## Appendix F N and P Budgets for Lingayen Gulf, Philippines

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### Introduction

Lingayen Gulf is found in the northwestern Philippines between 16.02° and 16.67°N latitude, and 119.89° and 119.90°E longitude. 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 (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 as hosts to visitors throughout the year.

The gulf has an average depth of 46 m and volume of $85 \times 10^9$ $m^3$. It has 3 major coastal types. The western section is dominated by fringing reefs surrounding two large islands (Santiago and Cabarruyan islands) and several smaller ones. The southern section has a mainly muddy bottom and is where most of the river systems of the gulf discharge. The Agno River, the largest river contributing about 67% of the gulf's surface water discharge of $10 \times 10^9$ $m^3$ $yr^{-1}$, is found 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. There are six major river systems that drain into the gulf. Groundwater input into Lingayen Gulf is approximately 10% of the reported river discharge rate. Over 50% of the groundwater discharge come from the western section of the gulf.

Due to economic growth of the provinces linked by Lingayen Gulf, the gulf's water quality as well as that of the rivers that drain into it is deteriorating. In 1995, all 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 even suitable for contact recreation (e.g. bathing). The various economic activities (e.g. agriculture, domestic sewage, livestock) along its perimeter have also contributed waste load of N and P into Lingayen Gulf waters.

The study aimed to quantify the fluxes of N and P into the gulf from the major inputs (economic activities, rivers, groundwater) and determine the balance of these two biogeochemically important elements in the system. In so doing, an understanding of the metabolic processes in Lingayen Gulf was derived. The N and P balances may be used to look into the consequences of altering the major inputs by anthropogenic influence.

### Methodology

In general, 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 nutrient concentrations are considered.

One-box models for nitrogen (N) and phosphorus (P) were originally developed for Lingayen Gulf to gain an initial understanding of the biogeochemical processes occurring in the system. Subsequent efforts were geared towards refining the budgets through better quantification of N and P inputs from sewage, groundwater, and the rivers; estimation of the dissolved organic nutrient contribution; and use of a multiple box approach. A preliminary carbon budget for the gulf was also developed.

In the multiple-box models, Lingayen Gulf was divided into three boxes, a nearshore box, Bolinao box, and upper gulf box (Figure 13, main report). 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. In the nearshore box are found the large river systems of the gulf. 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.

Particular attention is paid to the issue of waste loading into Lingayen Gulf since these are important inputs to the system. The waste load of N and P were estimated from relevant economic activities in the gulf (Table 3, main report). To briefly explain how the estimates were made, after identifying economic activities, total discharge of effluents were approximated using the rapid assessment method utilized by WHO (1993). 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 load make it to the gulf. According to Howarth et al. (1996), nitrogen fluxes in rivers are, on the average, only 25% of anthropogenic inputs (or there is 75% assimilation). 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 et al. (1999).

## Results and Discussion

Water and Salt Balance

Figure 14 (main report) represents the multiple-box model of the water and salt budgets for the dry season. 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 $8 \times 10^9$ m$^3$ yr$^{-1}$ (NWRC Phil, 1976). In the Bolinao box, the river discharge was $0.2 \times 10^9$ m$^3$ yr$^{-1}$, while in the upper gulf box the discharge is $2 \times 10^9$ m$^3$ yr$^{-1}$ (NWRC Phil, 1976). A mean annual pan evaporation of 2,060 mm was determined from the local weather office (PAGASA - Philippine Atmospheric, Geophysical, and Astronomical Services Administration) 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 $-8 \times 10^9$ m$^3$ yr$^{-1}$ from the nearshore box to the upper gulf box, $-1 \times 10^9$ m$^3$ yr$^{-1}$ from the Bolinao box to the upper gulf box, and $-11 \times 10^9$ 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 50m) 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 sets 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 $V_{X1}(S_3-S_1) = +260 \times 10^9$ psu-m$^3$ yr$^{-1}$ from the nearshore box to the upper gulf box, $V_{X2}(S_3-S_2) = +34 \times 10^9$ psu-m$^3$ yr$^{-1}$ from the Bolinao box to the upper gulf box, and $V_{X3}(S_{Ocn}-S_3) = +376 \times 10^9$ 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 $+87 \times 10^9$ m$^3$ yr$^{-1}$, $68 \times 10^9$ m$^3$ yr$^{-1}$, and $940 \times 10^9$ 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.

