5. BUDGET FOR A REGIONAL SEA

5.1 The Yellow Sea System

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

The Yellow Sea is an epicontinental-shelf surrounded by the contiguous landmasses of Korea and China. The Yellow Sea, including the Bohai Sea, has a total area of 517,000 km^2 with an average water depth of 44 m with asymmetrical V-shaped bottom. The western side is much shallower than the eastern side. The area budgeted in this analysis (Figure 5.1) has an area of approximately 420,000 km^2 and a volume of approximately 17×10^{12} m^3.

A deep trough, the old Yellow River Channel, made during the last glacial period, runs longitudinally east of 125ºE. Fresh water and aeolian material therefore play a major role in Yellow Sea biogeochemistry. The Yellow Sea is under the influence of the north-east Asian monsoon. The regional monsoon may be characterized as a strong north-westerly wind during the period from autumn to early spring, with a brief wet summer (Jangma) and a relatively dry season for the rest of the year. Precipitation over the Yellow Sea is estimated as 460×10^9 m^3 yr^{-1} (Lee and Kim 1989), which is about 4 times as large as the total river discharge ca. 120×10^9 m^3 yr^{-1} (Chough and Kim 1981; Milliman and Meade 1983; Wang and Aubrey 1987). The precipitation contains a large amount of nutrients (Zhang and Liu 1994). The winter monsoon winds transports aeolian material from the contiguous Chinese continent. The summer monsoon rain transports riverine material from the contiguous land masses. The Yellow dust storm in spring is the most salient geological feature in north-east Asia (Zhang *et al.* 1993).

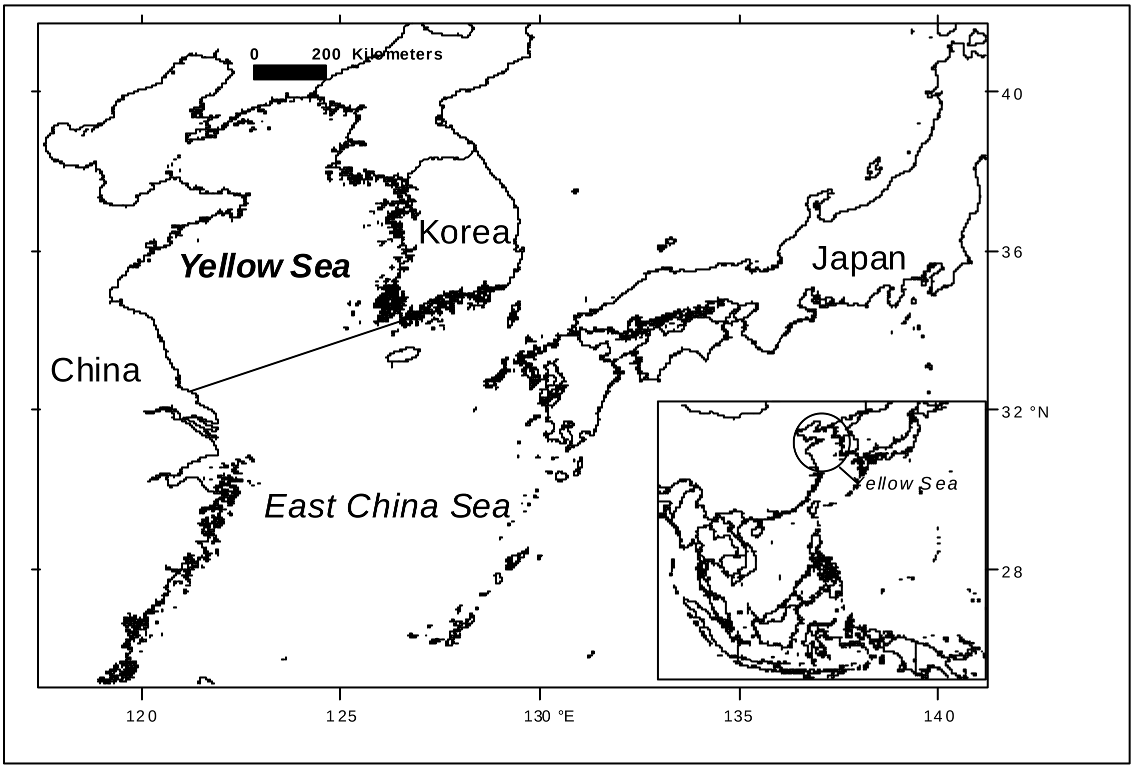

Figure 5.1. Map and location of the Yellow Sea.

