8. BUDGETS FOR ESTUARIES IN VIETNAM

8.1 PhanThiet Bay

Nguyen Huu Huan, Bui Hong Long and Phan Minh Thu

<u>Study area description</u>

PhanThiet Bay is located between 10.7° and 10.9°N, and 108.0° and 108.3°E, near the center of upwelling waters in the south of Vietnam (Figure 8.1). It has an area of about 370 km^2 and a total volume of about 5,500x10^6 m^3 (Vo Van Lanh 1996; Bui Hong Long 1999). The bay has a maximum depth of 25 m with an average depth of about 15 m. The area has a tropical monsoon weather regime, with two seasons: the wet season from June to November (maximum precipitation in July and October) and the dry season from December to May. The annual average range of precipitation is between 1,000 to 1,300 mm; with about 90% falling during the wet season. Annual evaporation is relatively high, about 2,200 mm, of which about 5 mm d^{-1} occurs in the wet season and about 7 mm d^{-1} in the dry season (Meteorological and Hydrographical Station of Southern Center 1996).

There are two main river systems flowing into PhanThiet Bay: the Cai and CaTy Rivers. From the Cai River, the annual average discharge of water is about 3,300x10^6 m^3 of which 8x10^6 m^3 d^{-1} flows in the wet season and 2x10^6 m^3 d^{-1} in the dry season. From the CaTy River, the annual average river discharge is about 3,700x10^6 m^3 of which 9x10^6 m^3 d^{-1} flows in the wet season and 1x10^6 m^3 d^{-1} in the dry season (Meteorological and Hydrographical Station of Southern Center 1996).

The population in the PhanThiet Bay region is about 403,000, involved mainly in agriculture and fishing (Bui Hong Long 1999).

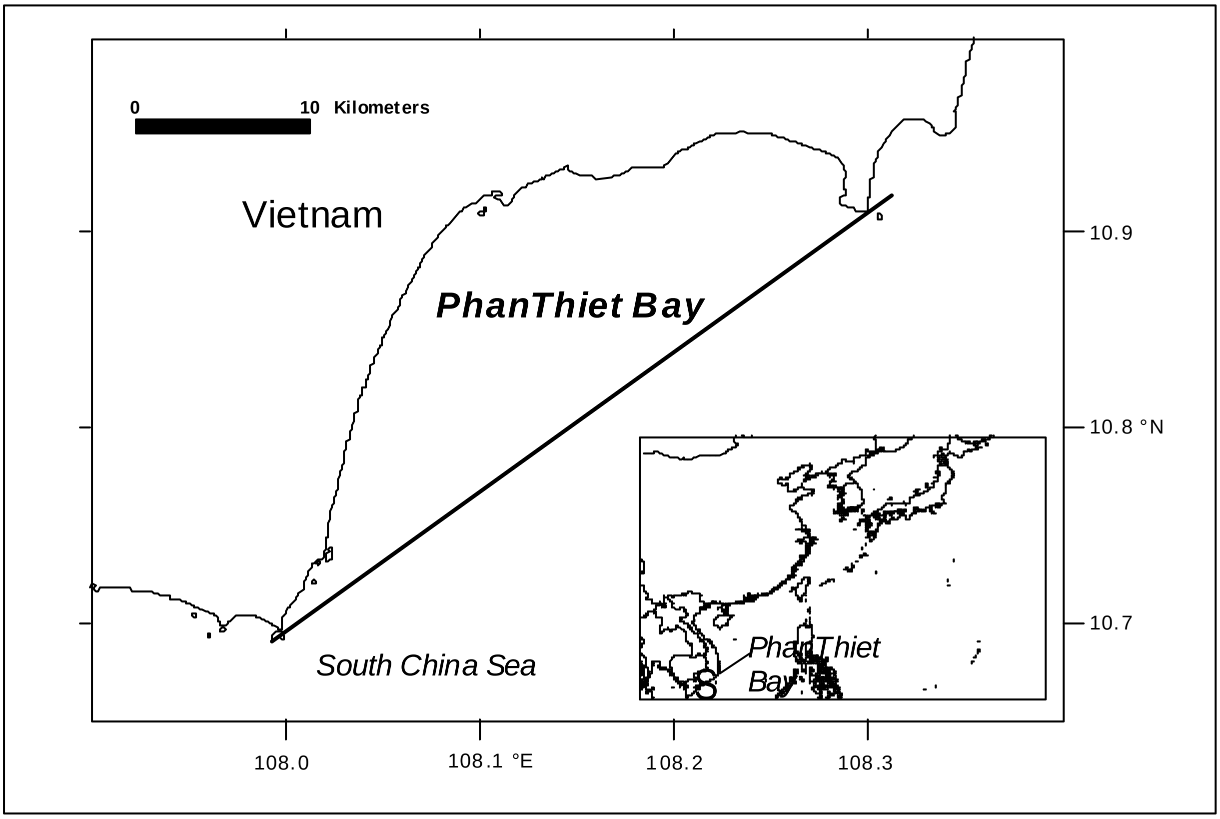


Figure 8.1. Map and location of PhanThiet Bay. The solid bar shows the boundary of the budgeted area of the bay.

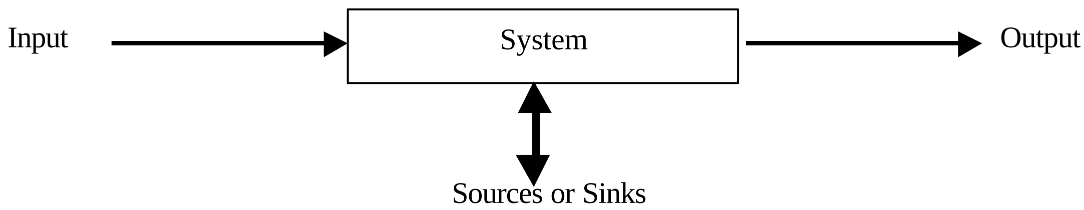
This paper presents the budgets for PhanThiet Bay using the LOICZ Biogeochemical Modelling Guidelines (Gordon *et al.* 1996) and using data of water, salt and nutrients collected during 1998 and 1999 (Tables 8.1 and 8.2). The budgeted area of PhanThiet Bay is shown in Figure 8.1.

Table 8.1. Water fluxes for PhanThiet Bay.

Water flux	**Dry season** (10^6 m^3 d^{-1})	**Wet season** (10^6 m^3 d^{-1})
V_P	0.3	2
V_E	3	2
V_O	≈ 0 (assumed)	≈ 0 (assumed)
V_G	≈ 0 (assumed)	≈ 0 (assumed)
V_Q	3	17
V_R	0.3	17
V_X	100	912

Water and salt balance

The conceptual model for transport of materials in a system is:



We can describe that process by:

$$\frac{dM}{dt} = \sum input - \sum Output + \sum (Sources - Sinks) \qquad (1)$$

Where: *dM/dt* is a change of mass of material of interest. Assuming that the system of interest is at steady state (*dM/dt = 0*), water and salt budgets for PhanThiet Bay are presented in Figures 8.2 and 8.3 for the dry and wet seasons, respectively.

The water exchange time in the system (t) can be calculated as the total water volume of the system (V_{syst}) divided by the sum of the absolute value of residual flow ($|V_R|$) and mixing volume (V_X). Thus, in the dry season:
$t_{dry} = V_{Syst}/(|V_{R1}| + V_{X1})$ = [5,500x10^6]/ [100x10^6] = 55 days.

Similarly, in the wet season:
$t_{wet} = V_{Syst}/(|V_{R2}| + V_{X2})$ = [5,500x10^6]/ [929x10^6] = 6 days.

Budgets for nonconservative materials
The data collected for phosphorus (P) and nitrogen (N) are shown in Table 8.2. Note that sources of DIP and DIN from human sewage (also called other sources) are calculated using a C:N:P ratio of 95:15:1 in domestic waste: DIP/TP ≈ 0.5; DIN/TN ≈ 0.5 (Jacinto *et al.* 1998) and using the WHO estimate of 20 kg per person per year BOD (Economopoulos 1993). It was assumed that the same amount of nutrients from waste reached the system for both seasons.

Table 8.2. The nutrient concentrations for water fluxes in PhanThiet Bay.

Sources	Seasons	Dry (µM)	Wet (µM)
Runoff	DIP	0.3	0.2
	DIN	8.2	18.1
System	DIP	0.4	0.3
	DIN	7.8	6.3
Ocean	DIP	0.2	0.2
	DIN	7.2	9.9

The calculated fluxes for the nonconservative materials are shown in Figures 8.3 – 8.7. The system is a net source for DIP and a net sink for DIN for both seasons.

Stoichiometric calculation of aspects of net system metabolism

The nutrient budgets can be used to estimate values of (*p-r*) and (*nfix-denit*). Net ecosystem metabolism (*p-r*) is estimated from *DDIP* and the ratio of C:P as follow:

$$(p - r) = - DDIP \times (C:P)_{part} \quad (2)$$

using $(C:P)_{part}$ is (106:1) using the Redfield ratio for phytoplankton.

The estimated results are presented in Table 8.3. Table 8.3 shows *DDIP* = +8x10^3 mol d^{-1} or +0.02 mmol m^{-2} d^{-1} in the dry season and *DDIP* = +81x10^3 mol d^{-1} or + 0.2 mmol m^{-2} d^{-1} in the rainy season. From equation (2), (*p-r*) is -848x10^3 mole C d^{-1} or -2 mmol C m^{-2} d^{-1} in the dry season, and about -8,586 mmol C d^{-1} or -23 mmol C m^{-2} d^{-1} in the rainy season. The system is heterotrophic for both seasons.

Table 8.3. Net ecosystem metabolizm (NEM) for PhanThiet Bay.

Seasons	***DDIP***		**NEM (*p-r*)**	
	10^3 mol P d^{-1}	mmol P m^{-2} d^{-1}	10^3 mol C d^{-1}	mmol C m^{-2} d^{-1}
Dry	+8	+0.02	-848	-2
Wet	+81	+0.22	-8,586	-23
Annual	+45	+0.12	-4,717	-13

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

$$(nfix\text{-}denit) = DDIN_{obs} - DDIN_{exp} = DDIN_{obs} - DDIP \times (N:P)_{part} \quad (3)$$

using $(N:P)_{part}$ ratio is 16:1 (Redfield ratio). The estimated results are presented in Table 8.4.

Table 8.4. The estimated value of (*nfix-denit*) for PhanThiet Bay.

Seasons	***DDIN$_{obs}$***		***DDIN$_{exp}$***		**(*nfix - denit*)**	
	10^3 mol N day^{-1}	mmol N m^{-2} day^{-1}	10^3 mol N day^{-1}	mmol N m^{-2} day^{-1}	10^3 mol N day^{-1}	mmol N m^{-2} day^{-1}
Dry	-120	- 0.3	+128	+ 0.3	-248	- 0.7
Wet	-3,610	-9.8	+1,296	+ 3.5	-4,906	-13.3
Annual	-1865	-5.1	+712	+1.9	-2,577	-7.0

These results indicate that the system is net denitrifying in the both seasons at a net rate of about -258x10^3 mol N d^{-1} or -0.7 mmol N m^{-2} d^{-1} in the dry season and about -4,914x10^3 mol N d^{-1} or -13.3 mmol N m^{-2} d^{-1} in the rainy season.

