History, development and results of the interdisciplinary project conducted 1996-1999

Renée van Kessel, WOTRO,
Hartwig H. Kremer, LOICZ-IPO,
Liana Talaue-McManus, Rosenstiel School for Ocean Sciences, Miami

1.1 Background: IGBP, LOICZ and START

The International Council of Scientific Unions established the International Geosphere-Biosphere Programme (IGBP) in 1986 to focus on the study of global change in the earth system including the extent to which these changes are influenced by human activities. In 1992 START (the Global Change **S**ys**t**em for **A**nalysis, **R**esearch and **T**raining) was established to implement the IGBP programme, and to act as the executive body of IGBP. START has divided the global research community in six regions, one of them being Southeast Asia. The head office of START is located in Washington DC, USA. The regional offices of START, through their committees, maintain close contact with the key researchers in the field of global change. Both the head office and the regional offices of START are in close consultation with the IGBP core offices.

Also in 1992, the Land-Ocean Interactions in the Coastal Zone (LOICZ) project was approved as one of eight programme elements of the IGBP, with the goal of characterizing the role of coastal systems in modulating changes occurring at the land, air, sea interface. In particular, LOICZ was and is expected to determine and assess at regional and global scales:

- the nature of the dynamic interaction across coastal boundaries,
- how changes in various components of the earth system are affecting coastal zones and altering their role in global cycles;
- how future changes in these areas will be generated by the people and in turn affectthe sustainability of coastal resource use by the people. This in particular aims to provide a sound scientific basis for future integrated management of coastal areas on a sustainable basis.

LOICZ commenced operations in 1993 with the establishment of the International Project Office at the Netherlands Institute for Sea Research on Texel, and with support from the Dutch Government.

One major impulse for the design of the LOICZ operation came from the apparent lack of studies that integrate the socio-economic and biophysical dimensions of environmental changes in the coastal areas at the regional scale. To meet this challenge LOICZ, through an initiative of its first Executive Officer, Dr. John Pernetta, established in 1993 a collaboration with the Southeast Asia Regional Committee for START, SARCS, and the Netherlands Foundation for the Advancement of Tropical Research (WOTRO), to design and implement a holistic pilot project in Southeast Asia. SARCS at that time had developed four foci for its research agenda and its Focus 2 on "integration of natural-social science assessments of changes in coastal zones of the SARCS region" fitted very well in LOICZ Focus 4 on the "economic and social impacts of global change in coastal systems". They both provided the research context for the new regional project, which from this time onwards carried the acronym SWOL (**S**ARCS/**WO**TRO/**L**OICZ)

WOTRO's mandate to promote tropical research and its considerable experience in Southeast Asia made it the logical sponsor for this initiative. It was envisioned that the project would serve as a model for the development of scientifically integrated projects in other regions, and that the data generated would contribute to the further development of a global typology of coastal systems and change scenarios. Dr Renée van Kessel, Secretary of the Board of WOTRO, and Dr Beverly Goh, then a Project Officer of SARCS, worked with Dr Pernetta to formulate the framework and to map out the process of planning and implementing the regional project.

1.2 SWOL: Team Composition and Research Methods

To have a reasonable regional coverage of typical coastal system with a potential to later upscaling, appropriate research sites and teams had to be identified. It was a critical requirement that the teams had already been involved in medium- to long-term studies of coastal ecosystems in Southeast Asia. During a general regional workshop held in Jakarta in May 1994, and a SARCS meeting in Singapore in August 1994, the major research topics and four research institutions were identified:

- the University Sains Malaysia Centre for Marine and Coastal Studies,
- the University of the Philippines Marine Science Institute,
- the Chulalongkorn University Marine Science Department, and
- the Vietnam National University Centre for Natural Resources and Environment Studies.

The core research sites (Figure 1) were the Sungai Merbok mangrove system (Malaysia), Lingayen Gulf with an extensive reef system (Philippines), Bandon Bay, mangrove-dominated (Thailand), and the Red River Delta, mangrove-dominated (Vietnam). All groups had at least ten years of research experience in their study sites. Each team was composed of natural and social scientists (mostly economists). The principal investigators included Prof. Ong Jin-Eong (Malaysia), Dr. Liana Talaue-McManus (Philippines), Dr. Gullaya Wattayakorn (Thailand) and Dr Nguyen Hoang Tri (Vietnam).

Hence the SARCS/WOTRO/LOICZ (SWOL) Regional LOICZ core project in Southeast Asia was born and Phase 1 began with meetings in Manila, Philippines, in April 1995 and Penang, Malaysia, in December 1995. The goal was to determine and standardize the methods the project would use across the study areas. Resource persons from the LOICZ Scientific Steering Committee (SSC) included the then SSC Chair Prof. Edgardo D. Gomez and SSC members, Prof. Stephen Smith, Prof. Fred Wulff, Dr Donald Gordon and Dr Jahara Yahaya. The latter meeting was in fact critical for the development of a corporate design of the four studies. It was decided to adopt the LOICZ Biogeochemical Modelling Guidelines (finally published the following year by Gordon *et al.* 1996) as a first approach in formulating stoichiometrically linked water-salt-nutrient budgets at the sites. For validation of this mass-balance approach other models could be employed.

During the meeting in Penang, the country teams further discussed possible approaches for doing the economic assessments and linking these with the biogeochemical models. Not surprisingly, the search for integrated modelling that would link economics with biogeochemistry (one of LOICZ's most challenging targets) was less straightforward. Consequently the SWOL regional project became a major partner in the efforts of LOICZ to evaluate and standardize the various possible approaches useful in the analyses of human influences on the functioning of the coastal ecosystems. SWOL researchers attended two LOICZ meetings that aimed to compile relevant principles and methods. The first meeting was held at the University of East Anglia (Norwich, England) in March 1997 with Prof. Kerry Turner, then the LOICZ SSC Focus 4 leader, as the main organizer. A follow-up workshop was convened in Kuala Lumpur, Malaysia in July of the same year. Conceptual modelling frameworks were presented in the latter meeting and a publication, focusing on principles and practices on integrated modelling, was released the following year (Turner *et al.* 1998).

In December 1997, during the third annual meeting of country teams in Bolinao, Philippines, the research partners agreed to use the economic Input-Output modelling tool as a method to quantify the impact of economic activities on the coastal zone. Specifically, the model allowed for the estimation of C, N and P residuals generated by economic activities. These estimates could be compared with empirical measures of ambient nutrient concentrations to determine the contribution of wastewater generated by economic activities to the ambient nutrient load as first approximations.

Among the technical resource persons who have interacted with the SWOL research team are Prof. Stephen Smith and Dr Bradley Opdyke for the LOICZ Biogeochemical Modelling Guidelines and Dr Jean Luc de Kok for approaches in dynamic modelling. In the field of economics, Dr Neil Adger and Prof. Jahara Yahaya facilitated discussions on integrated modelling approaches.

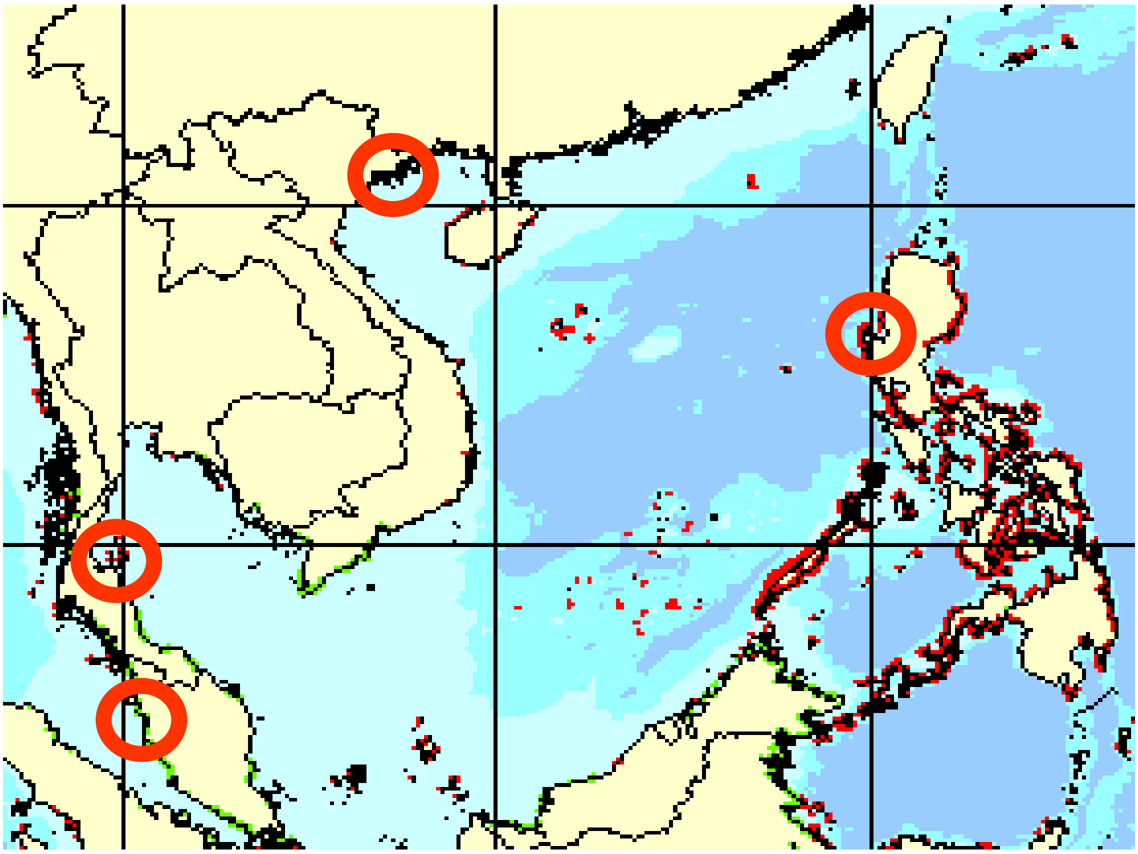

Figure 1: Study sites for the project.

1.3 Project Structure and Management

As the methods and approaches for integrative modelling were evolving, so did the manner through which the scientific work in SWOL was coordinated. With the overall mandate of describing the biophysical system using biogeochemical parameters (fluxes of nutrients and suspended solids) and of analyzing waste load derived from economic activities, each country team was autonomous in implementing its individual programme, with field work campaigns being one of the major components of the research. Annual regional project meetings were the main venue for discussion of both scientific and administrative concerns with the scientific resource persons and with those who provided the administrative support from the three partner institutions. Following the Penang meeting in 1995, the second annual meeting was held in Hanoi, Vietnam, in 1996 to discuss project coordination as well as modelling approaches that would allow the research team a first upscaling of site-specific results and obtain a scenario of coastal change for Southeast Asia. The 1997 annual meeting was held in Bolinao, Philippines, and the fourth in 1998 in Surat Thani, Thailand. Where appropriate, SWOL meetings were held in conjunction with international fora such as the 3rd LOICZ Open Science Meeting in Noordwijkerhout, the Netherlands in October 1997, and the 4th LOICZ Open Science Meeting in Bahia Blanca, Argentina, in November 1999. These meetings provided the SWOL team members and the challenging methodology involved in this project with global scientific exposure and were explicitly supported by the funding agencies as a means of capacity building.

In the 1997 annual meeting in Bolinao, it was agreed that the principal investigators would rotate in their various functions. Their task was to coordinate the science, represent the SWOL project in international meetings as well as to liaise with the research partners in accessing both scientific and logistical support. For 1998, Prof. Ong Jin Eon and Dr. Gullaya Wattayakorn served as project coordinators. In 1999, Dr. Liana Talaue-McManus and Dr. Nguyen Hoang Tri took over.

For project monitoring, annual reports were submitted to LOICZ, WOTRO and SARCS. WOTRO reviewed the annual reports using its network of scientists as a source of reviewers. For fiscal monitoring, semi-annual financial reports were provided to WOTRO and were used as bases for the annual release of funds. Dr. Renée van Kessel was the major resource and contact person from WOTRO. Drs Amador Argete and Tolentino Moya served as liaison and resource persons during their stint as Program Officers with SARCS. At the LOICZ International Project Office Dr. John Pernetta and Mr Paul Boudreau were the initial contacts, succeeded by Dr. Hartwig Kremer in 1998, who together with Dr Liana Talaue-

McManus saw the project through to completion of Phase 1 and prospective transition towards a second phase.

