2. BUDGETS FOR ESTUARIES IN RUSSIA

2.1 Amursky Bay

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Study area description

Amursky Bay is a 400 km^2 embayment (~ 15 m deep; volume ~ $6x10^9$ m^3) adjacent to the city of Vladivostok, Russia (Figure 2.1). The bay receives freshwater input primarily from the Tavrichanka Estuary, a short (2 km), narrow (2 km), shallow (0.3-5 m) lagoon located at the end of the bay, and exchanges water with Piter Great Gulf, Japan Sea (43.2°N, 131.5°E). Communication with the gulf is through three mouths in the southern zone, 150, 50 and 50 m wide. In addition to river flow (averaging about $4x10^6$ m^3 d^{-1} since 1936) (Gidrometeoizdat, Prymorye Hydrometeorological Administration 1998), the budgeted portion of the bay receives waste load from Vladivostok, Artem and Nadezhdinsky districts. The phosphorus content (DIP) of the waste load averages about 14 µM, and the nitrogen (DIN) averages about 390 µM. For the budgeted part of Amursky Bay, waste load was about $0.2x10^6$ m^3 d^{-1} in 1998 (Gidrometeoizdat, Prymorye Hydrometeorological Administration 1999).

The weather in the region is cold and humid. Annual mean temperature is 5°C, varying from -15°C in January to 20°C in July. The annual mean rainfall is 600 mm and evaporation is 450 mm. In this zone, two main seasons are recognized: the dry season with low rainfall (October-April, 0-60 mm), and the rainy season (May-September; >500 mm). The annual rainfall minus evaporation balance is positive but is negligible in the water budget (Gidrometeoizdat, Prymorye Hydrometeorological Administration 1996, 1997, 1998).

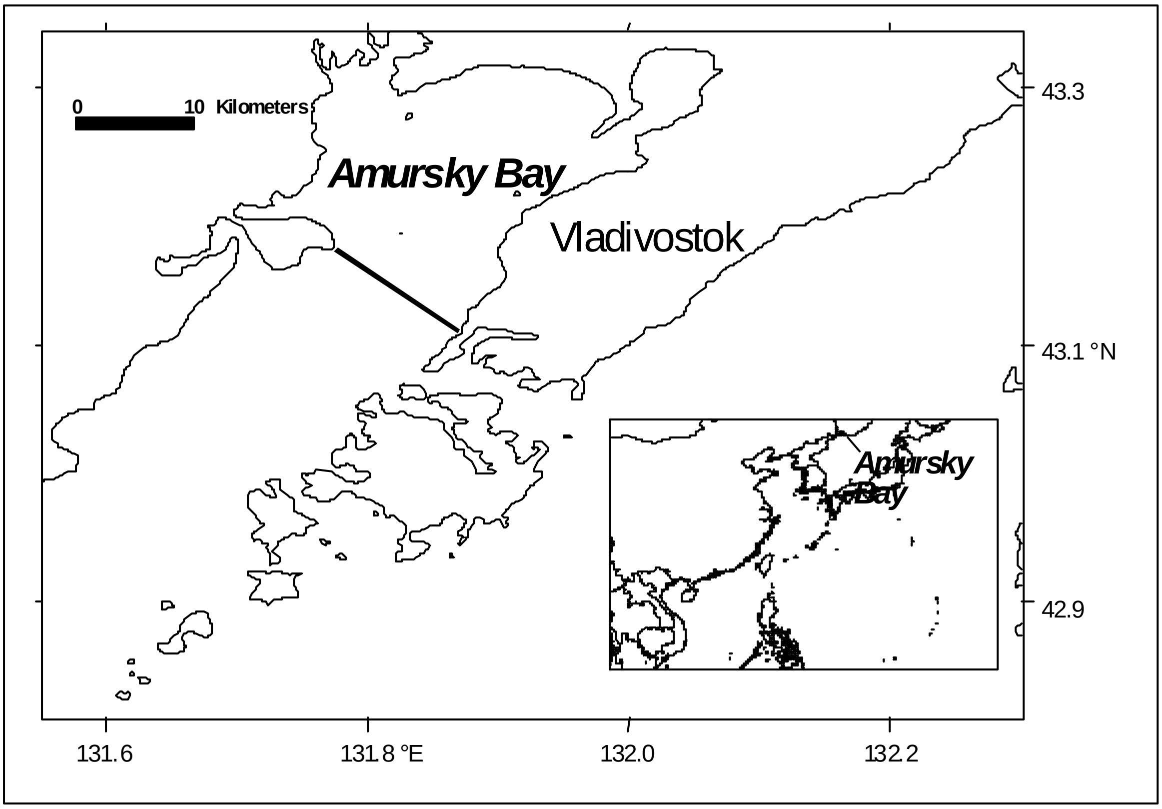

Figure 2.1. Map and location of Amursky Bay, Russia, with the budgeted area indicated.

The budgets undertaken here were based on hydrographic data collected on two dates in 1997 (10 and 28 September) (Cruise Report, R/V "Professor Gagarinsky" 1997, Gramm-Osipova 1997). River discharge at that time was about 2 x 10^6 m^3 d^{-1} (Gidrometeoizdat, Prymorye Hydrometeorological Administration 1996, 1997, 1998). Nutrient concentration data for the river were not obtained during the hydrographic survey but are interpolated (mean value for 1996-1998) from the data in Figures 2.2 and 2.3 to be 1 µM DIP and 40 µM DIN (Gidrometeoizdat, Prymorye Hydrometeorological Administration 1999).

Water and salt budgets

Water and salt budgets for Amursky Bay (Figure 2.4) were calculated with the "CABARET" program. The water exchange time averages about 250 days.

Budgets of nonconservative materials

DIP balance

The system appears to be a net DIP source (*DDIP* = +20x10^3 mol d^{-1}, or +0.05 mmol m^{-2} d^{-1}). There is apparently very low net flux in surface waters and some release in the deep water (Figure 5).

DIN balance

The system appears to be a net DIN sink (*DDIN* = -169x10^3 mol d^{-1}, or -0.4 mmol m^{-2} d^{-1}), with high net uptake in the surface waters and slight release in the deep water (Figure 6).

Stoichiometric calculations of aspects of net system metabolism

If it is assumed that the reacting material has a Redfield C:N:P composition of 106:16:1, then the slight net DIP release indicates an oxidation of approximately 5 mmol C m^{-2} d^{-1}. Similarly, the release of DIP and uptake of DIN suggests a net denitrification rate of approximately 1.2 mmol m^{-2} d^{-1}.