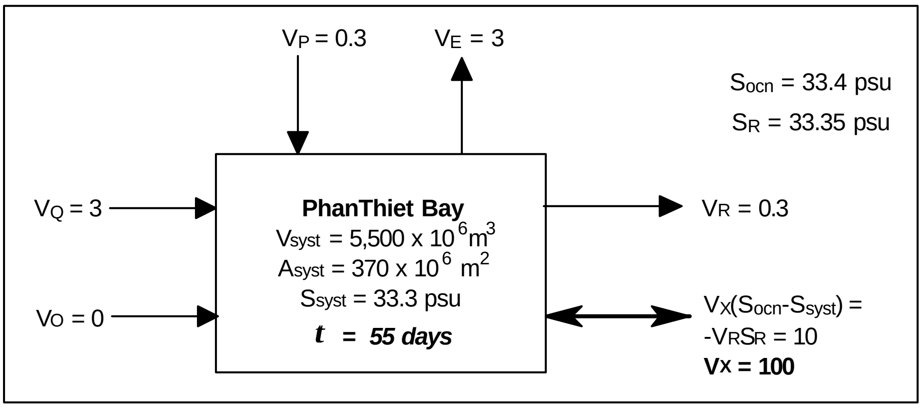


Figure 8.2. Water and salt budgets for PhanThiet Bay in the dry season. Water flux in 10^6 m^3 d^{-1} and salt flux in 10^6 psu-m^3 d^{-1}.

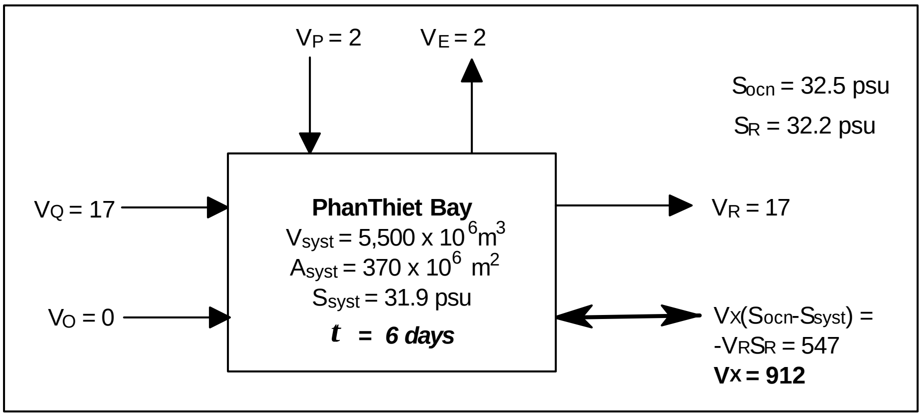


Figure 8.3. Water and salt budgets for PhanThiet Bay in the wet season. Water flux in 10^6 m^3 d^{-1} and salt flux in 10^6 psu-m^3 d^{-1}.

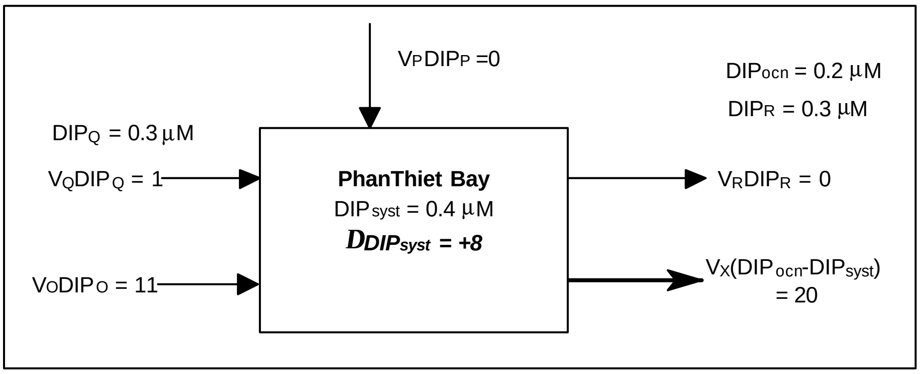


Figure 8.4. Dissolved inorganic phosphorus (DIP) budget for PhanThiet Bay in the dry season. Flux in 10^3 mol d^{-1}.

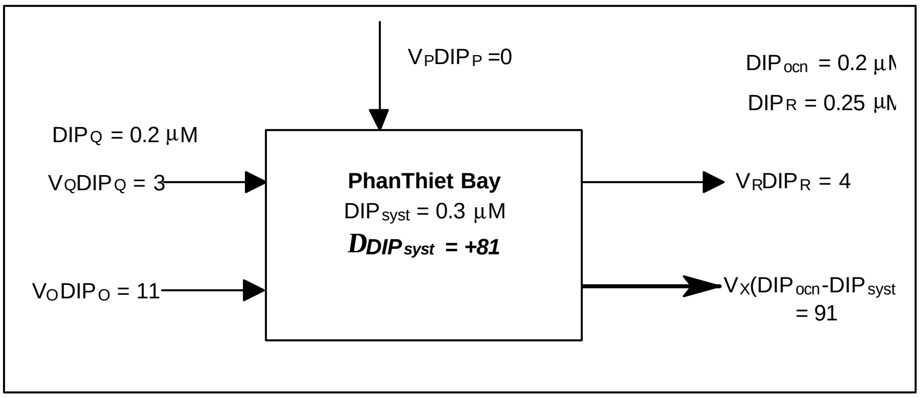


Figure 8.5. Dissolved inorganic phosphorus (DIP) budget for PhanThiet Bay in the wet season. Flux in 10^3 mol d^{-1}.

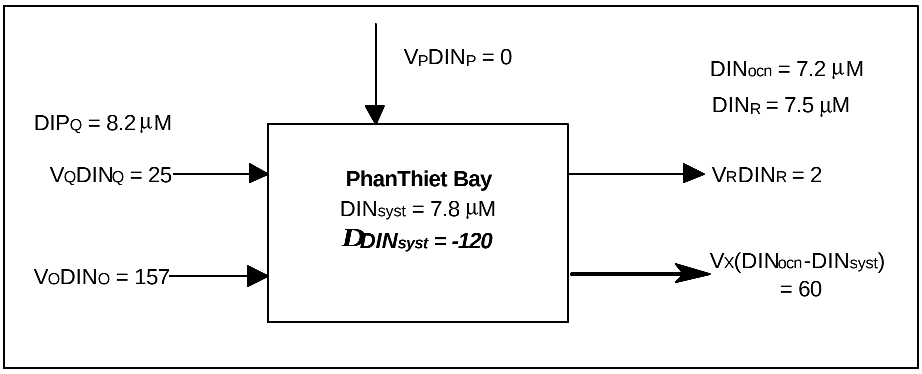


Figure 8.6. Dissolved inorganic nitrogen (DIN) budget for PhanThiet Bay in the dry season. Flux in 10^3 mol d^{-1}.

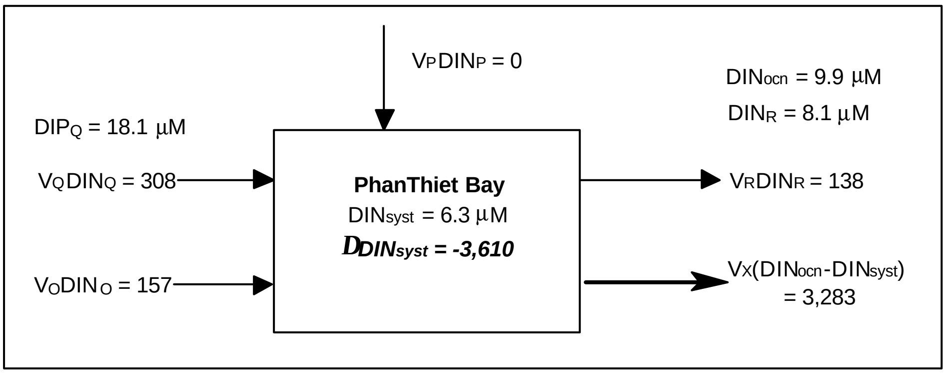


Figure 8.7. Dissolved inorganic nitrogen (DON) budget for PhanThiet Bay in the wet season. Flux in 10^3 mol d^{-1}.

8.2 ThuBon River estuary

Nguyen Huu Huan

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

The ThuBon River system rises in mountains reaching an elevation of over 1,500 m in KonTum Province. The river is about 200 km from its source to its mouth at HoiAn in QuangNam Province (15.88°N,108.8°E, Figure 8.8). The catchment area (from GiaoThuy a distance of 30 km to HoiAn) is about 3,800 km^2. The ThuBon River flows through KonTum Province for about 38 km with a catchment area of about 500 km^2. There are three main tributaries: Tranh River (length 130 km, catchment area about 1,640 km^2), Khang River (length 100 km, catchment area about 790 km^2) and Truong River (length 30 km, catchment area about 450 km^2) (Tran Dinh Hung 1995).

The boundary of the budgeted area is shown in Figure 8.8. The water area is about 12 km^2. The average depth is about 9 m in the rainy season and 4 m in the dry season with water volume of about $110x10^6$ m^3 and $50x10^6$ m^3, respectively (Nguyen Tac An 1995). The system flows through many inhabited and agricultural areas.

Located in the monsoon tropical semi-equatorial climate zone, the ThuBon River region experiences two seasons: the wet season (August to December) and the dry season (January to July). Average precipitation is about 14 mm d^{-1} in the wet season and 2 mm d^{-1} in the dry season. Average evaporation is about 3 mm d^{-1} and 4 mm d^{-1} for wet and dry seasons, respectively (Pham Ngoc Toan and Phan Tat Dac 1975; Tran Dinh Hung 1995).