1.4 Project Accomplishments

In implementing both the biogeochemical budget protocols and the input-output economic modelling, the country teams had to consider the applicability of these approaches given the spatial scale and geomorphology of their respective study areas. In addition, the data requirements of the models were reconciled with information that was available and useful. In most cases, primary data were generated to fill in the gaps. However, in looking at the results awareness of the inherent differences among the study areas was necessary, in terms of both the biophysical and socioeconomic aspects. The overall objective was to capture the diversity of biogeochemical scenarios in the Southeast Asian region and the overriding influences of human activities.

Table 1 shows an overview of the major accomplishments of SWOL-Phase 1. All research partners have developed C, N and P budgets for the four study sites. In the cases of Bandon Bay and Lingayen Gulf, the morphology of these embayments allowed for the identification of distinctive landward and seaward boundaries and was most amenable to budget modelling. Both systems are nitrogen sinks with nitrogen fixation exceeding denitrification, and net autotrophic at 5.4 moles m^{-2} yr^{-1} for Bandon Bay and 6.0 moles m^{-2} yr^{-1} for Lingayen Gulf. For the Merbok mangrove system and the Red River Delta, the difficulties involved in defining the spatial boundaries and in determining the water budgets within artificially defined spatial domains indicated the limited applicability of the budget modelling approach to these sites. The spatial boundaries may need to be redrawn to better meet the model requirements, e.g., at scales where salinity gradients would be significant for defining the seaward limits of the study areas.

The computation of an economic input-output table enabled preliminary assessments of wastewater generation by economic activities. The household sector, when endogenized in the economic modelling, was seen to contribute 15% to waste carbon generation in the watershed of Bandon Bay, and 18% to that of Lingayen Gulf. The natural resources sectors (agriculture, fishery, forestry and mining) together accounted for 74% and 92% of total residual carbon production in the Red River Delta and Merbok Mangrove system, respectively. These sectors produced carbon waste in the order of 23% of the total residual carbon production around Bandon Bay and 38% of the total in Lingayen Gulf.

A number of case studies and scenario simulations were produced by integrating economic parameters in the analyses of coastal resource use (see final country reports for details). For the Merbok system, an optimization model of mangrove timber extraction was developed. A valuation of carbon flows in a mangrove system and the latter's role in oyster production was assessed for the Bandon Bay study. In the Red River Delta, nitrogen loading was partitioned among economic sectors. For Lingayen Gulf, the contributions of economic activities in current and prospective scenarios were estimated.

1.5 Impacts of and Future Directions for the SWOL Approach

Having adopted a pioneering framework that integrates the natural and social sciences, the SWOL project has been adapted as a model for global change research at the regional scale. SWOL scientists have helped and continue to assist in training, capacity building and workshops on biogeochemical budgeting and socio-economic modelling and on analyses of human impacts in the coastal zone for other regions including South Asia and the Caribbean. In a thematic session of the 4th LOICZ Open Science Meeting, in November 1999, other studies following the SWOL approach were identified as potential demonstration sites for the coastal module of the Global Ocean Observing System (C-GOOS), an initiative of the International Oceanographic Commission (IOC) and the United Nations Educational, Scientific and Cultural Organization (UNESCO). In Southeast Asia, prospective interactions between the SWOL project and the recently approved South China Sea Project of the United Nations Environment Programme under the sponsorship of the Global Environment Facility and other regional projects are expected to continue.

A second phase of the project, consisting of two components, has been proposed. One component comprises continued process-oriented studies that would validate the empirical models developed in the first phase for sites along gradients of socio-economic pressures such as population and extent of urbanization. The second component would deal with a typology of the Southeast Asian coastal zones, taking into account both their biophysical and socioeconomic features. The typology approach is under continuous development by LOICZ as a major tool in upscaling site-specific estimates to regional and global assessments of biogeochemical fluxes and coastal change. Its capacity is to identify and visualize similarities and differences of coastal systems considering various sets of forcing functions with primary and secondary data. This part of a tentative SWOL II complemented by the site based scenario simulations in SWOL would provide not only a comprehensive Southeast Asian picture but also a better understanding of systems interactions with special significance for coastal management on various scales.

In conclusion, the development of analytical methods for integrating the human and natural dimensions of processes and forcing functions affecting the coastal zone in the study of global environmental change has been most challenging. The results obtained and insights gleaned through the SWOL project indicate the need for refining tools that would allow for the prediction of coastal ecosystem state changes and the formulation of appropriate management measures to ensure that these systems continue to function optimally in the long term. One strength of the approach used is that the determination of pressures and calculation of residual fluxes affecting the coastal zone applies the catchment scale as the integral part of the water cascade. Along with the growth and continuous development of global change science, the infrastructure needed to support and nurture international scientific collaboration has to evolve from that seeded by the committed partnership between WOTRO, LOICZ and SARCS.

Table 1. Summary of results obtained in SWOL – 1996-1999.

Results	Merbok mangrove system, Malaysia	Lingayen Gulf, Philippines	Bandon Bay, Thailand	Red River Delta, Vietnam
1. Biogeo-chemical budgets and processes	Budgets for inorganic and organic N and P in the Merbok system over tidal cycles formulated using LOICZ, mixing diagram, and mouth cross-section computation methods	Multiple-box model of inorganic N and P for dry season and annualized one-box models developed for Lingayen Gulf using LOICZ methods, including the influence of groundwater. Assessment of carbon production and support for fisheries using empirical measurements and ECOPATH.	Seasonal one- & two-box models developed for Ban don Bay using LOICZ methods; Mixing diagrams used for Tapi River during estuarine mixing in dry and wet seasons. Mouth cross-section method used to determine discharge over each tidal cycle. Primary production, fishery production, trophic relationships	Monthly and annual balance of water and salt were obtained using STELLA 2. Budgets of C, N & P were developed.
2. Socio-economic studies and integrated modelling	An 11- and 3-sector IO model (forestry, fisheries and agriculture). Identification of 5 approaches to integrated modelling (SWOL Meeting, 1998). An ecologic-economic model for optimal management of mangrove timber extraction.	A seagrass-based fishery model reflecting changes in seagrass cover and its impacts on fishery production. Estimates of economic residuals using WHO rapid assessment method and their contribution to ambient concentrations of DIN, DIP and suspended solids. A 12-sector IO (with household sector endogenized) model and comparisons of residual coefficients estimated through rapid assessment and those generated by the IO model.	Correlations between socio-economic characteristics and observed land use and cover change. An 11-sector IO model to obtain residuals. Valuation of carbon flows.	Modelling included the construction of IO model and estimating economic residuals, estimating GDP using 3 scenarios of economic growth by sectors, linking residuals with economic activities using STELLA, the WHO rapid assessment guidelines, and the National Monitoring Network for Environmental Assessment

<u>Reference</u>

Turner, R.K., Adger, W.N. and Lorenzoni, I. 1998 Towards integrated modelling and analysis in coastal zones: principles and practices. *LOICZ Reports and Studies* No. **11**, iv + 122 pages, LOICZ, Texel, The Netherlands.

MALAYSIAN SITE SYNTHESIS
1996-1999 FINAL REPORT

Carbon and Nutrient Fluxes and Socio-Economic Studies in the Merbok Mangrove Estuary
(A SARCS/WOTRO/LOICZ/USM PROJECT)

Universiti Sains Malaysia, Penang, 1999

SARCS/WOTRO/LOICZ Malaysian Site Synthesis

Carbon and Nutrient Fluxes and Socio-Economic Studies in the Merbok Mangrove Estuary

THE MALAYSIAN SWOL TEAM

Leader	Professor Ong Jin Eong
Ecologist	Dr Gong Wooi Khoon
Planner	Dr Alip bin Rahim
Economist	Dr Chan Huan Chiang
Research Officers	Ms Nor Haida bte Hassan
	Mr Kumaradevan a/l Saminithan
	Mr Wong Ya Ping
	Mr Lee Leng Choy
	Mr Adrain Chang Kok Teong
Laboratory assistants	Mr Mohd Hussain bin Yahya
	Mr Ab. Rahaman bin Abdullah
	Mr Abdul Mutalib bin Saad
Plus, for “Merbok 97”, “Bujang 98”, “BMD 98” and “MMD 99”:	
Collaborating scientists	Profesor John Simpson
	Dr Ross Vennel
Research Officer	Mr Omar bin Ahmad
Post-graduate students	Ms Foong Swee Yeok
	Ms Khairun bte Yahya

Universiti Sains Malaysia,
Penang, December 1999

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MALAYSIAN SITE SYNTHESIS REPORT

1. Introduction

1.1. Background

Although mangroves constitute only about 2 percent of the total tropical land area, they are a dominant tropical coastal ecosystem. This strip of vegetation between land and sea is thus a rare and therefore precious natural resource. In the ever-wet tropics, mangroves may be one of the most productive of natural ecosystems. They are believed to be important in coastal protection, maintaining coastal fisheries production, producing timber as well as sequestering carbon. Much of how the mangrove ecosystem function is however still not clear. Unfortunately, many of the world's tropical mangroves have been and are still being rapidly destroyed or degraded in the past half century.

The Malaysian team selected the Sungai (=River, abbreviated as Sg.) Merbok mangroves because some members of the team have been working on the ecology of mangroves since the mid-70s and through international collaboration (Australia, Japan, UNESCO-UNDP, United Kingdom and the United States) on the Sg. Merbok mangroves since the 1980s. Apart from acquiring considerable technical expertise and experience, the Malaysian team has also accumulated, from a number of grants (mainly AUSAID, IDRC and the Government of Malaysia's IRPA grant), an almost complete range of relevant field and laboratory equipment worth about US $1,000,000. This SWOL Project is thus based on extremely solid mangrove experience and infrastructural support.

The overall aim of the Universiti Sains Malaysia Mangrove Ecosystems Group is to try to close the carbon and nutrient budgets of a mangrove ecosystem. This may sound simple but, especially with a very open (horizontally to the land and sea, and vertically to the atmosphere and mud) mangrove ecosystem, is in fact an extremely ambitious task. So that we do not lose our focus, any project that the group undertakes must be in one way or another related to this overall aim. Also, any collaboration we undertake must be on a more or less equal partnership basis.

Focus 4 of LOICZ and Objective 2 of SARCS are thus related to our group's overall aim but has an additional element, the socioeconomic aspect. We are in agreement with the importance of the socioeconomic element and an economic budget is a logical extension of the carbon and nutrient (ecological) budgets. We have thus specifically recruited an economist and a sociologist into our team for the SWOL Project.

This is a report of the results of this 4-year WOTRO funded SARCS and LOICZ sponsored USM study.

1.2. Objectives

The main objective of this report is to document the experience of trying to integrate biogeochemical with socioeconomic studies on a mangrove ecosystem and its water catchment.

There are 3 sections in the substantive part of the report. The first section describes the types of biogeochemical studies that have been undertaken, the second, the socioeconomic studies and the third, which is the bottom line of this project, illustrates our attempt to integrate or at least link the biogeochemical studies with the socioeconomic studies.

1.3. Site description

1.3.1. The sg. Merbok mangroves

The Sg. Merbok mangroves (5^{o} 40 N, 100^{o} 25 W - Map 1), in the northwestern Peninsular Malaysian state of Kedah has been described by Ong *et al.* (1991). It comprises an area of approximately 45 km^2 of mangroves and waterways. The main river is approximately 35 km long, being tidal for about 30 km and varies in depth from 3 m to 15 m. The freshwater part of the river is only a few metres wide. Many small tributaries feed freshwater into the estuary, which is not gauged. The waterways, at low tide, covers approximately 10 km^2 and approximately 45 km^2 (of mainly mangroves) is inundated at high tide (Simpson *et al.*, 1997).

The Sg. Merbok is a tidally energetic estuary with a 1.7 m semidiurnal tide, peak currents of 1.3 m s^{-1} and a mean freshwater discharge of 20 m^3 s^{-1}. The estuary displays a pronounced fortnightly neap-spring stratification-destratification cycle. Various physical aspects of the estuary have been described in Uncles *et al* (1990 and 1992), Dyer *et al.* (1992), Ong *et al.* (1994) and Nakatsuji *et al.* (1998).