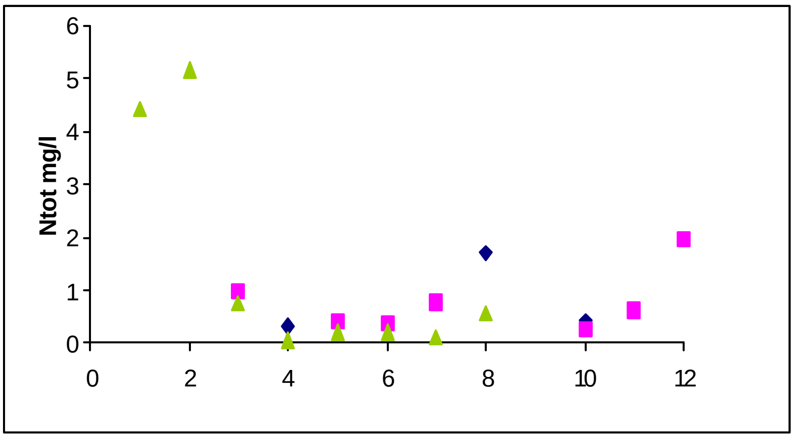

Figure 2.2. Plot diagram for nitrate in Razdol'naya River water for 1996-1998 .

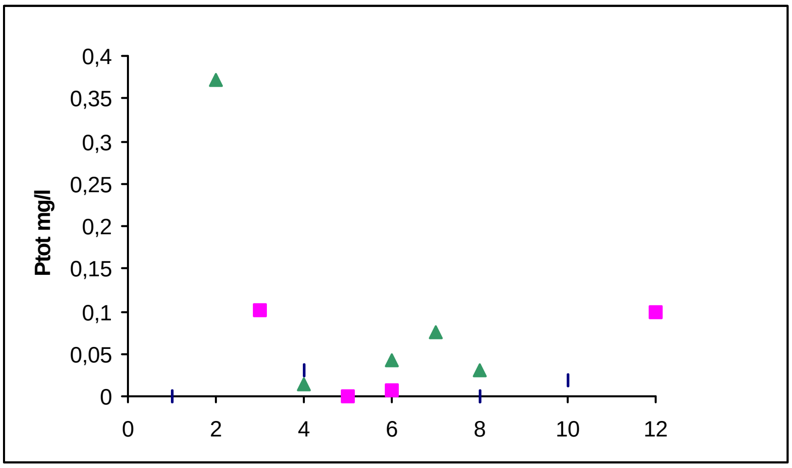

Figure 2.3. Plot diagram for phosphorus concentration in Razdol'naya River water for 1996-1997.

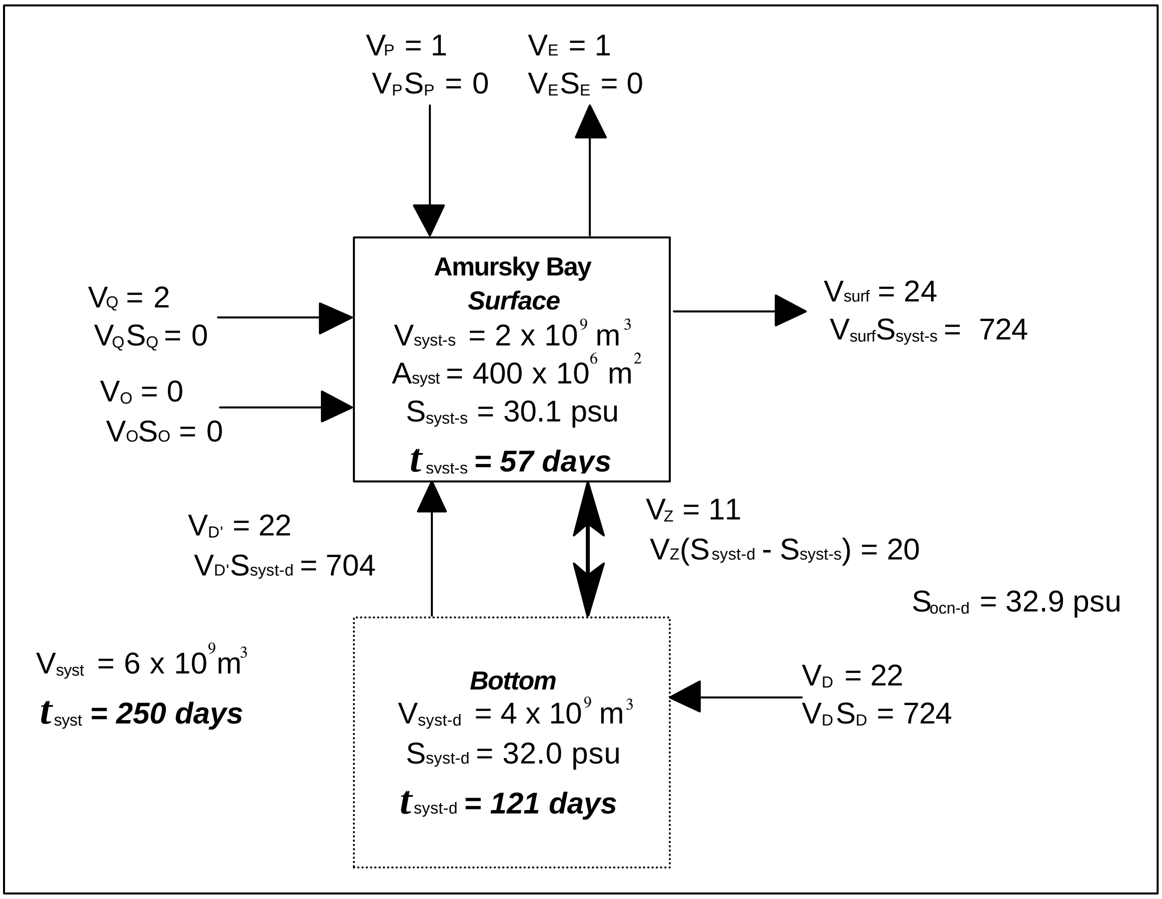

Figure 2.4. Water and salt budgets for two-layer model for Amursky Bay in September 1997. Water flux in 10^6 m^3 d^{-1} and salt flux in 10^6 psu-m^3 d^{-1}.

