Economic Evaluation and Biogeochemical Modelling of Lingayen Gulf In Support of Management for Sustainable Use

Synthesis Report
October 2000

Marine Science Institute, University of the Philippines, Quezon City 1101

1. Introduction

This report synthesizes primary data and secondary information on biogeochemical processes in Lingayen Gulf and its associated catchments and the socio-economic drivers that influence these. The data were obtained over a 4-year study from 1996-1999. The analyticial framework used was based on a watershed perspective, and considered interactions and feedbacks among upstream and downstream economic activities and the cycling of nutrients, sediments and freshwater within the Gulf. It linked the biogeochemical budget approach of LOICZ and an economic modelling tool (input-output model) to examine the impacts of anthropogenic drivers on the processing of materials at the coastal zone.

1.1 Design of the Philippine core site study

The overall framework of the Philippine study evolved as the appropriate scale for an integrated study was identified. In the initial proposal drafted in 1995, the major focus was the Bolinao-Anda fringing reef system with the Caquiputan Channel as the estuarine water body that would be used both for the biogeochemical and economic modelling. In subsequent discussions with Dr. John Pernetta, the Philippine team quickly realized that the fringing reef system was too much of an open system for the biogeochemical estimation of fluxes, and was also at too small a scale for economic modelling that had to heavily rely on government statistics. Before the Penang meeting in December 1995, the team decided that the entire Lingayen Gulf would be the appropriate scale for the integrated study.

Lingayen Gulf, and the Bolinao-Anda reefs on the northwest section of the gulf, is among the most data-rich estuarine systems in the Philippines. The major reason for this is its importance as a major fishing ground in the northern area of the country, and the presence of the Bolinao Marine Laboratory of the University of the Philippines Marine Science Institute next to the reef system. In the watershed areas, major economic activities in mining, forestry and agriculture have provided the impetus for government and private agencies to generate and archive data.

The identification of team members was easy because previous and concurrent bay-wide collaborative projects with the Marine Science Institute have always been interdisciplinary in nature. It was obvious as early as the first draft proposal that economics, watershed geology, marine geology, and physical, chemical and biological oceanography would be the major components of the study. In addition, expertise on hydrology and economic input-output data analysis at subnational level were tapped during the last year of the project.

Highlights obtained from the contributed papers of the various team members form this synthesis. These are included here as appendices so the reader may refer to them for a thorough discussion of methods and results.

- Appendix A. Land Use Changes within the Agno Watershed (1986-1993) - *Fernando Siringan and Elizabeth Francisco*
- Appendix B. Economic Modelling of Residual Generation for the Lingayen Gulf Watershed - *Douglas McGlone and Herminia Caringal.* (Only the section on Rapid Assessment of Residual Generation is appended for brevity)
- Appendix C. Sediment Load Partitioning of Agno River and Changes in the Shoreline Position - *Fernando Siringan and Zenon Richard P. Mateo*

Appendix D. Hydrologic and physico-chemical modelling of the watersheds draining into the Lingayen Gulf - *Roberto S. Clemente and Edwin N. Wilson*
Appendix E. Circulation in Lingayen Gulf inferred from temperature and salinity - *Cesar Villanoy*
Appendix F. N and P budgets for Lingayen Gulf, Philippines - *Maria Lourdes San Diego-McGlone, Vilma Dupra, Daisy Padayao and Judycel Abalos*
Appendix G. Primary production and fisheries in Lingayen Gulf, Northern Philippines - *Liana Talaue-McManus, Wilfredo Licuanan, Leah Asuncion, Kathleen Silvano, Merliza Bonga and Charisma de Castro*

1.2 Physiographic setting of the Lingayen Gulf watersheds

The terrain surrounding Lingayen Gulf can be divided into three physiographic provinces (Figure 1). To the east is the Cordillera Mountain Range; the northern edge of Central Luzon Plain forms the southern border and the northern extent of Zambales Mountain Range lies to the west. The north-northeast trending Cordillera Mountain Range attains an altitude of approximately 2,900 meters, with steep slopes averaging 65%. This region includes the drainage basins of the Bauang, Aringay, Bued-Patalan, Agno and several minor river systems. Between this mountainous region and the gulf is a narrow strip of low-lying hills with slopes of around 30%. This north-south to north-northwest trending curvilinear series of hills corresponds to the strike of the rock formations and the trend of the extensive folds and faults in this area.

South of Lingayen Gulf is the northern boundary of the northwest-southeast trending Central Luzon Plain; the southern limit of which is Manila Bay. The plain is mainly composed of undifferentiated alluvial deposits and some intervening Quaternary volcanic deposits. This broad and flat plain has a gradient ranging from 0% to only 3% for the patches of Quaternary volcanic cones that dot the area (McManus et al., 1990). The bayhead coast of Lingayen Gulf is occupied by fishponds while the rest of the area is extensively used for agriculture.

West of the Luzon Central Plain is another chain of mountains that rises to a maximum height of 1600 meters above the mean sea level. The steep slopes of the Zambales Mountain Range with more than 65% gradient (McManus et al., 1990) is generally barren with only grasses acting as vegetal cover. Only valleys are lined with trees. Such is attributed to the fact that an ophiolite suite mainly underlies this region. However, the landmass directly west of Lingayen Gulf is characterized by hills and terraces of lower elevation and is underlain by carbonate to tuffaceous materials.

1.3 Climate

Lingayen Gulf and associated watersheds experience two pronounced seasons: dry from November to April and wet the rest of the year. The average annual temperature based on data from 1951 to 1980 is 28 °C, reaching a maximum of 35 °C in April, and a minimum of 18 °C in January. Average annual rainfall is 2,500 mm, with a peak of 800mm falling in August and a low of 1mm in January.

1.4 River systems draining into Lingayen Gulf

Five major river systems drain into Lingayen Gulf (Table 1, Figure 1). Of the five, the Agno River is the longest, has the largest drainage area and the highest amount of freshwater input into the gulf. It empties through two tributary channels at Labrador and Lingayen. The Agno River originates from the Cordillera Mountains where it drains Cretaceous to Paleocene igneous basement rocks, and marine siliciclastic and carbonate rocks as it follows a southerly course after which it veers westward then northwestward as it traverses the Central Luzon Alluvial Plain before emptying into the gulf. The Tarlac River that further extends the southward limit of this river system joins the Agno River. Other river systems along the bayhead region of Lingayen Gulf are the Dagupan/Panto River and the Bued-Patalan River that directly drains the Baguio Mining District. To the east, the Bauang and Aringay rivers cut across the northwest Luzon coastal fold belt as they drain the flanks of the Cordillera Mountain Range. Along the western coast, small rivers draining the carbonate-tuffaceous terrain empty into Tambac Bay.

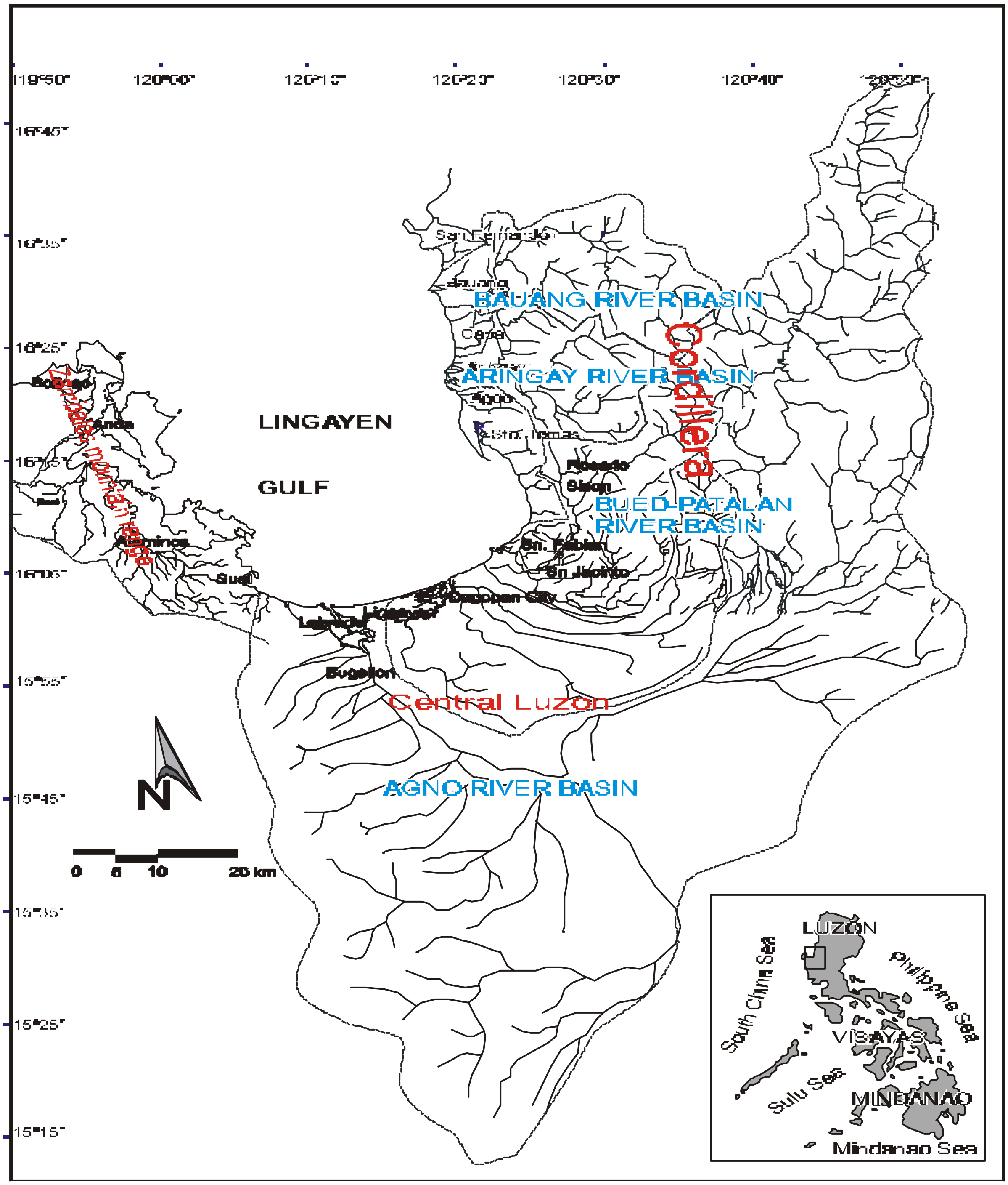


Figure 1. Watershed map of Lingayen Gulf with political boundaries.

Table 1. Major river systems draining into Lingayen Gulf.

RIVER SYSTEM	**Drainage Area (km^2)**	**Discharge (10^6 m^3y^{-1})**	**Length (km)**
Agno	5952 [a]	6664 [a]	275 [c]
Dagupan (Panto)	1115 [c]	1002 [a]	75 [c]
Bued-Patalan	630	388 [a]	61 [c]
Aringay	397	929 [b]	75
Bauang	516	674 [b]	92
Inerangan-Coliat-Barcadero-Garita	200 [a]	224 [a]	

[a] NWRC Phil. (1976) in *Philippine Water Resources (Ecological Profile of Pangasinan)* MHS/NEPC & NACIAD

[b] Bauang-Amburayan River Basin (Area Profile)

[c] Draft Final Report for Study of Agno River Basin Flood Control (JICA, 1991)

1.5 Circulation

The exchange of water masses between the coastal and open oceans play a direct role in the flux of materials either within the water column or indirectly through the sediments. The characterization of the transport processes that govern material transport is an important element in the understanding of complex interactions in the coastal zone. This includes interactions between material inputs (e.g. pollutants, nutrients, sediments), the various forms of chemical constituents and their associated chemical reactions, and the complex biological processes which can transform and exchange materials between the water column and the underlying sediments (Blumberg et al., 1993).

Hydrographic characteristics. Perhaps the most interesting feature of the hydrographic characteristics of Lingayen Gulf is the fact that most of the isotherms and isohalines in horizontal distributions show a high degree of orientation parallel to the Gulf axis (e.g. Figures 2 & 3). In some instances, it exhibits some crossing of the isoline across the gulf in the middle part of the Gulf. The general trend of the isotherms do not differ significantly between January and July which suggests that other processes other than the local wind forcing is important. The salinity distributions (Figures 4 & 5) indicate that the eastern side of the Gulf is slightly fresher than the western side. This may indicate that freshwater input into the Gulf is mixed and advected out of the Gulf through the eastern side.

Freshwater from both surface and groundwater runoff in Lingayen Gulf is significant enough to influence the density distribution up to depths of 100-140m. This may not be apparent, initially, because of the absence of strong horizontal salinity gradients. However, the relatively large salinity difference in the upper 100m between South China Sea and Lingayen Gulf waters indicate otherwise. It is likely that strong mixing within the gulf quickly erodes horizontal salinity gradients but may still be fresher that open ocean values at the same depths. During the dry season, when the influence of surface water runoff on the gulf salinity is reduced, subsurface groundwater discharge from the western and eastern sides of the gulf is evident.