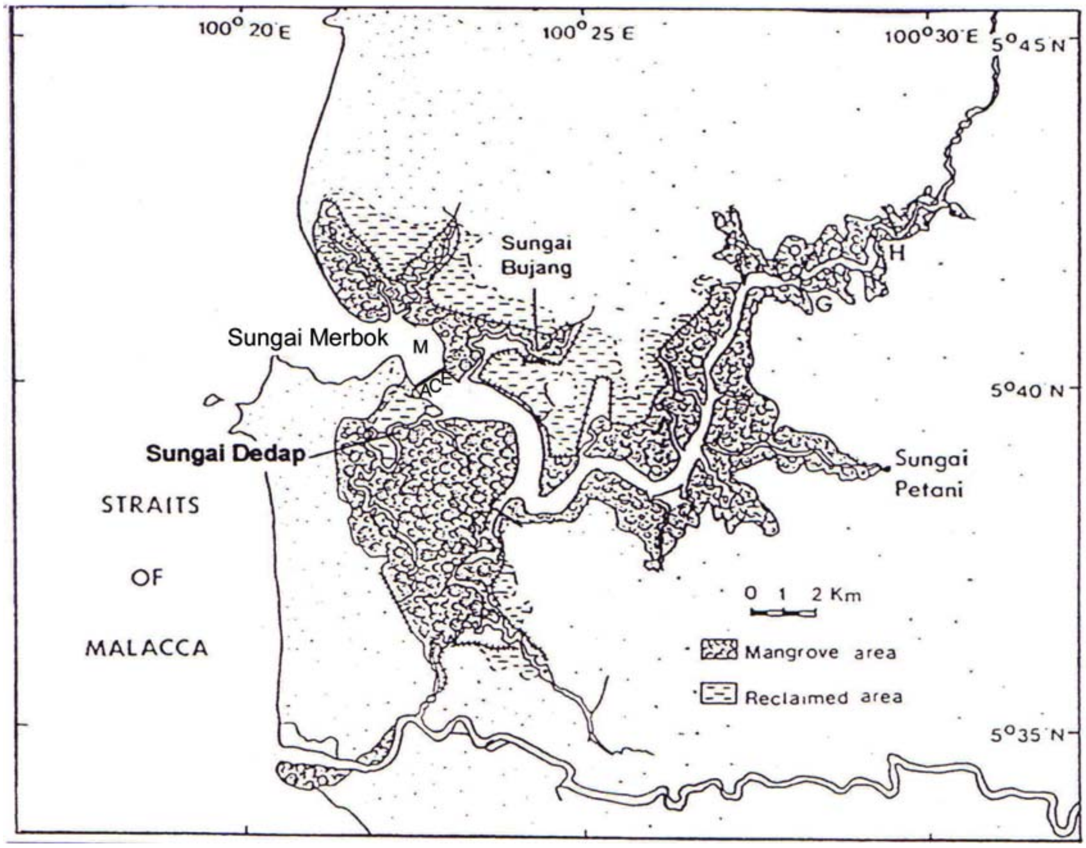
The mangroves are luxuriant, growing to about 30 m high and highly species diverse (Ong *et al.*, 1980 and Ong, 1995), although dominated by *Rhizophora apiculata* and *Bruguiera parviflora*. They are being rapidly depleted (conversion to aquaculture ponds and, more recently to housing estates). The mangroves have been harvested on a sustainable yield basis on a 30-year rotation.

There is a meteorological station situated in Sg. Petani. Daily temperature ranges from about $24^{o}C$ to $34^{o}C$ and is almost constant through the year. The region is dominated by the northeasterly monsoon from November to March and the southwesterly monsoon from May to September. The monsoons are very mild because of shielding by the peninsular mountain range and the island of Sumatra. The strongest winds rarely exceed 5 m s^{-1} (from the northwest) and there is no wind 60% of the time. There is no really dry month and the heaviest rains are inter-monsoonal (Figure 1). The annual rainfall is just over 2000 mm.

Geologically, the water catchment, which measures some 550 km^2, is made up of alluvium deposits overlying an extensive span of ferruginous shale and mudstone with a few scattered outcrops of granite and ferruginous sandstone/quartzite.

Most of the catchment is rice fields (some of which, mainly on the north, are reclaimed mangroves) but there are small patches (on higher ground) of rubber and oil palm. The main town is Sg. Petani, a typical medium size Malaysian town, with a human population of about 150,000. The total human population for the mangroves and catchment is around 300,000. There are no human dwellings within the mangroves but there are a number of villages on the fringes whose population rely on mangrove and its related resources (mainly mangrove timber and fish).

Map 1. The Sg. Merbok Mangroves and its water catchment.



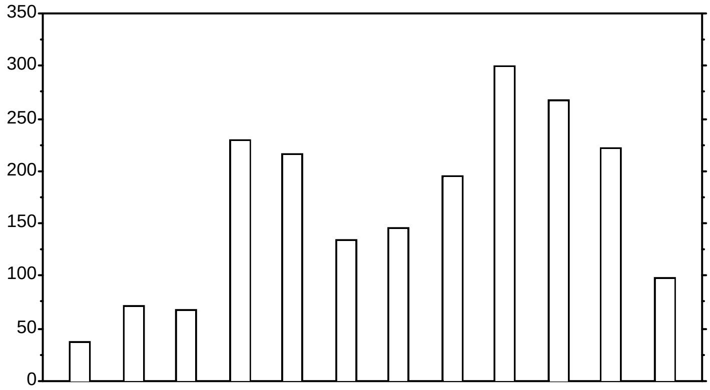


Figure 1. Monthly rainfall (10-year mean from 1976-1985) for Sg. Petani. Data from the Malaysian Meteorological Service.

1.3.2. Brief socioeconomic profile of the Merbok

The following is an outline of the main pressures that operate in the Merbok system.

1.3.2.1. Human population

Based on the 1991 population census (Malaysia, Department of Statistics, 1991), the study area experienced an increase in population from 137,115 in 1980 to 193,991 in 1990, with an annual growth rate of 3.8 percent. This growth rate is equivalent to the growth for the state of Kedah and slightly higher than the national average. However, to be able to gauge the population pressure, the population distribution and the growth rate is analysed (Table 1). The highest population growth occurs in the middle reaches of Sg. Merbok, mainly concentrated around the mukims (=sub-districts) of Sg. Petani and Sg. Pasir. The major tributaries of Sg. Merbok, Sg. Pasir and Sg. Petani and its branches Sg. Bakar, Sg. Gelugor and Sg. Mendideh pass through these mukims. The mukims population in 1980 was 65.2% of the total population of the study area whilst in 1991 the population was 74.2% of the total population. There is an increase from 89,449 in 1980 to 144,073 in 1991. The growth rates for the two mukims are 3.7 and 8.1 percent per annum respectively: these effectively show the rapid growing population and concentration in these two mukims. This is evidence of population pressure at the upper reaches of the Sg. Merbok Basin.

Table 1. Population distribution of the Merbok and its catchment. Population by sub-district (Mukim) 1980 and1991 percentage population growth rate.

Mukim	1980	1991	%
Merbok	12,562	12,433	-0.01
Bujang	5,204	5,897	1.3
Semeling	13,489	13,656	0.1
Sg. Petani	68,917	99,445	3.7
Sg. Pasir	20,532	44,628	8.1
Simpor	4,116	4,694	1.3
Bukit Meriam	4,766	4,977	0.4
Kota	2,643	2,974	1.2
Kuala	2,322	2,603	1.1
Rantau Panjang	2,564	2,684	0.4

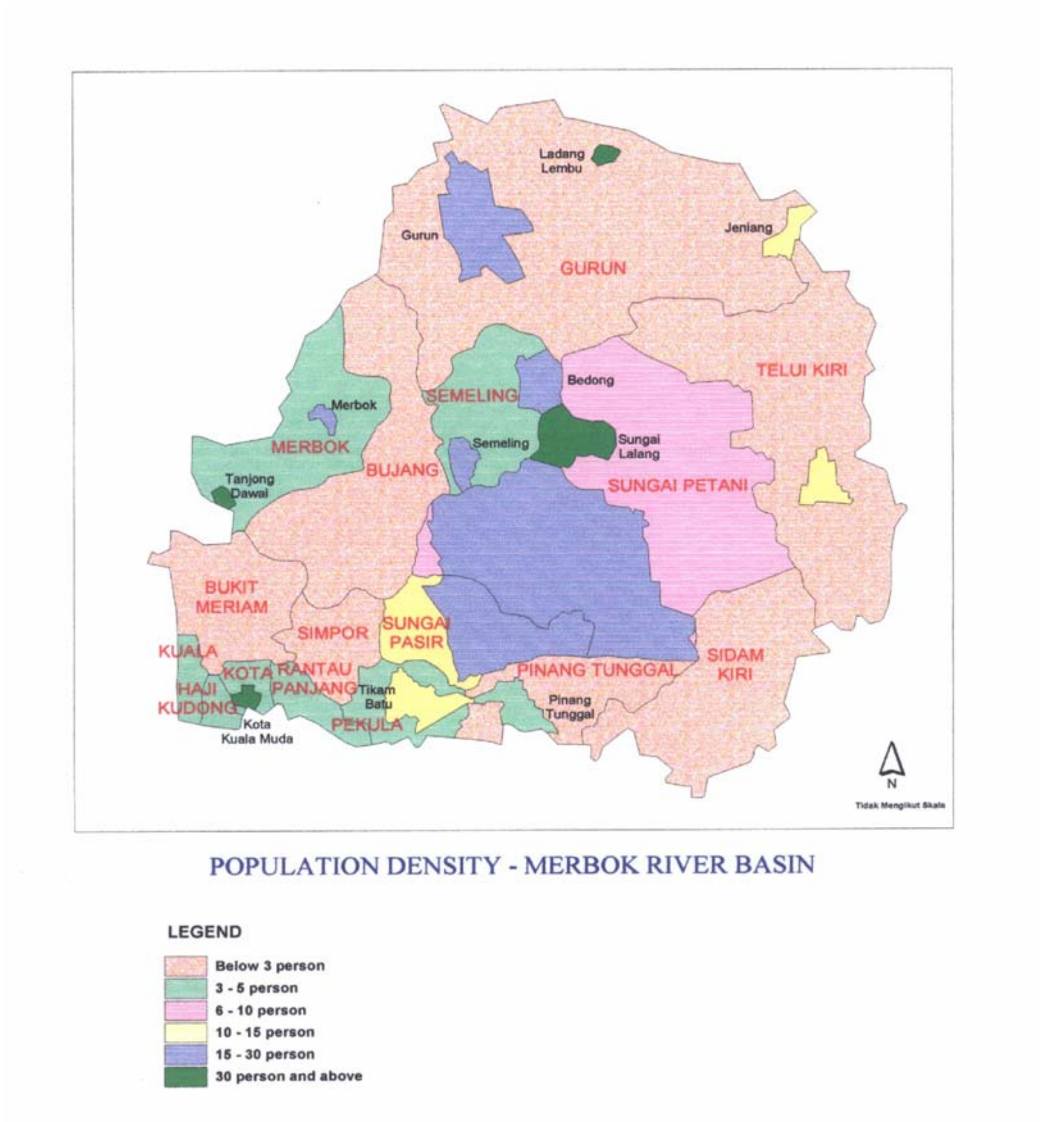
[Source : Malaysia, Department of Statistics (1980 and 1991); Malaysian Housing Population Census 1980 and 1991]

Further upstream, the river passes through the mukims of Semeling and Gurun. The 1980 population in Semeling was 13,489 and in Gurun 27,509, whilst in 1991 it was 13,656 and 31,929 respectively. Semeling experienced a minimal increase in population (growth rate of 0.1%) whilst Gurun's growth rate was 1.5%. This is the second area of population concentration centred in the town of Semeling, Bedong and further north in the town of Gurun. Although presently the growth rate is low, these areas are part of the linear conurbation of commercial-industrial-residential area which is expected to attract migrants. The Structure Plan Study projects the mukim (Semeling, Bedong and Gurun) growth rate between 2000-2006 to be 4.0% to 6.0% per annum. This trend suggests further population pressures.

The lower reaches of Sg. Merbok receive from the northwest side the tributaries of Sg. Bujang and Sg. Merbok Kechil which flow through the mukim of Merbok and Bujang. In 1980 the Merbok mukim population was 12,565 and in 1991, was 12,433 compared to the Bujang mukim's smaller population of 5,204 in 1980 and 5,897 in 1991. The Merbok mukim experienced a decline in growth rate of - 0.1% per annum whilst Bujang had a minimal increase of 1.3 percent which was much below the national average. This trend suggests that the rural mukims were experiencing out migration.