N, P, C Balance - One-box Model

The rivers, waste load, and groundwater account for all the inputs of DIP (dissolved inorganic phosphorus) and DIN (dissolved inorganic nitrogen) into the gulf with waste load predominating for both cases. In order to balance the DIP and DIN contributed by these sources with the residual and exchange fluxes across the mouth of the gulf, non-conservative processes inside the gulf must fix or remove DIP and DIN.

Based on the DIP balance, the gulf is a net source of DIP (i.e. $\Delta$DIP is positive) thus it is produced within the system. This implies that the system is net heterotrophic requiring an external source of organic matter to sustain the system. It is assumed that the organic material that enters the gulf is either plankton derived with a $(C:P)_{part}$ =106:1 or this may also contain any reacting terrigenous organic load of waste material with a C:P = 40:1 (San Diego-McGlone, et. al., 1999). From these extremes, (*p-r*) is estimated between -0.07 and -0.03 mol $m^{-2}$ $yr^{-1}$ Table 4 (main report)). Overall the small $\Delta$DIP flux and correspondingly the low (*p-r*) calculations suggest that the system is very nearly in balance metabolically. This is indicative of the efficiency of the gulf in recycling organic material.

Estimates of the DOP (dissolved organic phosphorus) fraction show that it is quantitatively important. The calculated $\Delta$DOP (+0.09 mol $m^{-2}$ $yr^{-1}$) two orders of magnitude higher than the $\Delta$DIP indicates export of DOP. Since the DOP in the rivers is not high and that it is only 18% of TP (total phosphorus) in waste materials, these may not be its likely sources. The DOP may be coming from the fringing mangroves found in the gulf.

Based on the DIN balance, Lingayen Gulf is a net sink of DIN (i.e. $\Delta$DIN is negative). Taking into account the amount of N expected from decomposition processes (heterotrophy) as determined by the DIP balance, a net (*nfix-denit*) of -0.1 mol $m^{-2}$ $yr^{-1}$ is obtained. This indicates that the gulf is net denitrifying. In actuality, both N fixation and denitrification can occur in Lingayen Gulf. The presence of coral reefs could account for N fixation in the system.

The net DIC ($\Delta$DIC) needed to balance the river, residual outflow and net export was estimated to be –1.2 mol $m^{-2}$ $yr^{-1}$. It is assumed that very little of the waste load is inorganic carbon in nature. This implies that the system is a source of DIC that is consistent with the $\Delta DIC_{org}$ of -0.7 mol $m^{-2}$ $yr^{-1}$ inferred from $\Delta$DIP and Redfield ratio. Given a primary production rate of 214 gC $m^{-2}$ $yr^{-1}$ or 18 mol $m^{-2}$ $yr^{-1}$ for the gulf, the net (*p-r*) or $\Delta$DIC is 0.3-0.5% of production.

N and P Balance - Multiple-box Model

Figure 15 (main report) illustrates the dissolved inorganic P 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. In the rivers of the nearshore box, the average $PO_4$ concentration is 11 mmol $m^{-3}$, 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 in the nearshore box is 8 mmol $m^{-3}$, 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 partly 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, non-conservative 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. This implies that the box is net autotrophic, *(p-r)* is +49 mol $m^{-2}$ $yr^{-1}$. Hence 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. The Bolinao box is also a net sink of DIP suggesting that this box is autotrophic, albeit not as strong as the nearshore box. The *(p-r)* is +23 mol $m^{-2}$ $yr^{-1}$. On the other hand, the upper gulf box is a net source of DIP to the South China Sea indicating net heterotrophy with *(p-r)* of –0.6 mol $m^{-2}$ $yr^{-1}$. This implies 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*) in the upper gulf (-0.6 mol m$^{-2}$ yr) suggests that this box is nearly in balance metabolically. This means that waste materials delivered to the upper gulf are broken down within this box, an indication of its efficiency in recycling organic material.