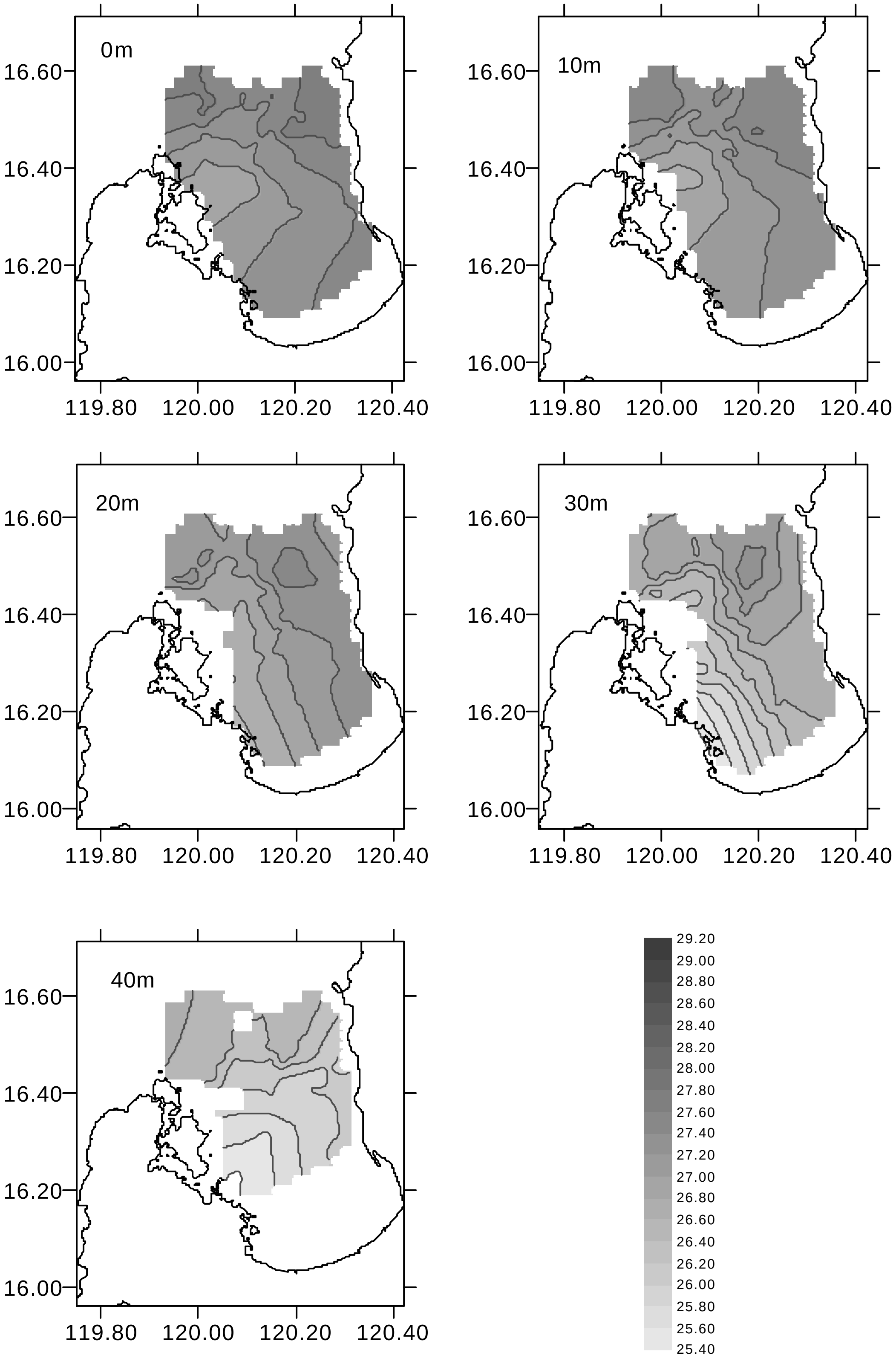


Figure 2. January temperature distribution.

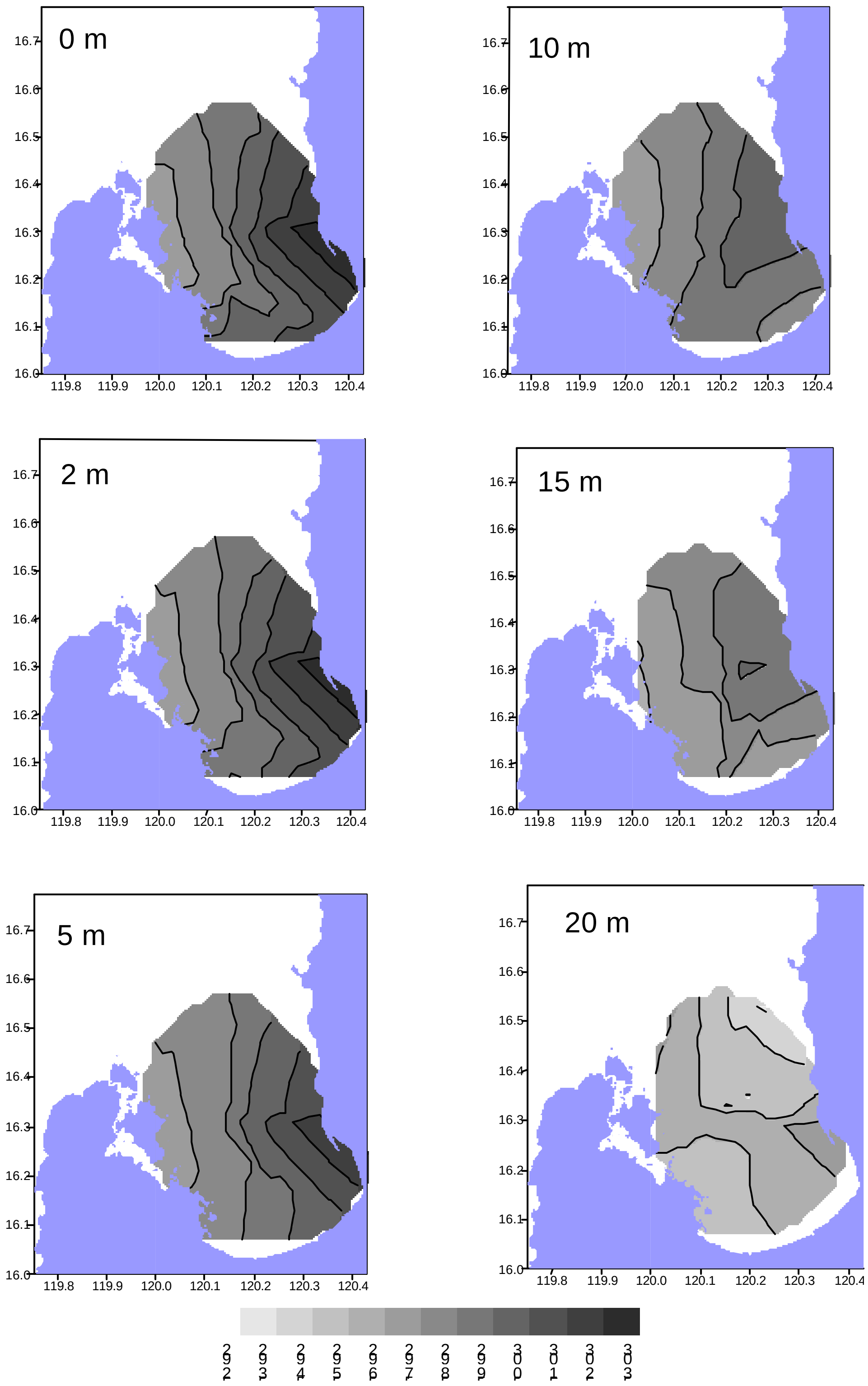


Figure 3. July temperature distribution.

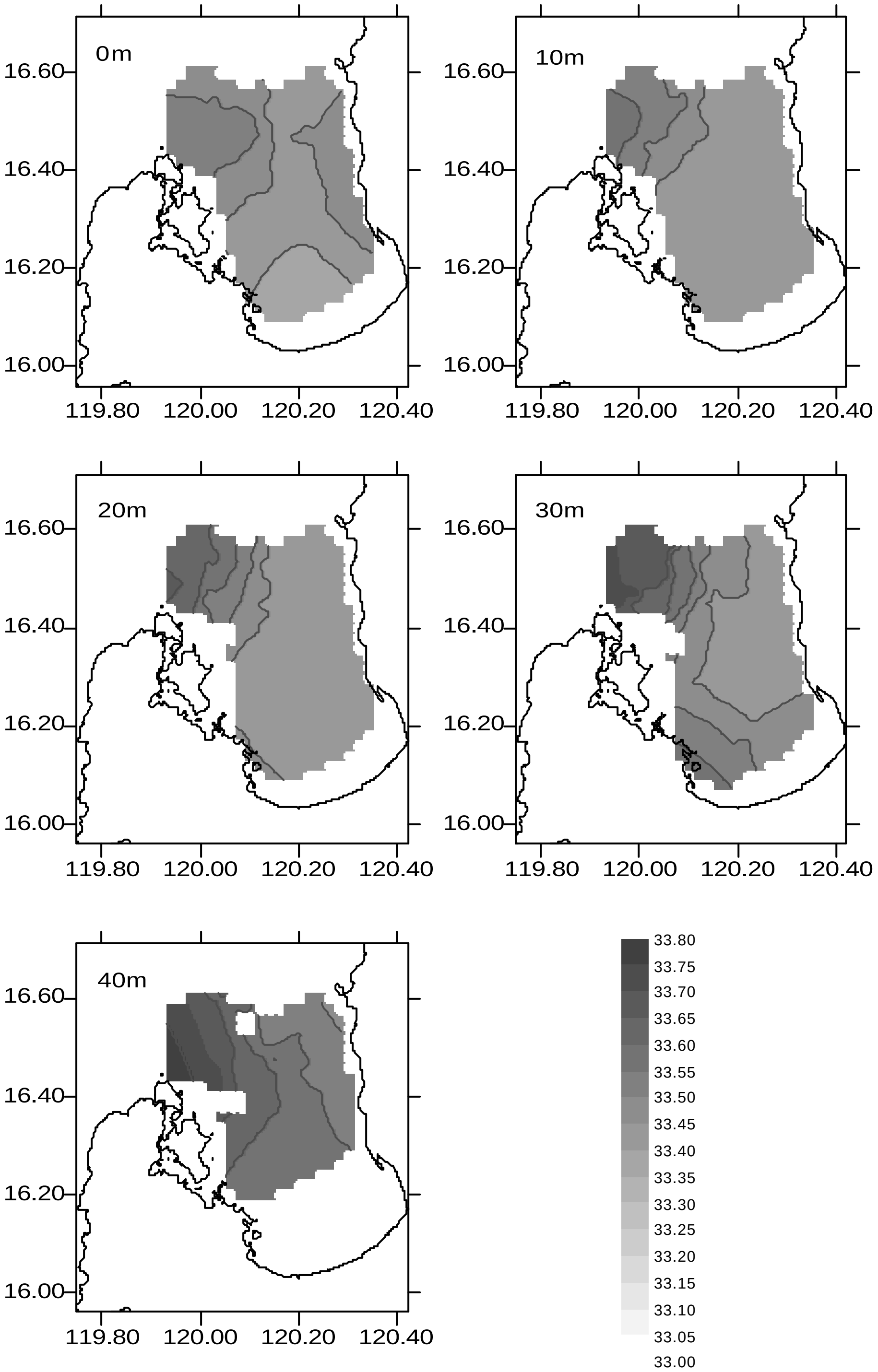


Figure 4. January salinity distribution.

Tidal circulation. The interaction of the tidal currents with topography and coastline shape can lead to a net transport of water over a spring-neap cycle (Figure 6). In the northern half of the Gulf, the residual flows are towards the south in the eastern part, turning west and out towards the northeast off Bolinao. Together with the northeastward residual flow off the mouth, this forms a clockwise gyre pattern centered at the mouth of the gulf. The southward residual flow in the eastern part of the Gulf persists along the eastern boundary up to the head of the Gulf. On the western side, the residual flow is towards the north off Cabarruyan Island but is southward south of the Hundred Islands.

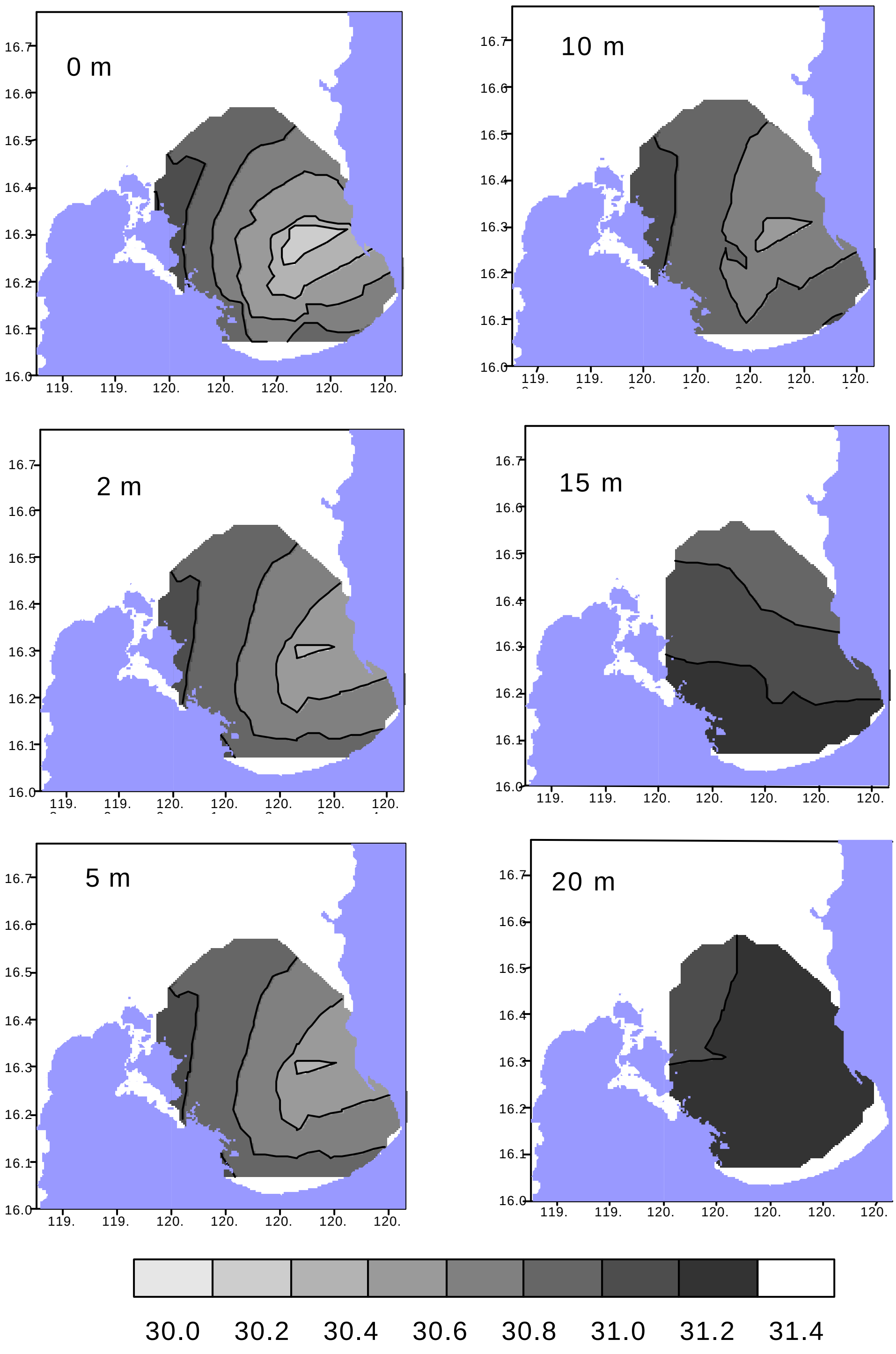


Figure 5. July salinity distribution.