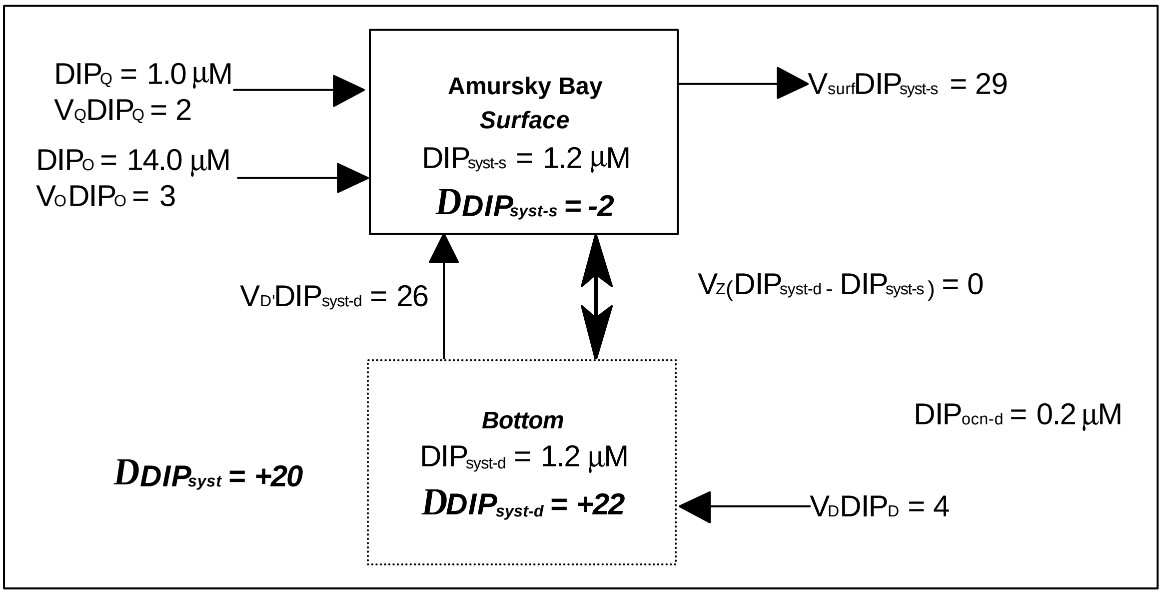

Figure 2.5. DIP budget for two-layer model for Amursky Bay in September 1997. Flux in 10^3 mol d^{-1}.

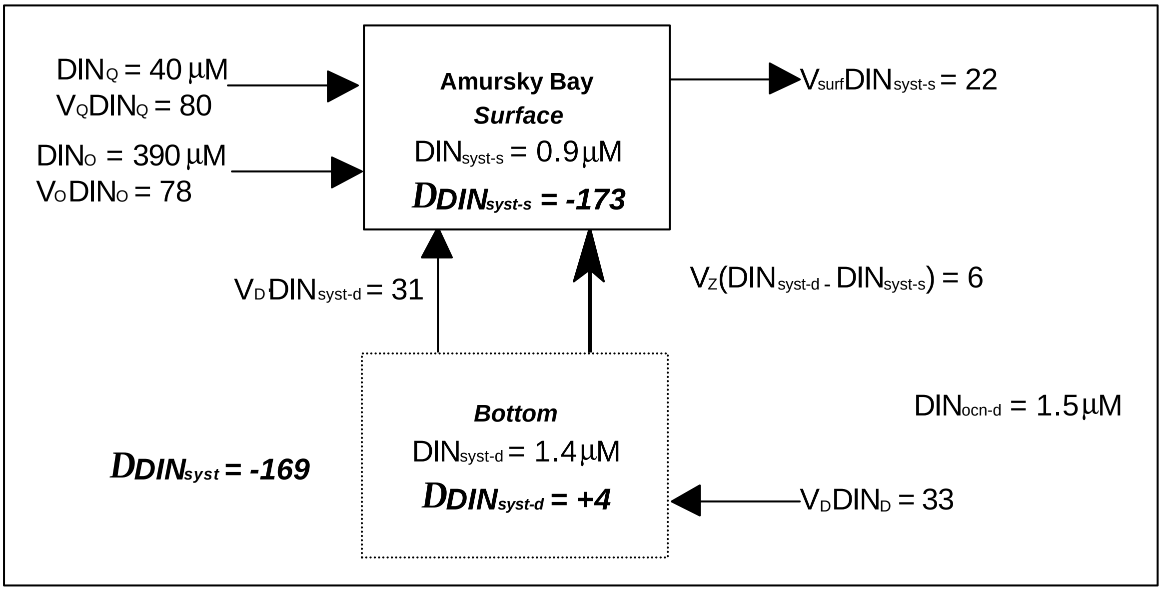

Figure 2.6. DIN budget for two-layer model for Amursky Bay in September 1997. Flux in 10^3 mol d^{-1}.

2.2 Amur River estuary

Anatoly V. Mozherovsky

<u>Study area description</u>

The Amur River (141.33 °E, 53.00 °N) is one of the largest rivers in the Far East region (Figure 2.7). The length is 4,400 km with an area of about 1,900 x 10^3 km^2. The annual river discharge is about 3,600 x 10^9 m^3. The fresh water discharge can be observed for more than 200 km out to sea from the mouth of the river.

The main sources of the river flow are the Sikhote-Alin Mountain Ridge and the southern part of Siberia. The area is characterized by high precipitation in the winter, which contributes about 18-22% of the annual river discharge. The spring flood during April and May supplies about 25-30% of the annual water discharge. Brief floods are common in the summer and autumn up until October or November. In the winter, the river discharge is relatively low, about 3-5% of the annual discharge. Complete ice cover usually starts in mid-November and continues until early May. Mean temperature ranges from -26°C in the winter to +18°C in the summer. Mean rainfall is 600-700 mm yr^{-1} and evaporation is 450-550 mm yr^{-1}.

Human population in this area is small. Agricultural and industrial activities are low. Main pollution sources are large towns (population 100,000-600,000), shipbuilding, pulp and paper, mining and timber industries.