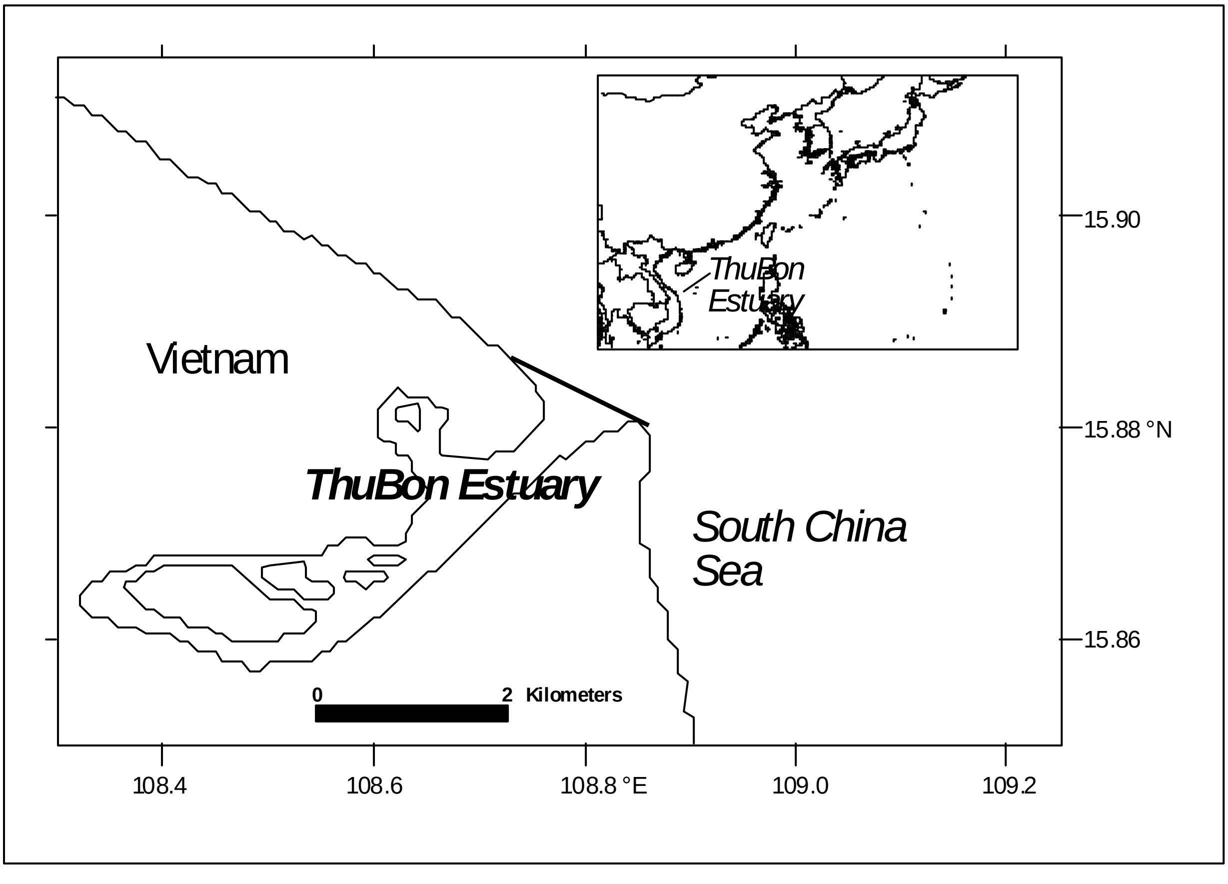


Figure 8.8. Map of the ThuBon River estuary. The solid bar shows the boundary of the budgeted area.

Collected data (from a project studying pollution derived from rivers) in March 1995 were used to budget N and P fluxes applying the LOICZ Biogeochemical Modelling Guidelines (Gordon *et al.* 1996). The mass balance budgets and stoichiometric calculations of aspects of net system metabolism are presented in this report.

Water and salt balance

The salinity data illustrate that the ThuBon River estuary is not vertically homogeneous, but instead has a two-layer flow. Pritchard (1969) developed a model for transport in such a two-layer system that allowed for the estimation of entrainment and mixing between the layers from conservation of salt and water (Webster *et al.* 1999). For budget calculations, the two-layer estuary concept was used, as shown in schematic form in Figure 8.9.

Exchange between the upper and lower layers occurs through the entrainment term $V_{deep}Y_{syst-d}$ and through the mixing term $V_Z(Y_{syst-d}-Y_{syst-s})$. Y_{syst-s} and $Y_{systs-d}$ are the concentrations in the upper and lower layers, respectively. Net freshwater discharge into the upper layer is expressed as $V_{R'}$. At steady state, the water balance is expressed as:

$$V_{R'} + V_{surf} + V_{deep} = 0 \qquad (1)$$

Where V_{surf} is surface flow, which is the outflow from the upper layer and V_{deep} is the inflow to the lower layer. We define material flows into an estuary compartment as positive.

The material budgets for the upper and lower layers are:

$$Y_{R'}V_{R'} + V_{surf}Y_{syst-s} + V_{deep}Y_{syst-d} + V_Z(Y_{syst-d} - Y_{syst-s}) + DY_{syst-s} = 0 \qquad (2)$$

$$V_{deep}Y_{syst-d} - V_{deep}Y_{syst-d} - V_Z(Y_{syst-d} - Y_{syst-s}) + DY_{syst-d} = 0 \qquad (3)$$

Adding equations 2 and 3 and using equation 1 to eliminate $V_{deep'}$, we obtain:

$$V_{R'}Y_{R'} + V_{surf}Y_{syst-s} + V_{deep}Y_{ocn-d} + DY_{syst-s} + DY_{syst-d} = 0 \qquad (4)$$

The terms of DY_{syst-s} and DY_{syst-d} are net internal sources or sinks of the substance within the upper and lower layer, respectively. For salt balance, we set Y to be S, S_Q and $\Delta S = 0$. Solving Equation 4 for the advective out flow in the upper layer gives:

$$V_{surf} = V_{R'}(S_{syst-s})/(S_{ocn-d}-S_{syst-s}) \qquad (5)$$

Based on calculation above, and using collected data for March 1995 (Table 8.5), the budgets of water and salt for the ThuBon River estuary are showed in Figure 8.10.

Table 8.5. Water fluxes for the ThuBon River estuary in the dry season.

Factors	Upper layer	Lower layer
Precipitation (10^6 m^3 d^{-1})	0	≈ 0
Evaporation (10^6 m^3 d^{-1})	0	≈ 0
Runoff (10^6 m^3 d^{-1})	10	≈ 0
Groundwater, other sources	≈ 0 (assumed)	≈ 0

The water exchange time for the ThuBon River estuary in the dry season can be calculated by:

$$t = V_{syst}/V_{surf} \qquad (6)$$

which gives: t = (50x10^6)/(173x10^6) ≈ 4 days. Thus, the water exchange time in ThuBon River estuary is very short.

DIP and DIN budgets

The average concentrations of inorganic nitrogen and phosphorus in the ThuBon River estuary for the dry season are shown in Table 8.6. N and P budgets are presented in Figures 8.11 and 8.12. Both *DDIN* and *DDIP* are negative. This denotes that the ThuBon River estuary is a net sink for both DIN and DIP in the dry season.

Table 8.6. DIN and DIP concentrations in ThuBon River estuary in the dry season.

Sources	**DIP** (ìM)	**DIN** (ìM)
Runoff	32.4	87.5
Precipitation	≈ 0 (assumed)	≈ 0 (assumed)
Evaporation	≈ 0 (assumed)	≈ 0 (assumed)
Ocean	0.1	19.6
System		
Upper	1.4	8.7
Lower	0.2	16.6

Stoichiometric calculation of aspects of net ecosystem metabolism

With the assumption that all the behavior of nonconservative materials is a result of biological processes, then the value of *DDIP* can be a measure of the net productivity of the system. The net ecosystem metabolism (NEM = [*p-r*]) is calculated as the negative *DDIP* multiplied by the C:P ratio of the reacting organic matter. Assuming that the bulk of the reacting organic matter is phytoplankton, the C:P ratio is 106:1. So,

$$(p\text{-}r) = -106 \times \Delta DIP \quad (9)$$

For the ThuBon River estuary, the value of (*p-r*) is shown in Table 8.7. Calculated net metabolic rate for the system is very high, which indicates that processes other than biological dominate the system.

Table 8.7. Net ecosystem metabolizm (NEM or [*p-r*]) for the ThuBon River estuary in the dry season.

Areas	***DDIP*** (10^3 mol P d^{-1})	**(*p-r*)** (10^3 mol C d^{-1})
Upper layer	- 307	+3,254
Lower layer	0	0
Whole system	- 307	+3,254

Based on the Redfield N:P ratio, $DDIP_{exp}$ is 16 x *DDIP*. The *DDIN* estimated from the water and salt balances presents the $DDIN_{obs}$. Therefore, the difference between $DDIP_{exp}$ and $DDIN_{obs}$ represents the difference between nitrogen fixation and denitrification, that is:

$$(nfix - denit) = DDIN_{obs} - DDIP_{exp.} \quad (7)$$

or: $(nfix - denit) = DDIN_{obs} - DDIP x (N:P)_{part}$ (8)

Results are presented in Table 8.8. These results indicate that the system is net nitrogen fixing in the dry season, (*nfix-denit*) = +342 mmole N m^{-2} d^{-1}).

Table 8.8. The estimated value of (*nfix-denit*) for the ThuBon River estuary in the dry season.

Areas	$DDIN_{obs}$	$DDIN_{exp}$	(*nfix - denit*)
	(10^3 mol N d^{-1})	(10^3 mol N d^{-1})	(10^3 mol N d^{-1})
Upper layer	-803	-4,912	+4109
Lower layer	-3	0	-3
Whole system	-806	-4,912	+4106

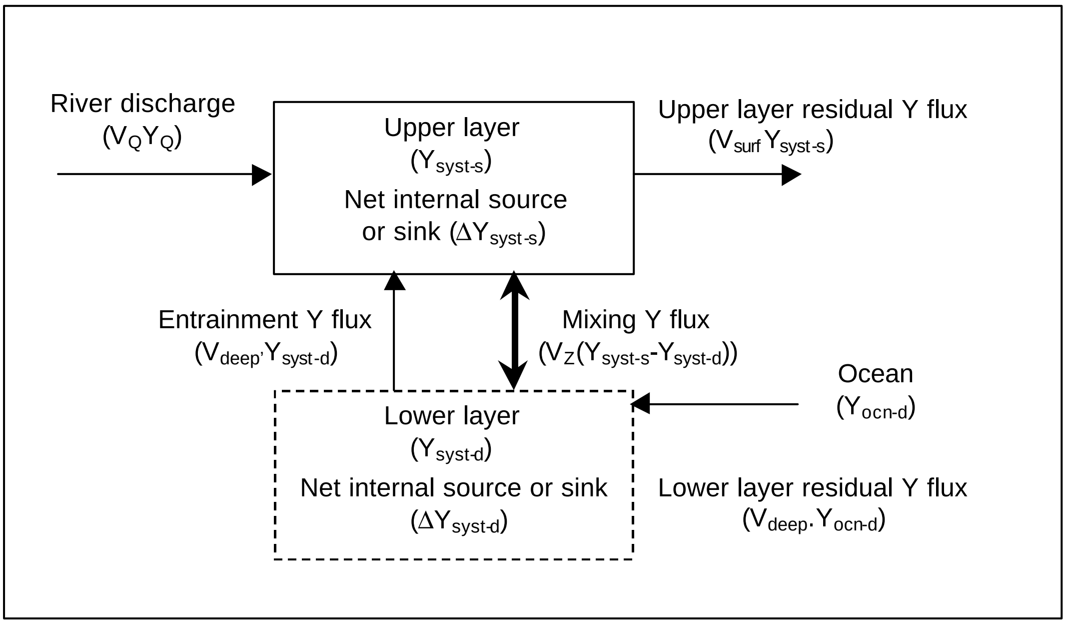


Figure 8.9. Schematic of a two-layer budget model.