Influence of alongshore shelf currents. The tidal model results show some degree of interaction between the tidal flow outside and inside the gulf. Off the western coast of Luzon, a northward coastal current appears to exist which persists throughout the year. Although no direct measurements are available, surface current derived from ship's drift (Richardson's Ship's Drift Database), dynamic calculations (Liu et al 1992), and modelling studies of the South China Sea (Shaw and Chao, 1994) all show northward flow east of Luzon. This current is considered to be the return flow of the dominant cyclonic gyre in the South China Sea. Dispersal of volcanic lava discharged from rivers in Zambales during the eruption of Mount Pinatubo show a net northward transport off the coast of Zambales.

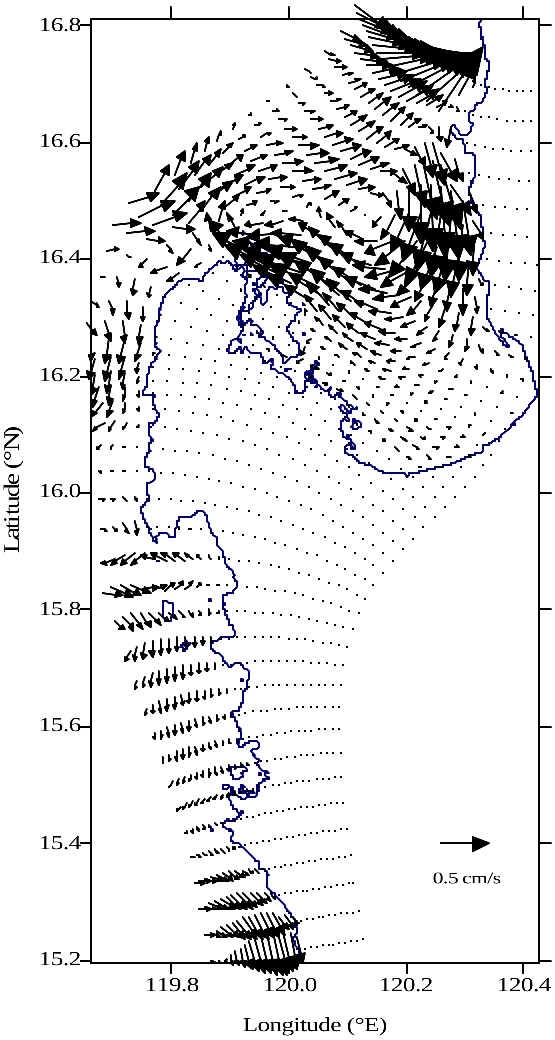


Figure 6. Velocity plot of tidal residual current velocity averaged over a spring-neap cycle.

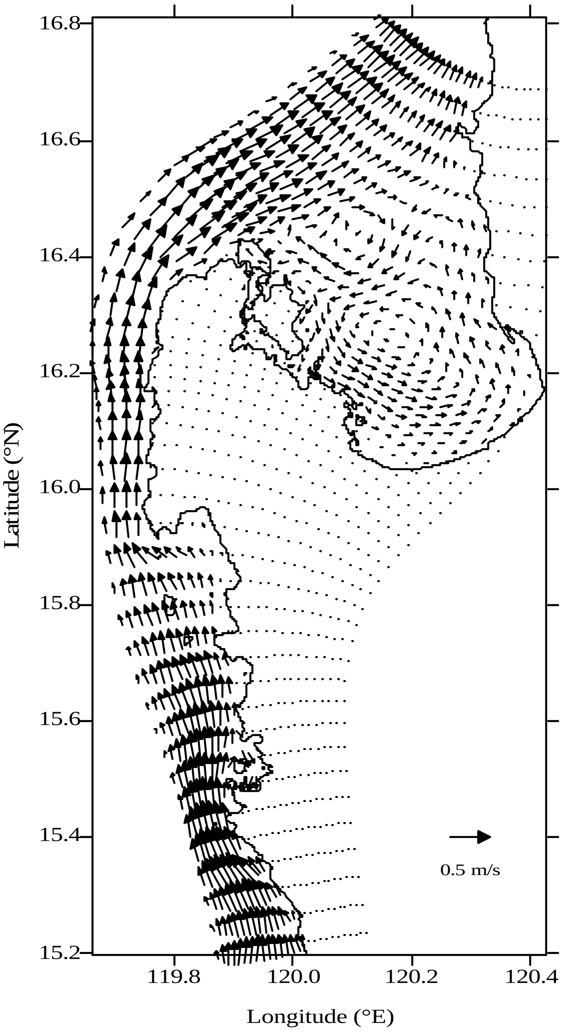


Figure 7. Velocity-averaged currents derived from model forced by northward shelf current.

The narrower shelf west of Zambales results in stronger currents compared to the broader shelf area to the north (Figure 7). Upon reaching the northern tip of Cape Bolinao, part of the flow turns southward into Lingayen Gulf forming an eddy on the leeward side of Cape Bolinao. The southern part of this eddy that flows westward extends up to about a third into the Gulf after back north off the eastern coast of Bolinao. The sea surface temperatures show a ridge of warm water extending from Bolinao to San Fernando, La Union which may be due to geostrophic adjustment by the northeastward alongshore current and the return flow inside Lingayen Gulf. The interior of the Gulf is characterized by a counterclockwise gyre.

Wind-driven circulation. In the presence of the wind, the vertically averaged currents outside Lingayen Gulf did not show a distinct variation from the purely coastal current forced model. The effect of local wind forcing was more evident in the interior of the Gulf. Both the vertically averaged currents and the surface currents for both northeast and southwest monsoon forcing are shown in Figures 8 & 9, respectively. The vertically averaged currents still show the leeward eddy off the eastern coast of Bolinao for both monsoon seasons albeit with slightly different magnitudes and location.

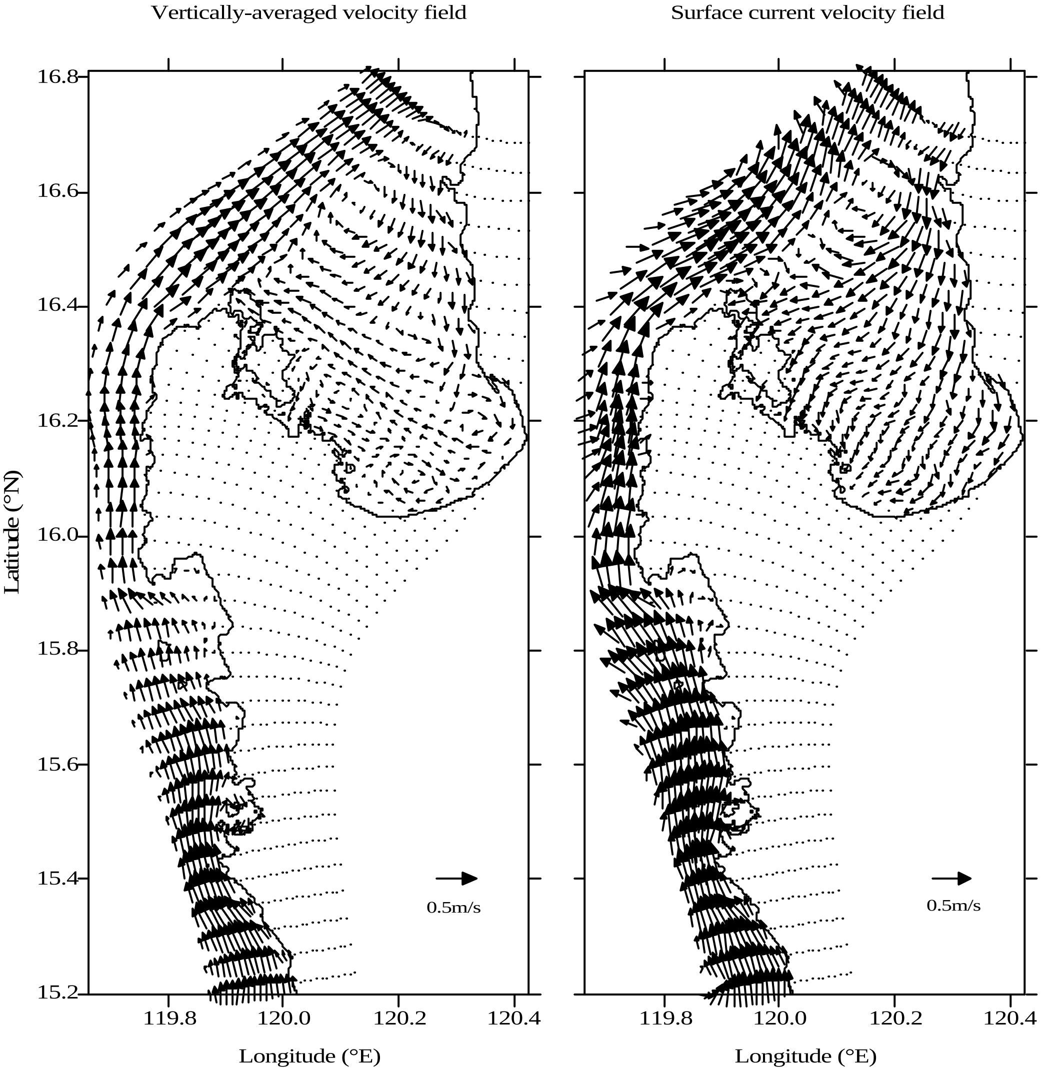


Figure 8. Vertically-averaged and surface currents from model forced coastal current and northerly wind.

In the southern half of the Gulf, the circulation exhibits a higher degree of variability with local wind forcing. During southerly wind forcing, a counterclockwise circulation in the southern half of the Gulf is formed but this pattern disappears at the surface where there is a net eastward flow off the Gulf head which turns north at the eastern side of the Gulf. The northerly wind-forced simulations, however, do not show such a distinct feature. Instead, the flow is dominated by a net southwestward flow at the surface and Gulf wide counterclockwise flow for the net transport.

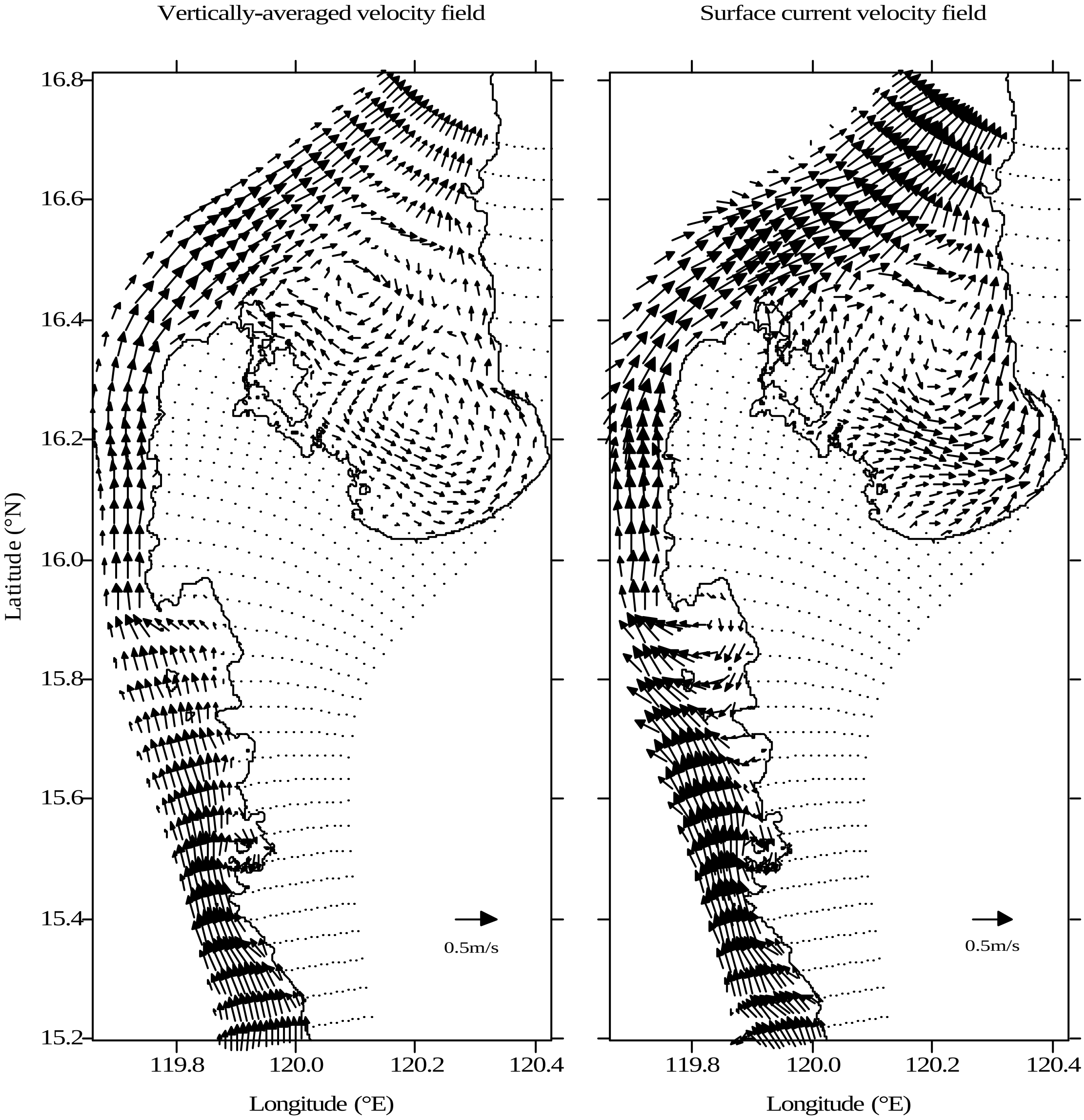


Figure 9. Vertically-averaged and surface currents from model forced coastal current and southerly wind.