On the southern bank, is the Sg. Terus tributary which links the Muda with the Merbok and flows through the mukims of Simpor and Bukit Meriam and the upper reaches of the tributaries flowing through the mukims of Kota, Kuala and Rantau Panjang on the border of the the state of Penang. The population of Simpor and Bukit Meriam was 4,116 and 4,766, respectively, in 1980 whilst in 1991, the population was 4,694 and 4,977. The population growth rate is low: 1.3 percent for Simpor and 0.4 percent for Bukit Meriam. Here again, the low growth rates indicate that the rural mukims are currently experiencing out migration.

In terms of population density (see Map 2), the highest density (above 30 persons per hectare) was at Sg. Lalang at the conurbation of Sg. Petani and Bedong; and the smaller urban centres of Kota Kuala Muda bordering Penang and the fishing town of Tanjung Dawai at the mouth of Sg. Merbok. The whole conurbation of Sg. Petani and Bedong (which also include the towns of Semeling, Merbok and Bedong) has a population density of between 15-30 persons per hectare.
The future population is expected to concentrate in the conurbation area of Sg. Petani, Sg. Lalang, Bedong and extending further north to Gurun.



Map 2. Population density (per ha) of the various mukims in the the Kuala Muda District, Kedah within which lies a major part of the Sg. Merbok Mangroves and its water catchment.

1.3.2.2. Land-Use Change

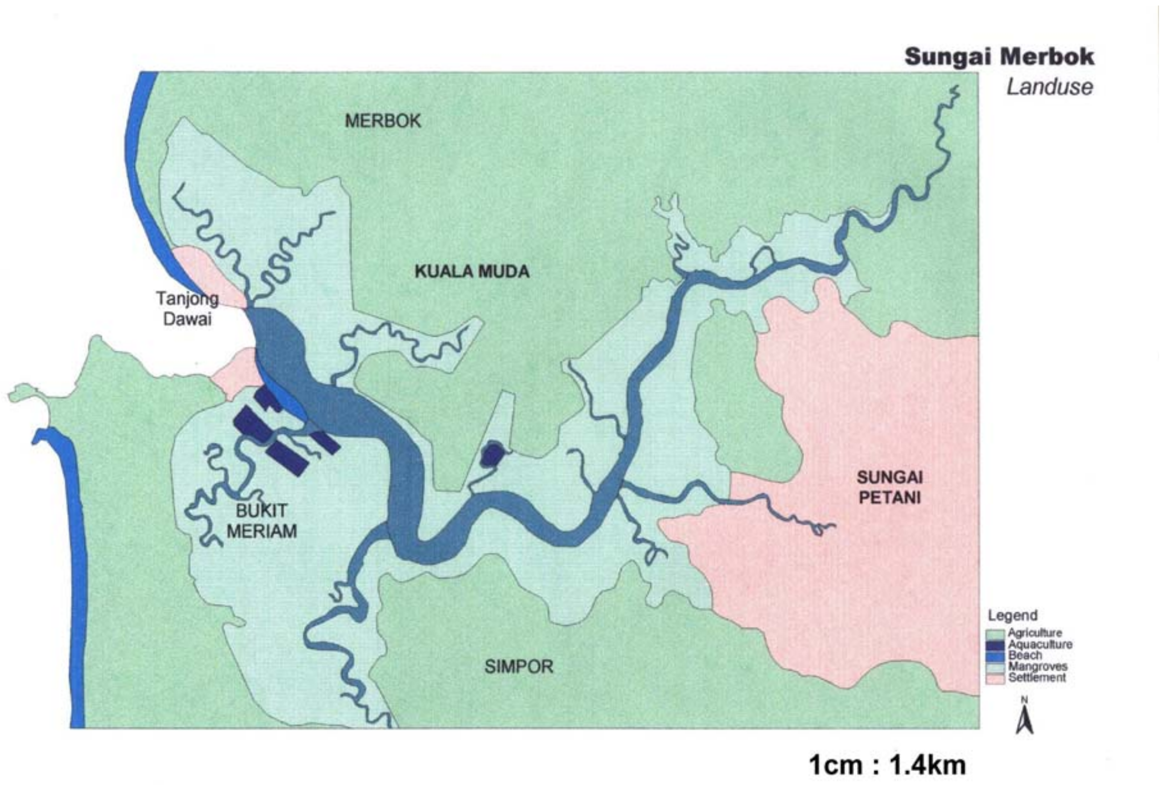
Based on the Kuala Muda Structure Plan Report 1991 for the whole district of Kuala Muda (acreage 9,268.4 ha), the largest land-use activity is agriculture (58.2%), followed by forest land (14.0%), mangroves (7.3%), housing (6.3%) and others - industry, commercial, open space (5%) (Map 3). In 1991, 2,418.7 ha of land have been approved for development out of which 91.3% is located in the existing urban settlement of Sg. Petani, Gurun, Sg. Lalang. The largest acreage is approved for housing (1,265.8 ha), followed by industrial development (720.4 ha), education (335.0 ha), institutional-government (227.8 ha), commercial (39.0 ha) and recreational (20.2 ha).

Nearer the middle reaches of Sg. Merbok, centred around the tributary of Sg. Petani and the branches of Sg. Petani and Sg. Pasir, the urban land-use is predominantly housing and industrial type. There were 39,932 living quarters in 1990 compared to 17,077 in 1980 for the two mukims. Included in the figure are units located in 20 squatters settlement in Sg. Petani. Further upstream at Semeling, Bedong and Sg. Lalang, the river flows through urban areas which are part of the Bedong /Sg.Petani conurbation. The industrial land-use acreage of 513.7 ha are found in three industrial estates of Bakar Arang, Tikam Batu and Sg. Petani , and about 449.8 ha are located outside the industrial estate mostly located linearly along major roads. Domestic discharge and industrial effluents affect Sg. Petani and Sg. Pasir.

The Sg. Merbok and its tributaries also flow through agricultural areas. At the lower reaches northwest of Sg. Merbok, rice is cultivated on the landward side along the Sg. Merbok Kechil and Sg. Bujang. On the northwest side, the irrigation system is dependent on the Sg. Merbok. There are three irrigation systems here, namely Ban Merbok (1,567 ha), Sg. Gelam (155 ha) and Tandop Pekan Merbok (77 ha). On the southwest landward side of Sg. Merbok, rice is cultivated in mukim Bukit Meriam, Kuala, Haji Kudong, Kota, Rantau Panjang and Simpor. The irrigation system here is supported by Sg. Muda. Paddy cultivation is also found further upstream especially at Sg. Petani and Sg. Pasir, bordering the urban landuse.

The land-use changes described earlier indicate that development is spreading eastward from Sg. Petani to the new town of Bandar Muadzam Shah and also westward into the mangrove areas in the middle reaches of Sg. Merbok. Expansion is also occurring linearly along the Federal road to Bedong, forming a massive urban conurbation. This encroachment affects mainly rubber estates which are converted into land for housing, commercial areas and industry.

Map 3. Pattern of land use in the Kuala Muda District of the state of Kedah, within which lies a major part of the Sg. Merbok mangroves and its water catchment.



2. BIOGEOCHEMICAL CYCLES and PROCESSES

2.1. APPROACHES

The main aim of the biogeochemical part of this exercise is to determine the flux of carbon and nutrients from the mangrove estuary into the surrounding sea as well as to try to understand the main processes involved. We are thus looking at the horizontal flows of water and the change in concentrations of carbon and nutrients accompanying these flows. Due to tidal influence many of the flows are bi-directional, greatly complicating computations. On top of this, salinity stratification during neap tides, leads to even more complications.

This is a complex task and Nixon (1980), in his lengthy and critical review on outwelling from salt marshes, had this to say:

> "The end result is that while the past 4 or 5 years have provided us with a number of studies which have attempted to obtain direct measurements of annual flux of material between coastal marshes and coastal waters, most, if not all, of these efforts did not attend closely enough to the problem of **water exchange** and did not provide us with the data needed to place any sort of **confidence estimate** on the results. We are left with a very large amount of information which we must admit is of very uncertain quality."

There are a number of methods that can be used to estimate water discharge and material fluxes from estuaries. For this exercise, the method used was the stoichiometrically linked water, carbon and nutrient budgets described in the LOICZ Guidelines (Gordon *et al.*, 1996). For comparison of this method in the mangrove ecosystem, the estuarine cross-section method was also applied. Mixing diagrams were also used.

It would be too unwieldy to present all the results here but rather the gist of what was obtained during the course of this study.

2.2. STOICHIOMETRICALLY LINKED WATER, CARBON AND NUTRIENT BUDGETS

We present here results of "BUJANG 98" which was carried out on the Sg. Bujang, a tributary of the Sg. Merbok Estuary (Map 1). The method has been described in detail in Gordon *et al.* (1996).

Water samples were collected along the entire estuary, from the sluice gate at the upper reaches of the estuary to the mouth, where the Bujang enters the Merbok.

Duplicate samples were taken at the surface and at mid-depth during a spring slack low tide and the following slack high tide, providing 4 duplicated data sets.

2.2.1. SALINITY DISTRIBUTION / MIXING

The salinity distribution during slack low tide and slack high tide for the Bujang are shown in Figure 2. For the slack low tide, a difference between surface and mid-depth salinity of up to about 7 psu can be seen with a mean difference of just less than 3 psu, indicating a partially mixed condition. During slack high tide the freshwater end of the estuary is stratified (maximum difference of about 8 psu and mean difference of about 5 psu) whilst the seawater end is almost well mixed (mean difference of less than 1 psu). Salinities ranged from about 1 to 26 psu during the slack low tide and from about 5 to 30 psu during the slack high tide.

It is obvious that it is very difficult to fulfil the well-mixed condition necessary for what is essentially a 1-dimensional model. Some sort of depth averaging may be necessary when the not too well-mixed condition occurs, or a multiple box model may be applicable (See Webster *et. al.* 2000, for relevant discussion).

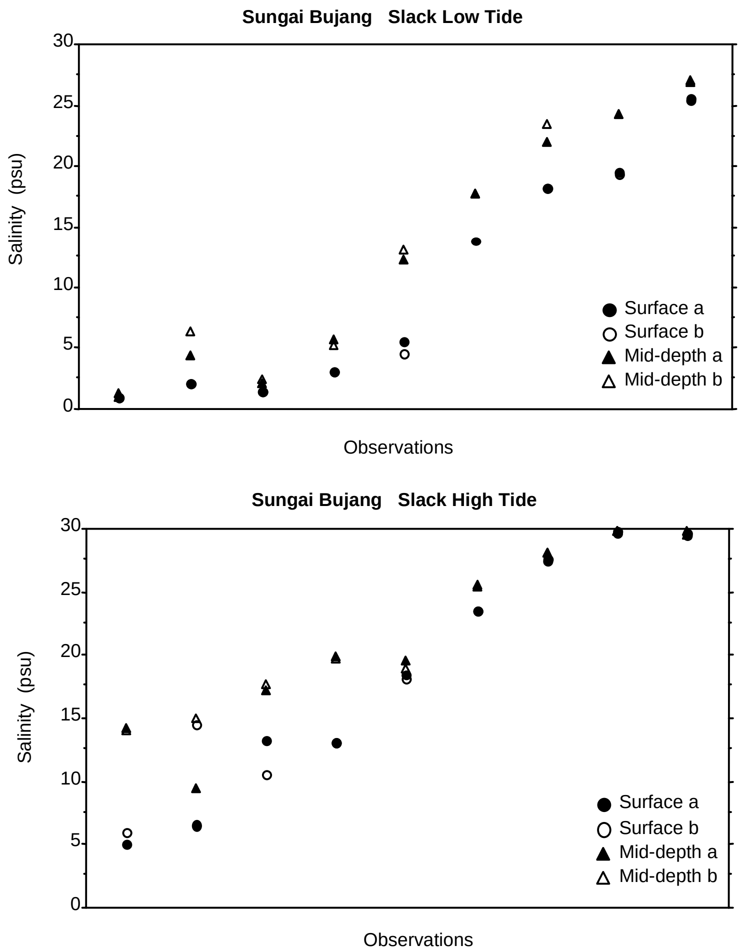


Figure 2. Surface and mid-depth salinities of the Bujang at slack high tide and slack low tide on 22 September, 1998.

2.2.2 WATER BUDGET

The estimate given here (Figure 3) is based on rainfall (2,068 mm per year) over an estimated catchment of 22 km^2 so the the amount of freshwater (V_Q) flowing into the Bujang mangrove estuary is an estimated 56% of the precipitation (i.e. an estimated 44% of precipitation is lost as evapotranspiration). This amounts to a mean (taken over a year) of $70X10^3$ m^3 d^{-1} (i.e. 0.8 m^3 s^{-1}). The amount of freshwater that goes directly into the mangrove estuary from the atmosphere (V_P -V_E) is smaller, $10X10^3$ m^3 d^{-1} (i.e. 0.1 m^3 s^{-1}). It must be emphasised that these are average numbers and are not the numbers at times of sampling and it may make a big difference whether sampling took place during the wet season or the drier season.