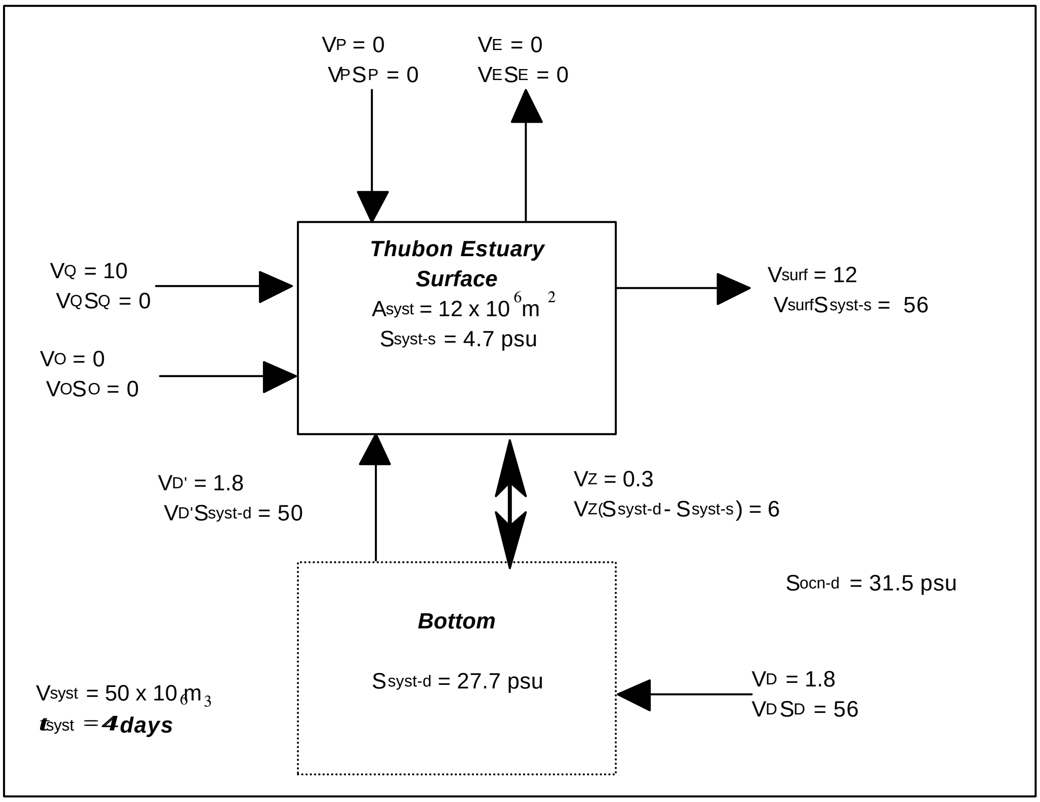


Figure 8.10. Two-layer water and salt budgets for the ThuBon River estuaries in the dry season. The box outlined with dashed lines represents lower layer of the system. Water flux in 10^6 m^3 d^{-1}, and salt flux in 10^6 psu-m^3 d^{-1}.

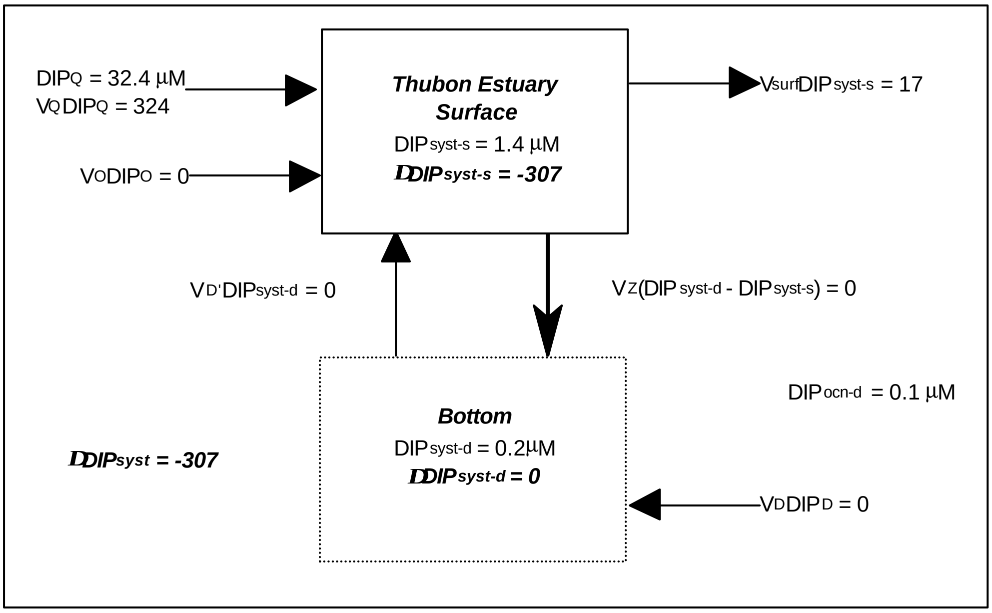


Figure 8.11. Two-layer dissolved inorganic phosphorus budget for the ThuBon River estuary in the dry season. The box outlined with dashed lines represents lower layer of the system. Flux in 10^3 mol d^{-1}.

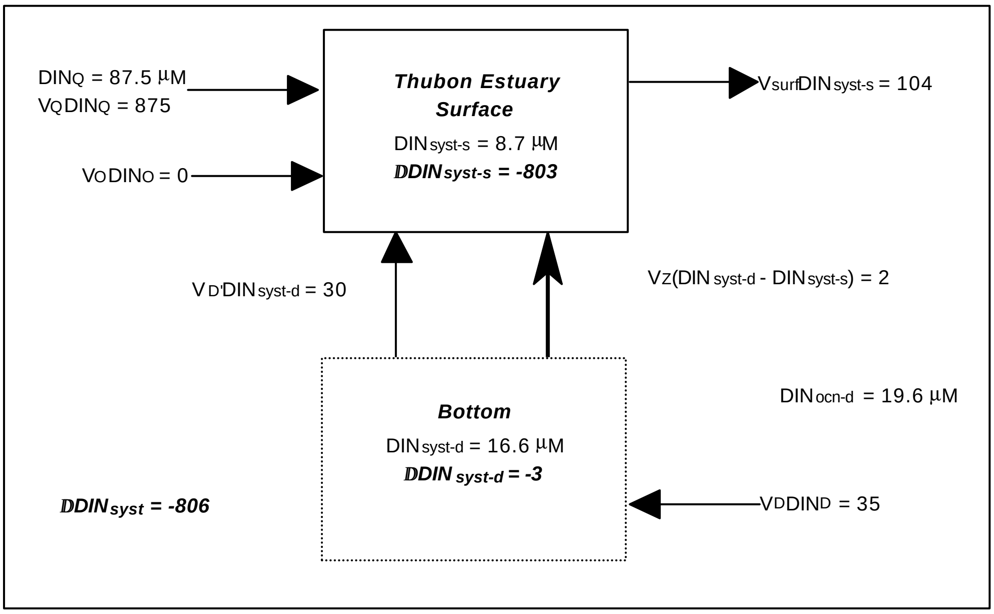


Figure 8.12. Two-layer dissolved inorganic nitrogen budget for the ThuBon River estuary for the dry season. The box outlined with dashed lines represents lower layer of the system. Flux in 10^3 mol d^{-1}.

8.3 Tien River Estuary, Mekong River Delta

Nguyen Huu Huan and Phan Minh Thu

<u>Study area description</u>

The Mekong River is one of the longest river system in the world with a length of about 4,000 km, running through 6 countries: China, Myanmar, Laos, Thailand, Cambodia and Vietnam. Hydrography in its lower basin is complicated. Water supplied by Boloven Rain Center (Laos) is 10% of the total water input into the river. The flow in 5 months of flood period reaches 75% of total annual flow. In the dry period, the hydrography of the river is affected by the BienHo and South China Seas (Nguyen Tac An 1997; To Van Truong 1997).

The Mekong River runs through Vietnam for a distance of more than 200 km and basin area of 45,000 km^2. The river divides into 2 branches: Tien and Hau. The Hau runs into the ocean through three estuaries: DinhAn, TranhDe and BatXac; the Tien runs into through six estuaries: Tieu, Dai, BaLai, HamLuong, CoChien and CungHau. The main water volume (over 79%) flows into the Tien River estuary. The Mekong Delta is a part of the basin of the Mekong River (Nguyen Tac An 1997).

The population density in the Mekong Delta is relatively high with an average of 400 inhabitants per km^2, which may reach as much as 1,000 inhabitants per km^2 in many villages along the main branches and canals of the delta. Most of sewage is discharged directly into the delta.

The Mekong Delta is a major agricultural region of Vietnam, where about 2,000-6,000 tonnes of chemical pesticides including organophosphate, carbonates, synthetic cyperthoids and even persistent organochlorine are now used annually in the cultivated fields. The use of pesticides significantly increases every year. Annually 500,000 - 800,000 tonnes of chemical fertilizers (phosphate and nitrate) are used, which represents a diffuse source of contaminants to the delta.

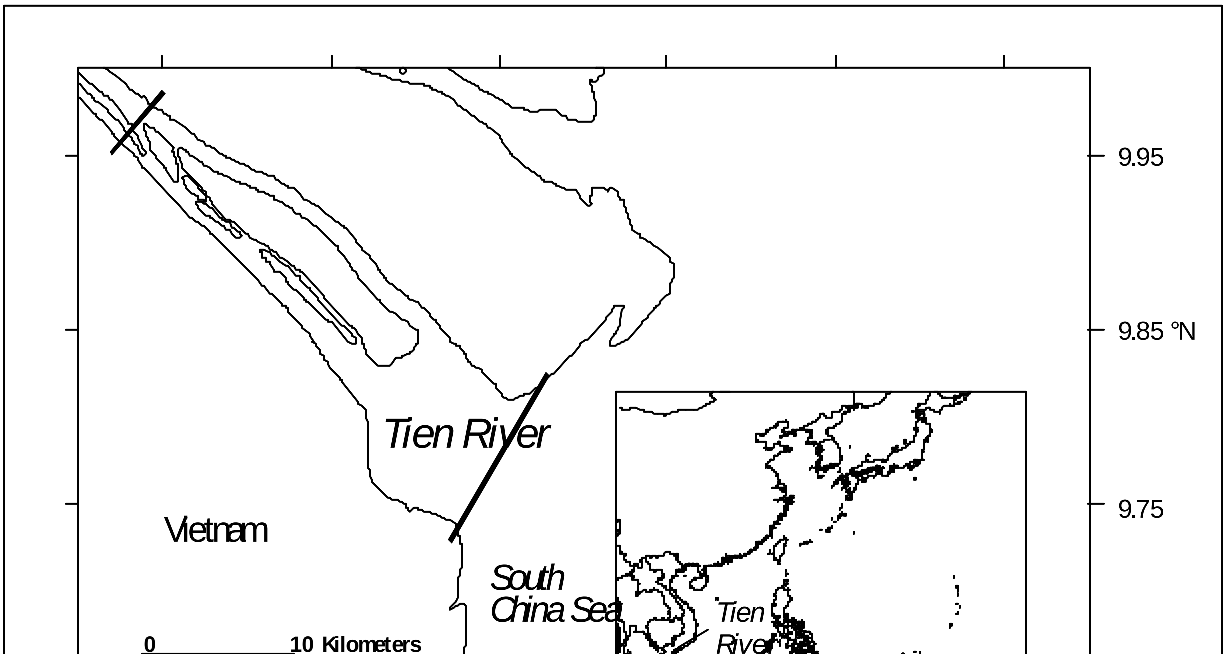


Figure 8.13. Location and map of the budgeted area of the Tien River estuary.

