3}mmol/day (-0.21 mmol N/m^2 day).

ΔDIP 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 C:P ratio equal ratio 106:1. NEM = (*p*-*r*) = (C:P) part x ΔDIP

In the rainy season:

(p-r) = -106 x (-9398.10^3) = + 996188.10^3 mmol/day (+9.77mmol C/m^2/day)

In the dry season:

(p-r) = -106 x (- 1128.10^3) = + 119568.10^3 mmol/day (+1.17 mmol C/m^2/day)

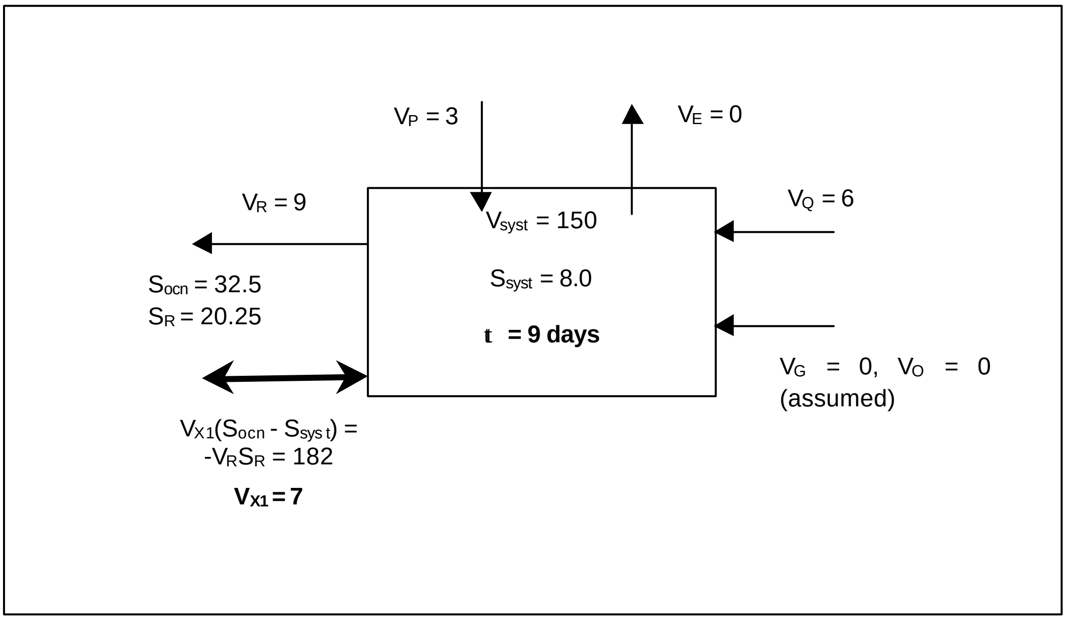

Figure 7.2. Water and salt budgets for Cau Hai lagoon in the wet season. Volume in 10^6 m^3, water fluxes in 10^6 m^3 day^{-1}, salt fluxes in 10^6 m^3 psu day^{-1} and salinity in psu.

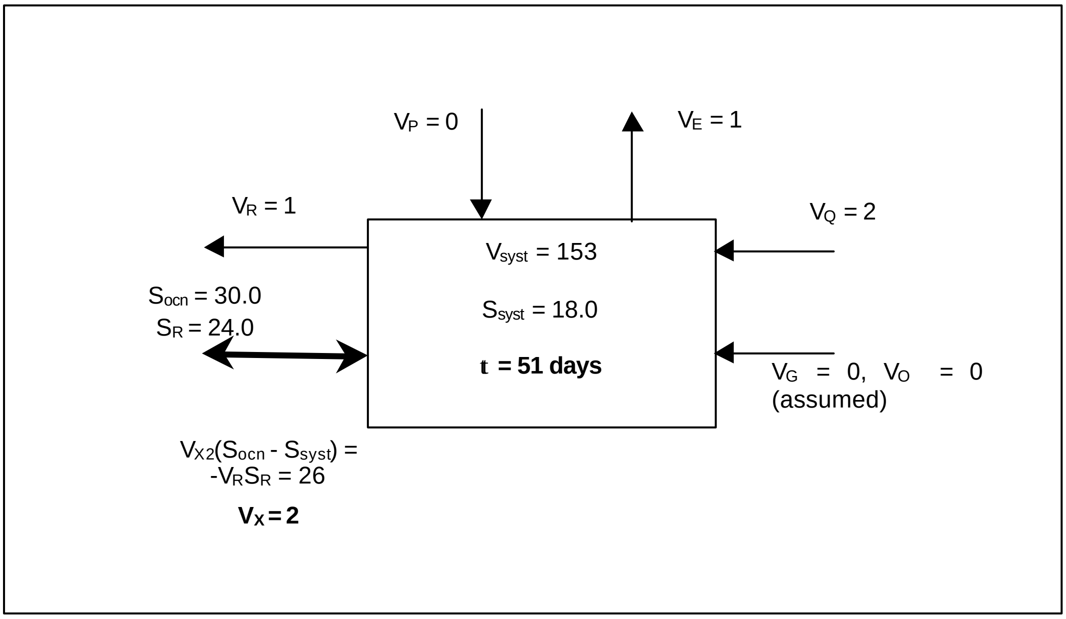

Figure 7.3. Water and salt budgets for Cau Hai lagoon in the dry season. Volume in 10^6 m^3, water fluxes in 10^6 m^3 day^{-1}, salt fluxes in 10^6 m^3 psu day^{-1} and salinity in psu.

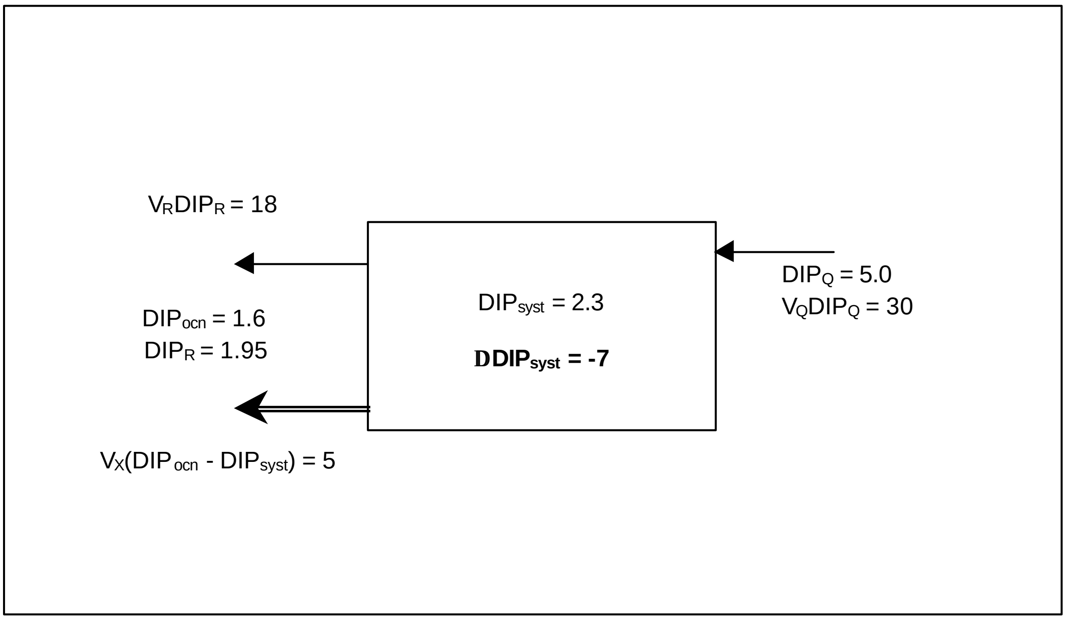

Figure 7.4. Inorganic phosphorus budget for Cau Hai lagoon in the wet season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

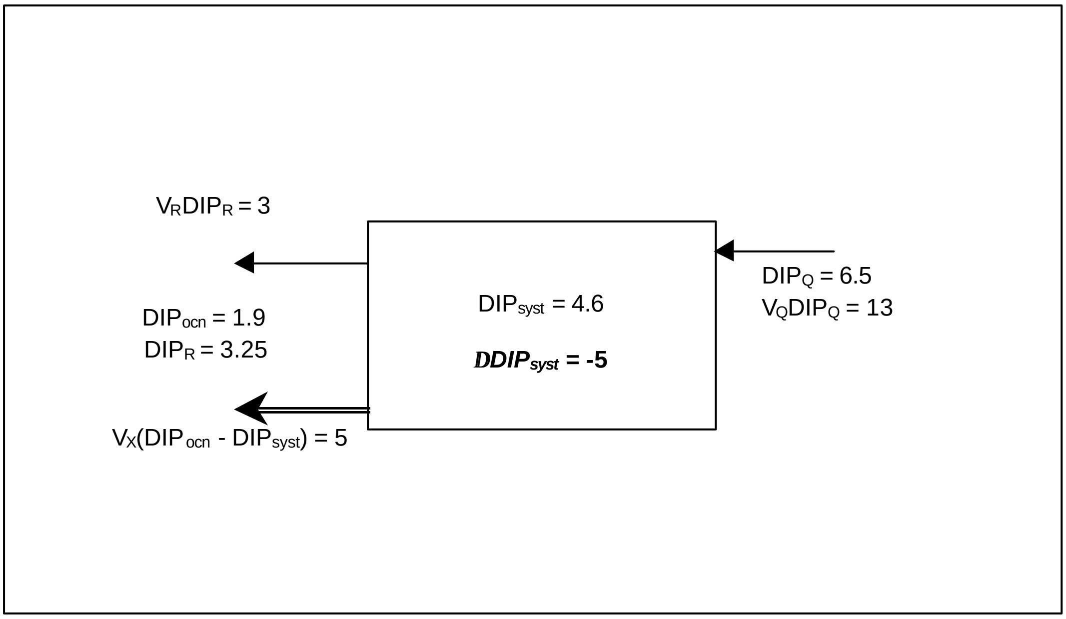

Figure 7.5. Inorganic phosphorus budget for Cau Hai lagoon in the dry season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

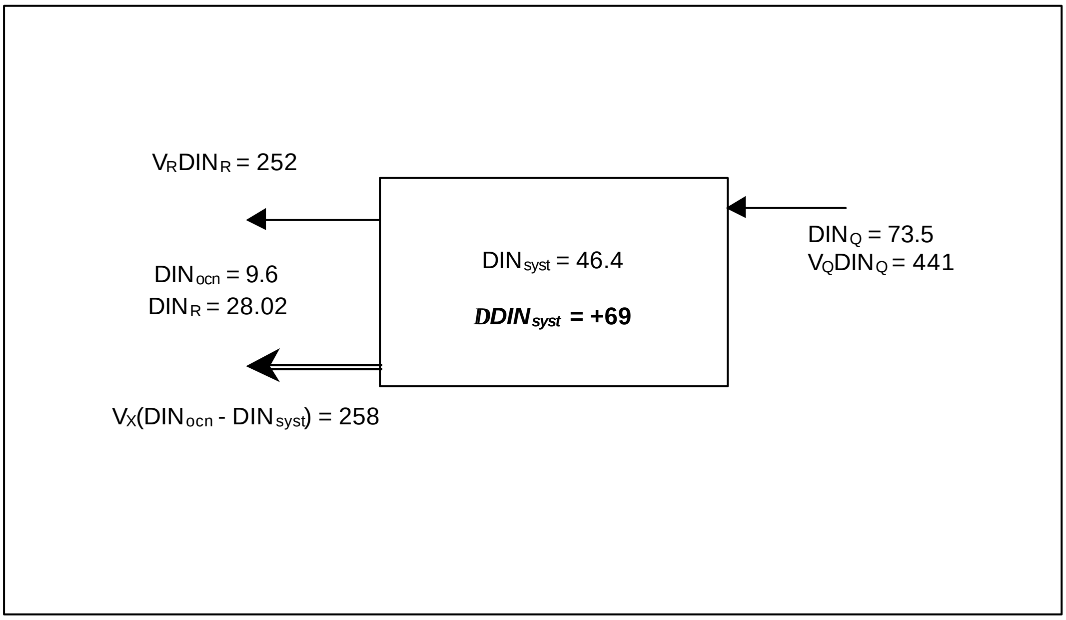

Figure 7.6. Inorganic nitrogen budget for Cau Hai lagoon in the wet season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

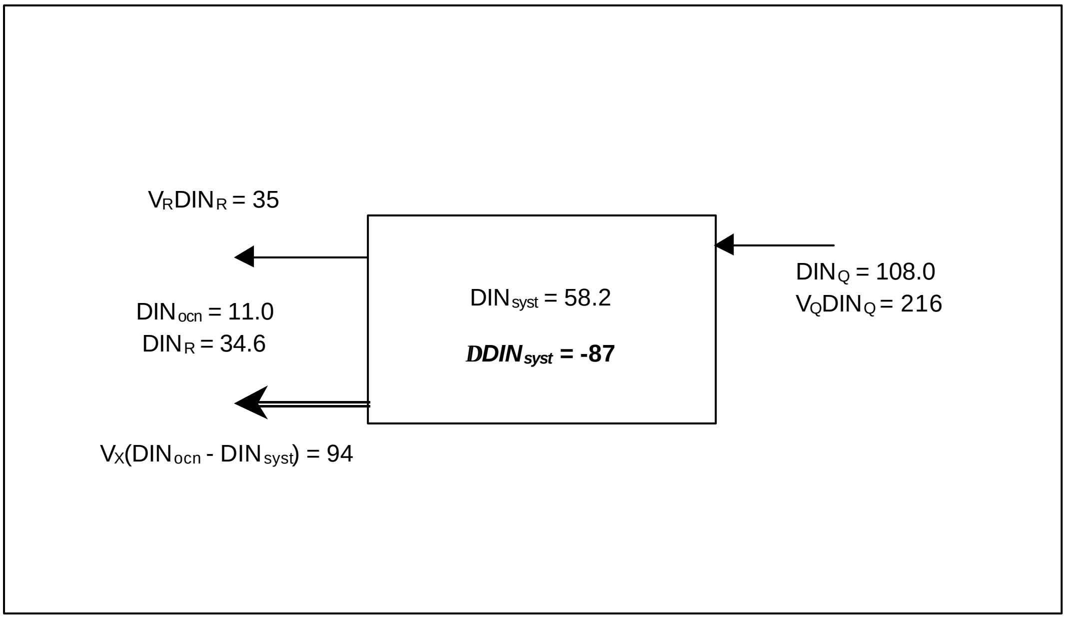

Figure 7.7. Inorganic nitrogen budget for Cau Hai lagoon in the dry season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

7.2 Hau River Estuary, Mekong River Delta

Phan Minh Thu

Study area description

The Hau River estuary (9.33°-10.12°N, 105.71°-106.42°E) is a part of Mekong River delta in Vietnam (Figure 7.8). The total catchment area of the study site is about 490 km^2. The Hau River flows through the provinces of An Giang, Can Tho, Vinh Long, Tra Vinh and Soc Trang. The total population of the five provinces was over 7 million people in 1997.