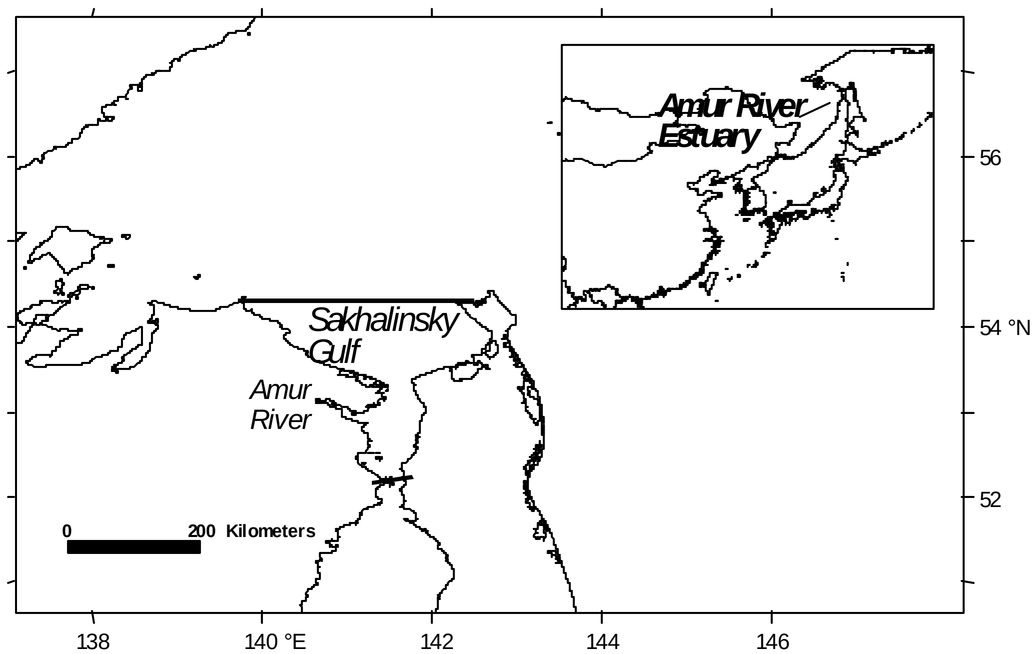

Figure 2.7. Map of the Amur River estuary. Solid bars show the boundary of the budgeted system.

For budgeting purposes, the Amur River estuary and Sakhalinsky Gulf were considered as one box. The Amur River estuary has an area of about 4,400 km^2 with a length of 130 km and width of 46 km. The average depth of the estuary is 30 m. Sakhalinsky Gulf has an area of 15,600 km^2 and depth range of 15-40 m.

Hydrology of the area was studied during five cruises held between 1986 and 1994 by Pacific Oceanological Institute (POI FEB RAS). Data was provided by I.D.Rostov (http://poi.febras.ru/stuff/rostov.htm). See Table 2.1.

Table 2.1. Hydrological data for the Amur River and Sakhalinsky Gulf

		Salinity psu		DIN µM		DIP µM	
		system	ocean	system	ocean	system	ocean
Amur River				34		0.8	
Sakhalinsky Gulf							
Cruise Jul 1992	0-5 m	31	32	5.0	0.7	0.5	0.3
	5-15 m	32	33	7.0	1.6	1.0	0.8
Cruise Aug 93	0-5 m	28	30	1.5	0.4	0.4	0.5
	5-15 m	31	32	4.0	0.7	0.7	0.8
Cruise Oct 94	0-5 m	20	30	1.7	0.1	0.9	0.6
	5-15 m	29	31	2.6	0.3	1.6	0.9
Average	0-5 m	24	30	3.0	0.2	0.6	0.2
	5-15 m	31	32	5.0	0.4	1.1	0.7

Water discharge for the wet season was calculated based on the river discharge data from 1963 to 1998 (Figure 2.8). Water discharge for the wet season is equal to $21x10^3$ m^3 sec^{-1} or $2x10^9$ m^3 d^{-1}. Nutrient concentrations in the river water discharge were calculated from data measured in 1996 (Figures 2.9 and 2.10). A one-box, two-layer model was used to budget for the wet season.

Water and salt balance

Water and salt budgets for the system (Figure 2.11) were calculated following LOICZ procedure (Gordon *et al.* 1996). Water exchange time was about 30 days.

Budgets of nonconservative materials

DIP and DIN balance

Figures 2.12 and 2.13 summarize the two-layer DIP and DIN budgets for the system. The net nonconservative nutrient fluxes for the whole system were calculated as *DDIP* = $+2x10^6$ mol P d^{-1}, or +0.1 mmol P m^{-2} d^{-1} and *DDIN* = $-45x10^6$ mol N d^{-1} or -2 mmol N m^{-2} d^{-1}.

Stoichiometric calculations of aspects of net system metabolism

If it is assumed that the reacting material has a Redfield C:N:P composition of 106:16:1, then the upper layer is autotrophic: *(p-r)* = +33 mmol m^{-2} d^{-1} and net nitrogen fixing: *(nfix-denit)* = + 0.3 mmol m^{-2} d^{-1}. The lower layer is heterotrophic: *(p-r)* = -46 mmol m^{-2} d^{-1} and net denitrifiying: *(nfix-denit)* = -5 mmol m^{-2} d^{-1}. This implies that whatever organic material is fixed in the upper layer is broken down at lower depths. Some organic material in the sediments may also contribute to heterotrophy and denitrification in the lower box. The whole system is heterotrophic: *(p-r)* = -13 mmol m^{-2} d^{-1} and net denitrifying: *(nfix-denit)* = -5.0 mmol m^{-2} d^{-1}.

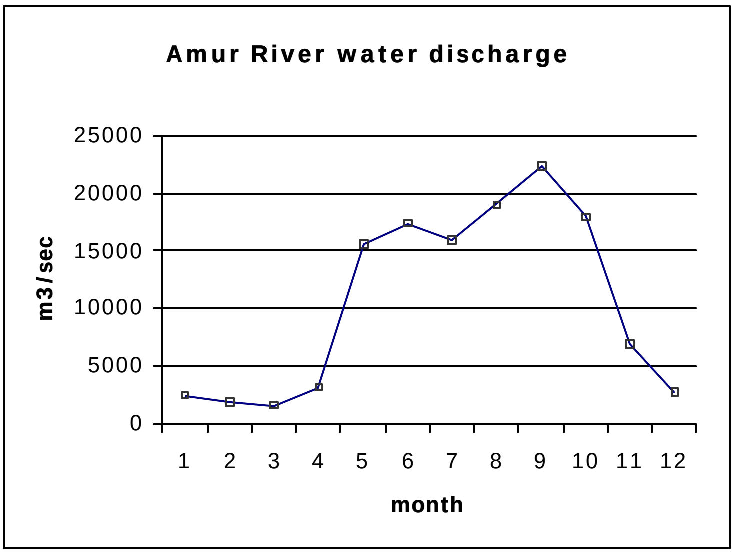

Figure 2.8. Plot diagram of average monthly discharge for Amur River.