1.6 Anthropogenic activities in catchment and coastal areas

1.6.1 Political boundaries.

The Lingayen Gulf watershed crosses four provinces in 3 political regions (Figure 10). For the study of inland influences on the coastal waters of Lingayen Gulf, emphasis is placed on the provinces and region that are adjacent to Lingayen Gulf proper.

Lingayen Gulf has an area of 2610 km^2, and a coastline 160 km long. It is bordered by 18 coastal municipalities, 11 in the province of Pangasinan, and 7 in the province of La Union. Pangasinan province consists of additional 37 inland municipalities. La Union has 13 more municipalities located north of the Gulf, 5 of which are coastal and 8 are located inland. These two provinces form an envelope around the Gulf (Figure 11). The furthest distance from shoreline to provincial boundary is approximately 60 km.

Pangasinan and La Union form a part of the political subdivision called Region 1, which includes the provinces of Ilocos Norte and Ilocos Sur. The Ilocos provinces are not adjacent to Lingayen Gulf, and are not a part of the Gulf's watershed. Other provinces overlapping the Lingayen Gulf watershed are Tarlac in Region 3, and Benguet in the Cordillera Autonomous Region.

For most descriptive purposes and for most of the rapid assessment model of residual generation, attention is directed to Pangasinan and La Union provinces, based on the expectation that these more proximal areas generate the majority of inland influences in the Gulf. For land use and cover change in the watershed areas, the discussion includes the three provinces of Benguet, Pangasinan and Tarlac. For the purposes of the input-output model of residual generation, data constraints require the inclusion of all of Region 1.

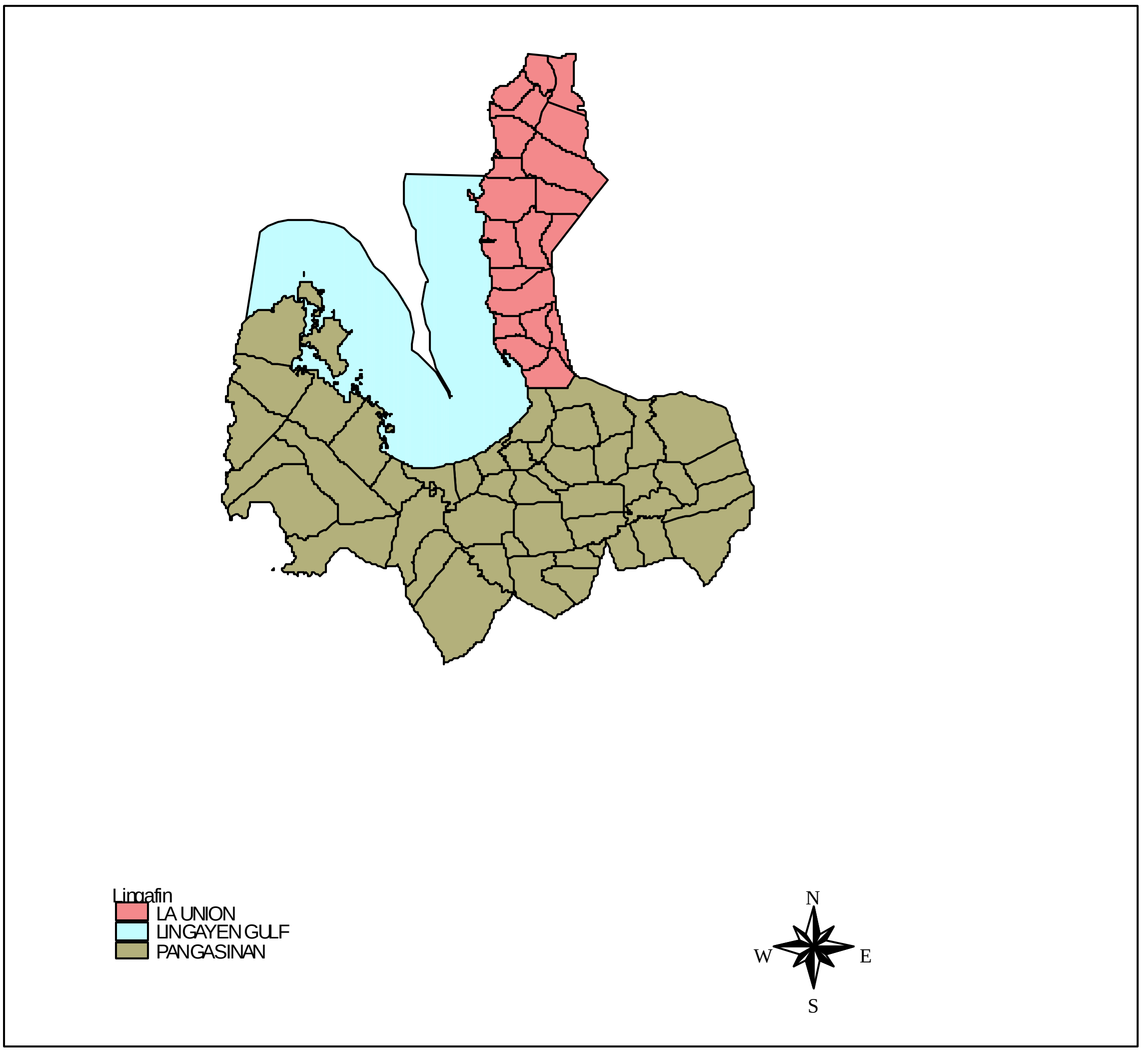
Figure 10. Political boundaries of the Agno River watershed (heavy line).

1.6.2 Human Resources

Demography. As of 1995, there were 2,775,854 people living in Pangasinan and La Union, with 2,178,412 in Pangasinan, and 597,442 in LaUnion. Population for both provinces increased by 23% from 1980-1990 and by 8% from 1990-1995. The national population growth rate 26% for 1980-1990 and 13% for1990-1995. The combined provinces experienced a slight overall out-migration of 13,000 (about 5 persons /1000) from 1990 to 1995. This reflects a trend of decreasing emigration rates since 1975. The emigration rate from 1975-1980 was 20 persons per thousand, and for 1985-1990, 11 persons per thousand. It should be noted, however, that the coastal towns within the coastal municipalities have experienced a rather large population growth, approximately 13% between 1985-1988. The extent to which this growth is due to immigration from within the provinces or from other regions is not certain.

Population density for the combined provinces was 404 persons/km^2 in 1995, 374 persons/km^2 in 1990, and 304 persons/km^2 in 1980. Pangasinan and La Union provinces rank 7th and 8h of 70 provinces nation-wide in terms of population density. Municipal population densities in 1995 ranged from 70 persons/km to 2200 persons/km. As of 1990, 42% of the population lived in urban areas, as opposed to 28% in 1980. The 1990 level is slightly greater than the regional urbanization level of 36.6%. The urbanization rate for the region has increased significantly since 1960. Between 1960 and 1970 the annual rate of increase was 0.97%. The rate increased to 2.04% from 1970-1980 and to 4.30 from 1980-1990.

Labor Force. In 1995 the potential labor force (age 15 years and above) was 1,822,000, or 66 % of the total population. The labor force participation rate was 58% of potential workers. The 1997 unemployment rate was 10%, while the visible underemployment rate was also 10% for 1997. These numbers have remained fairly steady since the mid-1980's. These figures demonstrate a general trend of underutilized labor, which is also reflected in the family income statistics. The trend in underutilized labor is expected to continue as population continues to grow. The manufacturing sector has lagged in labor absorption because of policies favoring inward-looking capital intensive industrialization (Medalla et al., 1992). This leaves agriculture and service sectors as the primary source of labor absorption. In the past, agriculture had been able to absorb the expanding labor force, but there is no longer much room for expansion of agricultural lands. It has been left to the low productivity informal service sector to absorb much of the increasing labor force.



Source: NEDA - Region I; NAMRIA, 1990

Figure 11. Pangasinan and La Union provincial boundaries.

Income. The average family income for 1995 was P68376 per year (approximately U.S. $2,600). In 1991, roughly 60% of families had per capita incomes below the poverty threshold.

With the low level of industrialization, and with a strong population growth rate, the trend of labor absorption in the low productivity, low wage range is likely to continue. One implication is that, with limited revenue sources, it is unlikely that local governments will be able to effectively address problems of waste disposal in the near future.

1.6.3 Economic Activity

Manufacturing. Industrial development in the study area is rather low. As of 1994, over 95% of roughly 5000 manufacturing firms were of the 'cottage industry' type, with fewer than 10 employees. Only 13 firms employed more than 100 workers.

The major industries in the study area include two gin bottling plants, 3 soft drink bottling plants, a fruit and vegetable processing plant, 16 sizeable rice noodle manufacturing firms, and a galvanized iron sheet manufacturing plant.

Agriculture. As of 1990, there were 209,473 farms in the study area covering a total of 235,554 hectares, which is 34% of the total land area. Rice covered about 88% of the total agricultural area, corn 2%, livestock and poultry farms 1.5%. The study area is a major producer of livestock. Pangasinan province has the largest livestock population in the country. Total livestock population in the study area was 740,000 heads and 3.6 million heads of poultry in 1993.

The agricultural land frontier has essentially been reached. Further increases in production will need to rely on improvements in technology and infrastructure, and increased irrigation capacity. A dam is currently under construction near the headwaters of the Agno River to substantially increase the potential for irrigation.

Capture Fisheries. Lingayen Gulf is the major fishing ground for northwest Luzon, providing roughly 1.5% of the Philippine fish supply. It also provides for over 50% of the livelihood of coastal village residents (Padilla et al., 1997). The fishing grounds are essentially open access, and are considered overfished. Maximum sustainable yield is estimated to be roughly 18,000 mt/year (Padilla and Morales, 1997). Maximum production was 24,015tin 1987. By 1995 it was down to 13,443 mt, despite an increase in standardized aggregate effort of over 150%.

Aquaculture. In 1993 aquaculture accounted for about 60% of the total Lingayen Gulf fish harvest. Just over 50% of the aquaculture harvest came from brackish water fishponds, and oyster farms account for almost 40% of total harvest. Recently, fish cage culture has become quite popular, although it has experienced some early setbacks due to storm damage. Production data for fish cage operations has not yet become available.

1.6.4 Land use and land use change

The combined provinces of Pangasinan and La Union occupy 686,127 hectares. Of this amount, 77% is classified as alienable and disposable (available for private ownership, whether industrial, residential, or agricultural). Agriculture occupies 34% of the land area, with 93% of agricultural land devoted to temporary crops, primarily rice. About 5% of the agricultural land are devoted to permanent crops, and the remaining 2% to livestock.

Approximately 23% of the land area are designated as some type of forestland, although the extent of effective forest cover is uncertain due to substantial encroachment upon these areas. Built-up urban areas cover 28,800 hectares, or 4.2% of the total land area.

The most extensive land use/cover classes within Agno River watershed are agricultural land, grassland, and forestland. Their sizes range form 200,000 to 400,000 hectares. The land use/cover classes that occupy smaller areas are built-up, wetland and bare land areas. The magnitude of these classes is around a few ten thousand hectares. For the entire region, agricultural land contributed the largest land use expansion at 34,153.1 hectares followed by grassland at 14,439 hectares and wetland at 10,193 hectares. In terms of previous area, forestland showed the greatest reduction at 42,729 hectares, followed by the built-up area, and bare land at 1,827 hectares. The calculated values for built-up areas must be treated with caution since the more recent land use data for Benguet and Tarlac showed an unrealistic decrease of more than 90% of previous size. The trend for built-up areas is usually increasing with the growing demand for residential and commercial land uses with time, unless seriously affected by natural disasters. While data used for land use/cover change calculation include within its period the eruption of Mount Pinatubo, built-up areas within Agno Watershed even those in Tarlac, were far from the influence of the volcano. The calculated change for the built-up class may reflect different methodology or procedure in delineating land use/cover. The S/LREP data employed survey and aerial photo interpretation whereas the JAFTA data used satellite image interpretation. Since some built-up areas are small, discrete, not continuously distributed and in close association with vegetated land uses, these features may not be pronounced in the image data, thus may have not been accounted for.