Based on salinity data measured during the dry season, the study area was divided into two segments: the upper Hau River estuary (about 150 km^2) and lower Hau River estuary (about 340 km^2) (Figure 7.8). The average depth of each segment varies depending on the season. Mean water depth of the upper area is approximately 8 m during the dry season and 12 m during the rainy season. The water depth of the lower area measures 7 m during the dry season and 8 m during the rainy season. The volume is then estimated to be 1,200x10^6 m^3 in the dry season and 1,800x10^6 m^3 in the rainy season for the upper estuary, and about 2,400x10^6 m^3 in the dry season and 2,700x10^6 m^3 in the rainy season in the lower estuary.

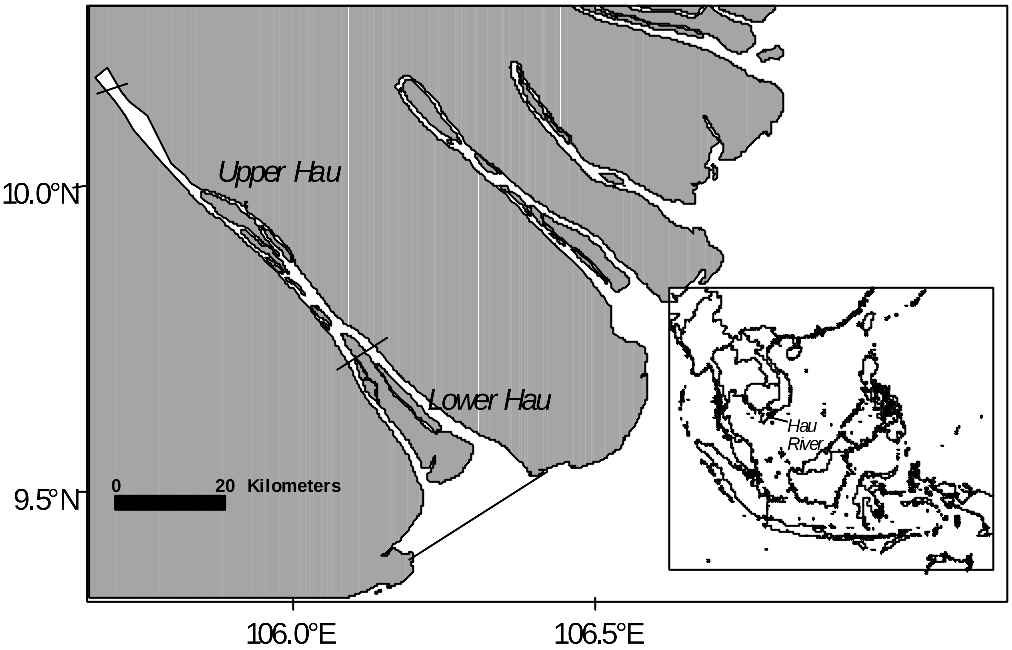

Figure 7.8. The Hau River estuary, Mekong Delta. Solid bars show the boundaries of the budgets.

Located in the monsoon tropical semi-equatorial climate zone, the climatic regime in the Hau River is dominated by the two monsoon seasons: the north-east (dry season, from December to April) and the south-west (rainy season, from May to November). Relative humidity is about 85-87% in the rainy season and below 80% in the dry season. The annual evaporation measures 1,000-1,200 mm by the Piche tool, and 1,500-1,800 mm by "A" pan or the Penman formula application. The annual average precipitation during the rainy season is about 1,450 mm within 100 to 110 rainy days. In Can Tho Province, the annual average precipitation is about 1,560 mm, with 1,440 mm in the rainy season. The annual average evaporation is about 1,070 mm, with evaporation in the rainy months of 700 mm (Pham Ngoc Toan and Phan Tat Dac 1975).

Methodology

The LOICZ procedure was applied to the entire basin of the Hau River estuary. The results and methods are discussed below.

Two-basin system

The two-basin system is described in the figures for the fluxes. Exchange between the surface and bottom layers occurs through the entrainment term ($V_{D'}Y_D$) and through the mixing term ($V_Z(Y_{syst\text{-}d} - Y_{syst\text{-}s})$). $V_{D'}$ and V_Z are volume entrained and volume mixing between the layers, respectively. $Y_{syst\text{-}s}$ and $Y_{syst\text{-}d}$ are the concentrations in the surface and bottom layers, respectively. Freshwater discharges into the surface layer are V_{Q*}, V_P and V_E. It is assumed that there is no internal loss or addition to the inflow in either layer. Thus the water budget is expressed as:

$$V_{Q*n} - V_{En} + V_{Pn} + V_{surf(n-1)} + V_{Dn} - V_{D(n-1)} - V_{surfn} = 0 \qquad (1)$$

where

$$V_{Q*n} = V_{Qn} + V_{On} + V_{Gn} \qquad (2)$$

Thus, for basin *n* bottom layer:

$$V_{Dn} - V_{D'n} - V_{D(n-1)} = 0 \qquad (3)$$

where the subscripts represent:

Q – river inflow
P – precipitation
E – evaporation
G – groundwater
O – other water

V_{surf1} is the inflow to the surface and V_{D1} is the outflow from the bottom layer for basin 2. V_{D2} represents the volume of inflow from the ocean. For the basin 1 (n=1), $V_{D0} = V_{surf0} = 0$, $V_{surf1} = V_{R1}$. For the well-mixed area $V_{Z1} = 0$.

The material budgets for the surface and bottom layers for basin 2 are:

$$dVY_{syst2\text{-}s}/dt = V_{Q*2}Y_{Q*2} - V_{E2}Y_{E2} + V_{P2}Y_{P2} + V_{D'2}Y_{syst2\text{-}d} + V_{Z2}(Y_{syst2\text{-}d} - Y_{syst2\text{-}s}) - V_{surf2}Y_{syst2\text{-}s} + \Delta Y_{surf2\text{-}s} \qquad (4)$$

$$dVY_{syst2\text{-}d}/dt = V_{D2}Y_{ocn\text{-}d} - V_{D'2}Y_{syst2\text{-}d} - V_{Z2}(Y_{syst2\text{-}d} - Y_{syst2\text{-}s}) - V_{D1}Y_{syst2\text{-}d} + DY_{syst2\text{-}d} \qquad (5)$$

$$V_{Q*2}Y_{Q*2} = V_{Q2}Y_{Q2} + V_{G2}Y_{G2} + V_{O2}Y_{O2} \qquad (6)$$

Where $DY_{syst2\text{-}s}$ and $DY_{syst2\text{-}d}$ are net internal sources or sink of the substance within the surface and bottom layers, respectively.

For water and salt budgets, we obtain an equation for the balance by setting Y to be S, $S_{En} = S_{Pn} = 0$, $\Delta S_{syst\text{-}d\ n} = DS_{syst\text{-}s\ n} = 0$ and dM/dt = dVS/dt = 0. Solving equation (2), (5) and (6), for the adjective outflow from the surface layer gives:

$$V_{surfn} = (V_{Q*n} + V_{Pn} - V_{En} + V_{surf(n-1)}) \text{ x } S_{syst\text{-}d\ (n-1)} / (S_{syst\text{-}d\ (n-1)} - S_{syst\text{-}s\ n}) \qquad (7)$$

Salinity and nutrient data for the Hau River estuary were collected during two cruises of the Cuu-long project in March and September, 1997.

Budgets were developed for the two sectors separately and for the two seasons separately to allow for variations in flow and concentration and large nutrient concentration gradients (see Webster *et al.* 1999). Finally the budgets were put together into annual averages.

Water and salt balance

The Hau River estuary is affected by the large flow of Mekong River and the tides of the South China Sea. In the rainy season, the annual flow in the Hau River occupies 90% of the total and peaks from

August to October (To Van Tuong 1997). In the dry season it is only 10%, with the lowest flows from March to April. The average total flow in the Mekong River at Phnom Penh is about 510,000x10^6 m^3 yr^{-1} (16,200 m^3 sec^{-1}) (Nguyen Viet Pho 1983; Nguyen Ngoc Huan 1991) but only about half of this runs into the Hau River (Pham Van Giap and Luong Phuong Hau 1996).

Salinity figures obtained in the dry season cruise show that tidal flow very strongly affects the Hau River estuary. The maximum salt intrusion into the river is during the lowest flow, from March to April, with a salinity level of 4 psu at a distance of about 40-60 km from the mouth (To Van Tuong 1997). In the salt intrusion area, the water is mixed up by two water budgets and divided into two layers: the freshwater budget in the surface layer and the seawater on the bottom layer. However, in the rainy season this mixed zone moves outside the mouth of the estuary.

Water and salt budgets for wet and dry seasons are illustrated in Figures 7.9 and 7.10. The key differences between the two seasons are apparent in evaporation, rainfall and runoff. River runoff dominates input factors in the surface layer of the upper area in both seasons. The marine water inputs dominate in the well-mixed lower area during the dry season.

The water exchange times in the Hau River estuary for every season can be calculated by following equation:

$$\tau = \frac{V_{System}}{(V_{Deep\,0} + \sum(V_{Q*n} + V_{Pn} + V_{En}))} \qquad (8)$$

Results are indicated in Table 7.3. The water exchange time of volume is about 14 days in the dry season and 4 days in the rainy season. The annual average water exchange time is 8 days calculated with 5 months dry season and 7 months wet season.

Table 7.3. Water exchange times for the Hau River estuary.

Season	**Water exchange times** (days)		
	Upper	Lower	Hau River estuary
Dry season (5 months)	8	9	14
Rainy season (7 months)	2	2	4
Annual			8

Budgets of nonconservative materials

DIP and DIN balance

Dissolved inorganic nutrients which behave nonconservatively can be assumed to be transported into and out of the system by the same general flows and mixing processes described for water and salt. The nutrient budgets for the wet and dry seasons are indicated in Figures 7.11 to 7.14. Due to the seasonal considerable differences in the water budgets there are corresponding differences in the nutrient budgets. It is likely that the nutrient budgets under the periods of high flow are not reliable because of the short water residence time. Note that under these conditions the nonconservative fluxes are small relative to the hydrographic fluxes.

In both seasons, the upper part of the Hau estuary receives nutrients from the local water mass as well as the DIN and DIP resources from the Mekong River.

In the lower part of the estuary, during the rainy season, DIP and DIN behave similarly to each other and to those in the upper part. The DIN and DIP resources in the lower part couple to those from the upper reaches and flow out to the South China Sea. These nutrient resources are necessary for the growth of phytoplankton in the coastal waters.

By contrast, during the dry season, in the lower part of the Hau estuary the exchange of nutrients occurs between water layers. The DIN behaviour differs from that of DIP. DIN on the bottom is moved to the surface. The value of sink DIN in the surface reveals that phytoplankton uses DIN for growth. The DIP in the deeper water of the ocean is not enough for active organisms, so DIP is obtained from the surface water and large amounts of DIP also come from the freshwater river inflow.

A summary of the nonconservative terms in each season is given in Tables 7.4 and 7.5. Thw data show that in both the upper and lower reaches of the estuary, DIN and DIP resources are sufficient for the growth of aquatic organisms. The very high residual nutrients have a potential impact on the coastal waters.

Table 7.4. Seasonal variation in non-conservative DIP fluxes (mmol $m^{-2}day^{-1}$) for the Hau River estuary.

Season	Lower			Upper	Both areas
	Surface	Deep	Surface+Deep		
Dry	+0.1	-0.1	-0.01	+0.2	+0.05
Rainy			+0.5	-0.06	+0.4
Annual			+0.3	+0.05	+0.2

Table 7.5. Seasonal variation in non-conservative DIN fluxes (mmol $m^{-2}day^{-1}$) for the Hau River estuary.

Season	Lower			Upper	Both areas
	Surface	Deep	Basin total		
Dry	-0.6	+0.4	-0.2	+0.3	-0.02
Rainy			+6.9	+18.4	+10.4
Annual			+3.9	+10.9	+6.1

Stoichiometric calculations of aspects of net system metabolism

If it is assumed that inorganic reactions are negligible within the estuary and that all the activity of nonconservative substance occurs as biological processes, then the *DDIP* value in the Hau River estuary is a measure of the net production in the system. The expected *DDIN* ($DDIN_{exp}$) can be *DDIP* multiplied by the N:P ratio of Redfield, ie $DDIN_{exp} = 16\ DDIP$. Large differences between $DDIN_{obs}$ and $DDIN_{exp}$ are indicators of other processes altering the fixed nitrogen. As nitrogen fixation and denitrification are important processes in coastal systems, the differences are taken as a measure of net nitrogen fixation minus denitrification:

$$(nfix\ -denit) = DDIN_{obs} - DDIN_{exp} = DDIN_{obs} - 16DDIP_{obs} \qquad (9)$$

The results of (*nfix-denit*) for each area are shown in Table 7.6. These results indicate that in the dry season the Hau River estuary is net denitrifying, with the greatest magnitude of denitrification occurring in the upper area, but in the lower area there is net nitrogen fixation on the bottom. By contrast, in the rainy season the lower part is net denitrifying and the upper is net nitrogen fixing. In general, the lower area is mostly dominated by denitrification, which seems reasonable, while the upper area alternates between two seasons. The wet season behaviour may not be reliable because of the large hydrographic flux.

Table 7.6. Stoichiometric analysis *(nfix-denit)* (mmol $m^{-2}day^{-1}$) for the Hau River Estuary.

Season	Lower			Upper	Both areas
	Surface	Deep	Basin total		
Dry	-2.2	+2.0	-0.2	-2.9	-0.8
Rainy			-1.1	+18.5	+4.1
Annual			-0.7	+9.6	+2.1

The net ecosystem metabolism (p-r) is calculated as the negative *DDIP* multiplied by the C:P ratio of the reacting organic matter. Assuming the bulk of the reacting organic matter is phytoplankton, the C:P ratio is 106:1. Thus:

$$(p\text{-}r) = -106\ DDIP \qquad (10)$$

For the Hau River estuary, (p-r) is shown in Table 7.7. Results show that the Hau River estuary is apparently a net respiration system. However, there are nutrient sources supplied to the ecosystem which are not analysed in this budget. These nutrients can be supplied from active economies (domestic, agriculture, aquaculture, industry and transport) to the studied area. Both phosphorus and nitrogen can be supplied from this source. Thus, it is important to obtain more data about groundwater and other water for the budget.

Table 7.7. Net ecosystem metabolism *(p-r)* (mmol $m^{-2}day^{-1}$) for the Hau River Estuary.

Season	Lower			Upper	Both areas
	Surface	Deep	Basin total		
Dry	-11	+11	0	-21	-5
Rainy			-53	+6	-42
Annual			-32	-5	-32

Acknowledgement

We would like to thank all staff of steering committee of EC-INCO-Cuulong project and LOICZ for their help to carry out the project and this report.