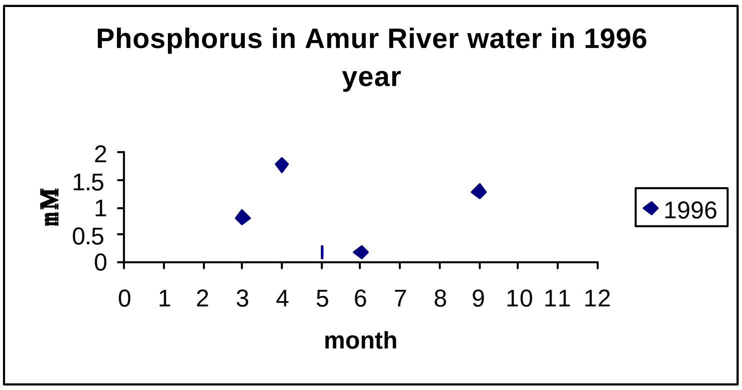

Figure 2.9. Plot diagram of dissolved inorganic phosphorus concentrations for the Amur River water discharge in 1996.

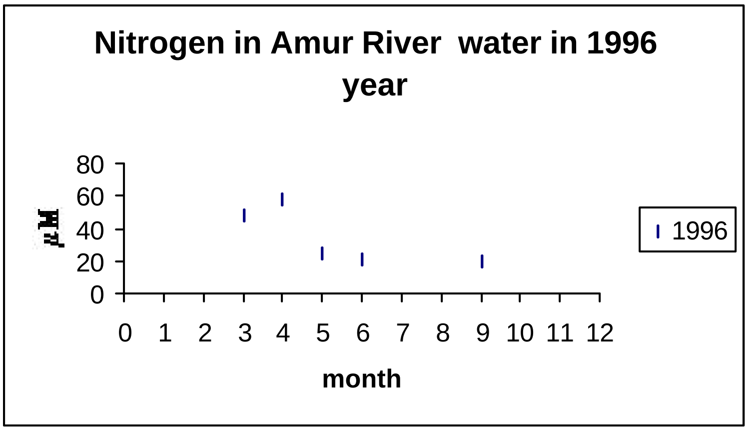

Figure 2.10. Plot diagram of dissolved inorganic nitrogen concentrations for the Amur River water discharge in 1996.

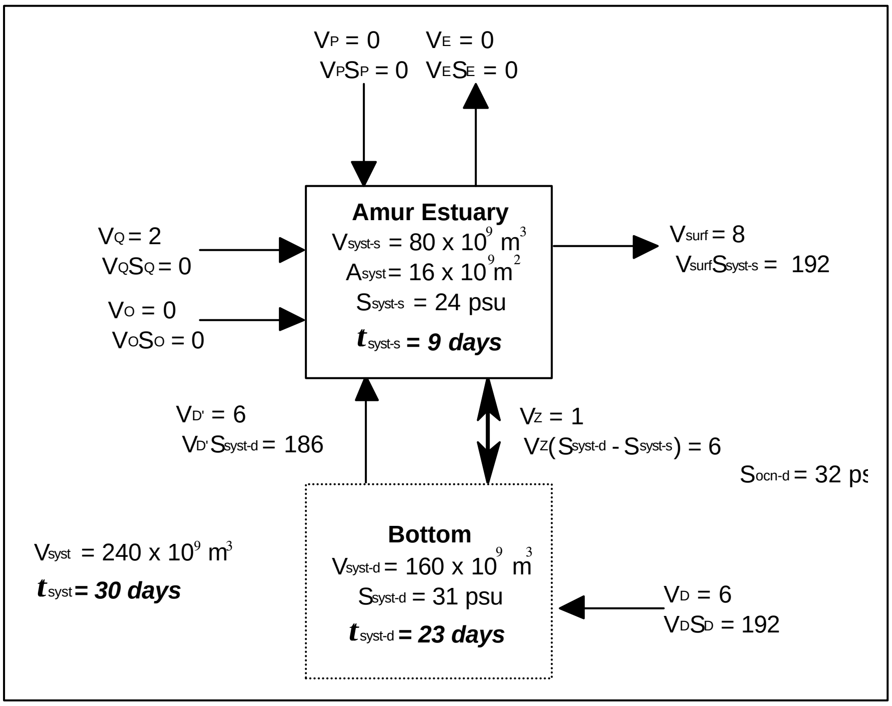

Figure 2.11. Water and salt balance for the Amur River estuary in the wet season. Water flux in 10^9 m^3 d^{-1} and salt flux in10^9 psu-m^3 d^{-1}.

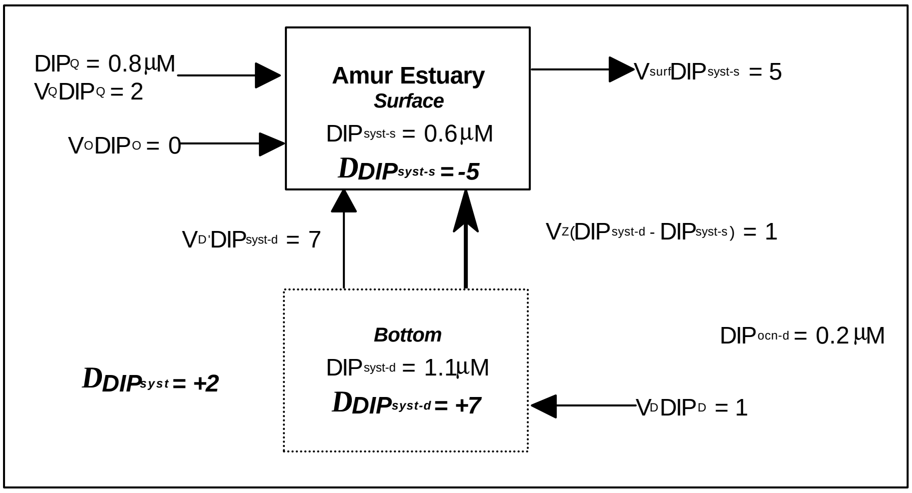

Figure 2.12. Dissolved inorganic phosphorus balance for the Amur River estuary in the wet season. Flux in 10^6 mol d^{-1}.