The Mekong River mainly depends on the rain regime on the basin, which has two seasons: the wet season from May to November which provides about 75% of total water volume for the whole year and the dry season from December to April. The relative humidity is about 85-87% in the rainy season and below 80% in the dry season. The annual evaporation varies from 1,000 to 1,800 mm by the Piche Tool and as much as 1,500 - 1,800 mm using "A" pan or the Penman formula. The annual range of precipitation is about 1,400-1,500 mm. In CanTho Province, the annual average evaporation is about 1,560 mm with about 4 mm d^{-1} in the rainy season and the annual average evaporation is about 1,100 mm with about 1 mm d^{-1} in the rainy season (Pham Ngoc Toan and Phan Tat Dac 1975).

The budgeted area is bounded by CoChien and CungHau mouths in the Tien River estuary (9.81°N and 106.56°E). Its area is about 230 km^2 with the average depth of 6 m (see Figure 8.13). The general methodology used here is as described by Gordon *et al.* (1996).

The following equation for conservation of mass is applied to any system:

$$dM/dt = S\ Inputs - S\ Sinks + S(Sources - Sinks) \qquad (1)$$

Where: dM/dt is a change of mass of the material. This equation represents the rates and quantities of materials movement through the system including the effects of internal sources and sinks. For estuaries with a two-layer flow (stratified water column), Pritchard (1969) developed a model for transport in such system that allowed for the estimation of entrainment and mixing between the layers from conservation of salt and water (Webster *et al.* 1999). For budget calculation, the two-layer estuary is used, as in the schematic diagram in Figure 8.14.

Water exchange between the upper and lower layers occurs through the entrainment term $V_{deep}Y_{syst\text{-}d}$ and through the mixing term $V_Z(Y_{syst\text{-}d} - Y_{syst\text{-}s})$. $Y_{syst\text{-}s}$ and $Y_{syst\text{-}d}$ are the concentrations in the upper and lower layer, respectively. Net freshwater discharge into the upper layer is expressed as $V_{R'}$. At steady state, the water balance is expressed as:

$$V_{R'} - V_{surf} + V_{deep} = 0 \qquad (2)$$

where V_{surf} is the outflow from the upper layer and V_{deep} is the inflow into the lower layer. Here, we define material flows as being positive for flows into an estuary compartment and negative for flows out from a compartment.

The material budgets for the upper and lower layers are:

$$V_{R'}Y_{R'} + V_{surf}Y_{syst\text{-}s} + V_{deep}Y_{syst\text{-}d} + V_Z(Y_{syst\text{-}d} - Y_{syst\text{-}s}) + DY_{syst\text{-}s} = 0 \qquad (3)$$

$$V_{deep}Y_{ocn\text{-}d} - V_{deep}Y_{syst\text{-}d} - V_Z(Y_{syst\text{-}d} - Y_{syst\text{-}s}) + DY_{syst\text{-}d} = 0 \qquad (4)$$

Adding equations 3 and 4 and using equation 2 to eliminate V_{deep}, we obtain:

$$V_{R'}Y_{R'} + V_{surf}Y_{syst\text{-}s} + V_{deep}Y_{ocn\text{-}d} + DY_{syst\text{-}s} + DY_{syst\text{-}d} = 0 \qquad (5)$$

The terms $DY_{syst\text{-}s}$ and $DY_{syst\text{-}d}$ are net internal sources or sinks of the substance within the upper and lower layers, respectively. For salt balance, we set Y to be S, S_Q and $\Delta S = 0$. Solving equation 5 for the advective outflow in the upper layer gives:

$$V_{surf} = V_{R'}(S_{syst\text{-}d})/(S_{syst\text{-}s} - S_{ocn\text{-}d}). \qquad (6)$$

Water and salt balance

Based on the calculation above, and using data collected in 1995 and 1996 presented in Table 8.9, the water and salt budgets in the Tien estuary are shown in Figures 8.15 and 8.16.

Table 8.9. Water fluxes for the Tien River estuary.

Water Flux	**Dry season** (10^6 m^3 d^{-1})	**Wet season** (10^6 m^3 d^{-1})
	Upper layer	Whole system
Precipitation (V_P)	0	2
Evaporation (V_E)	1	1
Runoff (V_Q)	77	567
Groundwater, other sources	≈ 0 (assumed)	≈ 0 (assumed)

The water exchange times within the Tien River estuary can be calculated by:

$$t = V_{syst} / \left| V_{surf} \right|$$

So, in the dry season: $\tau_1 = [(1{,}400x10^6)/(77x10^6)] = 11$ days.

In the wet season: $\tau_2 = [(1{,}400x10^6)/(1{,}136x10^6)] = 1$ day.

Thus, water exchange time in the Tien River estuary is very short, especially in wet season.

DIN and DIP budgets

The average concentrations of dissolved inorganic nitrogen and phosphorus in the Tien River estuary are presented in Table 8.10. N and P budgets are presented in Figures 8.17-8.20. With the assumption that all nutrients loads were included in the river discharge, the results indicate that the system is a net source in the dry season and a net sink in the wet season for DIP. The system is a net source of DIN for both seasons.

Table 8.10. Nutrient concentrations in the Tien River estuary.

Sources	**Seasons**	**DIP** (µM)	**DIN** (µM)
Runoff	Dry	0.7	4.1
	Wet	1.7	29.6
System	Dry (Upper layer)	0.7	7.0
	Dry (Lower layer)	0.6	4.5
	Wet	0.9	27.9
Ocean	Dry	0.2	6.1
	Wet	1.6 (Surface) 1.0 (Bottom)	28.3 (Surface) 16.7 (Bottom)

Stoichiometric calculation of aspects of net ecosystem metabolism

Ecosystem metabolism was calculated only for the dry season when water exchange time was long enough to allow the nutrients to be processed by organisms. If it is assumed that all the behaviors of nonconservative materials are biological processes, then the value of *DDIP* can be a measure of the net productivity of the system.

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

The value for (*p-r*) in the dry season is shown in Table 8.11. The estimated results denote that the system is net heterotrophic.

Table 8.11. Net ecosystem metabolism, NEM (*p-r*) in the Tien River estuary in the dry season.

Areas	*DDIP*		NEM (*p-r*)	
	10^3 mol P d^{-1}	mmol P m^{-2} d^{-1}	10^3 mol C d^{-1}	mmol C m^{-2} d^{-1}
Upper layer	+20	+0.09	-2,120	-9
Lower layer	+3	+0.01	-318	-1
Whole system	+23	+0.10	+2,438	-10

Based on the N:P Redfield ratio, expected nonconservative DIN ($DDIN_{exp}$) can calculated to be 16 x *DDIP*. On the other hand, the *DDIN* estimated from the water and salt balances presents the $DDIN_{obs}$. Therefore, the difference between $DDIP_{exp}$ and $DDIN_{obs}$ represents the difference between nitrogen fixation and denitrification, that is;

(nfix-denit) = $DDIN_{obs}$ - $DDIP_{exp}$ Or: *(nfix-denit)* = $DDIN_{obs}$ - $DDIPx(N:P)_{part}$. The results indicate that the system is net denitrifying (Table 8.12).

Table 8.12. Estimated value of (*nfix - denit*) for the Tien River estuary in the dry season.

	$DDIN_{obs}$		$DDIN_{exp}$		(*nfix-denit*)	
	10^3 mol N d^{-1}	mmol N m^{-2} d^{-1}	10^3 mol N d^{-1}	mmol N m^{-2} d^{-1}	10^3 mol N d^{-1}	mmol N m^{-2} d^{-1}
Upper	+728	+3.2	+320	+1.4	+408	+1.8
Lower	-470	-2.0	+48	+0.2	-518	-2.3
Whole system	+258	+1.2	+368	+1.6	-110	-0.5

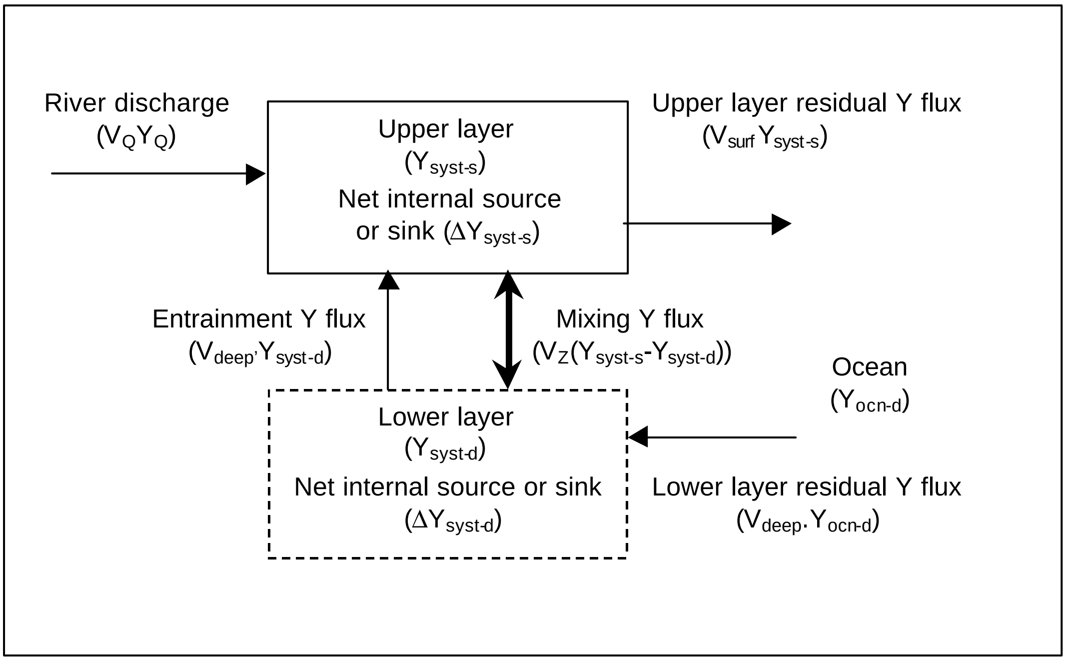


Figure 8.14. Schematic of a two-layer budget model.