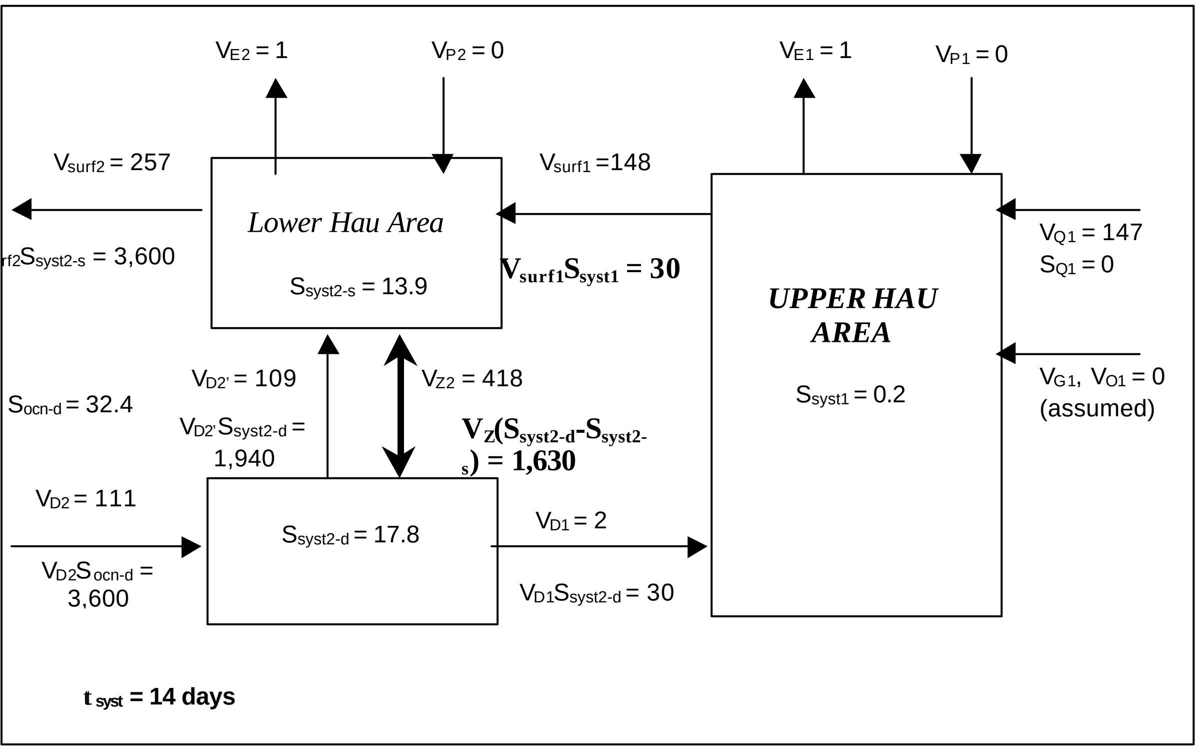

Figure 7.9. Water and salt budgets for the dry season in the Hau River estuary. Water fluxes in 10^6 m^3 day^{-1}, salt fluxes in10^6 psu m3 day^{-1} and salinity in psu.

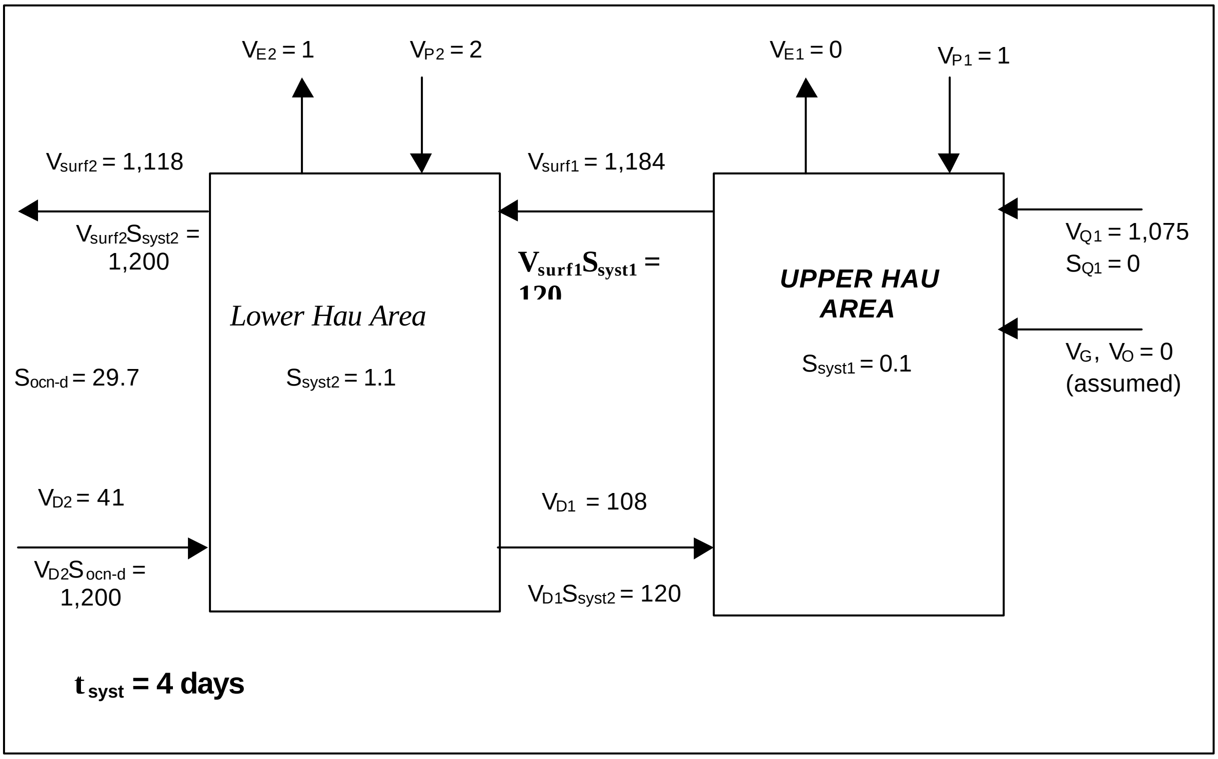

Figure 7.10. Water and salt budgets for the wet season in the Hau River estuary. Water fluxes in 10^6 m^3 day^{-1}, salt fluxes in10^6 psu m3 day^{-1} and salinity in psu.

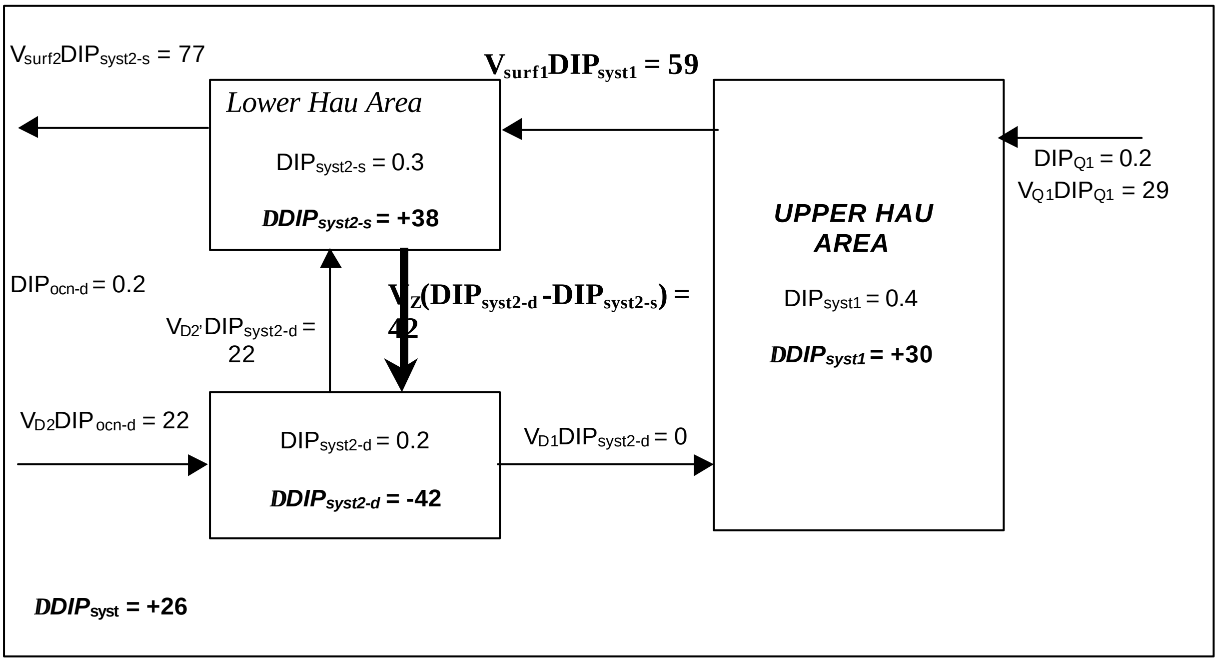

Figure 7.11. Dissolved inorganic phosphorus budget for the dry season in the Hau River estuary. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

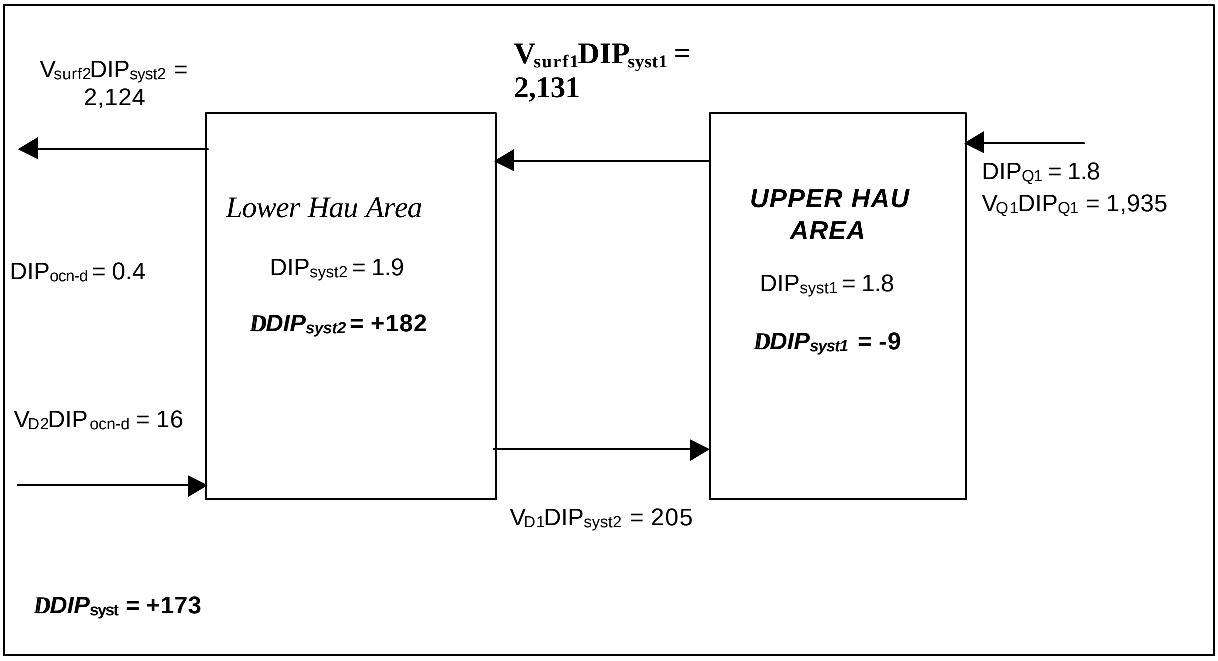

Figure 7.12. Dissolved inorganic phosphorus budget for the wet season in the Hau River estuary. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

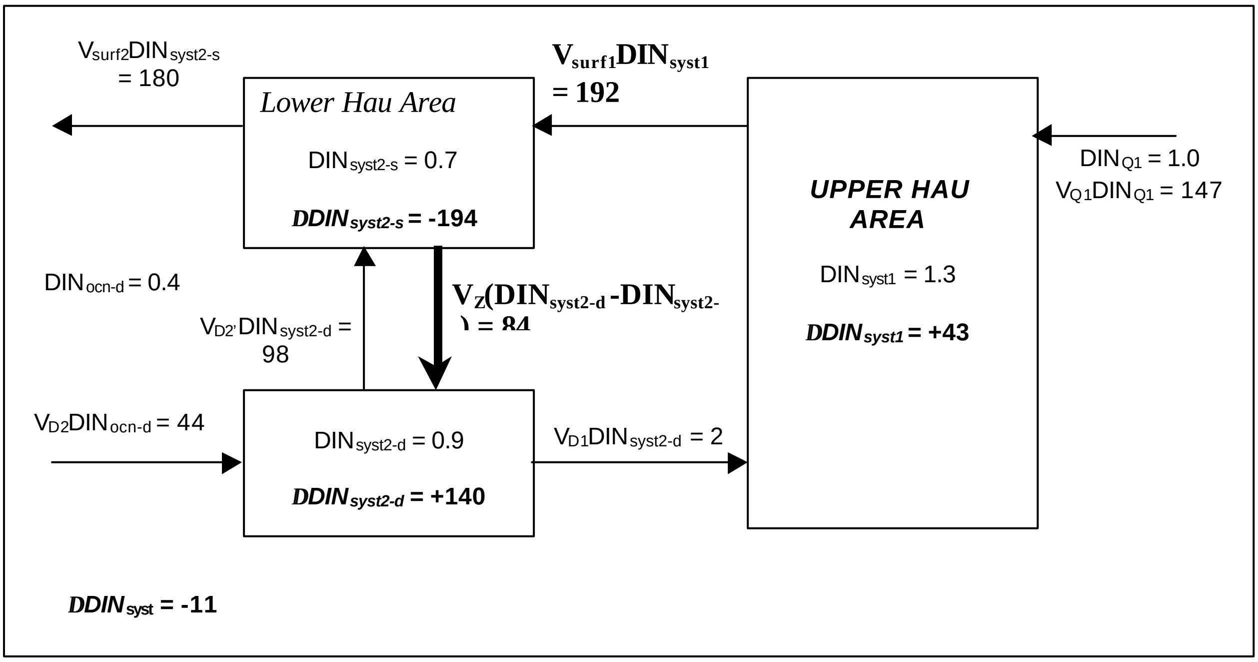

Figure 7.13. Dissolved inorganic nitrogen budget for the dry season in the Hau River estuary. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

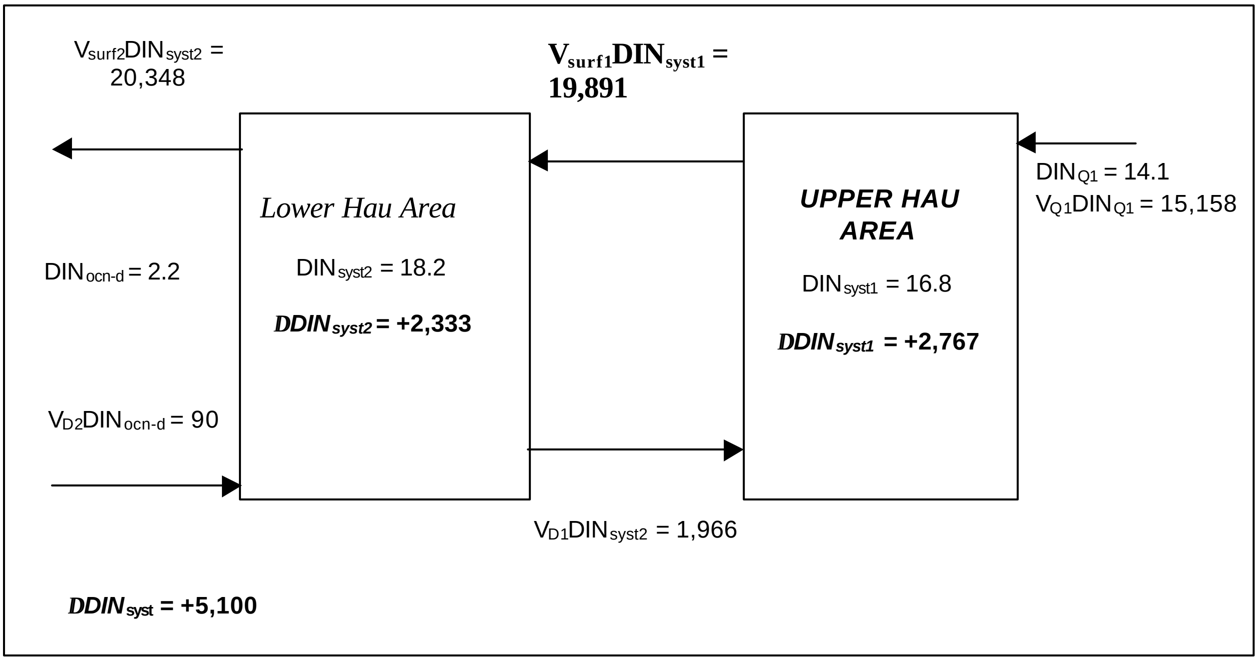

Figure 7.14. Dissolved inorganic nitrogen budget for the wet season in the Hau River estuary. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

7.3 NhaTrang Bay

Nguyen Huu Huan

Study area description

NhaTrang Bay is located in KhanhHoa Province, Vietnam (12.13°-12.32 °N, 109.18 °-109.37 °E) (Figure 7.15). It covers an area of about 376 km^2 of which the islands cover an area of 30 km^{2,}, with a net water area of 346 km^2 (Nguyen Khoa Dieu Huong *et al.* 1995; Nguyen Tac An *et al.* 1995). With a shoreline of more than 100 km, NhaTrang Bay has convenient conditions to develop coastal recreation, especially marine tourism and water sports. However, these are also conditions to pollute the marine environment Nguyen Tac An *et al.* 1995; Nguyen Khoa Dieu Huong *et al.* 1995). NhaTrang is already one of the relatively developed economic centres in central Vietnam, with industry, aquaculture, agriculture, tourism, etc.