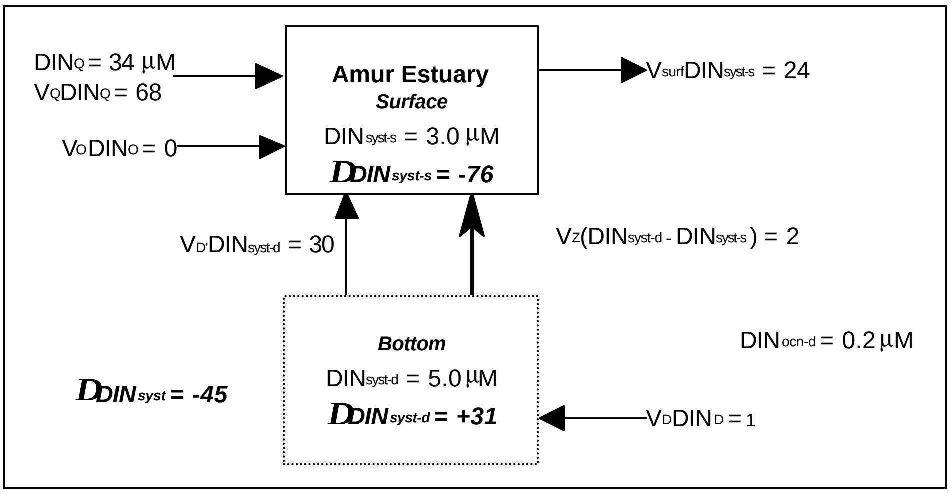

Figure 2.13. Dissolved inorganic nitrogen balance for the Amur River estuary in the wet season. Flux in 10^6 mol d^{-1}.

2.3 Ussuriyskiy Bay

Anatoly V. Mozherovsky

Study area description

Ussuriyskiy Bay (43.27°N, 131.82°E) is a relatively large embayment with an area of about 750 km^2. The average depth of the bay is ~ 40 m with a volume of ~ $30x10^9$ m^3. The bay is adjacent to the city of Vladivostok, Russia (Figure 2.14). Ussuriyskiy Bay exchanges water with Peter the Great Gulf, Japan Sea.

The weather in the region is cold and humid. The annual mean temperature is 5°C, varying from -15°C in January to +20°C in July. The annual mean rainfall is 600 mm and evaporation is 450 mm. In this zone, two main seasons are recognized: the dry season with low rainfall (October-April, 0-60 mm), and the rainy season (May-September; >500 mm).

The estuarine part of Ussuriyskiy Bay ranges from 5-10 km long, 3-5 km wide and 0.3-5 m deep. The estuary is located at the landward end of the bay. Freshwater inputs come primarily from the Artyomovka River (70 km long; watershed area of 1,500 km^2) and the Shkotovka River (60 km long; watershed area of 700 km^2). Measurements for river discharge and nutrient concentrations are not available for the Shkotovka River. Data for Shkotovka River discharge used in this paper were calculated based on the ratio and proportion of watershed and river discharge of Artyomovka River and Shkotovka River. Shkotovka River discharge is half of that of the Artyomovka River. Nutrient concentrations for the Shkotovka River discharge were assumed the same as Artyomovka River. Waste load and other sources both for water and nutrients are considered low in the area.

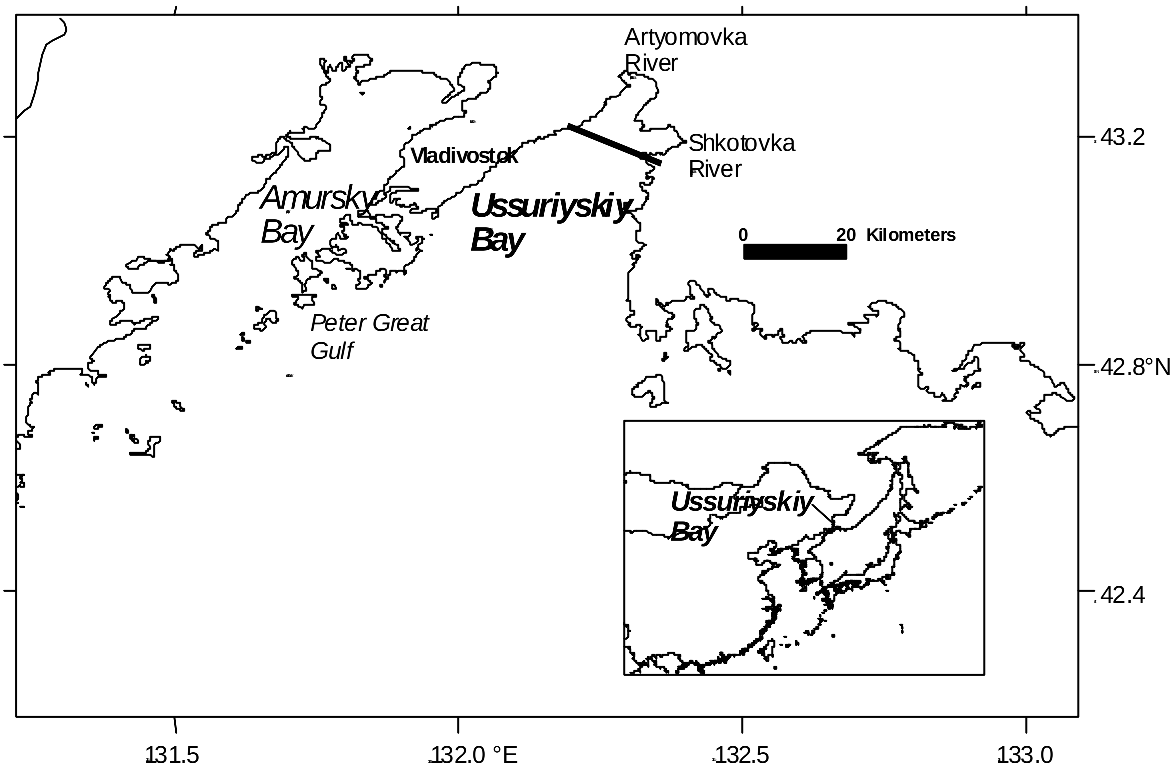

Figure 2.14. Map of Ussuriyskiy Bay. Solid bar shows the boundary of the budgeted system.