During our sampling periods for example, there was no rain so V_P would actually be zero and with evapo-transpiration, the mangrove estuary would be losing a small (but perhaps not insignificant) amount of water to the atmosphere.

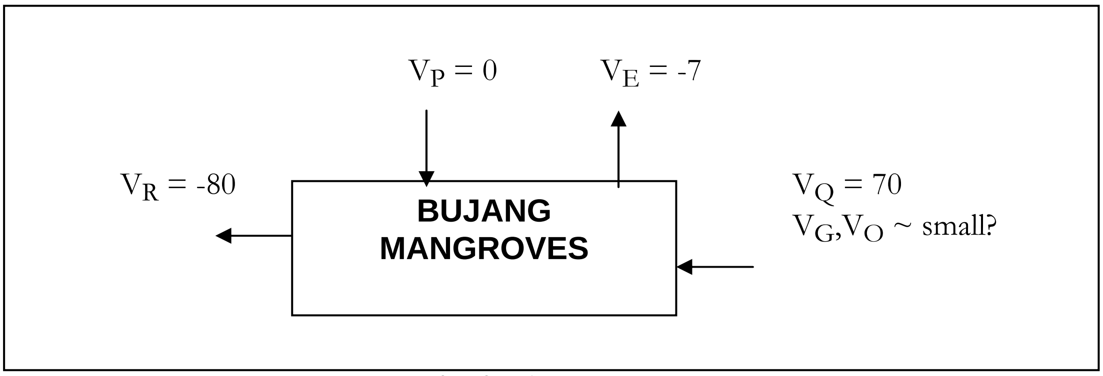


Figure 3. Water Budget (fluxes in 10^3 m^3 d^{-1}) where, V_P = precipitation;
V_E = evaporation; V_Q = stream runoff; V_G = groundwater;
$-V_O$ = other inflows (e.g. sewage) and
$-V_R$ = residual flow = - (70+17-7) X 10^3 m^3 d^{-1} = - 80×10^3 m^3 d^{-1}
(Negative sign indicates out from the mangroves).

The use of mean flows has a major problem in the Bujang because of the sluice gate and the way it is operated. The sluice gate is opened (except during the dryer season when stream flow is very small or absent) when the tidal level reaches the stream level (on an ebbing tide) and is closed before the flooding tide can intrude so freshwater flow into the mangrove estuary is restricted mainly to the second half of an ebbing tide and the first half of a flooding tide. In our case, we would likely have more freshwater during the first sampling at slack low tide than the mid-day sampling at slack high tide.

The ability to accurately measure the amount of water that gets into and out of the system is perhaps by far the most important aspect of carbon and nutrient flux measurements. But, as can be seen above, this appears to be the weakest link. The ability to measure the error involved in this step would at least allow us to state the confidence of our estimation of the fluxes of the other parameters.

We use mean data for our water estimate but "instantaneous" data for salt and nutrients. Perhaps we could improve the estimate if we are also able to provide mean data for the constituents. This would mean many more samples and over a time series. The question then would be how often do we need to sample? Quarterly, monthly or weekly? Our present exercise involved just a day of sampling but there was at least 2 weeks of preparation and another 2 weeks of analyses; with some dozen people involved. Logistically it would not be possible to cover shorter than monthly sampling.

2.2.3. SALT BUDGET

An example for calculating the salt budget is given in Figure 4.

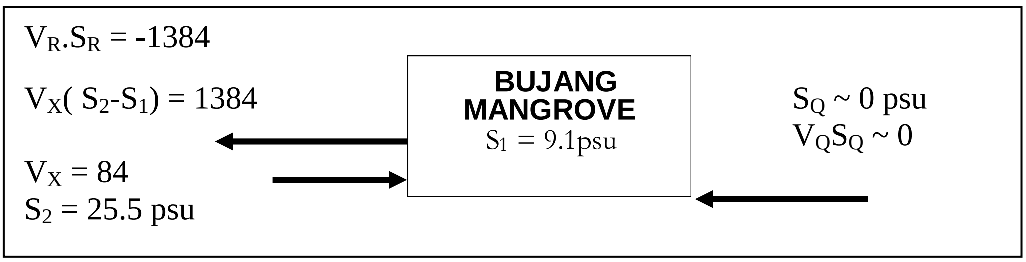


Figure 4. Salt Budget (fluxes in 10^3 kg d^{-1}) where S_1 = salinity of estuary (9.1 psu); S_2 = salinity of sea (25.5 psu); S_Q = salinity of stream runoff (0 psu); $S_R = (S_2+S_1) / 2 = (25.5+9.1)/2 = 17.3$ psu; $V_R.S_R$ = advective salt delivery = -80x17.3 = -1384; V_X = exchange of estuary water with ocean water needed to replace salt export, and $V_X.(S_2 - S_1) = 1384$. Therefore, $V_X = 1384/(25.5-9.1) = 84 \times 10^3$ m^3 d^{-1}. Surface sample, slack low tide.

The calculation of the salinity of the estuary (S_1) can be problematic. More often than not, only a single sample is taken in the estuary (where the water sample is collected for nutrient determinations); then this will be take as the salinity of the estuary. If, on the other hand, a number of samples are taken, then the mean of the salinities can be taken as the estuarine salinity. It would be even better if the bathymetry of the estuary is known and the mean salinity can then be averaged on a volume-weighted basis. In this case we use the average of 7 salinity determinations with no volume-weighted correction.

Another problem is that the salt budget relies on the water budget and thus can only be as accurate as the weakest link. Nonetheless, balancing the salt budget allows for some correction of the water budget.

2.2.4. DISSOLVED PHOSPHORUS BUDGET

Figure 5 is an example for the calculations of the phosphorus budget. DIP_P and DOP_P, dissolved inorganic and organic phosphorus that enters the estuary as rainfall, are taken as approximately zero. The budget was calculated using the single-box model for water and salt budgets. Our measurements (Foong, unpublished) indicated that DIP was negligible but the DOP input from precipitation was about 7 mol d^{-1}. The Δ(DOP and DIP) terms (known as the nonconservative nutrient flux) indicate whether the estuary is a source (-ve) or a sink (+ve) for that nutrient. This budget does not include any exchange that may occur at the water-sediment interface i.e. the exchange is assumed to be zero or close to zero

The concentrations of the different forms of dissolved phosphorus in the Bujang are extremely low (DIP ranging from 0.02 to 0.70 μM and DOP ranging from 0 to 0.79 μM). Robertson and Phillips (1995) reported PO_4 (we assume this is dissolved PO_4) ranging from 0.53 to 4.21μM in intensive shrimp ponds and 0 to 5.26 μM for pristine mangrove waterways. We had a mean total dissolve phosphorus (TDP) of 0.42 μM with a range from 0.2 to 1.14 μM. These values are comparable with the PO_4 values reported by Nixon *et al.* (1984) for the Sangga River and the Selangor River (also on the west coast of Peninsular Malaysia).

There is high variability (some 5 times difference between the lowest and the highest) and this may be in part due to our measuring accuracy at these low concentrations.

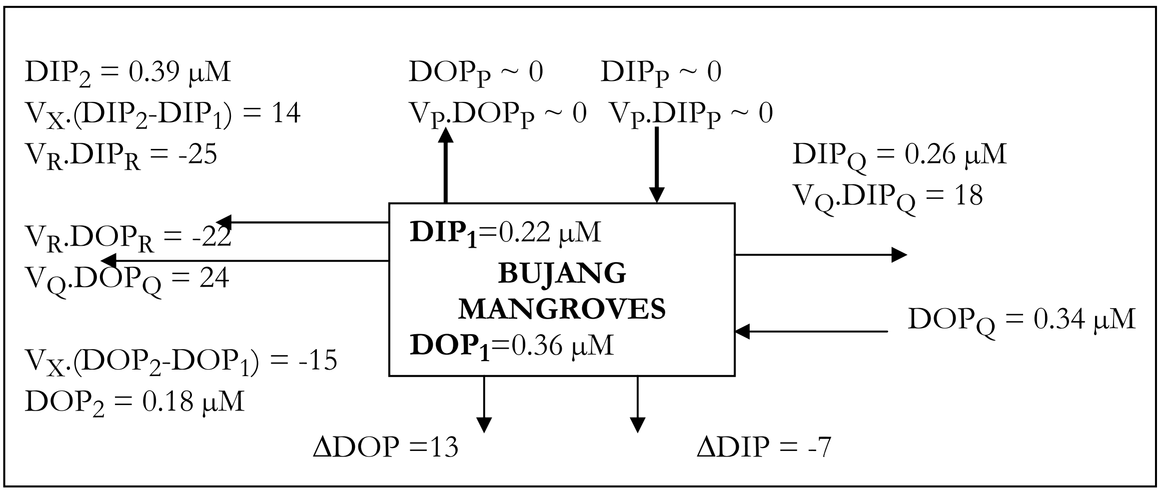


Figure 5. **Dissolved P Budget** (fluxes in mol d^{-1}) where: $DIP_R = (DIP_1+DIP_2)/2$ = 0.31 μM; $V_Q.DIP_Q$ = stream inflow of DIP (18 mol d^{-1}); $V_R.DIP_R$ = residual outflow of DIP (-25 mol d^{-1}) and $V_X.(DIP_2 - DIP_1)$ = DIP added by mixing (14 mol d^{-1}). Surface sample, slack low tide.

2.2.5. DISSOLVED NITROGEN BUDGET

Figure 6 is an example of the calculations of the nitrogen budget. DINp and DONp, dissolved nitrogen that enters the estuary as rainfall, are taken as zero. The budget was calculated using the single-box model for water and salt budgets. The Δ (DON and DIN) terms (known as the nonconservative nutrient flux) indicate whether the estuary is a source (-ve) or a sink for that nutrient. This budget does not include any exchange that may occur at the water-sediment interface (i.e. exchange is assumed to be zero or close to zero). While there is no or negligible loss of phosphorus through gaseous exchange, this is not true for nitrogen, where denitrification can yield loss to the atmosphere of gaseous nitrogen or gaseous nitrogen can be can be nitrified (fixed) from atmospheric nitrogen to nitrite. Of course dissolved forms of inorganic nitrogen, as is the case with dissolved forms of inorganic phosphorus, could be also be converted to the particulate form in the water column (e.g., inorganic nutrient uptake by phytoplankton which could be significant during a phytoplankton bloom). Conversely, declining population phases of phytoplankton populations could release dissolved inorganic as well as organic nutrients.

Robertson and Phillips (1995) reported a range of 1.97 to 73.15 μM for ammonia in intensive shrimp ponds and 0.10 to 1.42 μM for pristine mangrove waterways. Our ammonia values ranged from 2 to 19 μM in the Bujang. These are similar to values reported by Nixon *et al.* (1984) for the Sangga River in the Matang mangrove forests of Malaysia.

In the Bujang, there are shrimp ponds at the head of the estuary. These ponds discharge when the tidal level is low and effluent water is likely high in ammonia and other nutrients.

Robertson and Phillips (1995) quoted nitrate concentrations ranging from 0.05 to 1.54 μM for intensive shrimp ponds and 0 to 11.75 μM for pristine mangrove waterways. Our values for nitrite+nitrate, ranging from 1.0 to 43.0 μM in the Bujang, are thus high for mangrove waterways. These are similar to a high of just over 13 μM of (nitrite+nitrate) in the rather disturbed Selangor River in Malaysia (Nixon *et al.*, 1984).