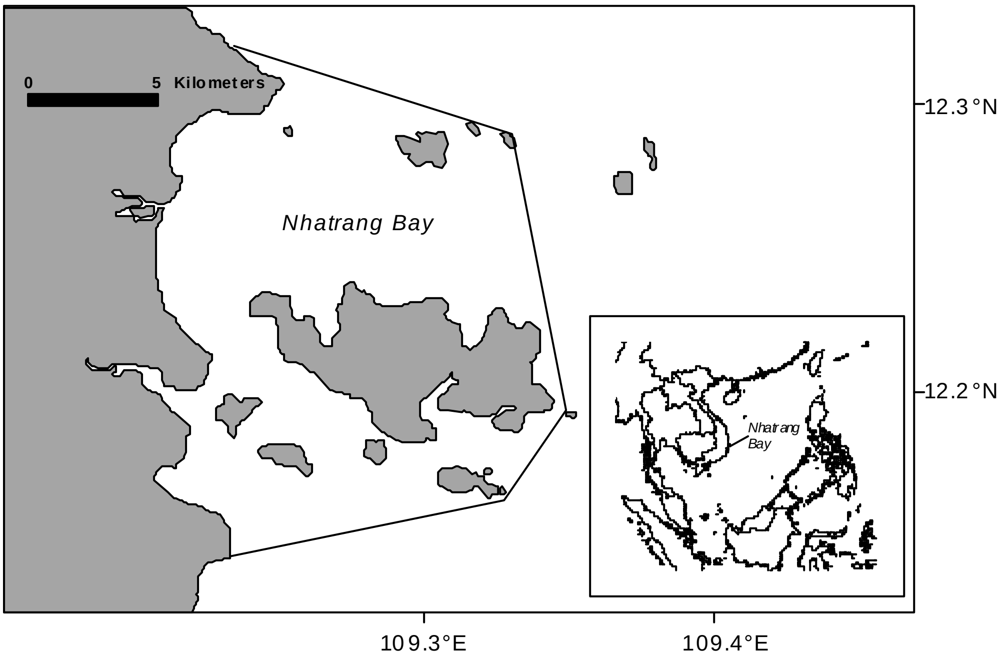

Figure 7.15. NhaTrang Bay. Solid line shows the boundary of the budgeted area.

Annual average precipitation is about 1,285 mm with about 117 rain days. Normally, the rainy season extends from September to December and the dry season from January to July. Annual evaporation is about 1,424 mm which exceeds precipitation (Nguyen Khoa Dieu Huong *et al.* 1995). Thus, in the dry season, salinity in NhaTrang Bay is usually higher than in the open ocean.

There are two river systems flowing into NhaTrang Bay: The Cai River flows into the north of the Bay and the Be River flows into the south. Total flow of the rivers is about $6x10^6$ m^3 day^{-1} of which about $5x10^6$ m^3 day^{-1} flows into NhaTrang Bay (Nguyen Khoa Dieu Huong *et al.* 1995).

Water and salt balance

Following the Biogeochemical Modelling Guidelines (Gordon *et al.* 1996), residual flows were $-12x0^6$ m^3 day^{-1} and $-3x10^6$ m^3 day^{-1} for the wet and dry seasons respectively.

For the salt balance, mixing of salt between the bay and the ocean must balance with the salt of residual flow. Thus:

$V_{R1} = (-9.9 - 2.8 + 1.3) \times 10^6 = -11.4 \times 10^6\ m^3\ day^{-1}$ in the rainy season

$V_{R2} = (-2.9 - 0.5 + 1.4) \times 10^6 = -2.0 \times 10^6\ m^3\ day^{-1}$ in the dry season.

Mixing volume is 178x10^6 m^3 day^{-1} for the rainy season and 101x10^6 m^3 day^{-1} for the dry season. Table 7.8 summarises the water budget for the bay for both seasons. Figures 7.16 and 7.17 represent the water and salt budgets for the wet and dry seasons, respectively.

The exchange time of water in the Bay is 37 days during the wet season and 67 days during the dry season.

Table 7.8. Water volume fluxes for NhaTrang Bay. (Nguyen Khoa Dieu Huong *et al.* 1995)

	Wet 10^6 m^3 day^{-1}	Dry 10^6 m^3 day^{-1}
V_P	3	1
V_E	-1	-1
V_Q	10	3
V_G, V_O	0	0
V_X	178	101

Budgets of nonconservative materials

DIP and DIN budgets were calculated using the data in table 7.9.

DIP balance

Figures 7.18 and 7.19 represent the DIP budgets for the wet and dry seasons respectively. The bay seems a source for DIP for both wet and dry seasons; *ΔDIP*(wet) = +99x10^3 mol day^{-1} or +0.3 mmol m^{-2} day^{-1} in the wet season, and *ΔDIP*(dry) = +18x10^3 mol day^{-1} or +0.05 mmol m^{-2} day^{-1} in the dry season.

DIN balance

Figures 7.20 and 7.21 illustrate the DIN budgets for the wet and dry seasons, respectively. The bay seems to be a sink of DIN for both seasons: *ΔDIN*(wet) = -130x10^3 mol day^{-1} or -0.4 mmol m^{-2} day^{-1} in the wet season and *ΔDIN*(dry) = -374x10^3 mol day^{-1} or -1.1 mmol m^{-2} day^{-1} in the dry season.

Table 7.9. Nutrient concentrations for NhaTrang Bay. (Nguyen Tac An *et al.* 1995; Phan Van Thom *et al.* 1996; Nguyen Huu Huan 1997; Nguyen Huu Huan 1998)

	DIP (mmol m^{-3})		DIN (mmol m^{-3})	
	Wet	Dry	Wet	Dry
River	1.4	1.0	26.7	3.8
Bay	0.8	0.4	10.0	5.1
Ocean	0.2	0.2	9.9	8.9
Others	0	0	0	0

Stoichiometric calculation of aspects of net system metabolism

If the positive *ΔDIP* values in NhaTrang Bay are a measure of the net organic matter oxidation in the system, and based on the Redfield N:P ratio, then the expected *ΔDIN* values (ΔDIP_{exp}) would be 16x*ΔDIP*. On the other hand, the *ΔDIN* calculated using the water and salt balance represents the *ΔDIN* observed (ΔDIP_{obs}).

The (*nfix-denit*) estimates for NhaTrang Bay are -5.0 mmol N m^{-2} day^{-1} for the wet season and -1.9 mmol N m^{-2} day^{-1} for the dry season. These calculated results showed that this system is denitrifying more than it is fixing nitrogen. With 117 rainy days and 248 dry days, the annual average (*nfix-denit*) is -2.9 mmol m^{-2} day^{-1}or -1.1 mol m^{-2} yr^{-1}.

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

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

*wh*ere $(C:P)_{part}$ represents the composition of particles decomposing in the system.

Taking the particle composition as the Redfield ratio (C:N:P = 106:16:1) and based on equation 11, the estimates of *(p-r)* each season of year are -30 mmol C m^{-2} day^{-1} for the wet season and -6 mmol C m^{-2} day^{-1} for the dry season. The system appears to be net heterotrophic in both the rainy and dry seasons. The annual average is -13 mmol m^{-2} day^{-1} or -5 mol m^{-2} yr^{-1}.

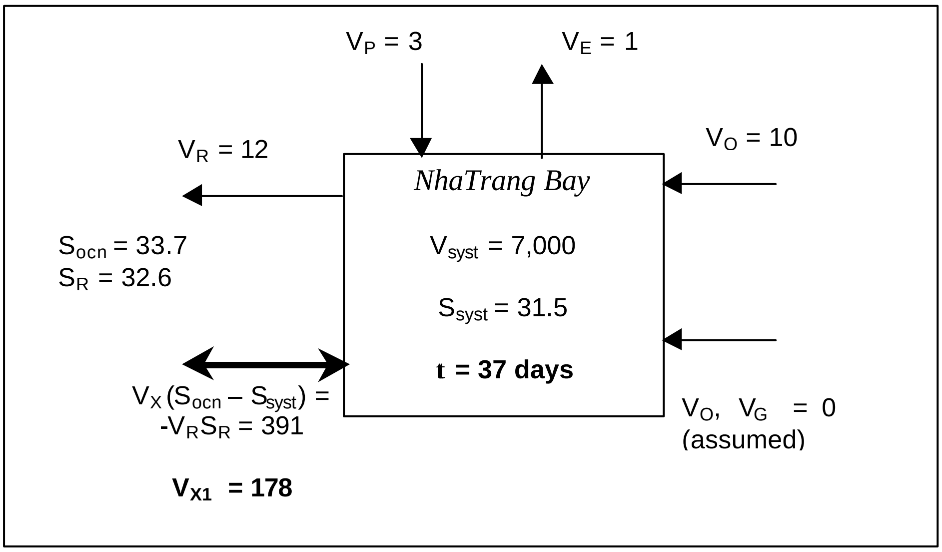

Figure 7.16. Water and salt budgets for NhaTrang Bay for the wet season. Volume in 10^6 m^3, water fluxes in 10^6 m^3 day^{-1}, salt fluxes in 10^6 psu-m^3 day^{-1} and salinity in psu.

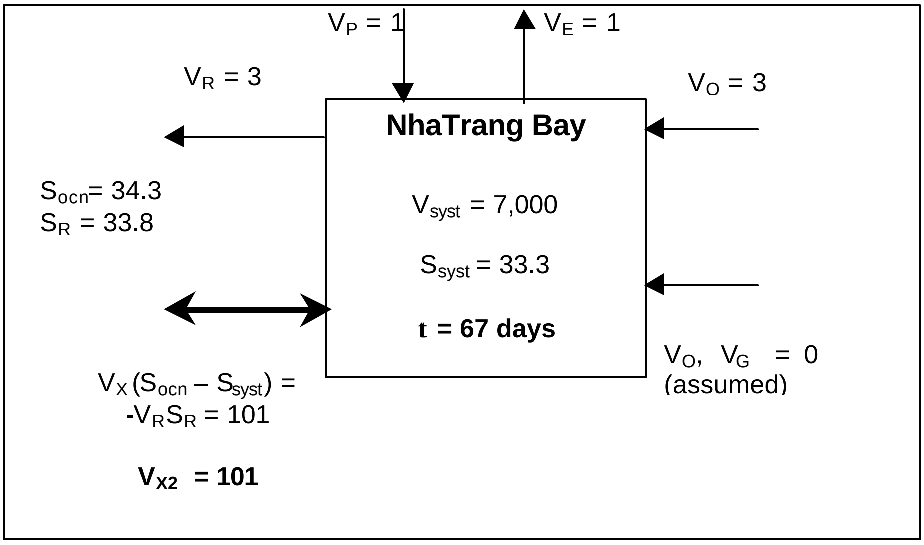

Figure 7,17. Water and salt budgets for NhaTrang Bay for the dry season. Volume in 10^6 m^3, water fluxes in 10^6 m^3 day^{-1}, salt fluxes in 10^6 psu-m^3 day^{-1} and salinity in psu.