The budgets were based on hydrographic data collected between 1999 and 2000 (November and December 1999, and March 2000) by the Pacific Oceanological Institute (POI FEB RAS). The data were provided by G. I. Yurasov. An area of 75 km^2 with an average depth of 3 m was considered in this budget.

Water and salt balance

Water and salt budgets for wet and dry seasons for Ussuriyskiy Bay were calculated following the LOICZ biogeochemical modelling guidelines (Gordon *et al.* 1996). Total flow from the two rivers was estimated as 4 $m^3\ sec^{-1}$ or $350x10^3\ m^3\ d^{-1}$ in the dry season and 11 $m^3\ sec^{-1}$ or $1,000x10^3\ m^3\ d^{-1}$ in wet season. The net balance of rainfall minus evaporation is positive but is negligible in the water budget. Results are very similar for both seasons (Figure 2.16). The water exchange times averaged about 9 and 3 days for dry and wet seasons, respectively.

Budgets of nonconservative materials

DIP and DIN balance
The dissolved inorganic phosphorus and nitrogen (DIP and DIN) were averages from measurements taken in 1996 to 1998 and interpolated as 1.3 µM (DIP) and 12 ìM (DIN) for dry season, and 1.8 µM (DIP) and 13 ìM (DIN) for the wet season (Figures 2.14 and 2.15).

Figures 2.17 and 2.18 illustrate the DIP and DIN budgets for Ussuriyskiy Bay both for the dry and wet seasons. Assuming that nutrient loads into the bay were delivered via rivers and the other sources were insignificant, the budgets show: *DDIP* = $+5x10^3$ mol P d^{-1} (+0.07 mmol P $m^{-2}\ d^{-1}$) and *DDIN* = $+22x10^3$ mol N d^{-1}(+0.3 mmol N $m^{-2}\ d^{-1}$) for the dry season; and *DDIP* = $+6x10^3$ mol P d^{-1} (+0.08 mmol P $m^{-2}\ d^{-1}$) and *DDIN* = $+25x10^3$ mol N d^{-1}(+0.3 mmol N $m^{-2}\ d^{-1}$) for the wet season

Table 2.2. Hydrographic data for Ussuriyskiy Bay.

	Salinity (psu)	**DIN** (µM)	**DIP** (µM)
Dry season			
System	33.5	4.9	0.8
Ocean	34.0	3.9	0.6
Wet season			
System	33.0	5.0	0.8
Ocean	33.5	4.5	0.7

Stoichiometric calculations of aspects of net system metabolism
If it is assumed that the reacting material has a Redfield C:N:P composition of 106:16:1, then the system is net heterotrophic: (*p-r*) = -7 mmol $m^{-2}\ d^{-1}$ and net denitrifying: (*nfix-denit*) = -0.8 mmol $m^{-2}\ d^{-1}$ for dry season; and (*p-r*) = -8 mmol $m^{-2}\ d^{-1}$ and (*nfix-denit*) = -1 mmol $m^{-2}\ d^{-1}$ for wet season.

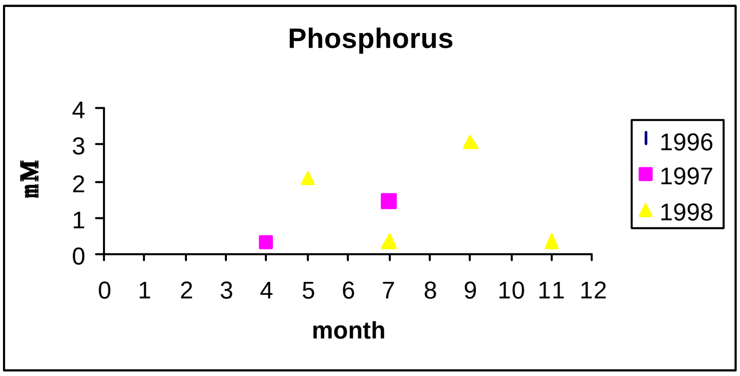

Figure 2.14. Plot diagram for dissolved inorganic phosphorus for the Artyomovka river water discharge in 1996-1998.

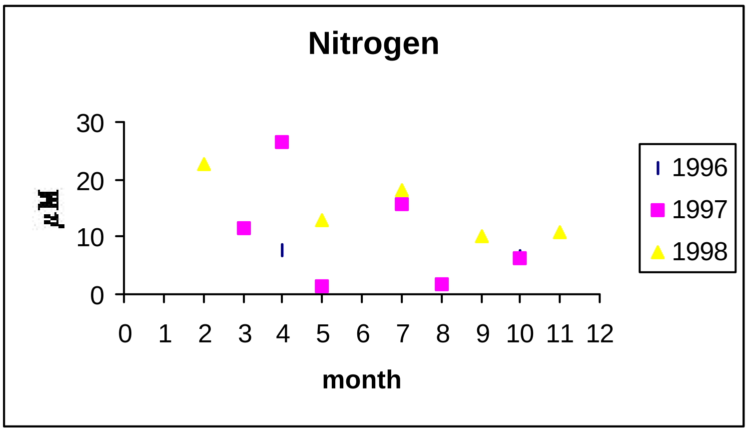

Figure 2.15. Plot diagram for dissolved inorganic nitrogen concentrations for the Artyomovka river water discharge in 1996-1998.