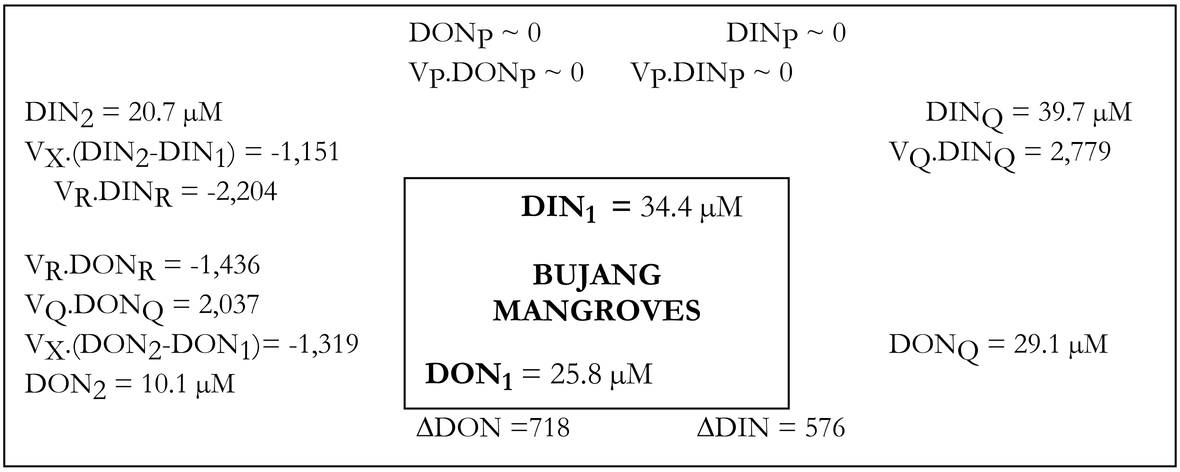


Figure 6. Dissolved N Budget (fluxes in mol d^{-1}) where:
$DIN_R = (DIN_1 + DIN_2)/2$ = 28 μM; $V_Q.DIN_Q$ = stream inflow of DIN (2,779 mol d^{-1}); $V_R.DIN_R$ = residual outflow of DIN (-2,204 mol d^{-1}) and $V_X.(DIN_2 - DIN_1)$ = DIN added by mixing (-1,151 mol d^{-1}). Surface sample, slack low tide.

The final dissolved nitrogen constituent is dissolved organic nitrogen (DON). The observed concentrations are similar to those reported by Nixon *et al.* (1984) for the Sangga River and Selangor River.

2.2.6. NONCONSERVATIVE FLUXES OF NUTRIENTS

The Δ terms in the phosphorus and nitrogen budgets, in the two examples above, refer to the nonconservative fluxes of DIP, DOP, DIN ($NH_4^+ + NO_2^- + NO_3^-$) and DON. Eight sets of data were collected and the calculated nonconservative fluxes are summarised in Table 2.

On the low spring tide (LoS and LoM), Δ phosphorus values are around zero, and consistently positive during high spring tide. ΔDIN values are positive and of similar order at both tidal extremes, with ΔDON being strongly negative on the high spring tidal phase.

Table 2. Summary of nonconservative fluxes of dissolved phosphorus and nitrogen fluxes (mol d^{-1}) for duplicate samples taken at the surface and at mid-depth during the slack low spring tide and slack high spring tide of 22 Sept., 1998.

Sample	ΔDIP	ΔDOP	ΔDIN	ΔDON
LoS1	- 8	13	586	724
LoS2	3	-11	3374	303
LoM1	- 2	2	3638	- 543
LoM2	-13	-11	3792	-3125
HiS1	37	51	1101	-3595
HiS2	35	31	3692	-2282
HiM1	46	46	4413	474
HiM2	68	75	5116	-6981
Mean	**21**	**25**	**3215**	**-1878**

[LoS=low tide, surface; LoM=low tide, mid-depth; HiS=high tide, surface;HiM=high tide, mid-depth; 1 and 2 are duplicate samples]

2.2.7. C:N:P RATIO

This is the molar ratio in particulate matter. Particulate or suspended organic matter (SOM) was measured after combustion (at 500^{o}C) of material retained on GFC glass filters. The carbon content was taken as 50% of the SOM. Particulate nitrogen was the difference between total nitrogen (TN) and total dissolved nitrogen (TDN) and particulate phosphorus was the difference between total phosphorus (TP) and total dissolved phosphorus (TDP). It is seen (Table 3) that the particulate C:N:P is variable and the mean $C:N:P_{part}$ ratio of about 1,400:9:1 is not very different from the value 1,300:11:1 quoted for mangrove litter by Gordon *et al.* (1996).

Table 3. Summary of the C:N:P ratios and stoichiometrically derived "p-r" (mmol C m^{-2} d^{-1}) and "nfix-denit" (mmol N m^{-2} d^{-1}) for duplicate samples taken at the surface and at mid-depth during the slack low spring tide and slack high spring tide of 22 Sept., 1998.

Sample	C:N:P	*p - r*	*nfix - denit*
LoS1	1,221:7:1	3.3	2.9
LoS2	564:9:1	- 0.6	11.0
LoM1	1,414:8:1	1.0	8.7
LoM2	1,667:5:1	7.1	1.1
HiS1	1,444:15:1	-17.8	-12.8
HiS2	935:1:1	-10.9	5.1
HiM1	1,343:2:1	-20.6	2.9
HiM2	2,838:11:1	-64.2	- 7.1
Mean	**1429:8.5:1**	**-12.8**	**1.5**

2.2.8. PRODUCTIVITY MINUS RESPIRATION (*p-r*)

The stoichiometric linkage of C:N:P ratio to nonconservative fluxes is discussed in Gordon *et al.* (1996). For the phosphorus-carbon stoichiometry:

> "the ratio of C:P in the particulate material $(C{:}P)_{part}$, multiplied by the nonconservative flux of DIP, becomes an estimate of organic matter (p-r):
>
> $$\Delta DIC_o = \Delta DIP \,.\, (C{:}P)_{part}$$
>
> That is, ΔDIP scaled by $(C{:}P)_{part}$ ratio becomes a measure of net ecosystem metabolism. A system with ΔDIP>0 is interpreted to be producing DIC via net respiration (*p-r<0*), while a system with ΔDIP<0 is interpreted to be consuming DIC via net organic production (p-r>0). This assumption is most likely not to work with systems with an anaerobic water column, or with sediments anaerobic to the sediment-water interface. Under either of these conditions, redox-mediated phosphorus desorption from organic particles is likely to occur."

The water column is not anaerobic in the Bujang system. Also, it is not likely that conditions are anaerobic at the immediate sediment-water interface, although anaerobic conditions would likely prevail within the sediment.

The (p-r) calculated for the 8 sets of data are shown in Table 3. These ranged from -64.2 to 7.1 mmol C m^{-2} d^{-1} (i.e., heterotrophic) on the high spring tide and around zero on the low spring tide, with a tidal cycle mean value of -12.8 mmol C m^{-2} d^{-1} (mildly heterotrophic but little different from zero).

Primary productivity in a mangrove estuary, like the Bujang, consists of 2 main components: the mangrove trees (mainly mangrove litter contributes to the C, N and P in the particulates, from which the C:N:P ratios are determined) and of phytoplankton. We do not know what proportion of the particulate C, N and P is contributed by mangrove litter, but it appears to dominate. Phytoplankton production in the mangrove estuaries tends to be very low (especially during the spring tides when the estuary is mixed and the light photosynthetic compensation depth is no more than a metre). Respiration in mangrove estuarine waters, on the other hand, tends to be very high due to the high organic carbon load (some 50% of organic matter is leached from mangrove leaf litter within a few days in the water).

2.2.9. NITROGEN FIXATION MINUS DENITRIFICATION

According to Gordon *et al.* (1996),

> "Assuming that the N:P ratio of particulate material in the system $(N{:}P)_{part}$ is known, the dissolved nitrogen flux associated with production and decomposition of particulate material is the dissolved phosphorus flux (ΔDIP + ΔDOP) multiplied by $(N{:}P)_{part}$. It follows, that (nfix - denit) is the difference between the measured dissolved nitrogen flux ($\Delta N = \Delta NO_3 + \Delta NH_4 + \Delta DON$) and that expected from production and decomposition of organic matter:
>
> $$(nfix - denit) = \Delta N - \Delta P.\ (N{:}P)_{part}$$
>
> ΔDON, ΔNH_4^+ and ΔDOP tend to be small relative to ΔNO_3^-."

For the Bujang, DON and NH_4^+ occur in about the same concentration as NO_3^- so these components cannot be ignored. ΔDOP is also found to be in the same range as ΔDIP so DOP must also be in corporated in estimation of N poise.

The (*Nfix - denit*) calculated for the 8 sets of data are shown in Table 3. These ranged from -12.8 to 11.0 mmol N m^{-2} d^{-1} with a mean of 1.5 mmol N m^{-2} d^{-1} (i.e. notionally N fixing, but little different from zero).

On the basis of this simple single-box model approach, a first-order assessment indicates that the system (while notionally net heterotrophic) is poised around zero for net C and N fluxes. Further assessment of data with multi-box models and comparison with other model approaches (see Section 2.3) may help elucidate the sensitivity of these estimates to changes in the various system parameters and, thus refine the estimates of the net C and N metabolism of the system.

2.2.10. DISCUSSION

Measuring nutrient fluxes from wetlands and estuaries is extremely difficult. Nixon (1980) in his comprehensive review of nutrient fluxes from salt marshes showed that although many measurements have been made, he was of the opinion that less than a handful may actually be reliable.

Perhaps there are methods that will work under a particular situation but it appears that there is no single method that works under all conditions.

The "LOICZ method" that we have applied to the Bujang mangrove estuary is a relatively simple one and has the advantage of being widely used and thus providing a global picture of nutrient flux from land to ocean (one primary objective of the LOICZ programme). This method has been described in detail (with many examples of different coastal ecosystems) and the numerous assumptions and caveats for the method to be applied also have been clearly stated (Gordon *et al.*,1996). It is thus inevitable that there will be systems where these conditions cannot be met and the method should not be used. However, it provides a basis for an initial first-order assessment of the performance and measurement of changes in estuarine net metabolism of C and N.

Nutrient distribution is unlikely to be homogeneous so variability between replicates is to be expected. This brings into question the number of replicates needed and sampling strategy. While a sensitivity analysis could assist in better describing the variability, it should be noted that some of the nonconservative flux estimates for the system are around zero. Here, neither small changes in sign nor small variation in values is of concern, recognising the potentially different biogeochemical "environment" that may be induced during the different tidal states.

These data can be compared with the metabolic performance of other mangrove systems. One example (Gordon *et al.* 1996), is the mangrove estuary (Klong Lad Khao Khao in Phuket, Thailand). This was a case study on the application of the "LOICZ method". A comparison of the Bujang mangroves with the Klong Lad Khao Khao mangroves (Table 4) may provide some insight into the suitability of the method applied to mangrove estuaries.

The area of the Thai mangroves ($6X10^6$ m^2) is twice that of the Malaysian mangroves ($3X10^6$ m^2) so, for comparison purposes, the Malaysian figure must be multiplied by 2 where rates are not given as per unit area.

It can be seen that the phosphorus concentrations of the two systems are about the same but the nonconservative flux of DIP in the Thai system is 30 times higher and that of DOP is 6 times higher. For nitrogen, both the concentrations and the nonconservative fluxes differ greatly between the two systems. The concentration of DIN is some 15 times higher in the Bujang but the concentration of DON is some 10 times lower. The Bujang exports DON but the Klong Lad Khao Khao is a comparatively massive sink. Both systems are sinks for DIN but the figure for the Bujang is 13 times higher.

Both the Bujang and Klong Lad Khao Khao can be viewed as heterotrophic systems but the Klong Lad Khao Khao is markedly so.

Table 4. Comparison of nutrient concentrations, nonconservative fluxes, C:N:P ratio, *p-r* and nfix-denit between the Bujang (this study) and the Klong Lad Khao Khao mangroves (Gordon *et al.* 1996). The area of the Thai mangrove is about twice that of the Malaysian mangrove.

Nutrient/Flux	**Bujang**			**Klong Lad Khao Khao**		
	Sea	System	Fresh	Sea	System	Fresh
DIP (μM)	0.2	0.3	0.3	0.3	1.5	0.4
DOP (μM)	0.2	0.4	0.7	0.3	0.6	0.7
DIN (μM)	11.2	30.0	33.1	1.1	1.9	4.3
DON (μM)	21.8	16.5	28.6	97.0	170.0	220.0
ΔDIP	21 mol d^{-1}			1,299 mol d^{-1}		
ΔDOP	25 mol d^{-1}			282 mol d^{-1}		
ΔDIN	3,215mol d^{-1}			500 mol d^{-1}		
ΔDON	-1,878mol d^{-1}			65,901 mol d^{-1}		
C:N:P	1,400:9:1			1,300:11:1		
p-r	-13 mmol m^{-2} d^{-1}			-230 mmol m^{-2} d^{-1}		
nfix-denit	1.5 mmol m^{-2} d^{-1}			8 mmol m^{-2} d^{-1}		

[**Note:** The figures for the Bujang were based on a mean of 8 separately measured/calculated data sets]

Overall both systems may be considered as net nitrogen fixers, although the number for the Klong Lad Khao Khao provides an unexplainedly high nitrogen-fixing environment.