Annual primary production may reach as high as 165 g C m^{-2} yr^{-1} or about 14 mol C m^{-2} yr^{-1} (Hong *et al.* 1995). However, in the central waters of the Yellow Sea, except in the coastal zone, primary productivity is limited by the lack of nutrients (Chung *et al.* 1991; Hong *et al.* 1993).

Three major potential sources of nutrient input into the Yellow Sea are river runoff (Zhang *et al.* 1995; Zhang 1996), the atmosphere (Zhang and Liu 1994; Chung *et al.* 1998) and intrusion of oceanic water from the Kuroshio Water. Recent studies have suggested that in certain parts of the Yellow Sea, biological productivity can be enhanced by the direct input of inorganic nutrients from atmospheric deposition (Zhang and Liu 1994). Among these nutrients, nitrogen and phosphorus are two of the most critical nutrients for biological growth. Therefore, information about these sources is essential in understanding and predicting the behavior of nutrients in the Yellow Sea.

Water and salt budgets were estimated, and nitrogen and phosphorus budgets were constructed, with relevant values obtained for river, atmosphere and the ocean boundary, using a simple one-box model described by Gordon *et al.* (1996).

Water and salt balance

It is difficult to set the geographical boundary of the Yellow Sea due to the continuous nature of the Yellow Sea and the East China Sea. Here, we have considered the open boundary as the straight line connecting the south-western tip of Korea to the Changjiang River mouth for convenience (Figure 5.1). Figure 5.2 presents the water and salt budgets for the Yellow Sea.

The water balance in the Yellow Sea is given by the conservation of water and salt (assuming steady state):

$$dV_{syst}/dt = 0 = V_Q + V_P + V_E + V_R$$

Groundwater is ignored, as discussed below. Salinity of river water, precipitation, and evaporation can be ignored. Therefore:

$$VdS_{syst}/dt = 0 = V_R S_R + V_x (S_{ocn} - S_{syst})$$

The freshwater flow (V_Q) is about 120×10^9 m^3 yr^{-1}. This discharge excludes the Changjiang River discharge. During the summer, Changjiang River water intrudes into the south Yellow Sea and may account for as much as a third of the total river discharge. However, this discharge is very difficult to quantify, so it is considered to be quantitatively unimportant to the overall budgets.

The precipitation (V_P) and the evaporation (V_E) are about 420×10^9 m^3 yr^{-1} and 390×10^9 m^3 yr^{-1}, respectively (Yang 1998). From the water balance, net freshwater input is approximately 150×10^9 m^3 yr^{-1} (V_R). The freshwater discharge through groundwater (V_G) was not considered because the data are not available. While there is evidence (discussed below) that this discharge may be important with respect to nutrient delivery to the coastal zone, it seems unlikely to be important at the scale of the entire system.

The average water exchange time in the Yellow Sea is estimated to be about seven years. This exchange time is similar to that derived from $^{228}Ra/^{226}Ra$ distributions (Nozaki *et al.* 1991).

Budgets of nonconservative materials

DIP balance

Figure 5.3 shows the DIP budget for the Yellow Sea. The riverine and atmospheric inputs by precipitation of dissolved inorganic phosphate (DIP) are 228×10^6 mol yr^{-1} and 168×10^6 mol yr^{-1}, respectively. Note the great importance of atmospheric inputs in this system. The average concentration of DIP is 0.4 µM in the

Yellow Sea and 0.2 μM in the East China Sea (Yang 1998).