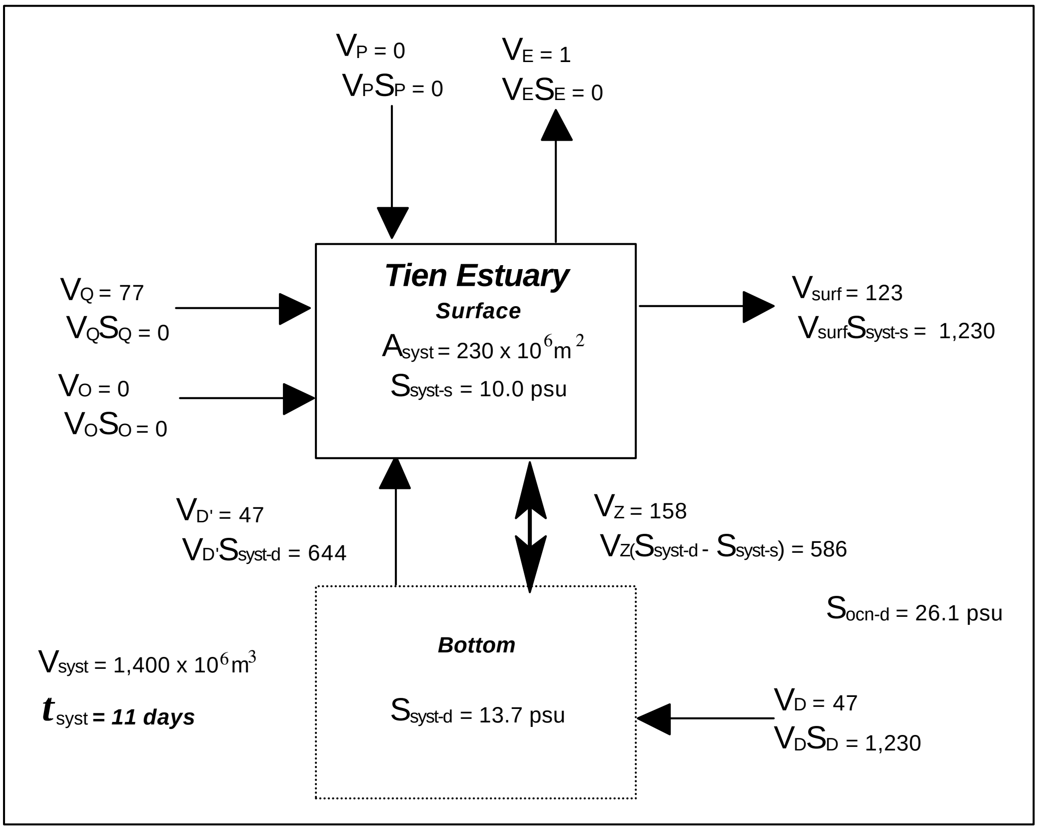


Figure 8.15. Two-layer water and salt budgets for the Tien River estuary in the dry season. Box outlined with dashed lines represents lower layer of the system. Water flux in 10^6 m^3 d^{-1} and salt flux in 10^6 psu-m^3 d^{-1}.

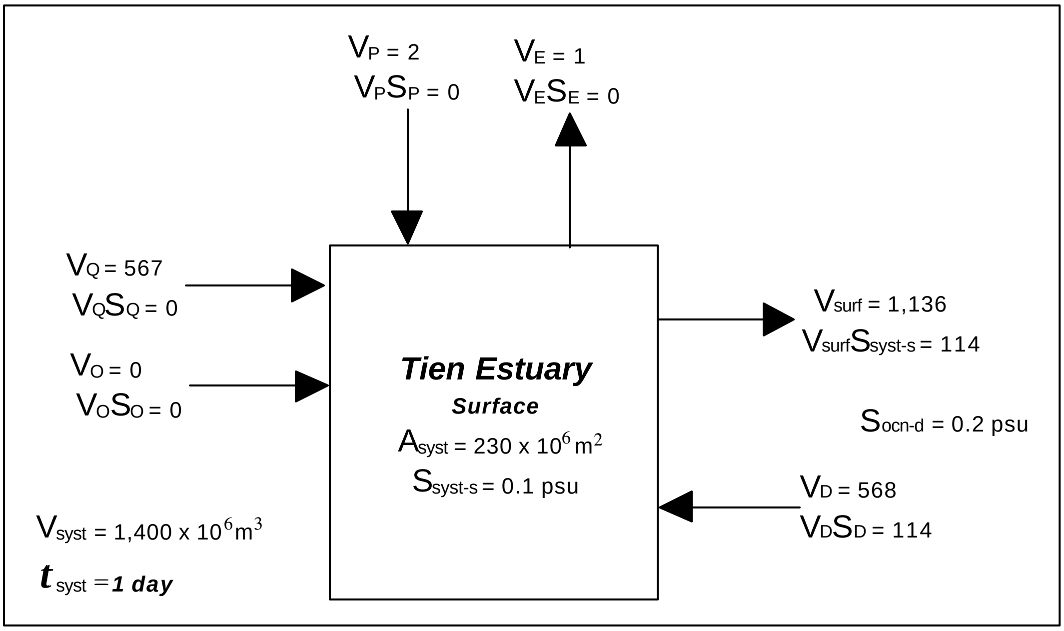


Figure 8.16. Water and salt budgets for the Tien River estuary for the wet season. Water flux in 10^6 m^3 d^{-1} and salt flux in 10^6 psu-m^3 d^{-1}.

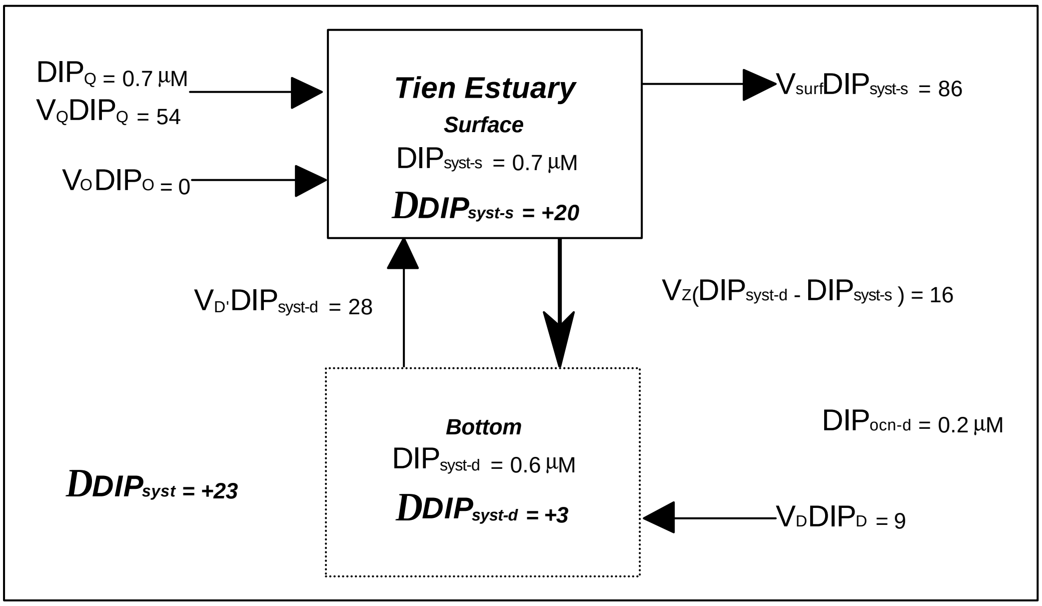


Figure 8.17. Two-layer dissolved inorganic phosphorus budget for the Tien River estuary in the dry season. The box outlined with dashed lines represents lower layer of the system. Fluxes in 10^3 mol d^{-1}.

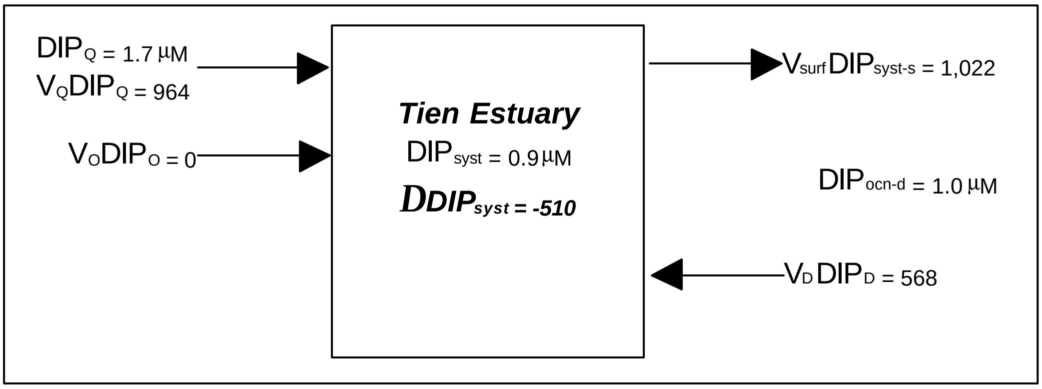


Figure 8.18. Two-layer dissolved inorganic phosphorus budget for the Tien River estuary in the wet season. Flux in 10^3 mol d^{-1}.

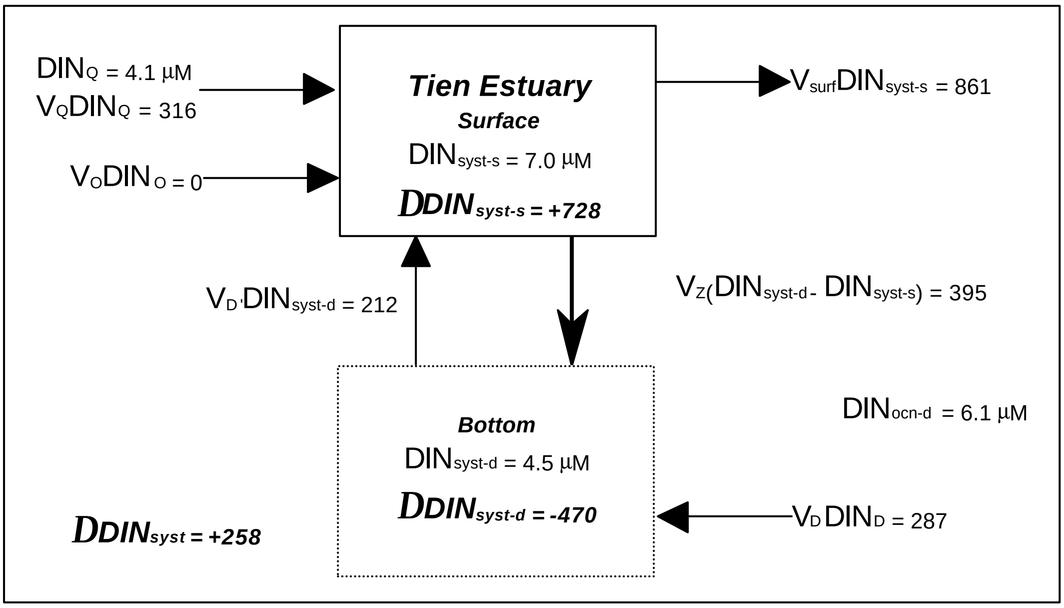


Figure 8.19. Two-layer dissolved inorganic nitrogen budget for the Tien River estuary for the dry season. The box with dashed outlines represents lower layer of the system. Flux in 10^3 mol d^{-1}.