In terms of percentage change from previous area, wetland class increased by 47.1%. Pangasinan contributed the largest area as well as the positive growth of this land use/cover class for the whole region despite the negative percent change for the other two regions. Agriculture showed a modest growth of 8.2% despite contributing the largest change in terms of size. Like the wetlands, Pangasinan has the largest share in the sum of all agricultural lands in Agno Watershed. A 4% increase occurred in the grassland areas, which is very extensive in the provinces of Pangasinan and Benguet. Disregarding built-up area, the class that showed the greatest negative change was forestland at 20%. The provinces of Benguet and Tarlac experienced contraction of forestland. As noted earlier, Pangasinan did not record any change in this class, despite its cities and many of its municipalities serve as settlement hubs within the Agno Watershed. Bare land experienced the least negative change at 6%. Per province, this class exhibited large magnitudes of positive or negative percentage change such as the doubling trend for Benguet and Tarlac, and a reduction by about 75% for Pangasinan. For the whole region, its land use/cover change showed less than 10% contraction for the Agno Watershed (refer to Table 2 and Figure 12).

Table 2. Land use changes for the Agno River watershed

Class	**19(?) to 1986 (area in has.)**	**%**		**1992 to 1993 (area in has.)**	**%**		**Change (in has.)**	**% change**
agriculture	416027.8	37.9		450181.0	41.3		34153.2	8.2
forest land	208670.0	19.0		165941.0	15.2		-42729.0	-20.5
grassland	361652.5	33.0		376092.0	34.5		14439.5	4.0
wetland	23828.0	2.2		34021.0	3.1		10193.0	42.8
bare land	29599.0	2.7		27772.0	2.5		-1827.0	-6.2
Built-up	56572.7	5.2		36226.0	3.3		-20346.7	-36.0
Total area	1096350.0	100.0		1090233.0	99.9			

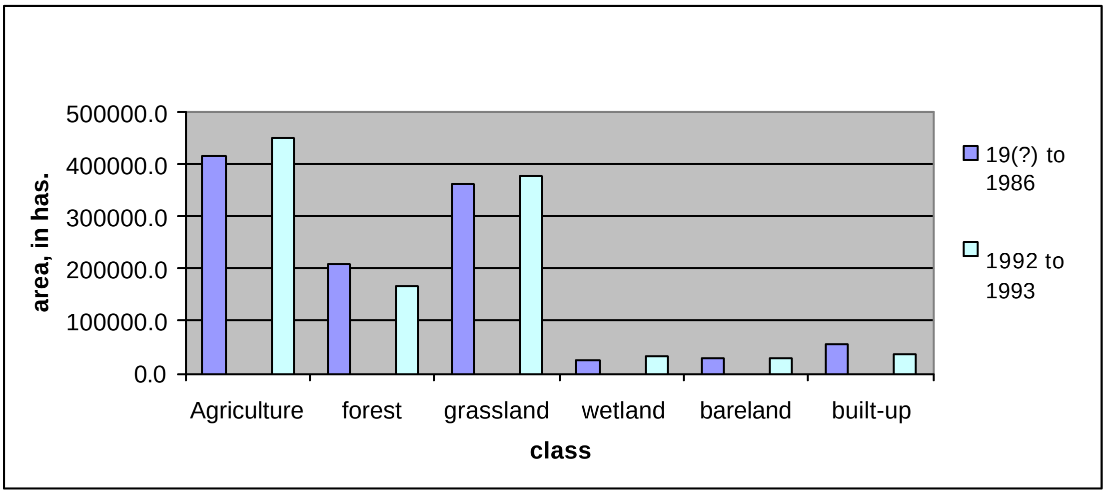


Figure 12a. Total area of land use/cover in Agno watershed.

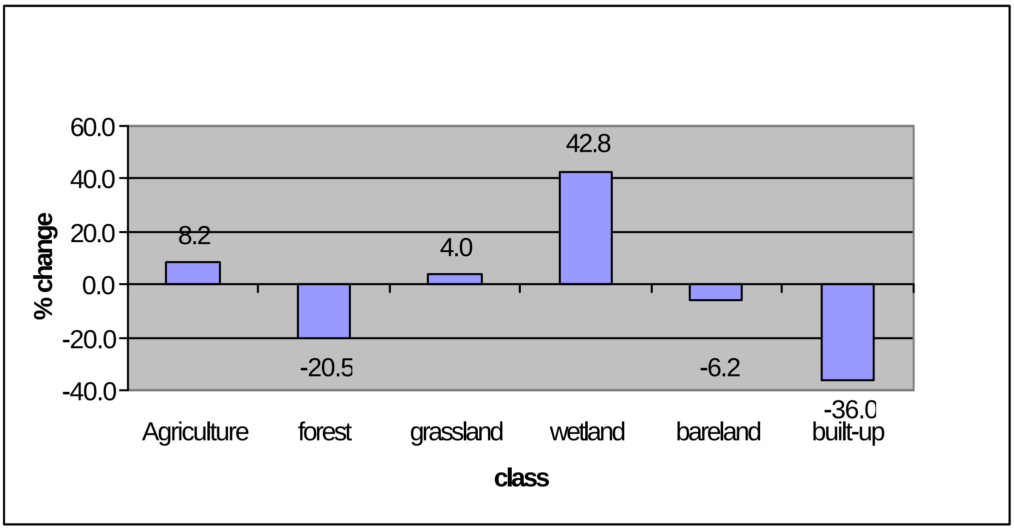


Figure 12b. Percent change of land use/cover in Agno watershed.

2. Socio-economic processes and models

2.1 Residual generation models

One of the important questions raised by LOICZ is how will a change in economic activity affect the flow of residuals (C, N, P, suspended solids) into coastal waters? In order to meet the objectives of LOICZ, a methodology is needed that is generally applicable and available across a wide variety of sites. For many of these sites data is scarce in a number of areas. With these factors in mind, we begin with rather simple models. For site specific purposes, these models may be expanded upon as data allows.

A regional economic activity model may be used to estimate the generation of residuals (James 1985). In its simplest form, residual discharges are given as

1) $r = CX$

where r = a matrix of residual discharges (residual type by economic activity)
C = a matrix of residual discharge coefficients
With c_{kj} = the quantity of residual k per unit of sectoral activity j
X = a diagonal matrix of sectoral activity levels.

Total discharges of each residual type are then given by

2) $R = rS = CX$

where R = a vector of residuals by type (summed across all activities)
S = a summation vector.

So each element of the column vector R represents the sum of the corresponding row in the r matrix. That is, the total discharge of residual type k is the sum of each activity's discharge of residual k.

In the above formulation, X is simply an exogenous estimation of output for each activity in the region. Allowing economic activity to be represented by a regional input-output model may expand the model. In such a model, production (X), or supply, is equated to the sum of intermediate (inter-industry) demand (AX) and final demand (Y):

3) $X = AX + Y$

with $A = [a_{ij}]$ where a_{ij} is the Leontief IO technical coefficient and

3a) $a_{ij} = z_{ij} / X_j$, where z_{ij} is the monetary value of the input flow from sector i to sector j

Manipulation of equation 3 yields

4) $X = (I - A)^{-1} Y$

where $(I - A)^{-1}$ represents the Leontief inverse matrix.

Substituting equation 4 into equation 2 gives

5) $R = C (I - A)^{-1} Y$

The total change in residual generation brought about by a change in one or more components of final demand are determined by

6) $\Delta R = C (I - A)^{-1} \Delta Y$

Using equation 4, equation 6 may be rewritten as

7) $\Delta R = C \ \Delta X$

Equation 7 may be used when analyzing the impact of growth in sectoral production or GDP.

In equations 5 - 7, matrix R represents the amount of residuals generated during both direct activities and the indirect "support" activities. For example, if fish aquaculture is the direct activity being addressed, agricultural activity may be considered an indirect or support activity, since aquaculture feeds are often derived from agricultural output. Thus, an increase in aquaculture may increase nitrogen loading into coastal waters not only from the application of feeds, but also via the increased use of fertilizers in the agricultural sector.

Equations 2 and 5 - 7 represent two alternatives but related approaches to addressing the question of how economic activity affects the generation of residuals. Equations 5-7 represent the input-output (IO) modelling approach discussed during the December 1997 Bolinao workshop (LOICZ, 1997). Equation 2 represents the rapid assessment (RA) method utilized by WHO (1993), which may readily be incorporated into a geographical information systems (GIS) modelling approach such as that discussed in Turner et al. (1997).

Each approach has its strengths and weaknesses. A favorable aspect of the IO approach is that it captures the interrelationships between sectors of the economy. A change in activity of one sector typically requires changes in activity in other sectors. These interrelations are not captured in the RA modelling approach, and thus may lead to an underestimate of residual discharges. On the other hand, data constraints typically require a considerable degree of aggregation of economic sectors in regional IO models. An RA/GIS model allows for a considerable degree of disaggregation, and allowance for consideration of spatial relationships. These relationships may be of particular importance when taking account of environmental assimilation of residuals.

It should be noted that the IO model by itself does not represent an integrated ecological-economic model. It is when the IO model output is combined with the biogeochemical model as an input that a step toward integration in a 'weak' sense occurs. In this case, "each discipline continues to use and refine its own paradigm, appropriate to the system it studies, but in which they together create combined models of the interactions between the two systems" (Russell 1996). Theoretically, this integration could be expanded if the outputs of the biogeochemical model (that is, some measure of water quality) could be incorporated in dose-response relationships that quantify the impact of changing water quality on habitats that affect, for example, fisheries or tourism. Thus far, obtaining such dose-response relationships has proven to be problematic.

2.2 IO Model

During the 1997 SWOL workshop in Bolinao, it was decided that each country should attempt to create an 11-sector regional IO model, preferably with an endogenized household sector as a twelfth sector. The Philippine study's approach to this objective was to create a 31-sector regional model based upon the 229-sector 1994 national model, adjusted with the simple location quotient method of reduction. Details of the creation of this IO model are found in Appendix B. **All tables referred to in this section are found in Appendix B.** The 31-sector model was then aggregated to the agreed upon 12-sector model. The sectors for the 31-sector model and their aggregation to 12 sectors are shown in Table B1.

Highlights of the input-output model components. This section gives a brief description of the development and the components of an IO model. The discussion will refer to the 11-sector model, with the appropriate tables referred to as 'Table _a'. The corresponding 12 sector model (households endogenized) tables will also be provided, as 'Table _b'.

Table 2a is the 1994 regional 11 x 11 sector IO table for Region 1 (Ilocos Norte and Ilocos Sur) of the Philippines. The upper portion (rows 1 –11 and columns 1-11, collectively referred to as the production sector) of the table shows the inter-industry flow of goods. Such an inter-industry transactions table is derived from a larger set of income and production accounts for a region (see Appendix B).

Each element of the transactions table (the z_{ij} terms of equation 3a, expressed in monetary units) represents the sale (supply) of sector i's outputs to sector j for use as inputs to j's production process. Thus, by reading row 1 it is seen that sector 1 supplies an amount 2399734 to sector 1 (itself), 200 to sector 2, 20 to sector 3, etc.. .

Reading the columns tells us the amount each sector purchases (demands) from all other sectors. Thus sector 2 demands (or buys) an amount 200 from sector 1, 149876 from itself, 0 from sector 3, etc. Such demand of one production sector for the output of other producing sectors for use as inputs is termed intermediate demand, and is represented by the 'AX' vector in equation 3.

One interpretation of Table B2a is that it is an account of the amounts that each sector demands from other sectors in order to satisfy their own production processes. That is, the inter-industry transactions table (in particular, the columns) represents intermediate demands. The values for the AX vector are determined by summation of each row sector. Thus, the right-most column of Table B2a, labelled Total Intermediate Demand, is the AX column vector of equation 3. The column sum of each production sector is termed Total Intermediate Inputs.

Table B2a can be expanded in a variety of ways. First, there are inputs to the production process that must be paid for other than those produced by other industries. The primary example of these value-added items is employee compensation. For the purposes of this model, other categories are lumped together under operating surpluses. This collection of inputs is known as the payments, or value-added sector.

A second point of expansion for Table B2a is to include the final demand sectors (see Table B3a). Final demands are demands derived from sources outside the production sector of the region. Examples of final demand sectors would include personal consumption expenditures of households (PCE), government consumption expenditures (GCE), business investment (gross fixed capital formation, GFCF), and net exports (E-M) to other regions. An adjustment for changes in stock inventory (CS) is also be included. Final demands are summed across rows to give the Total Final Demand column vector (TFD in Table B3a), denoted as 'Y' in equation 3. Adding the intermediate and final demand column vectors gives the total output (TO) column vector (the right-most column of Table B3a, for sectors 1-11), denoted as 'X' in equation 3.

Table B4a is the technical coefficient matrix, represented by the matrix 'A' in equation 3. To derive this matrix, each of the z_{ij} elements of Table B2a are divided by the appropriate column sum X_j, as shown in equation 3a. The column sums X_j are represented in Table B2a by the Total Input (TI) row. It should be noted that the column sum X_j is the sum of all inputs; those of both the production and payments sectors.

The technical coefficient a_{ij} may be interpreted as the (currency unit)'s worth of sector i input per (currency unit)'s worth of output of sector j. The technical coefficients are viewed as representing a fixed relationship between a sector's outputs and its inputs. If technology changes, then the values for the technical coefficients will change.

An alternative definition of the technical coefficient is that it indicates the portion of a column sector j's input demand that is provided for by row sector i. Thus, sector 1 (agriculture) provides 10% of it's own input demand.