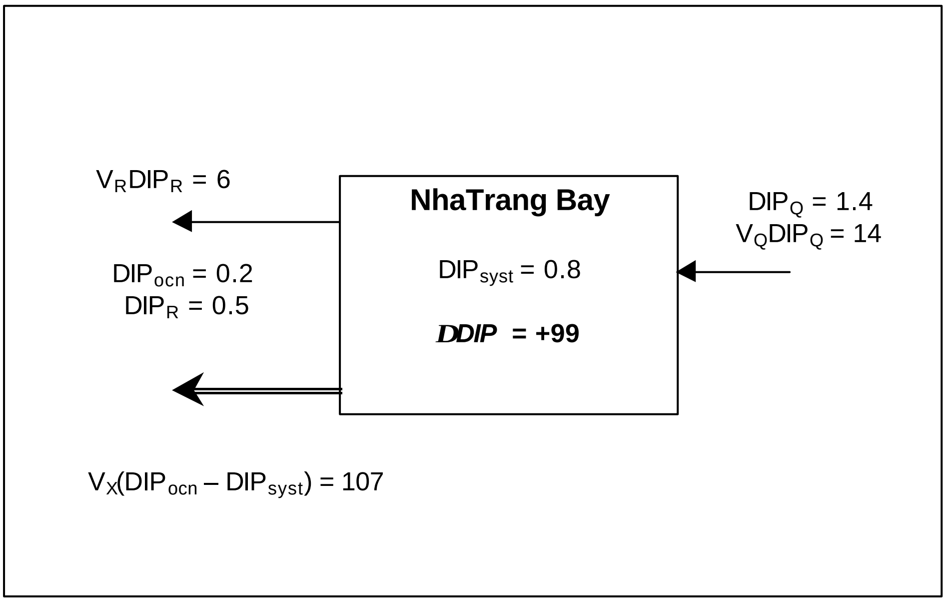

Figure 7.18. Dissolved inorganic phosphorus budget for NhaTrang Bay for the wet season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

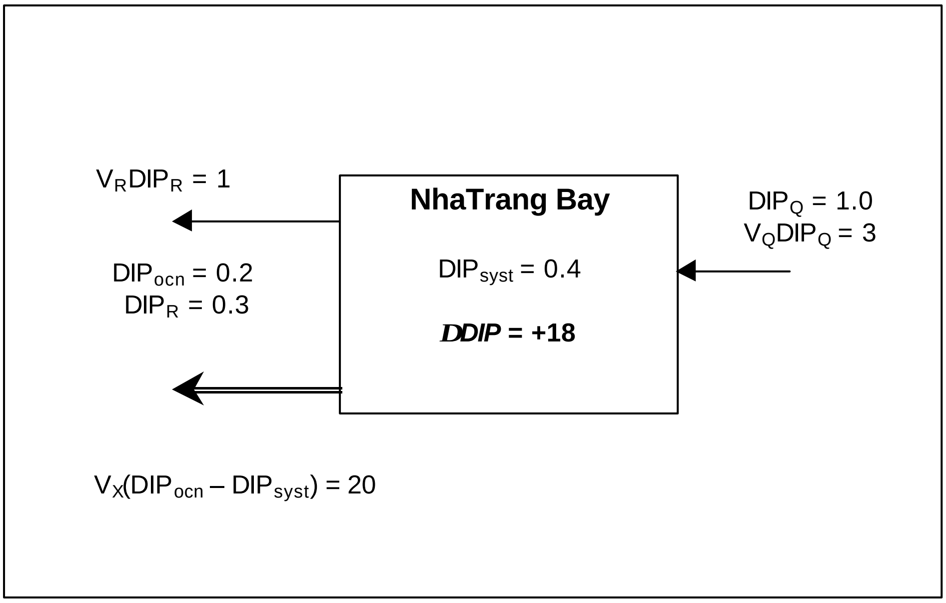

Figure 7.18. Dissolved inorganic phosphorus budget for NhaTrang Bay for the dry season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

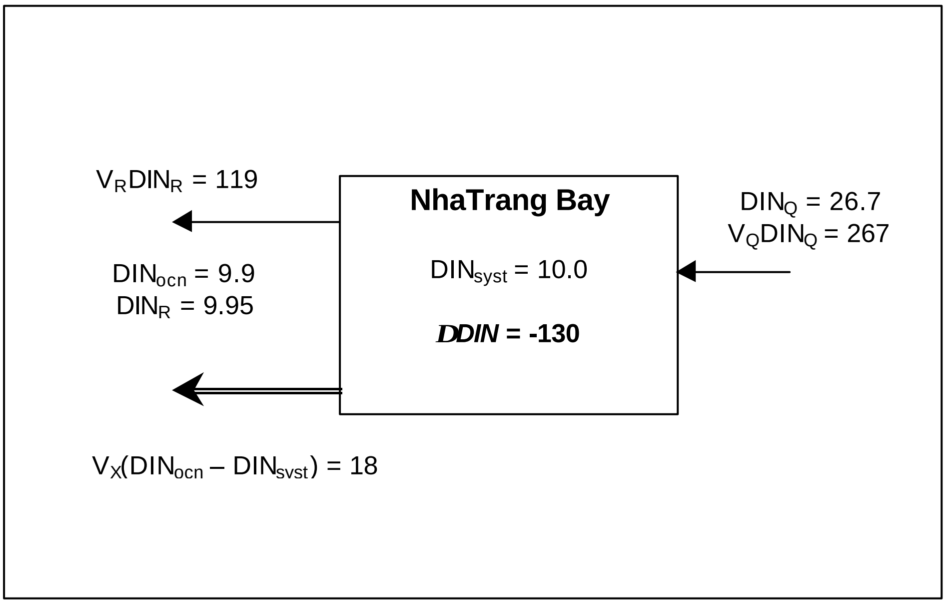

Figure 7.20. Dissolved inorganic nitrogen budget for NhaTrang Bay for the wet season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

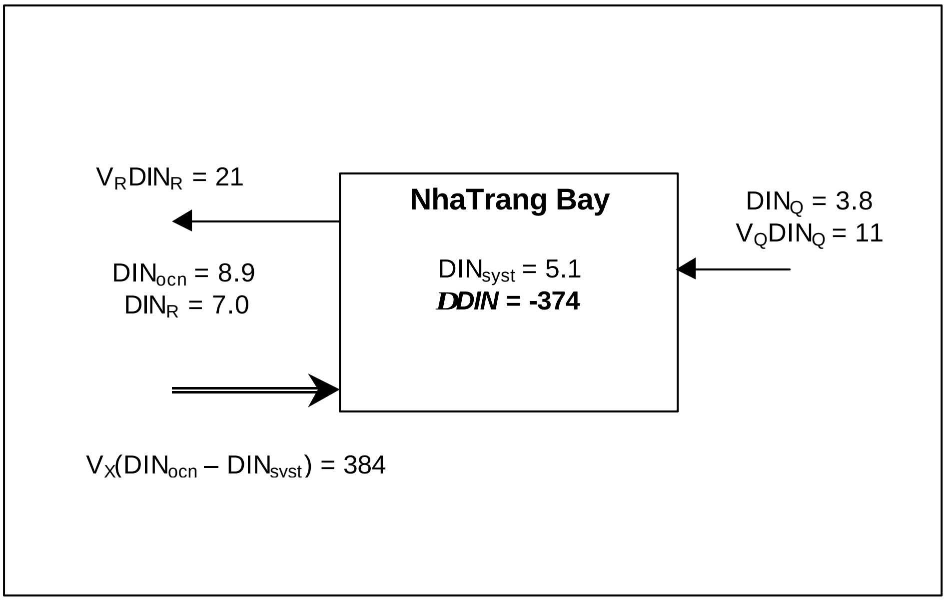

Figure 7.21. Dissolved inorganic nitrogen budget for NhaTrang Bay for the dry season. Fluxes in 10^3 mol day^{-1} and concentrations in mmol m^{-3}.

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APPENDICES

Appendix I. A preliminary typology of watersheds of the South China Sea

Liana Talaue-McManus

The coastal waters of the South China Sea occupy about 1.9×10^6 km^2, from shallow areas to the continental and insular shelves at 200 m deep (Pauly and Christensen 1993). On land in seven littoral countries, about 2.5×10^6 km^2 of catchment or watershed areas interact with this marginal sea through a network of about 130 major rivers that deliver fresh water, nutrients, sediments and pollutants to the coast (Table I.1). About 270,000,000 people or 5% of the world's population live in the coastal region of the South China Sea, which harbors the world's highest marine biodiversity and provides for 10% of the global capture fisheries and 55% of the world's coastal culture production. Rapid population growth (up to 2.7% per year in Cambodia), habitat loss and conversion, overexploitation and land-based pollution are among the major threats to the coastal zone of this basin (Talaue-McManus 1999).

This study attempts to classify 127 watersheds surrounding the South China Sea using available data on watershed areas, annual ranges of temperature and rainfall, annual total precipitation and annual river discharge. Data were obtained from the national reports of China, Cambodia, Vietnam, Thailand, Malaysia, Indonesia and the Philippines (submitted to the United Nations Environment Programme for the South China Sea Project, 1999), the NCDC Website, Guidebook on Water Resources, Use and Management in the Asia-Pacific (UN 1995), and David (this volume). Because the data had values in different units, these were transformed to z-scores before running the cluster analysis (Multi-Variate Statistical Package by Kovach Computing Services 1985-1999). A minimum variance method was used to identify groups with minimum within-cluster variation and maximum between-cluster variation (Hair *et al*. 1995).

Figure I.1 shows the 12 clusters discriminated by the typology analyses. These were done with and without the three big rivers, namely the Mekong, Pearl and Red Rivers. When included in the analysis, these rivers separate out as individual clusters as indicated by the arrows. Their removal does not alter the classification pattern, which is shown in Table I.2. It is heavily influenced by total annual rainfall. Climatologically as well as mathematically, this is expected since one rainfall value applies to a number of adjacent watersheds. The use of the same value for a geographic subdivision subsuming more than one watershed minimizes variation within this subdivision.

Figure I.2 shows rainfall distribution around the South China Sea. Continental countries like China, Vietnam except for its southern tip, Cambodia and Thailand have relatively less rainfall than archipelagic countries like the Philippines and Indonesia. The big island of Kalimantan (the states of Sabah and Sarawak) and peninsular Malaysia likewise have high rainfall (>2000 mm per year). A graphical representation of the 12 clusters shows the same pattern of classification discriminated by rainfall alone (Figure I.3).

The identification of sub-clusters seems to be influenced by temperature minima and maxima. This is evident in the manner which low rainfall identified clusters. Cluster E consisting of small rivers draining into Lingayen Gulf separated out from the high rainfall cluster because of a wide temperature range of 18-35°C, in contrast to the former where temperature did not fall below 20°C.

The influences of watershed area and discharge volume were less evident, as these were perhaps the most variable among the input data. Their effect on cluster discrimination becomes visible only when rainfall and temperature ranges are similar among watersheds. Thus, the big and small rivers of the Red River Delta separated out and formed clusters G and H respectively.

This typology exercise is the beginning of an attempt to classify coastal zones and their associated watersheds in a globally significant region and to quantify the role of these in biogeochemical processes that interact with economic systems. Widely available data to characterize coastal features and processes will be incorporated in subsequent analysis to refine the classification presented here and to allow for upscaling site-specific rates at which these processes proceed.

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Table 1. Geographic subdivisions of seven countries surrounding the South China Sea including associated catchment (watershed areas) (modified from Talaue-McManus 1999).

Country	**Major Cities (>100,000 population)**	**Major rivers**	**Watershed area (10^3 km^2)**	**Area of South China Sea subregion (10^3 km^2)**	**Population of subregion (10^3)**
Cambodia	3 cities	7 rivers	13.41	17.24	840
China (includes Hong Kong and Macau)	21 cities	11 rivers	518.72	137.61	65,354
Indonesia	7 cities	5 rivers	60.37	477.48	99,370
Malaysia	6 cities	51 rivers	231.42	280.47	8,787
Philippines	16 cities	10 rivers	30.30	50.05	23,632
Thailand	14 cities	18 rivers	320.55	321.93	37,142
Viet Nam	26 cities	25 rivers	1,289.08	137.95	32,558
Total	93 cities	127 rivers	2,463.85	1,422.73	267,683

Table 2. Classification of watersheds draining into the South China Sea.

Cluster	**Watershed, Location**	**Annual temp range(°C)**	**Annual rainfall range (mm)**	**Total annual rainfall (mm)**	**Discharge (km^3 yr^{-1})**
WARM, HIGH RAINFALL CLUSTERS (>2000 mm)					
A	Ilocos region, Phil.; Terengganu and Kelantan, Malaysia	22-27	23-1161	>4500	2-10
B	Sabah, Malaysia	27-28	112-465	3573	6
C	Johore and Pahang Malaysia; South Thailand; Mekong Delta, Vietnam; Jakarta and East Java, Indonesia	25.5-28.5	99-429	2029-2415	5-36
D	Sarawak, Malaysia; West and South Kalimantan, and Bangka-Belitung, Indonesia	25.5-28	152-610	3904-4172	3-22
COOL TO WARM, LOW RAINFALL CLUSTERS (generally <2000 mm)					
Big Rivers	Mekong River, Vietnam; Pearl River, China	13.7-29.8	257-1407	1372-1407	350-550
E	Lingayen Gulf Rivers, Philippines	18-35	1-800	2500	0-7
F	North Vietnam	7.1-21	0-137	615	1-2
G	Big rivers of the Red River Delta, Vietnam	16.5-29.5	18-343	1682	26-56
H	Small rivers of the Red River Delta, Central coastal Vietnam; Hainan, China	16.5-29.5	0.2-343	1383-1682	2-38
I	Guangxi and Guangdong, China	13.7-29.8	1-393	1372-1414	2-24
J	North Thailand	21-29	0-249	1081	1-10
K	South Central Vietnam, Central Philippines	25.5-29.5	3-432	1983-2085	5-30
L	East and Central Thailand; Cambodia	26-29.5	5-305	1397-1407	0-10

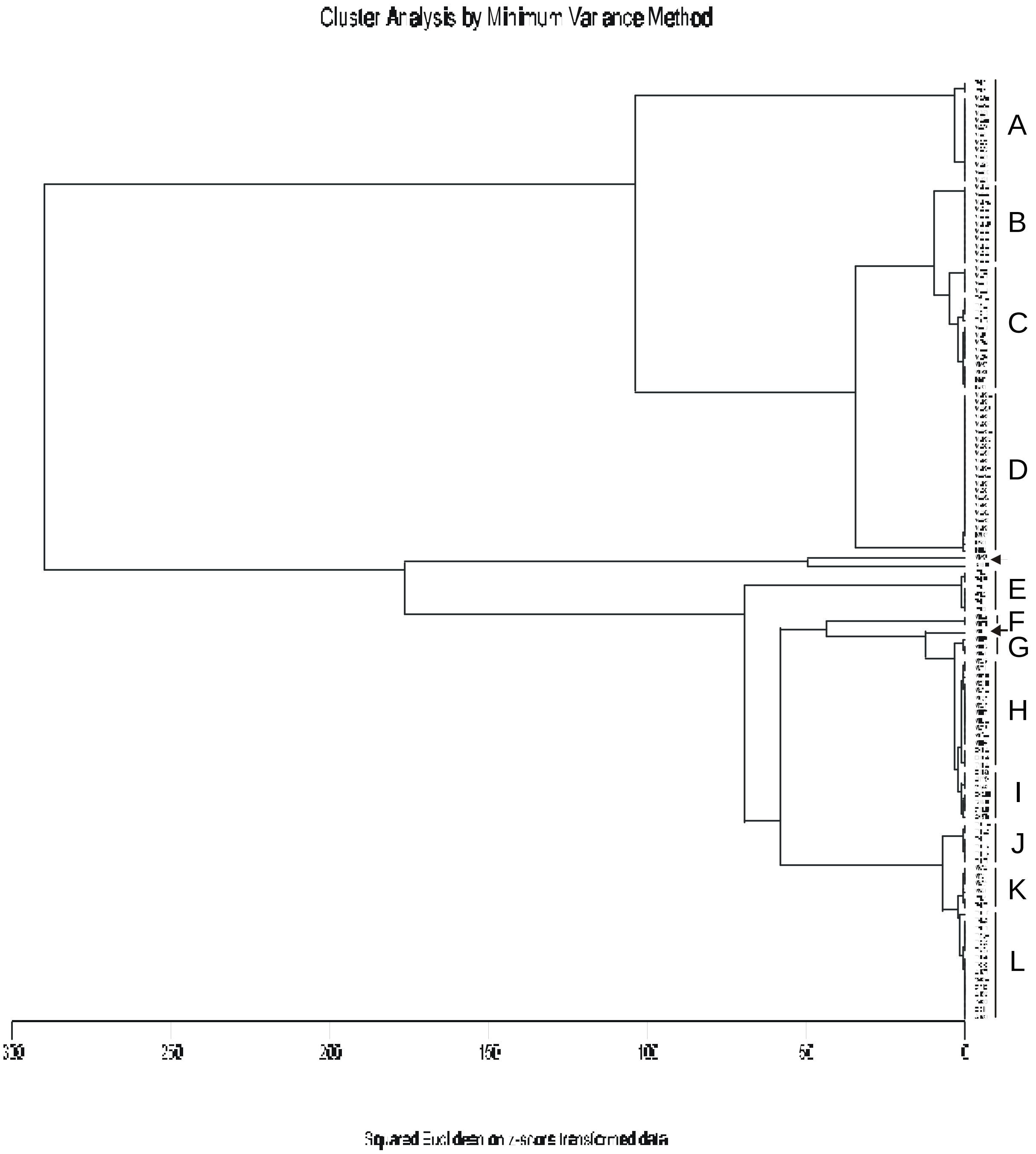

Figure I.1. The 12 clusters discriminated by the typology analyses, with and without the three big rivers (Mekong, Pearl and Red). The big rivers, when included, separate out as individual clusters as indicated by the arrows.