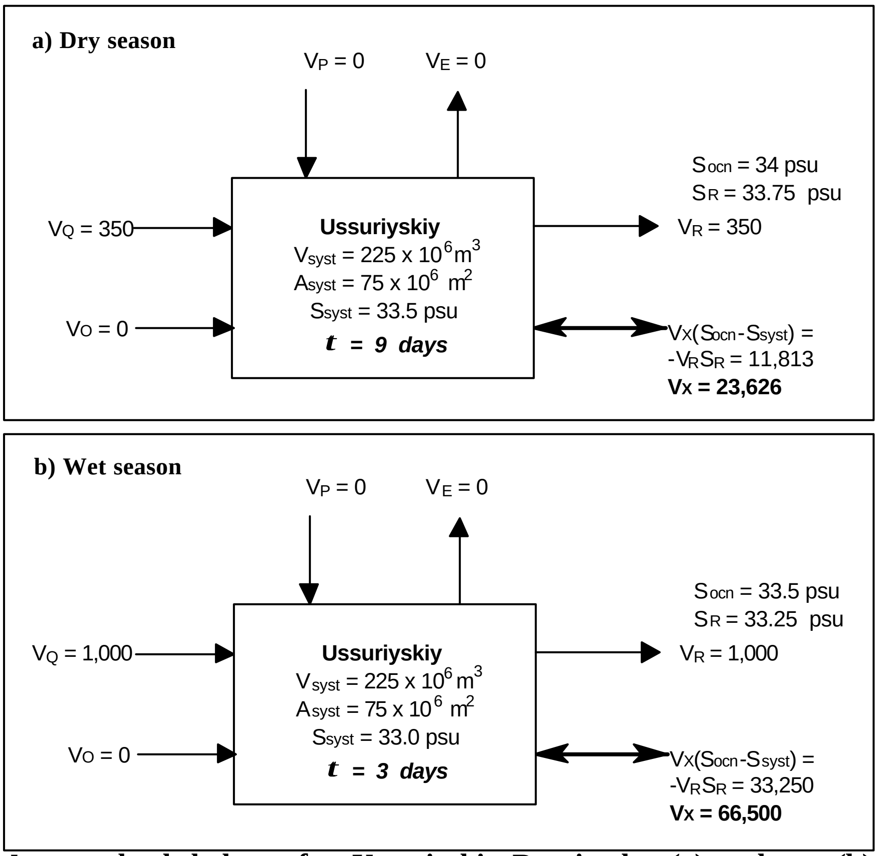

Figure 2.16. Water and salt balance for Ussuriyskiy Bay in dry (a) and wet (b) seasons. Water flux in 10^3 m^3 d^{-1} and salt flux in10^3 psu-m^3 d^{-1}.

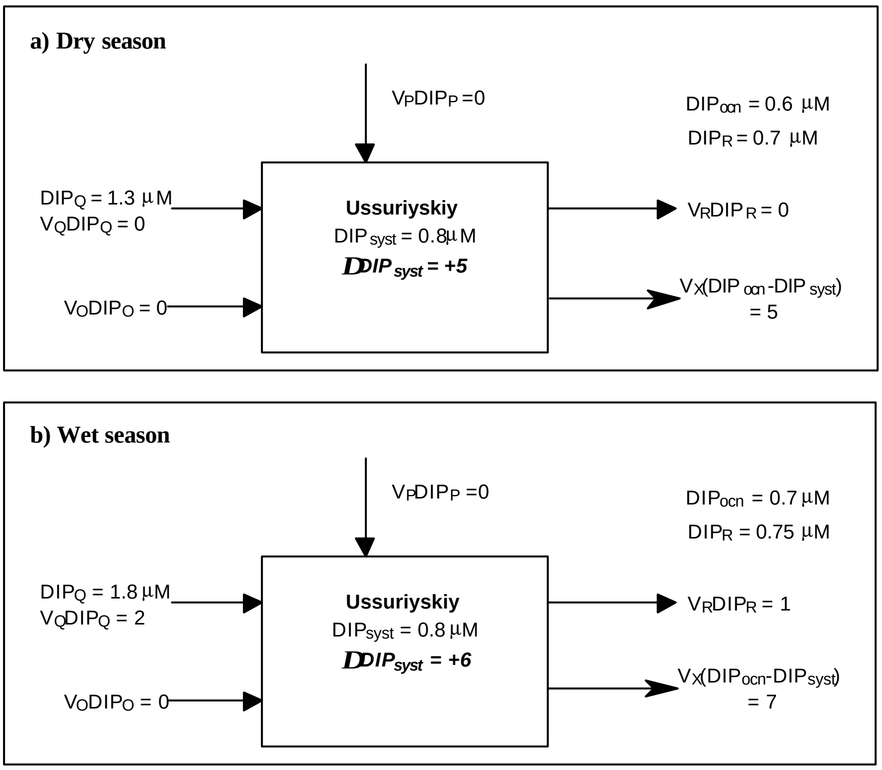

Figure 2.17. Dissolved inorganic phosphorus budgets for Ussuriyskiy Bay in dry (a) and wet (b) seasons. Flux in 10^3 mol d^{-1}.

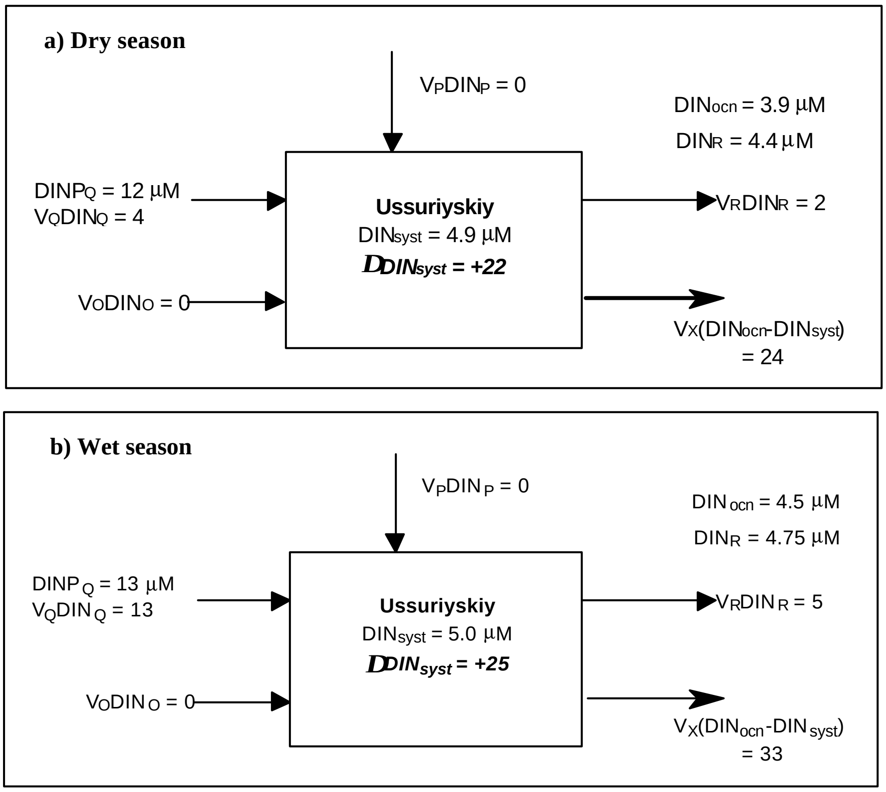

Figure 2.18. Dissolved inorganic nitrogen budgets for Ussuriyskiy Bay in dry (a) and wet (b) seasons. Flux in 10^3 mol d^{-1}.