The vector and matrix requirements of equation 3 are now provided for. To gain the form of equation 3, the Leontief inverse matrix $(I - A)^{-1}$ is created (Table B5a). The elements of the Leontief inverse are known as sectoral multipliers. Each element indicates the value of the change of a row sector's output because of a unit change in final demand for the column sector's output. This may be seen by rearranging equation 4a to give

8) $dX / dY = (I - A)^{-1}$

The column sums of the Leontief inverse (that is, the column sums of the sectoral multipliers) are known as simple output multipliers (in the case of an exogenous household sector) or total output multipliers (in the case of endogenized households). The output multiplier for a sector is the total change in production for all sectors needed to service a one unit (say, one peso) change in final demand for that sector. The simple output multiplier captures the direct and indirect impacts of a unit change in final demand of a sector. The direct impact is the unit change in production that satisfies the unit change in final demand. The indirect impact represents the additional production needed to satisfy the resulting changes in intermediate demands. In the case of an endogenized household sector, an induced impact is added to the simple multiplier impacts to provide the total output multiplier. The induced impact represents the additional consumer expenditures generated from the changes in income due to labor payments for the changes in production.

A low column sum (output multiplier) reveals a weak sectoral inter-linkage; otherwise, it shows a sector's strong dependence on the other sectors' output to meet a unit increase in final demand for its output. The sector with the largest multiplier provides the largest total impact on the economy. The simple and total output multipliers are provided on the bottom rows of Tables B5a and B5b, respectively.

The basic components of the IO model are now provided for. The next step in modelling residual generation with the IO model is to create the residual coefficient matrix 'C' of equation 1. This first required the quantification of residual generation in the study site, and then applying the information to equation 3a. The estimation of residual generation is described in Appendix B. The residual coefficient matrices for the various models are given in Tables B6a-b.

Analogous to the concept of the output multiplier is that of the residual multiplier. The residual multiplier matrix M is given as:

$M = C (I-A)^{-1}$.

The elements of $M = [m_{kj}]$ show the amount of residual k generated for a one unit change in final demand in sector j. These residual multipliers for the 12 sector model are provided in Table B7. As an example, in order to service a one unit (in the tables presented, one unit is one thousand pesos (1994), equivalent to about $40 U.S.) increase in agricultural final demand, approximately 0.00057 metric tons (or 0.57 kg) of nitrogen will be discharged into coastal waters.

The residual coefficient matrix is created from a pre-existing estimate of residual generation. This is then allocated among the sectors of the IO model. Thus the estimates of residual generation for the **given** levels of economic activity represented by the IO model are as good as (in fact the same) the estimates provided by the RA exercise. It is hoped that, despite the high level of aggregation in the IO models, estimates of **changes** in residual flows brought about by changes in economic activity will be better than estimates given by a RA model.

While the estimates of residual generation from the rapid assessment exercise are at best 'guesstimates', the quality of the estimates may be ascertained to some degree by comparing the obtained values to the results from the biogeochemical modelling. The results shown in Table B8 indicate the ambient concentrations of N, P, C, and SS in the water column, and the percentage of the ambient concentration that may be attributed to economic activity. The numbers do not seem to be too unreasonable.

With the completion of the residual coefficient matrix, we have the model of equations 5 - 7, and are now prepared to perform some scenario analyses.

Scenario analysis. Scenario analysis may take the form of projecting changes in either final demand (ΔY in equation 6) or in total output (ΔX in equation 7). The result for either approach will be an estimate of the overall change in residual generation brought about by a change in economic activity. Two scenarios are presented for the purpose of demonstrating the workings of the model, and to make comparison with results from a simpler rapid assessment approach.

The following scenarios are presented for the 12 sector model (see Table B9):

i) 53% growth in the net export of agriculture, translating into a 20% growth in final demand for agriculture. This scenario reflects potential expansion in the agricultural sector due to improved irrigation facilities and infrastructure, and a policy shift toward export-oriented activity, coupled with an emphasis on food security.
ii) 20% across- the- board growth in total final demands.

The change in Final Demand vectors for each scenario are given in Table B9. The resulting changes in Total Output are provided in Table B10. The changes in residual generation are shown in Table B11, along with the changes predicted by the RA methodology.

In the first scenario, a 53% growth in the net export of agriculture translates into a 20% growth in final demand for agriculture. Final demand for all other sectors is held constant. Table 12 shows that Total Output changes in all sectors, with percent changes ranging from 1.5% to 23.8%. This is a clear indication of the interrelationships present in the economy. Table B11 shows the resulting changes in residual generation. Nitrogen increases by 2117 t, (13.9%), phosphorus by 1349 t (11.1%), suspended solids by 517856 t(18.3%), and carbon by 3015 t (5.3%). The rapid assessment model would estimate lower increases in each residual (the increase in agricultural output necessary to meet the increased final demand, multiplied by the residual coefficients for agriculture). As shown in Table B11, the RA model would predict a 10 % increase in N, a 7.1% increase in P, a 15.1% increase in SS, and no change in C. Thus, the rapid assessment model would seem to underestimate residual generation by 28 % for N, 36 % for P, 17.4% for SS, and would completely ignore any changes in C.

The second scenario again shows how the rapid assessment model may underestimate residual generation. The RA method would essentially estimate a change in residuals equal to the change in sectoral output (set equal to the change in final demand) multiplied by the sectors share in residual generation. For example, the 20% increase in final demand for agriculture would be equivalent to a 15.6% increase in agricultural output. This would be multiplied by the 64.4% share that agriculture has in the generation of nitrogen, to give an estimated 10% increase in nitrogen generation. As seen in Table B11, for the second scenario the RA method would underestimate nitrogen generation by 49%, phosphorus by 60 %, suspended solids by 36%, and carbon by 90%.

The above scenarios serve to demonstrate how the rapid assessment methodology represented by Equations 1 and 2 may result in a significant underestimation of residual generation. The input-output model, by capturing intersectoral linkages, provides a more thorough assessment of the changes in activities that lead to residual generation. It should be noted that the economy of the study site is dominated by agriculture, with relatively little industrial development. In an economy with a more robust industrial sector, particularly in the agricultural product-based Manufacturing 1 sector, the inter-linkages among residual-generating sectors would be stronger, and the relative value of the input-output model would be that much greater.

One potential weakness of the specific IO model presented above deserves some discussion. Due to time and data constraints, the regional IO model as presented is of the competitive type. That is, no distinction is made in the transactions table between commodities produced within the region and those imported from other regions, whether domestic or international in origin. This provides no great obstacle in using the IO model for estimating residual generation. For this purpose, one must simply assume that during conditions of changing demand, the mix of regionally and non-regionally sourced inputs does not change. This assumption is an extension of the typical IO assumption that the technological input mix is constant (that is, the coefficients of the A matrix are constant). Of course, over longer time horizons, these assumptions become less tenable, and this is a common criticism of the use of IO tables. Typically, however, governments attempt to overcome this criticism by updating their IO tables every 5 or 10 years.

Use of the competitive type IO model becomes more problematic when using it for simple or total output multiplier analysis. In such cases, it becomes more important to make the distinction between inputs produced within the regional economy and those imported from outside. Analyses making use of output multipliers, however, is not of primary interest in terms of meeting the objectives of LOICZ. While analyzing the changes in multipliers and in the technological coefficient matrix over time could theoretically be of use, the practical fact is that the methods of constructing IO tables have changed over time, and typically, IO tables over time are not compatible for comparison. For example, the period between 1979 and 1985 saw the introduction of the distinction between commodities and industries, thus allowing an improved method of allocating secondary output of industries. The negative result of this is that pre- and post-1979 IO tables are no longer directly comparable.

Should the use of IO models prove to be of benefit to LOICZ, a primary concern for future studies should be an agreement on the particular type of IO model to be used, so that cross-country or cross-regional comparisons may be made. It seems likely that the non-competitive type model may be of more use, particularly in regard to making cross-country comparisions of forward and backward linkages between sectors. The choice between survey –based regional models and, for example, simple location-quotient reduction methods of regionalization, is also a question that should be addressed. The ultimate choice of model type should reflect the LOICZ objective of creating models in a wide variety of sites, and the need for cross-country comparison and scaling activities.

3. BIOGEOCHEMICAL CYCLES AND PROCESSES

3.1 Methods

Biogeochemical budgets. 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). 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). 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).

Table 3. Effluents produced by economic activities in Lingayen Gulf (in 10^6 mole yr^{-1})

Economic Activity		
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**

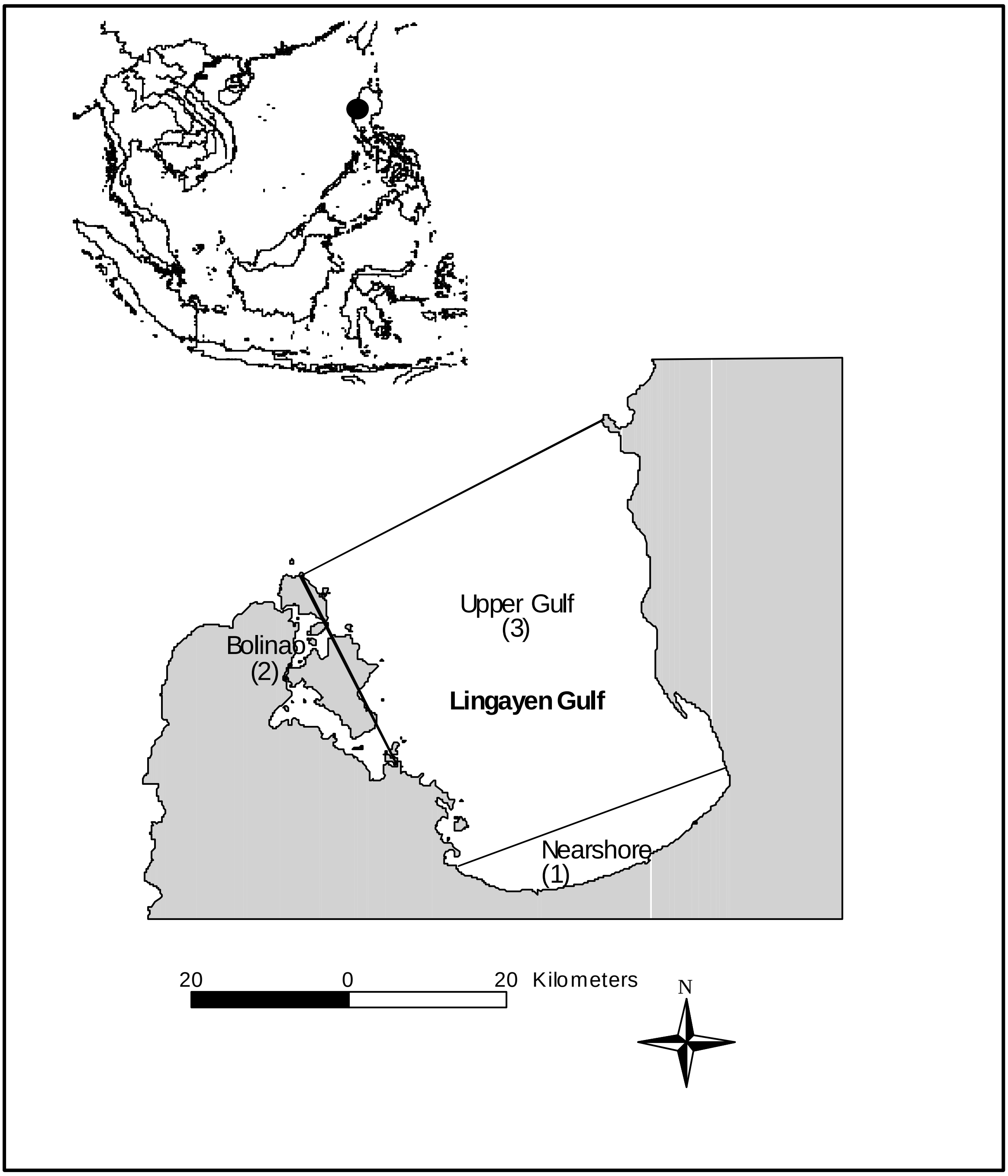


Figure 13. Map of Lingayen Gulf showing the boundaries of the budgets.

Total primary production. Primary production estimates for Lingayen Gulf were obtained using empirical data on chlorophyll a and bacterioplankton growth rates while coral and macrophyte production were derived from secondary literature.

Estimates for chlorophyll a were converted to production using a sinusoidally fitted light regime for a twelve hour day, an I_{sat} of 150 uE m^{-2} s^{-1} (McManus et al., manuscript) and a P_{max} (tropical and nitrogen poor waters) of 3.15 mg C Chl a^{-1} hr^{-1} (Parsons et al., 1984). In a number of stations, production estimates using the light and dark bottle method were obtained in waters with and without fishpens, to get values along a eutrophication gradient. Water samples were incubated *in situ*, and were fixed after a 4-hour incubation and analyzed following the modified Winkler method using an auto-titrator (Parsons et al. 1984, 751 GPD Titrino, Metrohm).

For bacterial production, water samples for bacterial counts and growth rates were collected from below surface (1 meter), at mid depth, and near bottom, using a Niskin sampler. A sample volume of 15-20 ml was taken and preserved to 1% gluteraldehyde final concentration. To determine growth rates, samples were incubated *in situ* by suspending the bottles at different depths (1, 5 & 10 m) and a subsample of 40 ml was taken at the start of incubation and every three hours thereafter for 24 hours (Agawin et al., unpublished). The samples were later filtered through a 0.20 µm black Nucleopore filter under 1-2 cm Hg pressure, and stained with DAPI solution. These were mounted in a glass slide with a drop of Zeiss immersion oil and examined under an epiflourescence microscope. Both hetero- and autotrophic bacteria fluoresce bluish white under UV excitation. Counts for autotrophic bacteria, which fluoresce yellow with blue light excitation, were provided by Agawin (pers. comm.). The latter were subtracted from the total counts to obtain cell counts for heterotrophic bacteria. Daily growth rates and mean cell densities together with values of cellular carbon content (0.123 pg C μm^{-3}; Waterbury et al.) and cell volume of 0.63 μm^3 (Agawin et al., unpublished) were used to obtain estimates of bacterial production. Estimates for coral and macrophytes growth rates were derived from secondary literature and converted into carbon production following Westlake (1963).