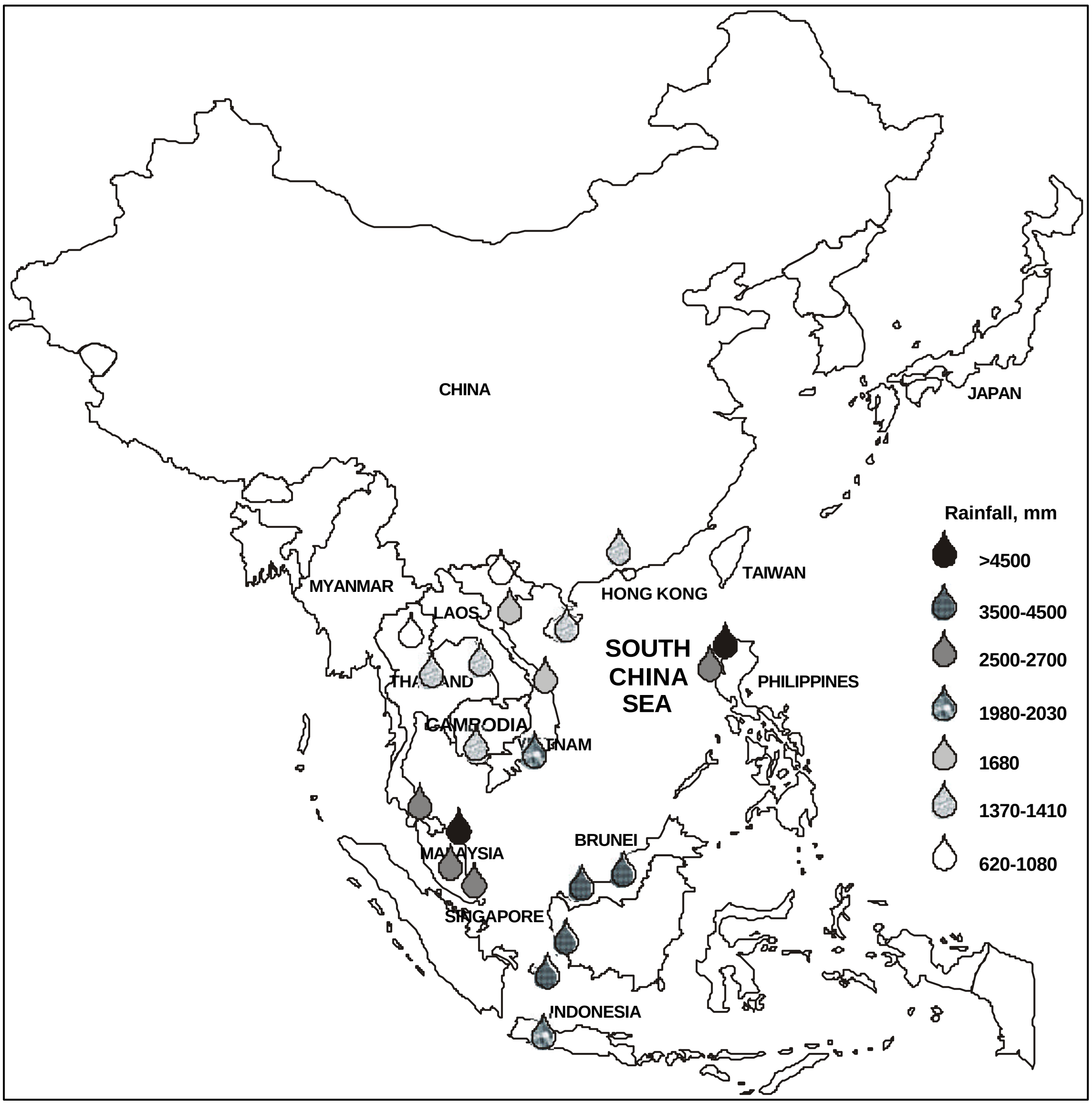

Figure I.2. Rainfall distribution around the South China Sea.

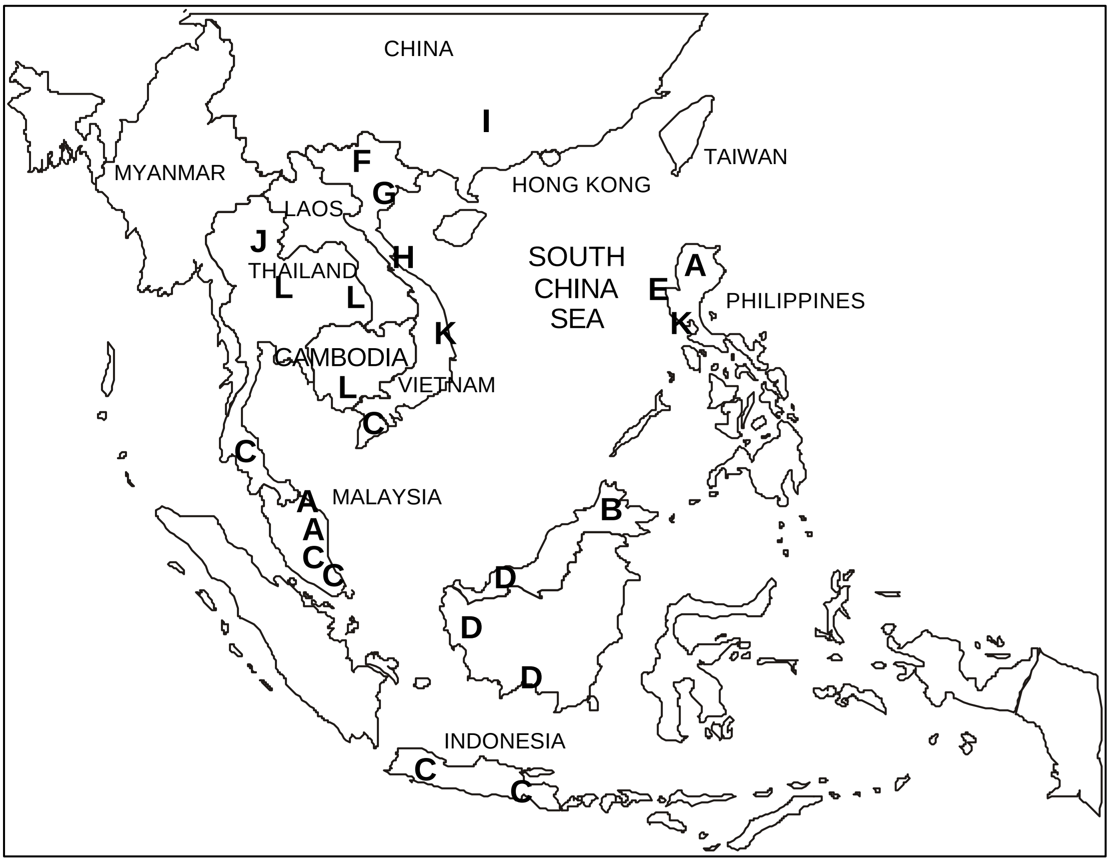

Figure I.3. Rainfall patterns in the South China Sea region. Letters indicate areas with similar rainfall.

Appendix II Estimation of Waste Load

M.L. San Diego-McGlone

In many systems, organic material and nutrient load from domestic, agricultural, or industrial wastes are important but poorly characterized portions of biogeochemical budgets. This section presents a procedure for estimating N and P loading from these wastes using information on economic activities.

The discussion below describes what is termed a Rapid Assessment method of determining effluent generation from economic activities. It should be noted that economic activities maybe either productive (creation of a physical item, or a service) or consumptive (use of a physical product, or a service) in nature. An effective approach to this task is to first take an inventory of activity types within the study area, and to then compare this inventory with similar previous studies and databanks (see, for example WHO 1993). Economic sectors that are typically important include households (in particular, household wastes that result from consumption activities), agriculture (from accelerated erosion of disrupted soils, fertilizer runoff, livestock feeds and waste), food processing, forestry, leather and textile manufacture and aquaculture.

After the relevant sectors have been identified, the activity level of each sector is determined. An example of activity level is the size of the population that generates waste. Information on activity level is typically obtained from government statistics (preferably at a local level that best matches the area of the study site), but could also be obtained through surveys of the producing or consuming entities.

After the activity levels have been determined, they are matched with the appropriate effluent discharge coefficient (effluent per unit of activity). A listing of some of these coefficients is given in Table II.1. Total effluent discharge is then calculated as:

Total effluent discharge = activity level x discharge coefficient

For example, the generation of sewage-derived N may be found as:

Total N = population x 4 kg N person^{-1} year^{-1}

Another example, the generation of P from prawn aquaculture is given as:

Total P = prawn harvest (tons) x 4.7 kg P per ton harvest.

For the nitrogen example, the effluent coefficient is from World Bank (1993). For the P example, the effluent coefficient is from Gonzalez *et al.* (1996). The Gonzalez study is an example of a locally-determined (for the Philippines) effluent coefficient. Locally derived coefficients, when available, are generally preferred as they should better reflect local conditions. When local coefficients are not available, sources such as WHO (1993) and World Bank (1993) can be used.

After effluents are generated, they are discharged to the environment, where they undergo some degree of assimilation before reaching coastal waters. Assimilation levels depend upon a wide variety of factors, including the path through which they flow (groundwater or surface water) and the type of treatment they receive upon discharge (such as sewage treatment plants or septic tanks). Assimilation levels during movement through groundwater or surface water paths are likely to be quite site-specific, and information is typically lacking in this regard. According to Howarth *et al.* (1996), nitrogen fluxes in rivers are on the average only 25 % of anthropogenic inputs, thereby implying 75 % assimilation. In areas where waste from economic activities may be directly discharged into coastal waters, the percentage assimilation could be much less.

Since only the inorganic forms of N and P in effluent wastes are considered in the DIN and DIP budgets, the TN and TP values generated from economic activities must be converted to their inorganic fraction. Table 2 presents the stoichiometric ratio among the different forms of N and P scaled to TN and TP. These ratios were derived from various types of organic wastes and they may be used in the conversion. The example given below uses the PO_4:TP ratio (0.5) given in the table.

If 2000 mt yr^{-1} TP is generated by economic activities,
2000 mt yr^{-1} TP = 2 x 10^9 g yr^{-1} TP
2 x 10^9 g yr^{-1} TP ÷ 31 g /mol P = 64 x 10^6 mol yr^{-1} DIP
64 x 10^6 mol yr^{-1} DIP x 0.5 (PO_4:TP) = 32 x 10^6 mol yr^{-1} DIP

In cases where only the BOD information in waste is available, conversions to DIN and DIP can also be done. BOD is converted to TN using a stoichiometric ratio in organic waste of 0.5 (Table 3). The TP:BOD ratio is 0.042 (Table 3). With a TOC:BOD ratio of 1.7 (Table 3), organic waste from various sources has a C:N:P ratio of 40:12:1. Once the TN and TP are derived, subsequent steps as shown above can be used to convert into the DIN and DIP fractions.

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Table II.1. Effluent discharge coefficients for some economic activities.

Economic Activity	**Discharge Coefficient**	**Source**
Household activities		
- solid waste	1.86 kg N person^{-1} yr^{-1}	Sogreah, 1974
	0.37 kg P person^{-1} yr^{-1}	Padilla *et al.* 1997
- domestic sewage	4 kg N person^{-1} yr^{-1}	World Bank 1993
	1 kg P person^{-1} yr^{-1}	World Bank 1993
- detergent	1 kg P person^{-1} yr^{-1}	World Bank 1993
Urban runoff (unsewered areas)	1.9 mg N/(liter runoff)	Gianessi and Peskin 1984
	0.4 mg P/(liter runoff)	Gianessi and Peskin 1984
Livestock		
- piggery	7.3 kg N head^{-1} yr^{-1}	WHO 1993
	2.3 kg P head^{-1} yr^{-1}	WHO 1993
- poultry	0.3 kg N bird^{-1} yr^{-1} (boilers)	Valiela *et al.* 1997
	0.7 kg N bird^{-1} yr^{-1} (layers)	Valiela *et al.* 1997
Aquaculture	5.2 kg N/(ton of prawn harvest)	Gonzales *et al.* 1996
	2.9 kg N/(ton of milkfish production)	Padilla *et al.* 1997
	4.7 kg P/(ton of prawn production)	Gonzales 1996
	2.6 kg P/(ton of milkfish production)	Padilla and Tanael 1996
Non-point agricultural runoff	1.68 kg N/(ton of soil eroded)	Padilla *et al.* 1997
	0.04 kg P/(ton of soil eroded)	Padilla *et al.* 1997

Table II.2. Stoichiometric ratio among different forms of N and P scaled to TN and TP where the 95% confidence criterion is satisfied.

	Category*	**n**[b]	**Ratio**[c]	**CD**[d] **(F test)**
TKN:TN	**1**	**4**	**1.0**	**0.9999 (1%)**
	4	**12**	**0.96**	**0.9895 (1%)**
	1, 4	**16**	**0.97**	**0.9983 (1%)**
(NO_3+NO_2):TN	**1**	**9**	**0.01**	**0.8893 (1%)**
NH_4:TN	**1**	**15**	**0.24**	**0.8533 (1%)**
	4	**18**	**0.55**	**0.7331 (1%)**
	1, 4	**33**	**0.38**	**0.9101 (1%)**
PO_4:TP	**1**	**8**	**0.45**	**0.8466 (1%)**
	4	**11**	**0.54**	**0.8113 (1%)**
	1, 4	**19**	**0.50**	**0.9164 (1%)**

[a] Categories:
1 = Animal Agriculture and Livestock Production
2 = Food, Tanneries, Leather, Wood mfg., Paper mfg.,
3 = Industrial Chemicals
4 = Sanitary Services

[b] number of data points

[c] stoichiometric ratio (molar)

[d] coefficient of determination

(from San Diego-McGlone *et al.* 1999)

Table II.3. Stoichiometric ratio of variables scaled to BOD where the 95% confidence criterion is satisfied.