For two mangrove systems that are apparently very similar, the results obtained are remarkably different. For the Bujang, only the combination of 8 different data sets appear to make some sense (but may not do so when taken individually). Comparison with other estuaries (mangrove–dominated and others in Mexico, South America, Australia and South East Asia), shows the metabolic performance of the Bujang system (around zero poise for net C and N metabolism) fits the central tendency of global data (see http://www.nioz.nl/loicz/) and is "low" compared with other mangrove systems. The "moderate" heterotrophic values for net C metabolism in the Klong Lad Khao Khao system are more representative of low latitude mangrove ecosystems.

2.3. MIXING DIAGRAMS

This approach was succinctly described by Officer (1983) as follows:

> "At some distance away from the source and providing that the waters are well mixed in the vertical and lateral directions, the conservative quantity, *c*, will mix, or dilute, in the same manner as the fresh-water fraction, *f*, in a down-estuary direction from its source, and will mix in the same manner as the salt, *s*, in an up-estuary direction. In either case the quantity d*c* / d*s* is a constant. This, then, provides a simple means for ascertaining whether a given quantity remains conservative during its passage through an estuary."

We use the same "BUJANG 98" data set for the mixing diagrams as that used previously in the stoichiometrically linked analysis.

2.3.1. SALINITY DISTRIBUTION / MIXING

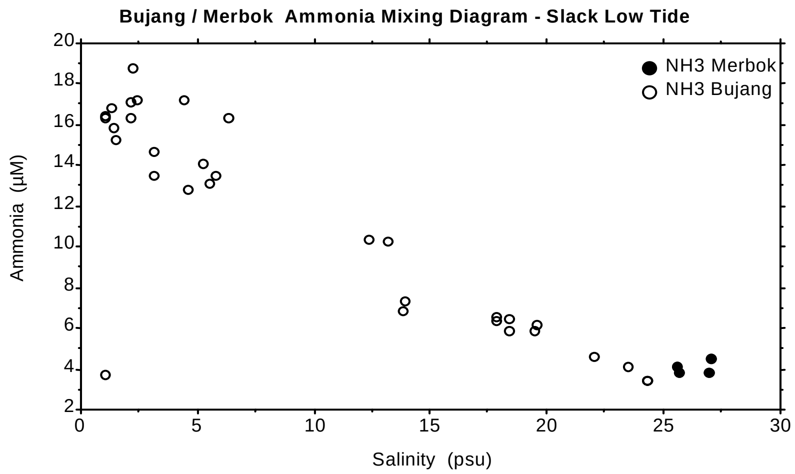
This is shown in Figure 2 in the previous section. As stated earlier, mixing is good in certain parts of the estuary but not in others. Here again, the approach was basically a 1-dimensional model, so a well-mixed condition is a prerequisite for mixing diagrams

2.3.2. AMMONIA

Ammonia appeared to act conservatively (i.e. a straight line against salinity) in the Bujang at slack low tide (Figure 7). The source of ammonia is at the top end of the estuary where the water runs through hardly used rice fields (but with cattle and some human habitation) as well as a few shrimp ponds (which discharge prior to and during the slack low tide).

At slack low tide, ammonia levels dropped linearly with salinity, until it reaches the Merbok, where it levelled off. This would imply that ammonia is conservative in the Bujang.

These observations can be explained. In the Bujang, there are shrimp ponds at the head of the estuary. These ponds discharge (effluent water is possibly high in ammonia and other nutrients) when the tidal level is low and would appear to be the main source of ammonia in the slack low tide mixing diagram. Seemingly, the ammonia from the ponds is diluted as the tide ebbs. During the slack high tide (when no discharge from the shrimp ponds is expected) the ammonia concentration at the top of the estuary is similar (at the same salinities) to that seen during slack low tide which means that there was no flushing between the slack low tide and the slack high tide. This is logical since this is the flood period. So during this period, water moved into the estuary and mangroves, and little ammonia may have been absorbed (bearing in mind that the picture may have been complicated by the lack of complete mixing).



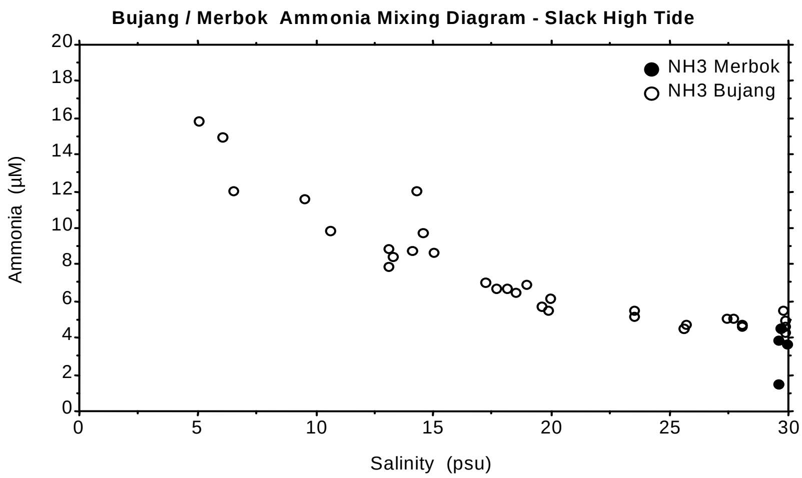
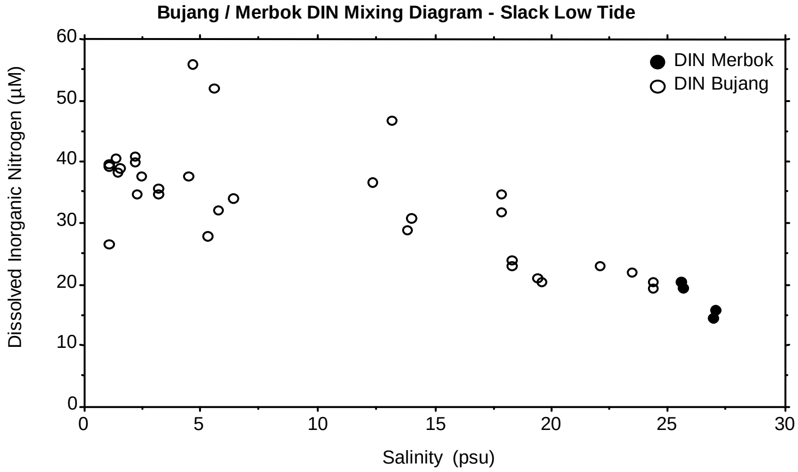


Figure 7. Distribution of ammonia with salinity along the Sg. Bujang on the spring tide of 22 September, 1998.

During the slack high tide, there is a concavity in the curve suggesting that the mangroves act as a weak sink for ammonia.

From the above, it would appear that different outcomes can result from different stages of the tide in a mixing diagram.



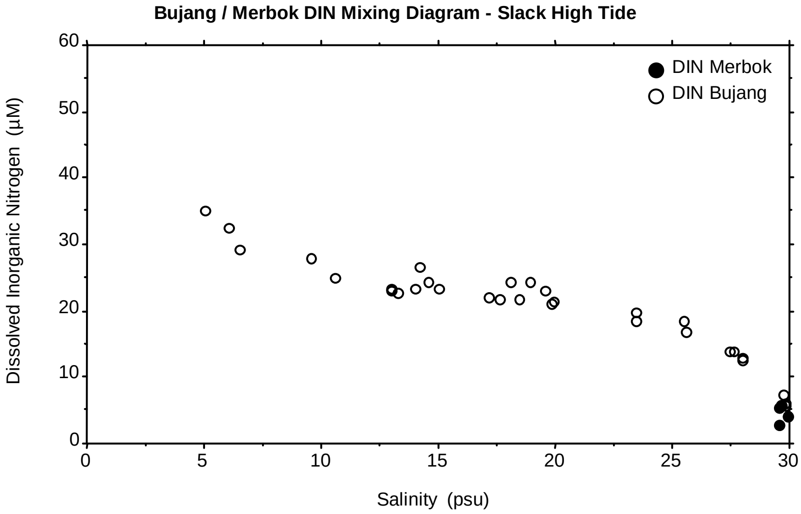


Figure 8. Distribution of dissolved inorganic nitrogen with salinity along the Sg. Bujang on the spring tide of 22 September, 1998.

2.3.3. DISSOLVED INORGANIC NITROGEN (DIN)

The dissolved inorganic nitrogen (DIN) curves show the sum of the ammonia plus nitrite+nitrate characteristics. The distribution of dissolved inorganic nitrogen (DIN) along the Bujang at slack low tide and slack high tide is shown in Figure 8. During slack low tide, the DIN concentrations ranged from 14 to 56 µM, the highest concentrations being at the freshwater end, indicating a source in the freshwater. A straight line may be drawn through the points, indicating conservative behaviour. During the slack high tide the DIN concentrations ranged from 3 to 35 µM, again with the highest concentrations in the freshwater end and lowest concentrations in the seawater end. There is a suggestion of slight concavity in the fresher waters and a slight convexity in the saltier waters, suggesting that the top part of the estuary acts as a weak sink and the bottom end of the estuary behaved as a weak source of DIN. It must be cautioned that these interpretations are under partially mixed (and not well-mixed) conditions and that data are limited.

DIN concentrations are highest in the fresher water and we suspect that shrimp ponds may be the source. The concentrations observed here are up to about 3 times that reported by Nixon *et al.* (1984) for the Sangga River and Selangor River.

2.3.4. DISSOLVED ORGANIC NITROGEN (DON)

There is a rather pronounced discontinuity in the DON mixing diagram for slack low tide (Figure 9), indicating that the estuary may be a sink of DON. The high concentration of DON in the Merbok waters as well as the high concentration at the top end of the estuary would suggest that the estuary is a strong sink for DON. It would be interesting to find out what is sequestering this DON. During the slack high tide, the mixing diagram shows a linear trend from freshwater to about 20 psu salinity, indicating the DON may be conservative for most of the upper end of the estuary during the incoming tide. Again, as during the low tide, the DON concentrations are higher in the Merbok. Thus there are DON sources from the top of the estuary and from the Merbok.

2.3.5. DISCUSSION (Nitrogen)

We have good confidence in the nitrogen data. Dissolved organic nitrogen is obtained by the difference between total dissolved nitrogen and dissolved inorganic nitrogen. The fact that there were only two (low) negative points was reassuring.

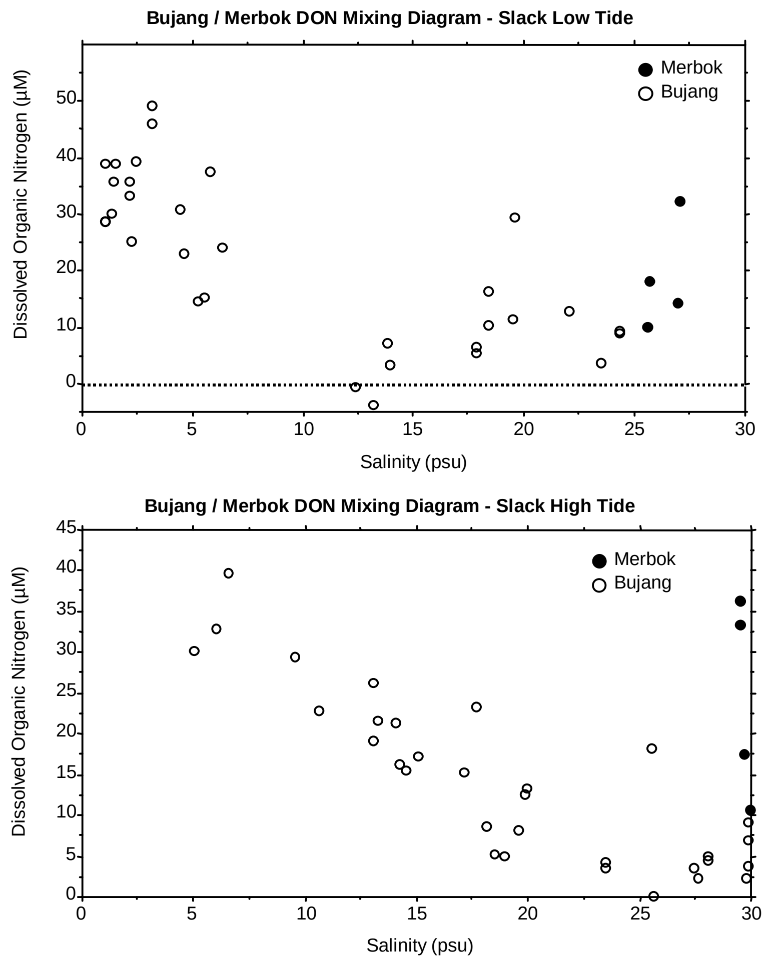
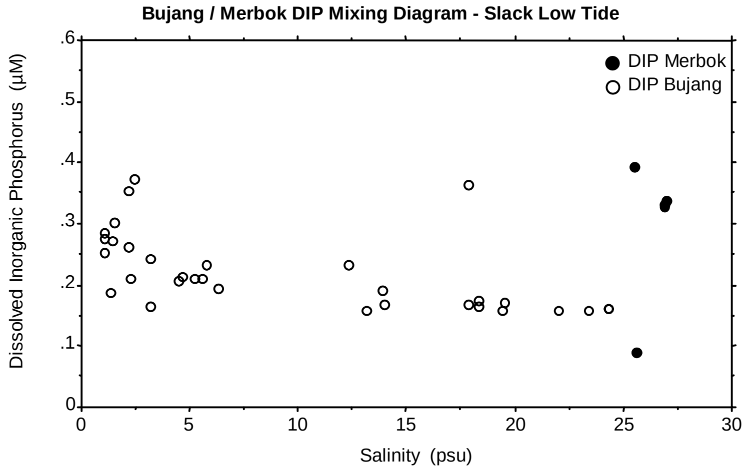


Figure 9. Distribution of dissolved organic nitrogen with salinity along the Sg. Bujang on the spring tide of 22 September, 1998.