Fisheries and primary production required. The primary production required (PPR) was estimated using two methods. The first was computed using Ecopath 3.0 by deriving steady state biomasses for each fish group and computing the needed phytoplankton production to support these. The catch statistics were summarized into ten groups (herbivorous fishes, miscellaneous demersals, leiognathids, crustaceans, small pelagics, intermediate predators, scombrids, barracuda, *Loligo* spp., phytoplankton, zooplankton, zoobenthos, and juvenile fish) modified from those used by Guarin's (1991) model of Lingayen Gulf. Summaries were constructed for every year from 1978 to 1987. Data for succeeding periods are available but were not used since there were a change in the agency conducting the monitoring, the area covered, and the types of fish groups recorded. Corresponding diet compositions, production/biomass ratios, (and ecotrophic efficiencies), as well as biomass estimates for those groups for which no data were available (phytoplankton, zooplankton, zoobenthos, juvenile fish) were likewise taken from Guarin (1991) but updated using summaries in Fishbase 97. From the above data, ECOPATH estimated the "best" balanced combination of biomasses. Net PPR required was then computed as the product of the estimated phytoplankton biomass (the only primary producer in the model), the production/biomass ratio, and the ecotrophic efficiency (i.e., the proportion of the energy input into the phytoplankton group that is exported).

The second method used the basic equation of Pauly and Christensen (1995), which incorporated the parameters for weighted mean trophic level and biomass of the harvested fish. For both analyses, catch data in Lingayen Gulf for the period 1978-1987 were used. A conversion factor of 9 for wet weight to dry weight ratio was used in the first analysis. Ratios of 0.14 fish wet weight to dry weight and 0.38 fish dry weight to carbon (Parsons et al., 1984) were used in the second analysis.

3.2 Results

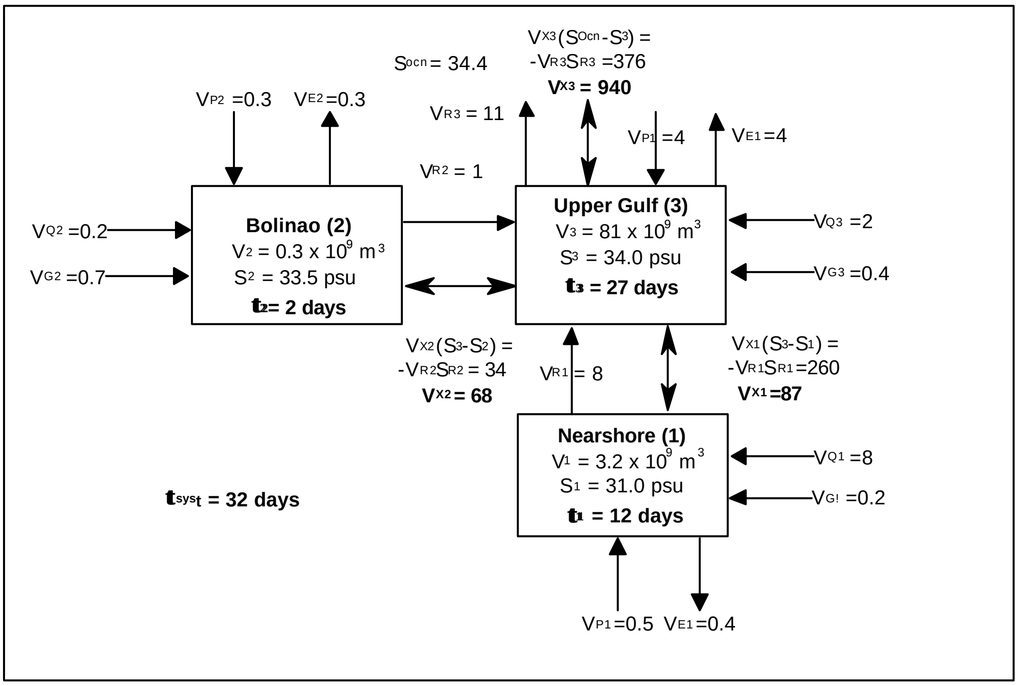


Figure 14. Water and salt balance for Lingayen Gulf. Water fluxes in 10^9 m^3 yr^{-1} and salt fluxes in 10^9 psu-m^3 yr^{-1}.

Water and salt balance. Figure 14 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 x 10^9 m^3 yr^{-1} (NWRC Phil, 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 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 -8x10^9 m^3 yr^{-1} from the nearshore box to the upper Gulf box. In addition, -1 x 10^9 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 are required.

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 set of WOTRO (1997, 1998). The residual fluxes of salt (V_RS_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 x 10^9 psu-m^3 yr^{-1} from the nearshore box to the upper Gulf box, $V_{X2}(S_3-S_2)$ = +34 x 10^9 psu-m^3 yr^{-1} from the Bolinao box to the upper Gulf box, and $V_{X3}(S_{Ocn}-S_3)$ = +376 x 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 x 10^9 m^3 yr^{-1}, 68 x 10^9 m^3 yr^{-1}, and 940 x 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. ΔDIP 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). Overall the small ΔDIP 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.

Table 4. Summary of non-conservative fluxes in Lingayen Gulf (one-box model)

Process **(Area, Vol.)**	**Lingayen Gulf** (2,100 km^2, 84.5 km^3)	
	10^6 moles yr^{-1}	mol m^{-2} yr^{-1}
DDIP	+1.2	+0.0006
DDIN	-210	-0.1
(*p-r*)	-147	-0.07
(*nfix-denit*)	-420	-0.2
DDOP	+189	+0.09
$DDIC_t$	-2,100 to 1,770,000	-1 to +843

Estimates of the DOP (dissolved organic phosphorus) fraction show that it is quantitatively important. The calculated ΔDOP (+0.09 mol m^{-2} yr^{-1}) is orders of magnitude higher than the ΔDIP and 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.

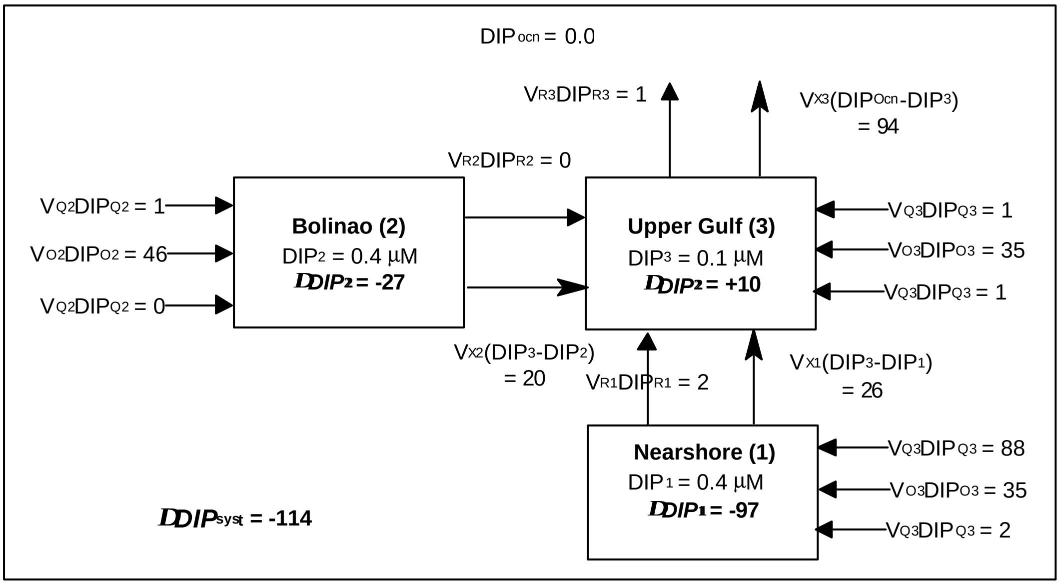


Figure 15. Dissolved inorganic phosphorus (DIP) budget for Lingayen Gulf. Fluxes in 10^6 mol yr^{-1}.

Based on the DIN balance, Lingayen Gulf is a net sink of DIN (i.e. ΔDIN 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 (ΔDIC) 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 ΔDIC_{org} of -0.7 mol m^{-2} yr^{-1} inferred from ΔDIP 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 ΔDIC is 0.3-0.5% of production.

N and P Balance - Multiple-box Model. Figure 15 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 is 0.4 mmol m^{-3} for the nearshore box, 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_ODIP_O) in each box was determined from the waste load estimated for the entire gulf scaled down to the gulf's coastline within the box. This assumes that most of the 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_QDIP_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. 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 dissolved organic P or trapped in the sediments. The Bolinao box is also a net sink of DIP suggesting that this box is autotrophic, albeit not as strongly 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 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.

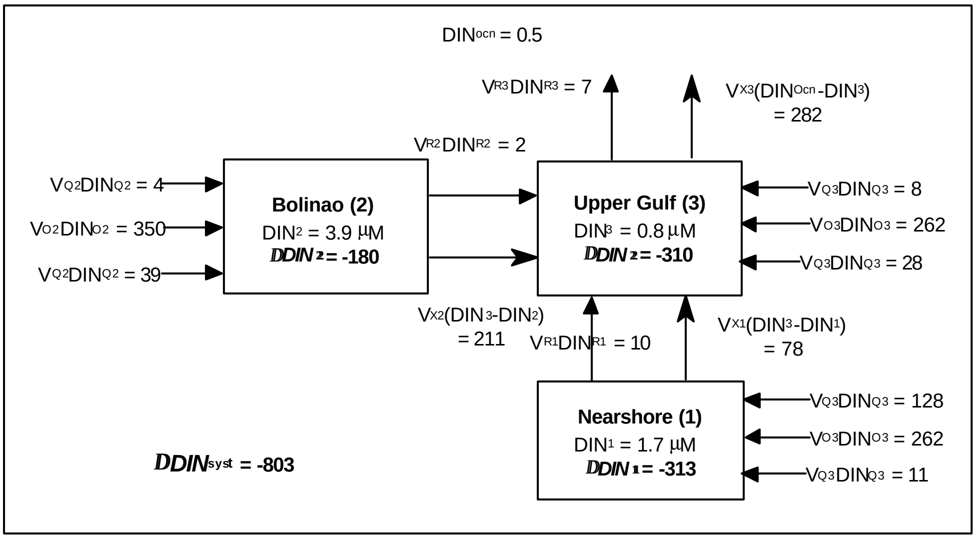


Figure 16. Dissolved inorganic nitrogen (DIN) budget for Lingayen Gulf. Fluxes in 10^6 mol yr^{-1}.

Figure 16 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_ODIN_O) in the boxes was estimated using similar methods as (V_ODIP_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 is given in Table 5. 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.

Table 5. Summary of non-conservative fluxes in the three boxes of Lingayen Gulf

Process (Area, Volume)	*NEARSHORE BOX* (210 km^2, 3.2 km^3)		*BOLINAO BOX* (126 km^2, 0.3 km^3)		*UPPER GULF BOX* *(1,764 KM², 81 KM³)*		*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}
ΔDIP	-97	-0.46	-27	-0.21	+10	+0.006	-114	-0.05
ΔDIN	-313	-1.5	-180	-1.4	-310	-0.2	-803	-0.4
(p-r)	+10,282	+49	+2,862	+23	-1,060	-0.6	+12,084	+6
(nfix-denit)	+1,239	+5.9	+252	+2.0	-918	-0.5	+573	+0.3

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 of interest would be to see the response of the system for reduced or added waste load (Table 6). 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.

Table 6. Effects of changing waste load on (*p-r*) and (*nfix-denit*)

Change in waste load	**(*p-r*) in mol m^{-2} yr^{-1}**	**(*nfix-denit*) in mol m^{-2} yr^{-1}**
Current load	+6	+0.3
0 load	-0.5	-0.03
0.5 x current load	+2.5	+0.2
2 x current load	+11	+0.9

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.

Carbon Production and Fisheries. Production of carbon in Lingayen Gulf by various components is shown in Table 7. Phytoplankton accounts for 29%, bacterioplankton 42%, and corals and macrophytes 29%. Of the bacterioplankton production, autotrophic cyanobacteria account for only 1% and heterotrophic bacteria contribute 99%. This validates the heterotrophic condition of the upper Gulf indicated by the budgets discussed above.

A conversion of harvested fish biomass into net phytoplankon production requirement was compared with the empirical estimates in Table 8. The net phytoplankton production estimated by chlorophyll a and by biogeochemical budgets were reasonably close at 100.5 and 75 t C km^{-2} yr^{-1}, respectively. When compared with that required to sustain the harvested fish biomass, a proxy of exploitation rate was calculated using phytoplankton required and phytoplankton production as inputs in an index ratio. The latter indicates a level of fisheries exploitation beyond optimal at 67%.

A comparison of the per year PPR computations (using ECOPATH) with the catch is shown in Figure 17. Computed PPR (averaging around 360 t wet weight /km^2/year) essentially followed the trend in catch over the ten year period, with total catch increasing 90% and PPR increasing 95%. Total biomass estimated by ECOPATH only increased 32% over the same period showing increased fishing pressure (which is mainly on the higher trophic levels) and consequent increases in primary production required.

There was an overall increase in the catch of all groups in the ten-year period from 1978 to 1987 (Figures 18 & 19). Those with steepest slopes of the regression line were miscellaneous demersals and scombrids while barracuda had the least. Note though that barracuda, crustaceans, and herbivorous fishes actually had slight decreases in the first five years (1978 to 1982) while scombrids had marked decreases in the succeeding five years (1983 to 1987).

The simultaneous initial decline of both barracuda and herbivorous fishes (in contrast to one increasing while the other decreases) is not unexpected since barracuda has a greater trophic impact on the intermediate predators (of herbivorous fish). Hence a decrease in barracuda because of fishing could benefit the predators of herbivorous fish.