DIP mixing flux across the ocean boundary between the Yellow Sea and the East China Sea, estimated using the previous salt balance model, is an export of about 432×10^6 mol yr^{-1}, suggesting that DIP is supplied from the Yellow Sea to the East China Sea. The net internal source *(DDIP)* in the Yellow Sea is estimated to be about $+81 \times 10^6$ mol yr^{-1}.

DIN balance

The DIN budget is shown in Figure 5.4. Here, nitrate, nitrite and ammonium are lumped into DIN. Nitrogen removal (internal sink), *DDIN*, is estimated to be about $-43{,}000 \times 10^6$ mol yr^{-1}. The point to note here is that, despite the very large inputs of DIN via rivers and the atmosphere, virtually no DIN is transported from this system.

In the two steady-state DIP and DIN budgets described above, freshwater discharge through the submarine groundwater (V_G) was not considered because we do not have a quantitative data set. However, it is known that groundwater may enter coastal surface waters as dispersive seepage along shorelines. For example, in Great South Bay, New York, 10-20% of the freshwater entering the bay was from groundwater, and submarine groundwater discharge attributed up to 50% of the nitrate in the bay (Capone and Bautista 1985). Dry deposition of N and P were not considered here either, due to lack of data, although they are probably not negligible. Therefore, assessment of freshwater discharge through the submarine groundwater and dry deposition in the Yellow Sea is necessary. It seems unlikely that groundwater discharge is important at the scale of the entire system, but it may be important in inshore waters.

Stoichimetric calculations of aspects of net system metabolism

The *DDIP* of $+81 \times 10^6$ mol yr^{-1} for the Yellow Sea suggests that the system is apparently net heterotrophic; (*p-r*) is -9×10^9 mol C yr^{-1} or about -21 mmol C m^{-2} yr^{-1}. This rate of net heterotrophy represents well less than 1% of the estimated primary production rate of about 14 mol C m^{-2} yr^{-1}.

System nitrogen metabolism includes both denitrification and nitrogen fixation. As DIP has no volatile phase, we can estimate the net internal sink of DIN from the net internal sink of DIP using a Redfield ratio (N:P = 16:1). The estimated net internal source of DIN (*DDIP* x 16) would be about $+1{,}300 \times 10^6$ mol yr^{-1}. Nitrogen fixation minus denitrification (*nfix-denit*), the difference between the internal sink and the net internal source of DIN amounts to about -42×10^9 mol yr^{-1} or about -100 mmol N m^{-2} yr^{-1}. This is well within the range of typical coastal ocean net denitrification rates; the actual rate would be higher if dry deposition of N and groundwater were included in the budget.

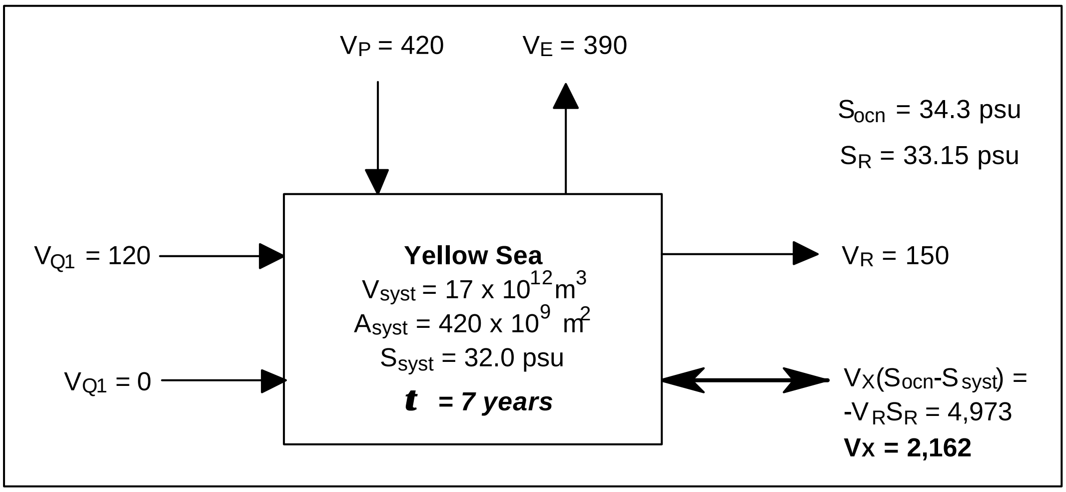

Figure 5.2. Water and salt budgets for the Yellow Sea. Water flux in 10^9 m^3 yr^{-1} and salt flux in 10^9 psu-m^3 yr^{-1} .