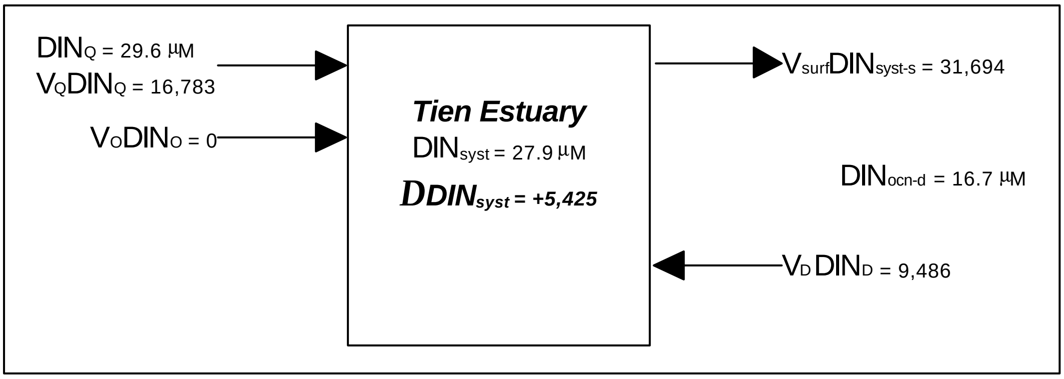


Figure 8.20. Two-layer dissolved inorganic nitrogen budget for the Tien River estuary for the wet season. Flux in 10^3 mol d^{-1}.

8.4 VanPhong Bay, Vietnam

Nguyen Huu Huan and Nguyen Tac An

Study area description

VanPhong Bay is situated in the northern part of KhanhHoa Province between 12.4° and 12.8 °N, and 109.3° and 109.8 °E. The bay has a total area of approximately 460 km^2 of which the total area of the islands is about 50 km^2. The average depth of the bay is about 17 m and the total of water volume is about $7x10^9$ m^3 (Nguyen Tac An 1996; Bui Hong Long 1996). The budgeted area of the bay is shown in Figure 8.21.

TruongSonNam Mountain is located at a distance of about 25 km from the western shore of the bay. To the north-east of the bay is HonGom Peninsula, a range of small mountains and banks of sand, which extend 30 km. VanPhong Bay has two connections to the sea: Be mouth (in the south of HonGom Peninsula), more than 2 km wide and VanPhong mouth, about 17 km wide.

Annual average precipitation is about 1,300 mm with about 117 rainy days. Normally, the wet season lasts from September to December, and the dry season from January to July. Average annual evaporation is about 1,400 mm, which exceeds annual precipitation. In the dry season, salinity in VanPhong Bay is usually higher than in the ocean (Nguyen Khoa Dieu Huong 1995).

The population density along the coast of the bay is low. The standard of living is relatively low in this area. Economic activities in and around VanPhong Bay include agriculture, marine exploitation, aquaculture, and salt production. Some economic centers are being constructed, including HonKhoi Cement Factory, DamMon Port for sand export and Hyundai-Vinashin Ship Manufactory.

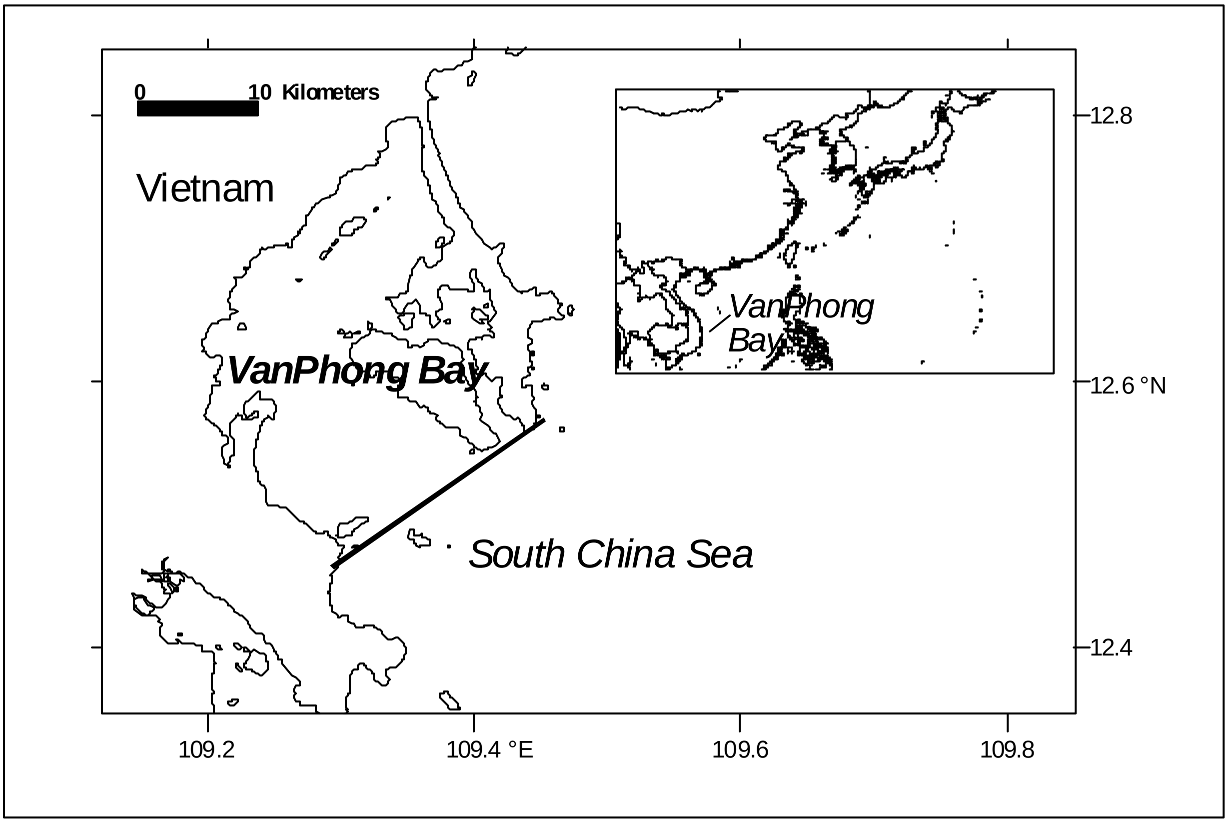
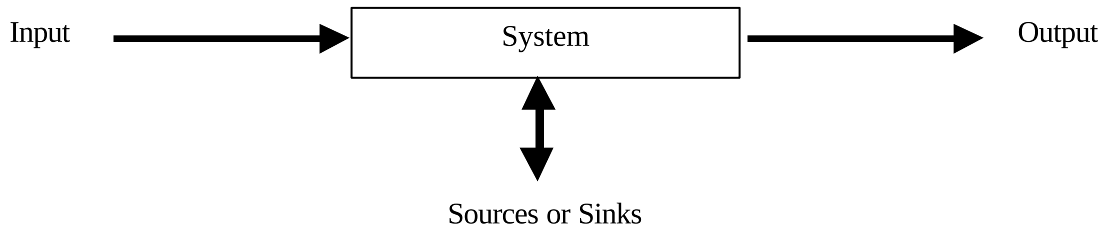


Figure 8.21. Map and location of VanPhong Bay. Solid bar shows the boundary of the budgeted area of the bay.

The LOICZ Biogeochemical Modelling Guidelines (Gordon *et al.* 1996) were applied to the data collected from 1994 to 1998 in VanPhong Bay.

Water and salt balance

The conceptual model for transport of materials in a system is:



We can describe the process by:

$$\frac{dM}{dt} = \sum input - \sum Output + \sum (Sources - Sinks) \qquad (1)$$

where dM/dt is the change of mass of material of interest. Assuming the system of interest is at steady state (dM/dt = 0), based on data in Table 8.13, the balances of water and salt are shown in Figures 8.22 and 8.23.

The water exchange time in the system (τ) can be calculated as the total volume of the system divided by the sum of the absolute value of residual ($|V_R|$) and volume of mixing (V_X). Thus:

In the dry season: $\tau_2 = V_{syst.} /(|V_{R2}| + V_{X2}) = 7x10^9/(1 \text{ x } 10^6 + 113x10^6) = 61$ days.

In the rainy season: $\tau_1 = V_{syst.} /(|V_{R1}| + V_{X1}) = 7x10^9/(1 \text{ x } 10^6 + 160 \text{ x } 10^6) = 43$ days.

Table 8.13. Water fluxes for VanPhong Bay.

Factors	Dry season	Wet season
V_P (10^6 m^3 d^{-1})	1	3
V_E (10^6 m^3 d^{-1})	2	2
V_O (10^6 m^3 d^{-1})	≈ 0 (assumed)	≈ 0 (assumed)
V_G (10^6 m^3 d^{-1})	≈ 0 (assumed)	≈ 0 (assumed)
V_Q (10^6 m^3 d^{-1})	≈ 0 (assumed)	≈ 0 (assumed)

As VanPhong Bay is a relatively closed system (without any river), water exchange time is only affected by evaporation, precipitation and tidal regime.

DIP and DIN budgets

The balance of any nonconservative material (Y) at steady state is calculated as follows:

$$d(VY)/dt = V_Q Y_Q + V_P Y_P + V_G Y_G + V_E Y_E + V_R Y_R + V_X(Y_{ocn} - Y_{syst}) + DY \qquad (2)$$

where the various "VY" terms involve fluxes of Y with water sources and ΔY represents the net internal source or sink of element Y. In the case of VanPhong Bay, the equation (2) can be simplified and solved for ΔY as follow:

$$d(VY)/dt = V_R Y_R + V_X(Y_{ocn} - Y_{syst}) + DY \qquad (3)$$

Assuming that at steady state in any system: d(VY)/dt = 0, solving for *DY* from equation (3):

$$DY = - V_R Y_R - V_X(Y_{ocn} - Y_{syst}) \quad (4)$$

From equation (4) and data in Table 8.6, we can calculate *DY* (DIP and DIN) as shown in Figures 8.24 – 8.27. The results show that the system is a net source in the rainy season and a net sink in the dry season for DIP. The system is a net source for DIN for both seasons.