There seem to be some shifts in the trophic levels of the groups harvested, i.e., fishing may be closer to the base of the trophic pyramid and thus more and more omnivores and herbivores are being caught. Proportional catch of groups higher in the food web such as of small pelagics and intermediate predators

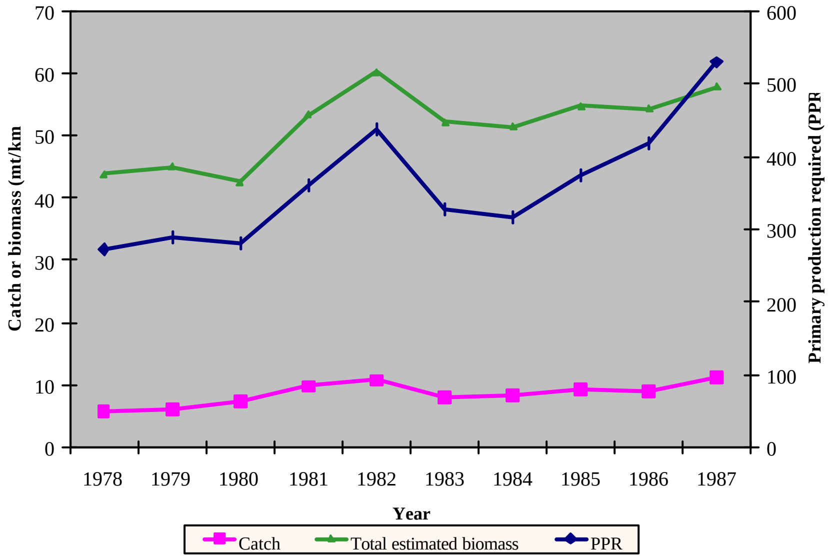


Figure 17. Comparison of raw total biomass (from catch data), total balanced biomass (balanced using ECOPATH on the same groups), and primary production required to support the latter for Lingayen Gulf.

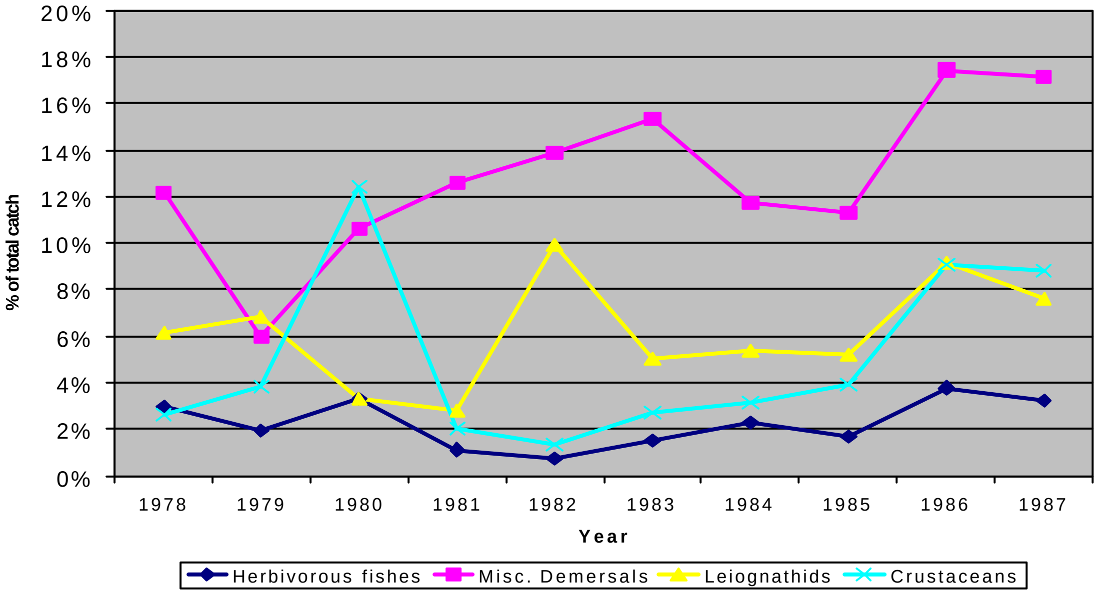


Figure 18. Catch (as a proportion of total catch) of groups lower in food web in Lingayen Gulf.

declined (Figure 18), as did the scombrids after a period of increase. Catch of groups lower in the food web (as a proportion of total catch; Figure 19) increased as is the case with leiognathids, miscellaneous demersals, and herbivorous fishes. However, factors such as influence of market demand and changes in gear composition and effort cautions against detailed interpretation of catch data in terms of trophic levels. For one, the decline in scombrids does not seem related to such trophic cascades. ECOPATH shows fishing mortality in scombrids is only half of total mortality, which at face value does not suggest overfishing. However, fishing mortality for predators such as *Loligo* (mean trophic level of 3.5) small pelagics (trophic level of 3.6), intermediate predators (trophic level of 3.8), and barracuda (trophic level of 4.4) range from 70 to 95% of total mortality in 1987. This indicates severe overfishing of these predator stocks if the Lingayen Gulf system is assumed closed. However, it is more likely that fishing boats going after these stocks fish farther out in the South China Sea, and that Lingayen Gulf is actually supporting a smaller biomass of these predators.

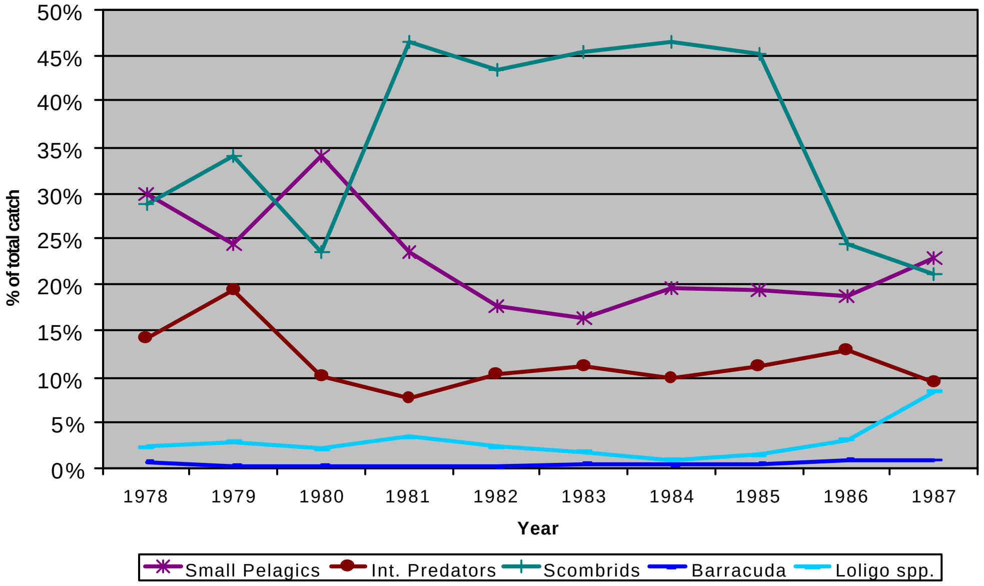


Figure 19. Catch as a proportion of total catch of groups higher in the food web in Lingayen Gulf.

4. RECOMMENDATIONS AND FUTURE DIRECTIONS

4.1 Strengths and weaknesses of the overall SWOL approach

The SWOL approach provided a mandate to integrate anthropogenic influences and biogeochemical processes in coastal waters using quantitative approaches. It also provided basic approaches to assess biogeochemical fluxes using the LOICZ budget method for carbon and nutrients. For evaluating socio-economic drivers, the project agreed on common economic tools such as the use of the input-output model to quantify the generation of residuals by economic activities. The application of these methods and approaches has paved the way for initiating the integration among economic and biogeochemical variables in more robust ways.

The application of the SWOL approach in data-rich sites including Lingayen Gulf have allowed for refinements of existing and the application of appropriate analytical approaches for studying global change in the context of the coastal zone. The quantification of groundwater and better estimation of freshwater runoff and sediments through hydrological modelling represent a qualitative expansion of the scope of tools that were developed and applied in this study. The disaggregation of biogeochemical budgets from one box to multiple boxes allowed for better characterization of spatially distinct sub-environs and their interactions in the gulf. In the case of economic tools, this study compared a rapid assessment method with the input-output model in terms of their ability to quantify residual generation. While the former could allow for a better definition of spatial boundaries, it failed to capture the interactions among economic sectors and which resulted in underestimates of waste generation. The input-output model seemed more robust in accounting for these sectoral interactions.

The SWOL approach has both horizontal and vertical dimensions. Because it is attempting to assess the functioning of the global coastal zone, it has to give priority to the development of methods that are not data-intensive but are rigorously quantitative to allow for evaluation at the regional and global scales. However, the development of such methods usually comes from data-intensive study sites where modelling and validation have substantively progressed. The four study sites (Merbok, Malaysia; Lingayen Gulf, Philippines; Ban Don Bay, Thailand; and the Red River Delta, Vietnam) fall along a gradient of data richness and of intensity in scientific investigation. In all cases, the synthetic work in all four sites contributed more to the vertical dimension of the LOICZ overall goal.

The apparent weakness of the SWOL approach lies in its inevitable prioritization to get a wide geographic spread of study areas as a matter of exigency towards a global assessment over the need to test the validity and robustness of its methods in well-studies sites. Biogeochemical budgets alone are not scientifically satisfying to characterize coastal zones nor are input-output models sufficient to define the impact of global trade on environmental degradation. A delicate balance has to be defined and one route may be pursued more than the other depending on data availability. Viewed from the larger context of global assessments, this seeming weakness can be overcome by clearly defining objectives when analyzing secondary information for many sites (the horizontal component) or collecting primary data to understand processes in one site (the vertical component).

4.2 Strengths and weakness of studying biological and economic processes

The more study- and data-intensive steps of measuring biogeochemical rates and associated natural and man-made processes under variable economic policy regimes or technological interventions are necessary in realizing the vertical dimension of the SWOL approach. Where data or resources allow for such measurements to be made at appropriate spatial and temporal dimensions, the current modelling approaches can only be enhanced both in their descriptive and predictive capacities. These detailed studies however, will need to be put in the bigger context of regional or global applications. Thus, while methods may be involved, one would still attempt to minimize data requirements in consideration of relative scarcity of data over wide areas. One promising approach is to use intensive data sets to develop predictive typologies that can be used to classify coastal areas given readily available regional and global data sets.

Intensive studies can become points of weakness when one fails to see their broader applications. In this study, an inventory of primary producers was done to determine carbon partitioning. The contribution of phytoplankton to carbon production was used to evaluate the impact of harvest on net carbon production, and as a check on the metabolic state of the gulf determined by the biogeochemical budget approach. One can take this approach further to examine such partitioning along gradients of eutrophication, siltation or harvest in various coastal habitats to seek general patterns of man-induced impacts on carbon cycling. Regarding data availability, phytoplankton production estimates may not be readily available but proxy estimates such as surface chlorophyll a concentrations obtained by satellite-borne sensors (e.g. Coastal Zone Color Scanner in the 1980's, SEAWIFS) can be used for these assessments.

In the case of economic processes, the current study has evaluated a rapid assessment method and a sub-national regional input-output model in terms of their capacity to estimate residual generation and found the latter to be more robust. Prospectively, a subsequent study will extend the use of the input-output model to consider the influence of the import and export sectors and that of human migration along a gradient of economic development on residual generation and assimilation. In terms of data availability, the use of I-O models among nations with emerging and existing free market economies is common and their use for integrated economic-environmental modelling for inter-regional comparisons seems a viable approach.

Thus, process-oriented studies can contribute significantly to global assessments by providing a sound database for integrating more socio-economic and biogeochemical variables in a model and testing this under variable boundary conditions. They become limiting when data requirements cannot be met at wider spatial scales where assessments are needed.

4.3 Utility of research results to management

The information and data so far gathered in this four-year study indicate a gulf that is impacted mostly by waste from agriculture and household activities. Although it is nearly in balance metabolically, i.e. with a high assimilative capacity, the gulf remains vulnerable to unregulated deliveries of sediments, and nutrients through surface runoff or groundwater seepage. The responses of the system to such loading are dramatic on nearshore environs such as in embayments, channels and along river mouths, and which are diluted as one proceeds away from shore.

These results are important to management, but will need to be translated in more practical terms to be useful to policy and regulation. The use of desired environmental states vis-à-vis target scenarios or standards against which to compare current states will have to be done so that the status of the system becomes more transparent to management. Scenario building as has been done in this paper remains preliminary, as the consequences of waste reduction or increase were not fully explored. For management, scenarios of mitigation versus non-mitigation are crucial in defining concrete interventions. Reduction of waste through adoption of best practices and through technological interventions can then be justified, and where appropriate, monetized.

Often, science desires more unequivocal results before linking up with management. The use of integrated modelling approaches should at the very least provide advice on what non-mitigation can result in, using the precautionary principle as a first line of defense and best science, a second one.

4.4Utility of research results to characterisation of coastal zones within country and Southeast Asia

Lingayen Gulf typifies rural coastal areas in the Philippines, and insular coasts of Southeast Asia. High population growth rates and agriculture-based economies are common features. Geomorphologically, this gulf subsumes coastal habitats including fringing reefs, seagrass and algal beds, soft-substrate channels and bays with *Nipa* and occasional mangrove stands, all of which sustain heavy exploitation rates. Upstream threats include deforestation-derived sediments, sewage and mining-related pollutants.

As such, the insights derived from this study and from the other SWOL sites form a core database upon which a regional typology can be derived as a necessary step in formulating a regional assessment of the Southeast Asian coastal zone. Preliminary work on a regional coastal typology using climate, hydrology and population variables indicated that the Lingayen Gulf and Ban Don Bay (Thailand) could potentially represent about 30% of the coastline of the South China Sea (Talaue-McManus, 1999).

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