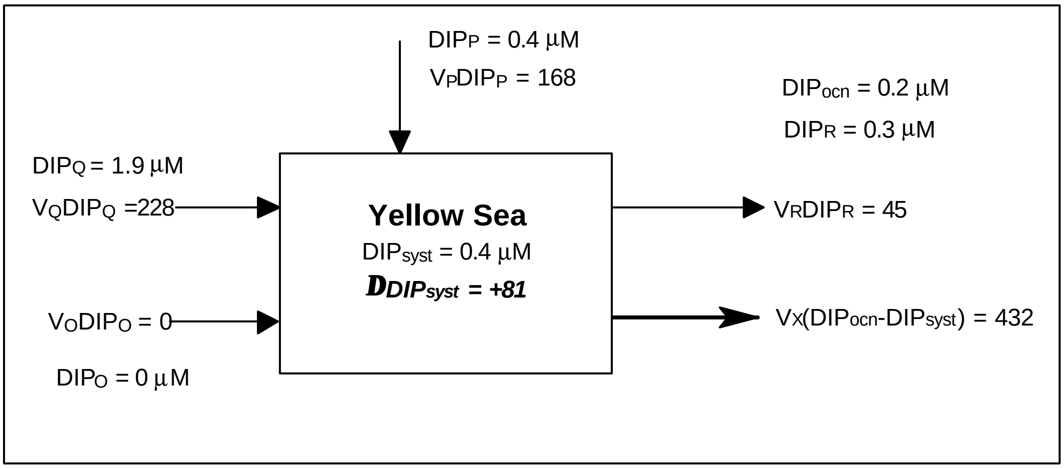

Figure 5.3. Steady-state DIP budget for the Yellow Sea. Flux in 10^6 mol yr^{-1}.

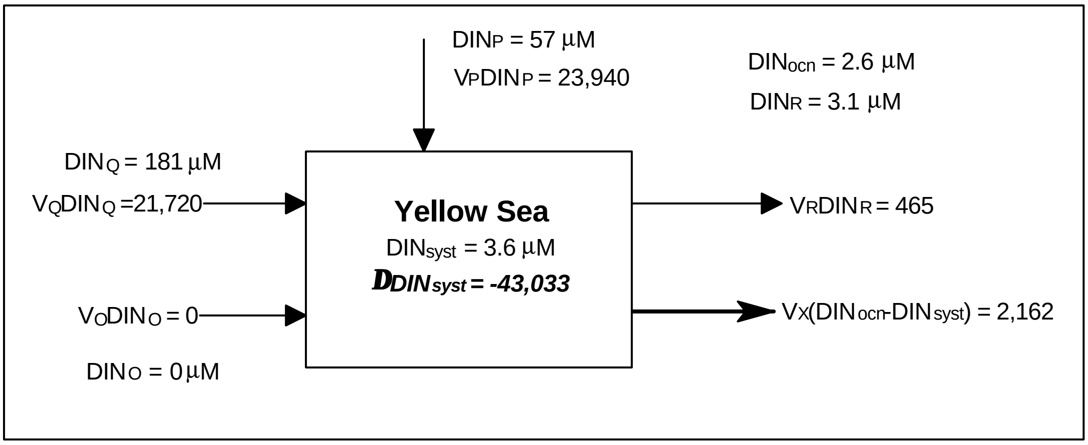

Figure 5.4. Steady-state DIN budget for the Yellow Sea. Flux in 10^6 mol yr^{-1}.