Table 8.14. Nutrient concentrations of water fluxes in VanPhong Bay.

	Seasons	DIP (μM)	DIN (μM)
System	Dry	0.1	19.5
	Wet	0.1	5.6
Ocean	Dry	0.1	7.9
	Wet	0.1	4.6

Stoichiometric calculation of aspects of net system metabolism

With the assumption that the behavior of nonconservative materials is primarily due to biological processes, the value of *DDIP* is a measure of the net productivity in the system. The net ecosystem metabolism (NEM = [*p-r*]) is calculated as the negative *DDIP* multiplied by the C:P ratio of the reacting organic matter. Assuming that the bulk of the reacting organic matter is phytoplankton, the C:P ratio is 106:1. Thus, $(p\text{-}r) = - 106 \times DDIP$

In the case of VanPhong Bay, the net ecosystem metabolism (*p-r*) is very low for both seasons. This suggests that the system seems to balance production and respiration (see Table 8.15).

Table 8.15. Net ecosystem metabolism (NEM) for VanPhong Bay.

Seasons	*DDIP*		NEM (*p-r*)	
	10^3 mol P d^{-1}	mmol P m^{-2} d^{-1}	10^3 mol C d^{-1}	mmol C m^{-2} d^{-1}
Dry	-0.1	0	+10.6	+0.03
Wet	+0.1	0	-10.6	-0.03
Annual	0	0	+2.9	+0.01

Based on the (N:P) Redfield Ratio, we can calculate $DDIP_{exp}$ to be 16(*DDIP*). On the other hand, the *DDIN* estimated from the water and salt balances presents the $DDIN_{obs}$. Therefore, the difference between $DDIP_{exp}$ and $DDIN_{obs}$ represents the difference between nitrogen fixation and denitrification, that is, $(nfix\text{-}denit) = DDIN_{obs} - DDIP_{exp}$ Or: $(nfix\text{-}denit) = \Delta DIN_{obs} - \Delta DIP \times (N:P)_{part.}$

The estimated results are presented in Table 8.16. (*nfix-denit*) is +163x10^3 mol N d^{-1} or +0.4 mmol N $m^{-2}d^{-1}$ in the wet season and +1,299x10^3 mol N d^{-1} or +3.2 mmol N m^{-2} d^{-1} in the dry season. VanPhong Bay appears to be a net nitrogen fixing system with annual *(nfix-denit)* of +2.2 mmol N $m^{-2}d^{-1}$.

Table 8.16. The estimated value of (*nfix - denit*) for VanPhong Bay.

Seasons	*DDIN*		*DDIP*(N:P)		(*nfix - denit*)	
	10^3 mol N day^{-1}	mmol N m^{-2} day^{-1}	10^3 mol N day^{-1}	mmol N m^{-2} day^{-1}	10^3 mol N day^{-1}	mmol N m^{-2} day^{-1}
Dry	+1,297	+3.2	-2	0	+1,299	+3.2
Wet	+165	+0.4	+2	0	+163	+0.4
Annual	+885	+2.2	-0.5	0	+885	+2.2

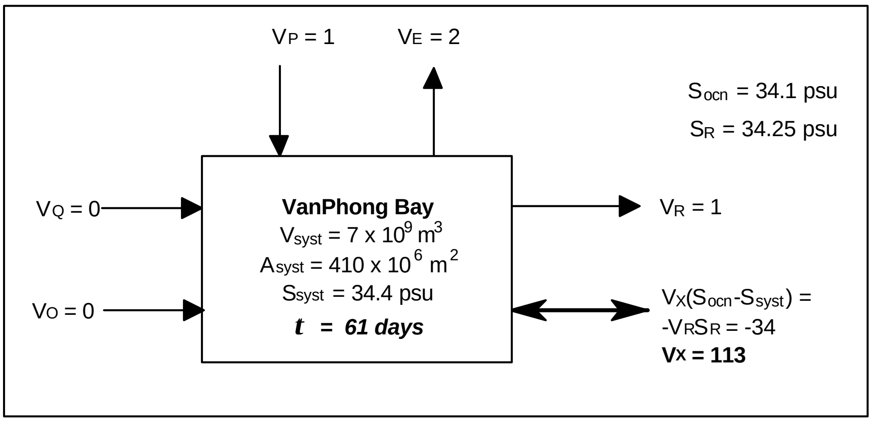


Figure 8.22. Water and salt budgets for VanPhong Bay in the dry season. Water flux in 10^6 m^3 d^{-1} and salt flux in 10^6 psu-m^3 d^{-1}.

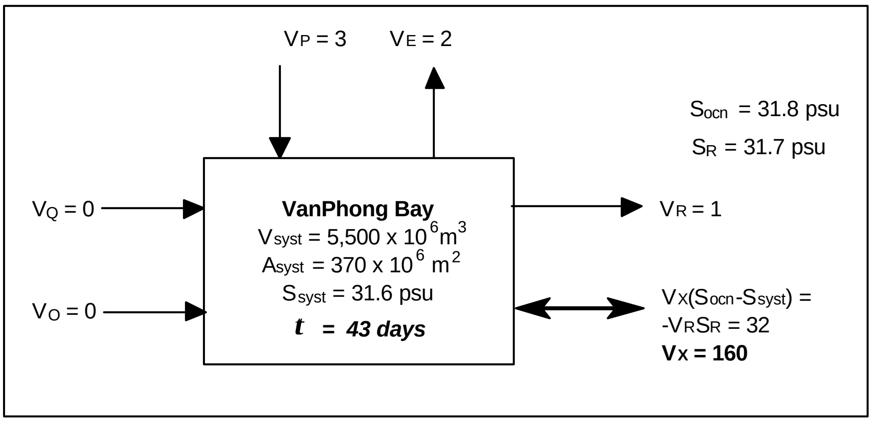


Figure 8.23. Water and salt budgets for VanPhong Bay in the wet season. Water flux in 10^6 m^3 d^{-1} and salt flux in 10^6 psu-m^3 d^{-1}.

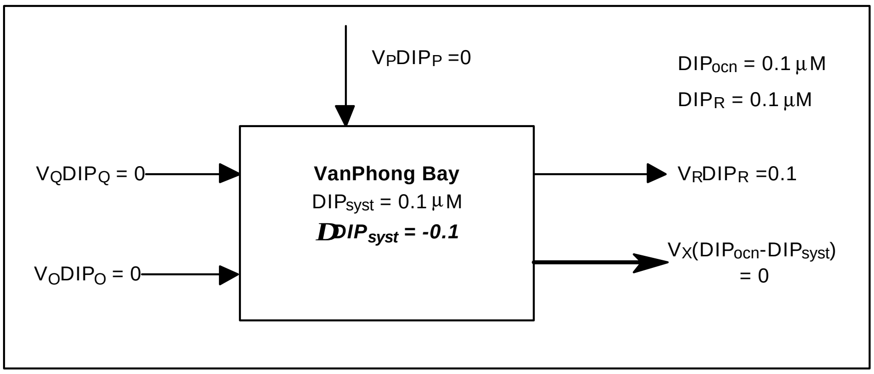


Figure 8.24. Dissolved inorganic phosphorus budget for VanPhong Bay in the dry season. Flux in 10^3 mol d^{-1}.

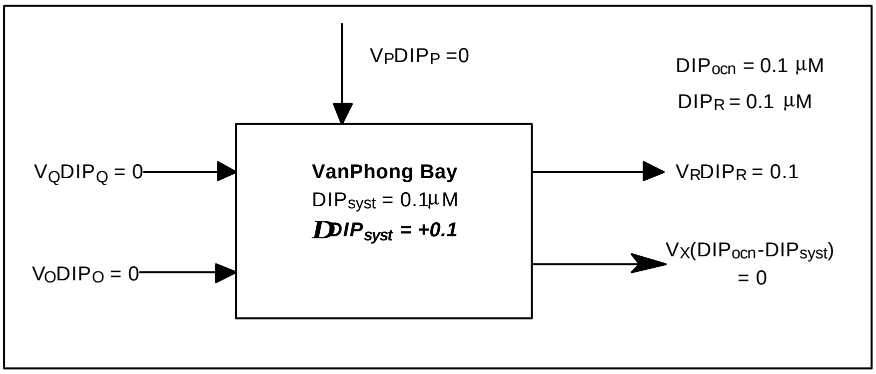


Figure 8.25. Dissolved inorganic phosphorus budget for VanPhong Bay in the wet season. Flux in 10^3 mol d^{-1}.

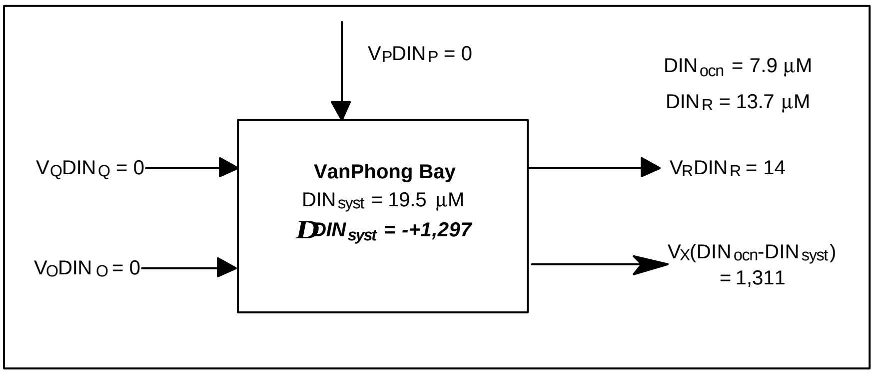


Figure 8.26. Dissolved inorganic nitrogen budget for VanPhong Bay in the dry season. Flux in 10^3 mol d^{-1}.

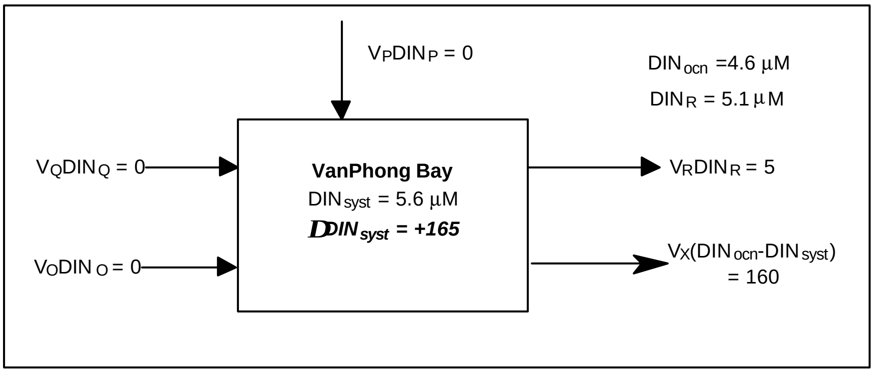


Figure 8.27. Dissolved inorganic nitrogen budget for VanPhong Bay in the wet season. Flux in 10^3 mol d^{-1}.