Figure 16 (main report) illustrates the dissolved inorganic N budget. Dissolved inorganic nitrogen (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. In the nearshore box, the average DIN concentration is 1.7 mmol m$^{-3}$, 3.9 mmol m$^{-3}$ for the Bolinao box, and 0.8 mmol m$^{-3}$ for the upper gulf box. In the rivers of the nearshore box, the average DIN concentration is 16 mmol m$^{-3}$, 22 mmol m$^{-3}$ for 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 in the nearshore box is 53 mmol m$^{-3}$, 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 ($V_O DIP_O$). 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). However the amount of DIN fixed with DIP in the nearshore box and Bolinao box via autotrophic processes exceed the net DIN calculated from the balance of inflow and outflow in the boxes. Hence in these boxes, N fixation is in excess of denitrification. The (*nfix-denit*) are +5.9 and +2 mol m$^{-2}$ yr$^{-1}$ in the nearshore box and Bolinao box, respectively. In the upper gulf box that was estimated to be net heterotrophic from (*p-r*), the DIN released and that due to the balance of DIN fluxes resulted in a (*nfix-denit*) of –0.5 mol m$^{-2}$ yr$^{-1}$, indicating net denitrification. The N fixed in the Bolinao box and nearshore box is most likely exported as organic N into the upper gulf box and this could be the material that fuels denitrification in the upper gulf box. Dissolved organic N in the nearshore box has been estimated to be 60% of total dissolved N.

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 reef (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.

The comparison of the non-conservative fluxes estimated from the one-box model and the multiple boxes in Lingayen Gulf shows that the metabolic processes inferred from the one-box model are similar to those obtained for the upper box of the gulf. This implies that the one-box model approach was examining biogeochemical processes characteristic of the upper gulf. The multiple-box approach has been effective in defining ecosystem metabolism in other parts of the gulf.

The net fluxes of N and P for the whole Gulf are given in Table 5 (main report). Although the upper gulf box is heterotrophic there is a tendency for the whole system to fix carbon (autotrophic). The carbon that stays inside the gulf may be trapped in the sediments, particularly in the nearshore area and Tambac Bay. The predominance of a muddy substrate in these parts of the gulf over sandy bottom towards the middle and deeper parts indicate high organic C content in the sediments of the nearshore area and Tambac Bay (Geology Component). Together with P, N is also fixed in these parts of the system. Hence even though the upper gulf is net denitrifying, there is net N fixation in the whole system.

### Scenario building

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 whole system were indeed net autotrophic with inorganic nutrients primarily coming from decomposed organic wastes utilized to sustain production, then it would be of interest to see the response of the system to reduced or additional waste load (Table 6 main report). Keeping all other inputs and concentrations constant, the only way to achieve a metabolically balanced system (*p-r = 0*) is to completely eliminate waste load. However this being a non-realistic strategy, other possibilities should be explored. Balance estimates show that reduction of present waste load by half will not achieve metabolic balance but will decrease present (*p-r*) thereby making the system less autotrophic. A doubling of waste load would double present (*p-r*) and make the system more autotrophic. Removing waste load would also result in a balanced (*nfix-denit*). With current load, the gulf is fixing N. Even if the waste load is reduced by half the present amount, the system would still be fixing N but at half the current rate. When the waste load is doubled, N-fixation in the system is increased.

Although the gulf is net autotrophic, the largest area of the gulf (upper gulf) is net heterotrophic. This implies that the system is able to breakdown waste inputs and export most of these as N and P out of the gulf with some amount retained, perhaps in the sediments. Since the average nutrient concentrations of N and P have not varied much over the years, this is an indication of the gulf's current assimilative capacity. The N and P trapped in the sediments have not reached levels where benthic flux of these materials would be a highly significant contribution to the inventory of N and P in the water column.

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