	Category[a]	N[b]	Ratio[c]	CD[d] (F test)
COD:BOD	1	14	3.5	0.9750 (1%)
	2	10	2.3	0.8750 (1%)
	3	5	2.9	0.8648 (5%)
	4	24	2.3	0.9532 (1%)
	1, 4	38	2.7	0.9707 (1%)
	1, 2, 3, 4	53	2.6	0.9608 (1%)
TN:BOD	1	10	0.64	0.8807 (1%)
	4	23	0.44	0.9819 (1%)
	1, 4	33	0.50	0.9698 (1%)
TP:BOD	1	18	0.20	0.7838 (1%)
	2	10	0.004	0.5493 (5%)
	4	30	0.038	0.9674 (1%)
	1, 4	48	0.071	0.8764 (1%)
	1, 2, 3, 4	62	0.042	0.7315 (1%)
TOC:BOD	2	5	2.1	0.9758 (1%)
	4	5	1.4	0.9770 (1%)
	2, 4	10	1.7	0.9888 (1%)
TKN:BOD	1, 4	26	0.35	0.5741 (1%)
NH_4:BOD	4	23	0.23	0.4601 (1%)
PO_4:BOD	1	9	0.06	0.5586 (5%)
	4	14	0.04	0.8938 (1%)
	1, 4	23	0.04	0.7543 (1%)

[a] Categories:
1 = Animal Agriculture and Livestock Production
2 = Food, Tanneries, Leather, Wood mfg., Paper mfg.,
3 = Industrial Chemicals
4 = Sanitary Services

[b] number of data points

[c] stoichiometric ratio (molar)

[d] coefficient of determination

(from San Diego-McGlone *et al.* 1999)

Appendix III Calculation of River Discharge

Laura T. David

For many a study area, often there is incomplete information on river discharge, if any data exist at all. This especially holds true for watershed areas of developing countries, as well as areas that are not readily accessible. The former case is of great interest because most of these areas are also those that suffer from high anthropogenic impacts, while the latter is also of interest because these areas most probably represent the more pristine areas. Together they provide the extremes of the spectrum.

One way of circumventing this shortcoming is to apply a simple climatological model (Schreiber 1904; Sellers 1965; Holland 1978; Kjerfve 1990). The minimum raw data required as input parameters are: monthly precipitation, monthly atmospheric temperature, total watershed area. The latter can be calculated using a topographic map, making the highest points surrounding the river system indicators for the natural boundary for the watershed (See Figure III.1 for an example).

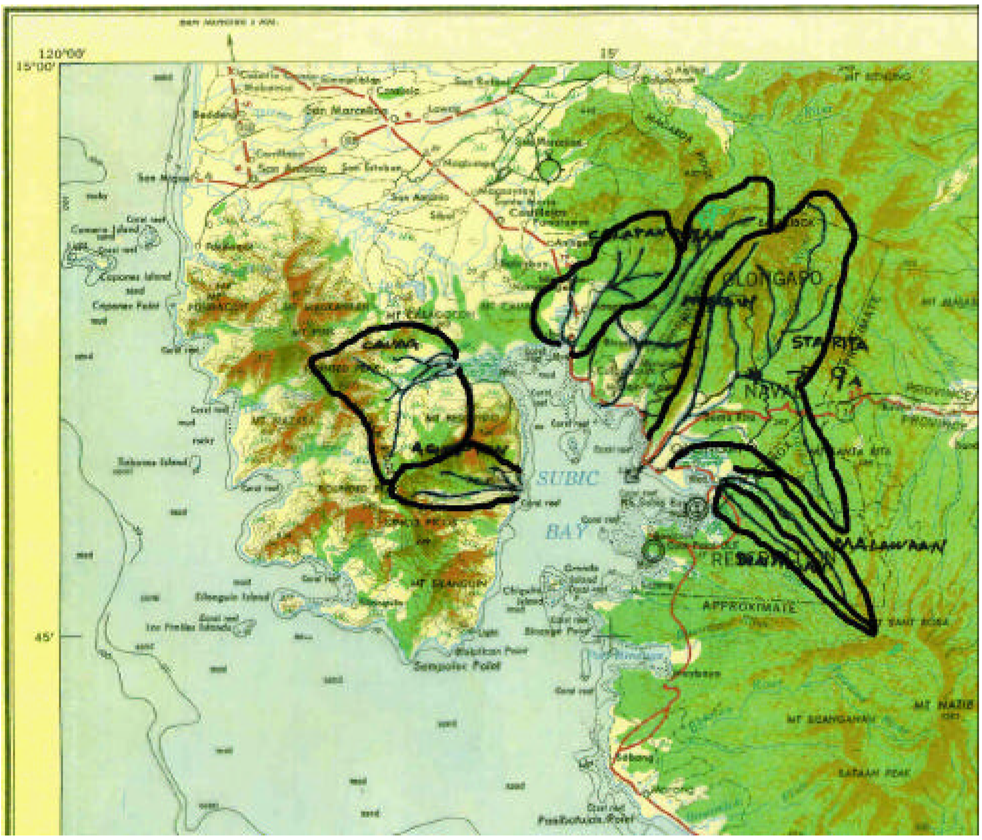

Figure III.1 Watershed calculations for Subic Bay, Philippines.

The following equations can then be used to calculate for the annual mean discharge in $m^3\ yr^{-1}$.

$$q_R = A_x (\Delta f/r)\ (r/(2.74\ D_i \text{ x } 10^{-6}))$$

$$\Delta f/r = \exp\ (-e^0/r)$$

$$e^0 = 1.0 * 10^9 \exp(-4.62\text{x}10^3/[T + 273])$$

where A_x (km^2) is the total watershed area; r is the monthly precipitation; D_i is the number of days in the i^{th} month; Δf/r is the monthly runoff to rainfall ratio ; e_0 (mm) is the calculated potential evapotranspiration; and T is the monthly atmospheric temperature in degrees C. The annual mean discharge is then the average of all the total calculated monthly runoff. As an example, the calculations for Subic Bay are presented.

CASE 1: SUBIC BAY, PHILIPPINES

Multiple rivers and rivulets discharge into Subic Bay (14.75-14.83 ^{o}N, 120.15-12.28 ^{o}E). The seven most significant ones have a total watershed area of 361 km^2. The calculation of q_R, based on a 42-year monthly rainfall (r in mm) and air temperature (T in ^{o}C) measured at Cubi Point in Subic Bay (US Naval Oceanography Command Facility) gave an annual mean discharge of 870 x 10^6 m^3 yr^{-1}. Details of the calculations are given in Table III.1.

Table III.1. Statistics for total river discharge into Subic Bay.

Month	Temp (C)	Rain (mm)	df/r	Discharge * (10^6 m^3/yr)
Jan	26.7	3.6	0.00	0
Feb	27.2	3.6	0.00	0
Mar	28.3	3.6	0.00	0
Apr	30.0	13.7	0.00	0
May	30.0	246.6	0.38	394
Jun	28.3	604.5	0.69	1842
Jul	27.8	713.7	0.74	2243
Aug	27.2	1082.0	0.82	3791
Sep	27.8	571.5	0.69	1722
Oct	28.3	228.9	0.38	370
Nov	27.8	91.9	0.10	38
Dec	27.2	17.8	0.00	0
Average				867

* A discharge of zero does not mean the riverbed becomes dry, instead the measurements are below significant limits.

The results agree well with the Coronas Classification of Philippine Climate where the region to which Subic Bay belongs is described to have two pronounced seasons; dry from November to April and wet during the rest of the year. As a means of further verifying the model results, comparison of calculations using the runoff model as applied to a sample drought year (1968) and a sample flood year (1978) when we have data of river discharge for one of the rivers, Agusuhin were made (Woodward-Clyde 1999). For the drought years the model results gave an annual discharge of 26x10^6 m^3 yr^{-1} as compared to 21x10^6 m^3 yr^{-1}, while for the flood years the model calculated an annual discharge of 79x10^6 m^3 yr^{-1} as compared to 65x10^6 m^3 yr^{-1}.

As can be seen in figure III.2, the monthly trends are similar for the calculated and actual data for both precipitation regimes

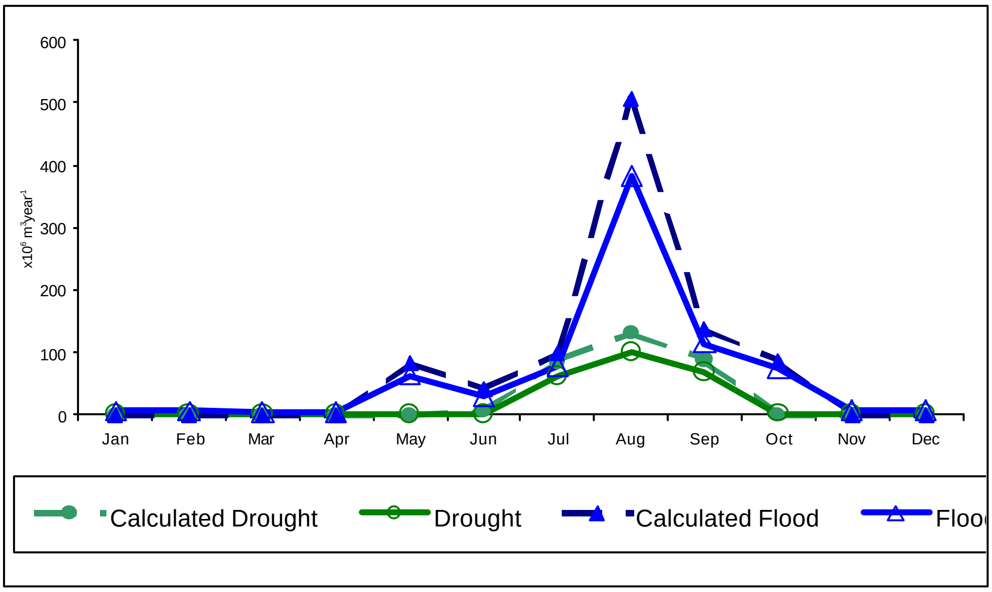

Figure III.2. Comparison of model results with data from a drought year (1968) and a flood year (1978) for the Agusuhin River.

There are also instances where river data has been previously measured. In most of there measurements however, these data were correctly collected not at the mouths of the river but somewhere higher upriver so as to negate the tidal influence. The inherent shortcoming of this technique, however, is that the measured discharge no longer accounts for the watershed input below the measuring station. In order to compensate for this shortcoming the amount of discharge contributed downstream of the measuring station is calculated similar to the approach used above. The result of these monthly calculations is termed q_R. This is then added to the measured discharge termed q_M and the total is then reported as q_T. As an example the case of Laguna de Terminos, Mexico is presented.

CASE 2: LAGUNA DE TERMINOS, MEXICO

Laguna de Términos is the largest estuary-lagoon in México, located at the southern extreme of the Gulf of México (18.47 - 18.80 °N, 91.25 - 91.90 °W). Three rivers provide most of the freshwater input to the lagoon (Yáñez-Arancibia and Sánchez-Gil 1983; EPOMEX 1993). The largest is the Palizada River, near the western extreme of the lagoon, with a mean discharge of 8,300x10^6 m^3 yr $^{-1}$as gauged at Palizada Bridge 75 km upstream (CNDCRAA 1993).

An estimate of the actual monthly discharge (q_T) from Palizada River into Laguna de Términos was calculated as the sum (q_T) of the gauged discharge at Palizada Bridge (q_M) and the computed surface runoff from the drainage basin between Palizada Bridge and the mouth of the Palizada River (q_R).

$$q_T = q_M + q_R$$

q_R is estimated based on the same climatological model (Schreiber 1904) used for Subic Bay, Philippines, but using the area of the drainage basin between Palizada Bridge and the mouth of the Palizada River (A_x in km^2). The combined results yield a mean discharge of 9,100x10^6 m^3 yr^{-1} for the Palizada River, including the non-gauged area (Table III.2).

Discharges were similarly calculated for Chumpán River, thirty kilometers to the east of the mouth of the Palizada River, and the Candelaria-Mamantel rivers, located 32 km further northeast. Flow for the Chumpan River was measured 44 km upstream at Carretera Bridge, for the Candelaria River 92 km upstream at Ferroc Bridge, and for the Mamantel gauged 32 km upstream at Mamantel Town. The calculations yielded a mean discharge of 600x10^6, 1,500x10^6, and 160x10^6 m^3 yr^{-1} respectively (Table 2). Thus, the combined mean freshwater runoff into Laguna de Términos is estimated to be 11,900x10^6 m^3 yr^{-1} from the three major river systems.

Table III.2. Statistics for the rivers discharging into Laguna de Términos.

	Palizada	Chumpan	Candelaria	Mamantel
Total Drainage Basin Area (km^2)	40,000*	2,000	7,160	540
% Gauged Area	97	85	81	81
Original Measured Mean Discharge (10^6 m^3 yr $^{-1}$)	8,300	442	1,514	110
Adjusted Mean Discharge: (10^6 m^3 yr $^{-1}$)	9,080	570	2,110	160
Average Drainage Basin Temp. (^{O}C)	27	25	27	27
Annual Drainage Basin Rainfall (mm)	1,844	1,602	1,457	1,517
Δf/r	0.24	0.23	0.18	0.27

- Including the entire Usumacinta drainage basin area.
- The measured and adjusted river discharges are shown on Figure III.3.

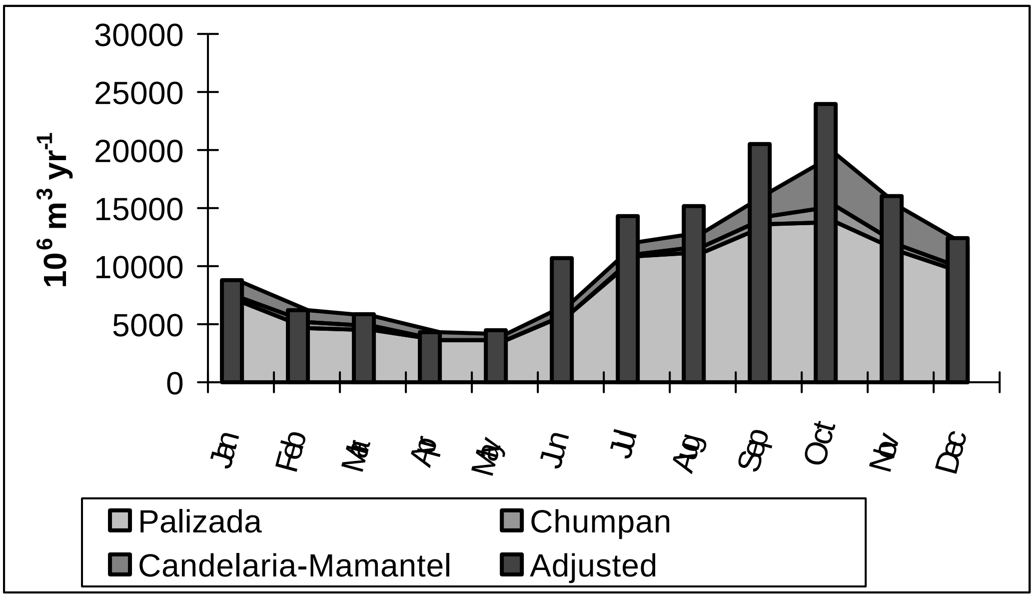

Figure III.3. Measured discharge from each of the rivers vs. the total adjusted monthly discharge Q_T.

Another useful application of the model is in offering a broad scope calculation of discharges in a regional level. Using secondary data, calculation of monthly discharges from the countries surrounding the South China Sea boundary is presented (Table 3) (Talaue-McManus 1999; website ncdc.noaa; website online weather). Aside from providing a synoptic picture, the following case study can also contribute to the typological classification of the region. For example, it can be seen from figure 4 that Malaysia and Indonesia are significantly out of phase in terms of seasonal signature compared with the other countries. Thailand and Cambodia look similar and so do China, Vietnam and the Philippines.

Table III.3. Countries with rivers discharging into the South China Sea.

Country	Major Rivers discharging into SCS	Watershed area (10^3 km^2)	Total Discharge (10^6 m^3 year^{-1})
Cambodia	7	13.14	3,002
China	11	518.72	226,205
Indonesia	5	60.37	41,515
Malaysia	51	231.42	452,344
Philippines	5	27.43	42,336
Thailand	18	320.55	158,023
Vietnam	25	1,289.08	341,406
Total	122	2,460.98	1,264,832

Scope and limitation of the model

The model is most reliable and effective when applied to the latter case where actual data are already available and need only be adjusted for additional watershed input. It has been shown to be an acceptable alternative in estimating river discharge when there is no other source of primary or secondary data as in the first case. It should be noted however, that in applying the model the following scope and limitations need be observed:

- The model is applicable for monthly data, not annual data. Moreover, since the equation using both the rainfall data and the river input are exponential in nature, the temperature and rainfall data cannot be treated as additive. Annual data cannot be averaged into 12 months in order to get “monthly” data. The nature of the equations makes the model sensitive to watershed area measurement. Care should therefore be exercised when watershed area needs to be estimated from a topographic map.
- Unrealistic results for months that are very dry and warm such that the drought years of Subic Bay, Philippines when the calculated corresponding river discharge comes out to be <<0. The sensitivity lies in the calculation of f/r. For the tropical systems tested it seems that a monthly rainfall of less than 40 mm would result in a calculated discharge close to zero, whereas, for subtropical systems the practical limit is 10 mm. For these instances it is best to report the data to be below significant limits.
- Overestimate for months of torrential rains has been observed for some river systems. Part of the reason might be because the model does not account for groundwater recharge. This is especially true in regions where groundwater recharge is significant (e.g., some parts of Mexico).

The model should also not be used directly to predict flow for systems in which the runoff is highly manipulated (for example, by water storage and release via water catchment reservoirs). Under such circumstances the runoff is clearly not hydrologically controlled in any simple fashion. Examples of such manipulated flow can be found for several of the Thai river systems discussed in this workshop report. It would be possible, in such systems, to combine this runoff model with budgetary constraints on the reservoirs themselves (e.g., change in water storage volume from month to month).

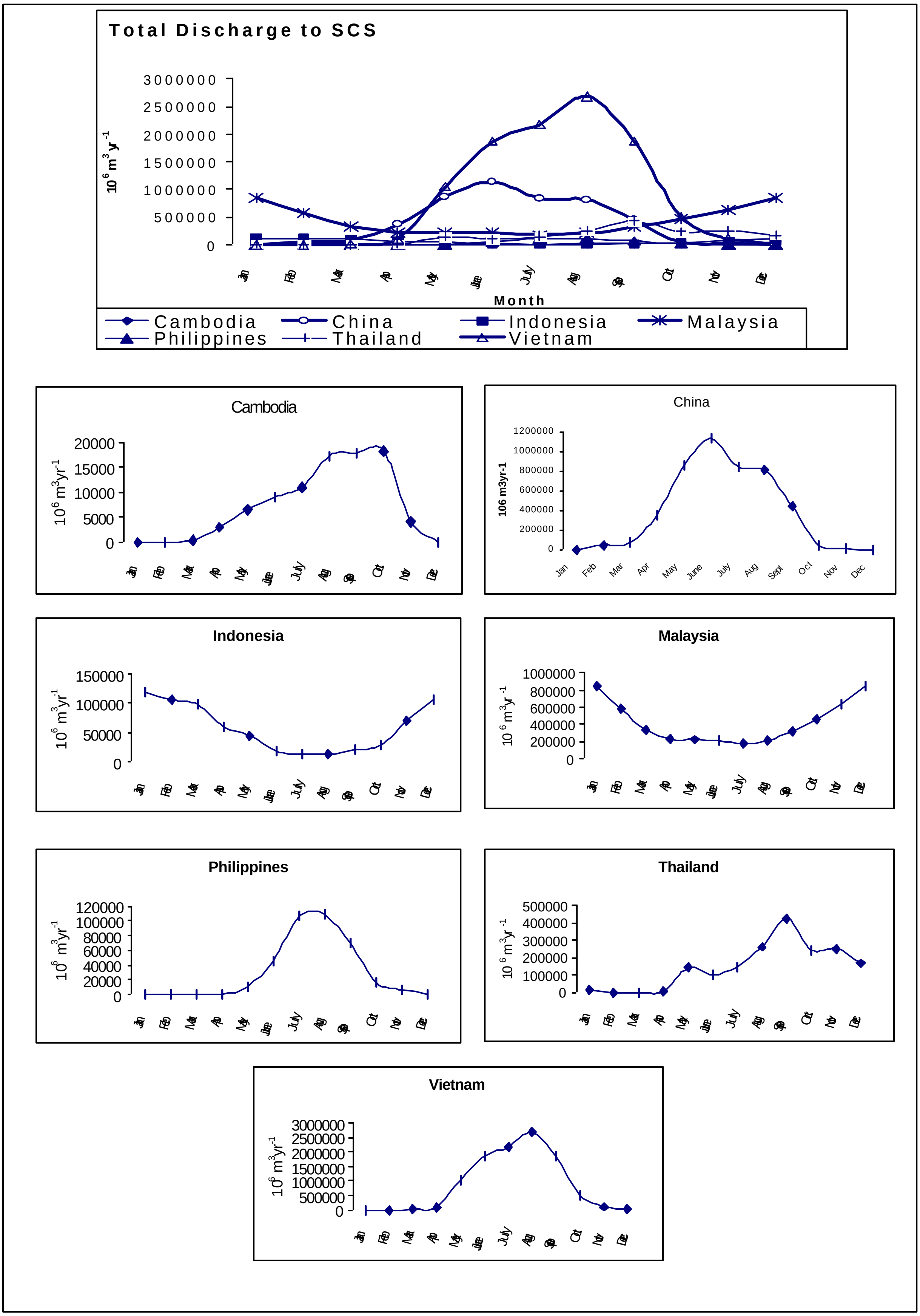

Figure III.4. **Calculated monthly river discharge for the countries surrounding the South China Sea.**

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Figure III.4. Calculated monthly river discharge for the countries surrounding the South China Sea.

Appendix IV Workshop Report

Welcome

Participants (Appendix V) were welcomed to the venue at the Sulo Hotel, Quezon City, the Philippines by the Workshop leader, Prof. Stephen Smith; round-table introductions were made and the purpose of the Workshop was outlined. Dr Liana McManus welcomed participants to the Philippines on behalf of the local organisers – the Marine Science Institute, University of the Philippines – and reviewed the support arrangements. The agenda (Appendix VI) was introduced and working documents and diskettes of electronic information and tutorials were distributed.

Introduction and Background

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

As an introductory tutorial, Ms Vilma Dupra led the participants through the development of the Pelorus Sound, New Zealand site model which involved a multi-compartment and stratified model system. Discussion ranged across various elements from the selection of compartment boundaries to interpretation of model values. It was noted that it is often the “ideal” to use a 2-box “stratified” model to describe the site system – subject to the local characteristics and available data.

A summary of estuarine biogeochemical budget models currently developed (10 completed and 6 in progress) for the Philippines was presented by Ms Vilma Dupra.

A key issue of how to assess and deal with waste-load estimations for the estuarine systems in the absence of detailed data was addressed by Dr Maria Lourdes (Malou) McGlone using examples of Lingayen Gulf and Manila Bay (Appendix II). In addition, estimation of run-off values and characteristics (in cases where data or direct values are unavailable) was considered by Dr Laura David, and a model and approach (key functions required: rainfall, temperature and catchment area) was recommended (Appendix III); noted as being particularly applicable to small watershed situations.

An expert typology overview for the South China Sea region was introduced by Dr Liana McManus, and will be refined (Appendix I). The expert typology forms a starting point for subsequent typology development within the wider project. While the LOICZ approach seeks to establish biogeochemical models for sites across the range of pressures, from relatively pristine to polluted, the regional typology has the advantage of extrapolating human pressure information to identify “hot spots”. These could be priority sites for biogeochemical budget assessments that can assist in evaluation of system status and changes.

Prof. Stephen Smith provided an overview of the progress being made by LOICZ in the development of typology approaches and some preliminary products for coastal classification. The linkage with biogeochemical model data was discussed in the context of the wider project objectives, including needs and potential application of products in the region. It was noted that a number of typologies will probably be developed to meet the range of needs and purposes; the key to LOICZ is providing a predictive outlook for undescribed areas of the 500 000 km long global coastal zone.

Presentation of Biogeochemical Budgets

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

Indonesia
Memberamo River estuary, northern Irian Jaya
2 potential sites in northern Java and southern Borneo
Philippines
12 sites in the Philippines (including revisions for Lingayen Gulf, and Manila Bay), predominantly around Luzon
Subic Bay, Luzon
Thailand
Mae Klong River estuary
Petchaburi River estuary
Songkhla Lagoon
Rayong and Prasao River estuaries
Pang Rong Creek, Phuket
Tachin River system
Chao Phraya River estuary
Bandon Bay
Hong Kong, China
Pearl River estuarine system
Deep Bay, northwest Kowloon
Mirs Bay, northeast Kowloon
Malaysia
Terengganu system, east Malaysia
Vietnam
Hau River, Mekong Delta
Cau Hai Lagoon
NhaTrang Bay

Budgets Development

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

Outcomes and Wrap-up

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

22 July	Complete rough-draft versions of budgets either brought to or completed during workshop - including box diagrams, descriptive text, and maps.
31 July	Revisions (editorial and substantive) for budgets submitted during workshop. Submission of budgets not quite completed by 22 July.
22 August	All other (non-budget) writing assignments to SVS.
31 August	Absolute deadline for additional budgets to be included in report.
30 September	Workshop proceedings to printer.
15 November	Additional budgets for inclusion on CD-ROM should be submitted.
15 January	Completion of draft CD-ROM.

NOTES All material should be submitted electronically to Stephen Smith (SS), with copies to Chris Crossland (CC) and Vilma Dupra (VD). SS and VD will be responsible for the technical editing before the material is submitted to CC for final editing and report preparation.

A number of additional sites was identified for which data are available and which may yield budgets. Participants committed themselves to making other site budgets, subject to data availability, and to encourage others to make further site assessments. In particular, the Pearl River system will be addressed, further coastal sites in Vietnam should be achievable from the coastal monitoring database, and a wealth of Indonesian river data may provide the basis for a small national workshop. Mr Nguyen Huu Huan is expected to spend 4-6 weeks at the University of Hawaii working on allied system analyses (subject to organisational agreement), and supported by the LOICZ/UNEP Regional Training Scholarship (South China Sea Region).

The participants joined with LOICZ in expressing thanks to the group from the Marine Science Institute, University of the Philippines, for unstinting support and hosting of the Workshop in Manila. The financial support of the Global Environment Facility was gratefully acknowledged.

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Appendix VI Workshop Agenda

LOICZ/UNEP Workshop on
Estuarine Systems of the South China Sea Region
Manila, Philippines
19-22 July 1999

July 19

0900-0915	Welcome, introduction and housekeeping (S. Smith, L. McManus, L. Asuncion, C. Crossland).
0915-0930	Brief overview of LOICZ (C. Crossland).
0930-1000	Tutorial example of LOICZ budgeting (V. Dupra).
1000-1030	Coffee break and discussion.
1030-1100	Summary of Philippine budgeting (V. Dupra).
1100-1130	Estimating Waste Loads, with examples from two Philippine Systems (M. McGlone).
1130-1200	Estimating Runoff (L. David).
1200-1230	Expert Typology of the South China Sea Region Coastal Zone (L. McManus).
1230-1330	Lunch break and discussion.
1330-1400	Budgets, via Expert Typology and Statistical Typology, to Fluxes in the Global Coastal Zone (S. Smith).
1400-1530	Brief (~5 minute) discussion of budgets available for this workshop (participants).
1530-1600	Coffee break and discussion.
1600-1700	Discussion of ongoing workshop structure: What mixture of tutorial, formal presentation, and/or plenary discussion will fit the needs of the workshop participants? (Chair: S. Smith).

July 20

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

July 21

0900-1230	Morning: Breakout groups or plenary, as required, to refine and present budgets. Coffee break and discussion as above.
1230-1330	Lunch break and discussion.
1330-1700	Afternoon: Plenary, to present or discuss budgets. Coffee break and discussion as above.

July 22

0900-1230	Plenary, to develop preliminary synthesis. Coffee break and discussion as above.
1230-1330	Lunch break and discussion.
1330-1500	Afternoon: Plenary wrap-up discussion (Chair: S. Smith).
1445-1500	Closing announcements (S. Smith & others, as needed).

Appendix VII Terms of Reference for Workshop

LOICZ/UNEP Workshop on
Estuarine Systems of the South China Sea Region
Manila, Philippines
19-22 July 1999

Primary Goals:
To work with researchers dealing with estuarine systems of the South China Sea, in order to extract budgetary information from as many systems as feasible from existing data. The South China Sea systems extend around the perimeter of one of the Earth's major shelf seas; many of these systems are among the coastal ecosystems most heavily influenced by anthropogenic activity. Moreover, many of these estuarine systems have relatively detailed data. The workshop provides the opportunity to characterise terrigenous inputs to the estuaries of the region, and outputs from the estuaries - hence the net role of the estuarine zone of this region as a source or sink for carbon, nitrogen and phosphorus.

This Workshop will complement earlier, successful workshops in Ensenada, Mexico, in June 1997, a second Mexican workshop in January 1999 (Merida, Mexico), an Australasian workshop (Canberra, Australia) in October 1998, and a South American workshop to be held in November 1999 (Bahia Blanca, Argentina) by the analysis of data from another relatively well-studied region.

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

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

Participation:
The number of participants will be limited to fewer than 20 persons, to allow the active involvement of all participants. Nominees include:
- Three external resource persons;
- Approximately 15 researchers from the region;

Several of the participants will have the experience to serve as regional resource persons.

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

Further Details:

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

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

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

Several budgets for the region are already available. It is preferred that the participants offer new budgets, unless the budgets they will present are substantial improvements on existing budgets.

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

July 18: Arrival
July 19: General introduction to the budgeting procedure and related issues of typology; presentation of preliminary budgets (no details, simply a quick summary to see who has what.)
July 20: Breakout groups to revise and refine budgets. This will vary, as needed, from tutorial, through detailed help, to procedural discussions.
July 21: Continue breakouts; afternoon plenary to evaluate progress.
July 22: Breakouts/plenary as required to develop synthesis.
July 23: Departure.

Background documents (to be furnished by the LOICZ IPO):

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

Smith, S.V., Ibarra-Obando, S., Boudreau, P.R. and Camacho-Ibar, V.F. 1997 Comparison of carbon, nitrogen and phosphorus fluxes in Mexican coastal lagoons. *LOICZ Reports and Studies* **10**, 84 pages.

LOICZ Modelling web-page, for everyone with access to the world wide web: (http://data.ecology.su.se/MNODE/)

NOTE: It would be helpful if prospective participants would let us know if they can access the World Wide Web. If they can do so, this is the easiest way for us to make the documents available rapidly.

Appendix VIII Glossary of abbreviations

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