Overall it would appear that most forms of dissolved nitrogen, except DON behaved more or less conservatively in their passage through the mangrove estuary. The mangrove estuary may be a relatively strong sink for DON. It would be most interesting to find out the mechanisms involved in the uptake of DON by the mangrove estuary, and the temporal constants.

2.3.6. DISSOLVED INORGANIC PHOSPHORUS (DIP)

The concentrations of DIP in the Bujang are low and ranged from 0.1 to 0.4 μM during slack low tide and 0.02 to 0.58 μM during slack high tide (Figure 10). DIP concentrations did not appear to change with salinity except at around 30 psu salinity during slack high tide where the DIP concentration is lower. However, many high salinity samples at slack low tide, and the 30 psu salinity samples at slack high tide, are near the limits of DIP analysis.



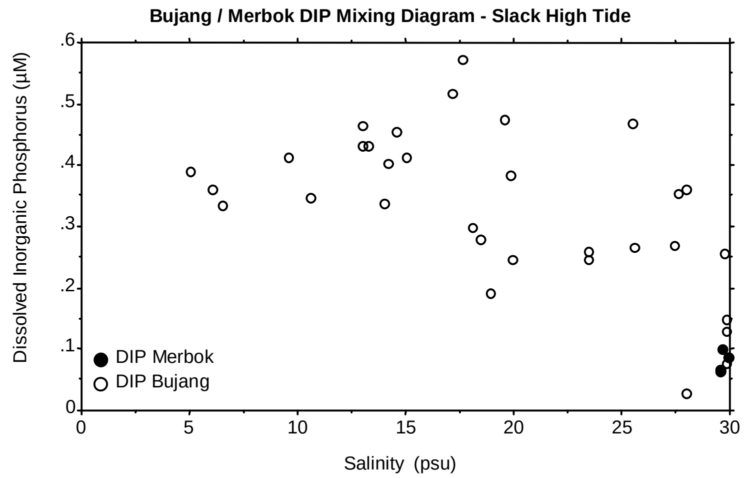


Figure 10. Distribution of dissolved inorganic phosphorus with salinity along the Sg. Bujang on the spring tide of 22 September, 1998.

2.3.7. DISSOLVED ORGANIC PHOSPHORUS (DOP)

As with DIP, the concentrations of DOP in the Bujang are low and ranged from 0.02 to 0.79 μM during slack low tide and 0 to 0.65 during slack high tide (Figure 11). DOP concentrations showed no pattern of change with salinity and exhibited a high scatter of values.

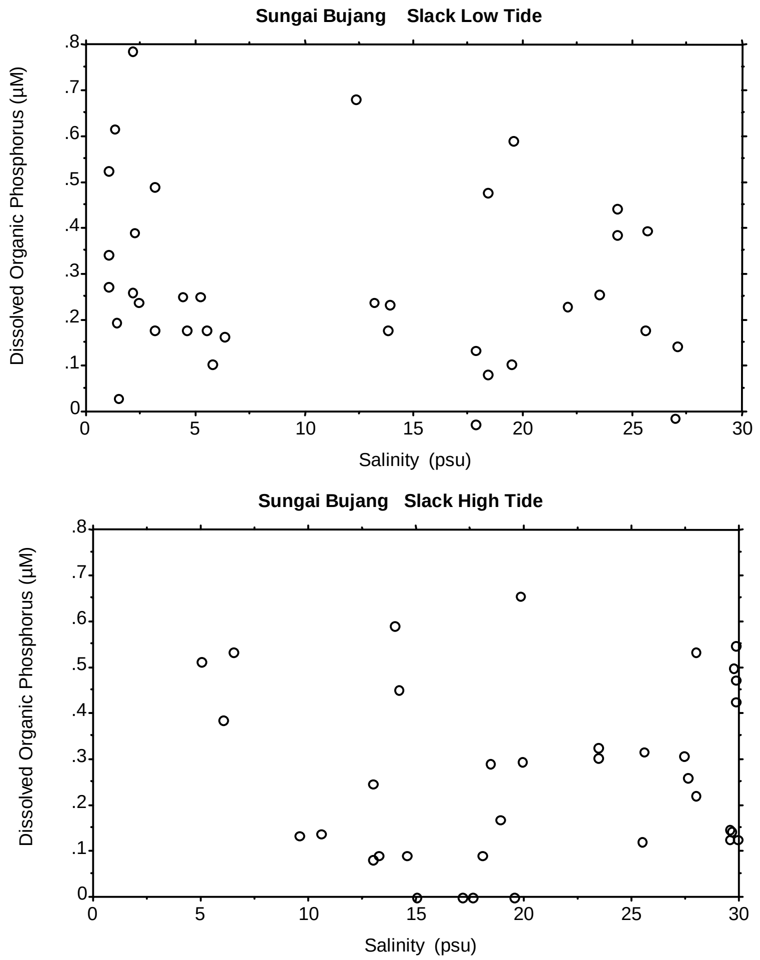


Figure 11. Distribution of dissolved organic phosphorus with salinity along the Sg. Bujang on the spring tide of 22 September, 1998.

2.3.8. DISCUSSION (Phosphorus)

The concentrations of the dissolved inorganic (ranging from 0.02 to 0.70 µM) and organic (0 to 0.79 µM) phosphorus are low in the Bujang. Robertson and Phillips (1995) gave PO_4 (we assume this to be dissolved PO_4) values ranging from 0 to 5.26 for pristine mangrove waterways in Australia, putting our values on the low side. Our values are however comparable to those reported by Nixon *et al.* (1984) for the Sangga River and Selangor River in Malaysia.

2.4. WATER DISCHARGE AND MATERIAL FLUXES FROM AN ESTUARINE MOUTH CROSS-SECTION

This method is that described by Kjerfve *et al.* (1981). It involves the establishment of a number of stations across an estuarine mouth cross-section and sampling (current speed, current direction, salinity and material whose flux is to be determined) at a number of depths over a few tidal cycles. The currents are vectorised and interpolated (spline fitted) over depth and with the sub-cross-sectional area, the water discharge can be calculated. The computation takes into account the change in depth over each tidal cycle - what is known as StokeÕs drift (this correction is more important the shallower the cross-section). The material flux is then the covariance of the water discharge and the concentration of the (strictly speaking dissolved) material in the water. The entire computation procedure was obtained from Kjerfve as a number of FORTRAN programmes that ran on a mainframe computer. We have just completed converting the programmes so that they will run on a WINDOWS OS personal computer.

We use "MERBOK 97" as an example of this approach. "MERBOK 97" was a massive exercise with very intensive measurements covering a neap-spring tidal period. Some 50 people were involved in the 2 weeks of field work.

2.4.1. DATA FROM "MERBOK 97"

The main aim is to determine the fluxes of carbon and nutrients from the estuarine - marine coastal interface of the mangrove ecosystem. The Sg. Merbok mangrove estuary was selected because the estuary has a single opening with most of the mangrove forests located behind this opening. The study involves the establishment of a number of stations to monitor and collect water samples for salt, carbon and nitrogen and phosphorus. By measuring over an entire neap-spring tidal cycle, it should be possible, in theory at least, to determine the water discharge, carbon and nutrient fluxes. Salt is measured as a conservative element so that achieving a salt balance would lend confidence to the method.

In practice, despite having carefully made many of these time-series measurements (some for as long as 31 continuous tidal cycles) on the Sg. Merbok estuary over the years, a satisfactory solution is still not in sight. The problem was summed up in Simpson *et al.*, (1997) as follows:

> "Perhaps the most serious and intractable problem we have encountered in attempting to deduce fluxes in the Merbok system is associated with the large variability of the system. The amplitude of the tidal transport (~3,000 m^3 s^{-1}) is more than two orders of magnitude greater than the estimated river input. Combined with the considerable variations observed in nitrogen levels, this leads to high variability in the daily mean total nitrogen flux and limits our ability to determine a useful average as in the present case, where our conclusion is a near-zero net flux but with wide error bounds."

This essentially means that we need to make more accurate current speed and direction measurements.

Our previous attempt with deflected-vane current meters has uncertainties and their low resolution resulted in error bands too wide to be useful (Simpson *et al.* 1997). This time we rely primarily on the better accuracy and sampling intensity of an RDI Broad-Band Acoustic Doppler-effect Current Profiler (BB ADCP) as well as 6 moored vector-averaged recording current meters.

Four water sampling stations were established: A, C and E along the main transect and M, about a kilometre downstream (this was mainly to facilitate potential numerical modelling studies) - Map 1. A NISKIN current meter was deployed at Station A. At Station C, 3 current meters were deployed (an AANDERAA RCM7 near the surface, a General Oceanics NISKIN at about mid-depth and another RCM7 near the bottom). All 3 meters were fitted with temperature and conductivity sensors. An AANDERAA DL7 conductivity-temperature chain with five sets of sensors at 2-metre intervals (starting 2 metres from the bottom) was also deployed at Station C. An RCM7 was also deployed at about mid-depth at both Station E and Station M. All these meters were set to record vector averaged measurements at 10-

minute intervals. 2 tide gauges (ENDECO) were also deployed on the north bank of the estuary, near the stations. These were also set to record at 10 minute intervals.

Despite biofouling (resulting in having to discard about a third of the collected data) and late deployment of 2 of the current meters (RCM7s at Station E and M which had last minute problems with their data storage units) the deployed instruments yielded over 50,000 usable individual data points. This does not take into account the enormous amount of data from the ADCP (which in itself will require many months of data analyses). The data are being processed and will be compared and merged with the processed ADCP data when they become available. These will then be used to compute water discharge and checked for salt balance. They will then be used, with the carbon and nutrient data to compute the residual fluxes of carbon and the various nutrients.

Water samples were also collected continuously (every other hour at 3 depths and at mid-depth) from Station C at lunar hourly intervals over 29 tidal cycles and from all 4 stations (3 depths) lunar-hourly over the 36-hours Intensive Neap and the 24-lunar hours Intensive Spring periods. In all, over 2,000 samples of water (filtered and unfiltered) and 5,000 filters with suspended matter were collected during the field exercise. These were returned to the laboratory and analysed for salinity, total suspended solids, dissolved organic matter, total nitrogen, dissolved inorganic nitrogen, total phosphorus and dissolved inorganic phosphorus, and will result in over 12,000 data points, when all the samples are analysed. It took over a month to complete the nutrient analyses (total nitrogen and total phosphorus) and at least twice that time to complete the particulate organic matter (POM) analyses. POM analysis is done by combusting individual filters in a muffle furnace at 500^{o}C for 3 hours.

The following are examples of some of the instrument tracings obtained during MERBOK 97. The main problem was rapid biofouling which affected the rotor type current meters as well as the conductivity sensors. For future studies, it would be advisable to recover, clean and re-deploy all these instruments after a week in the water. Only the tide gauges were not affected by biofouling.

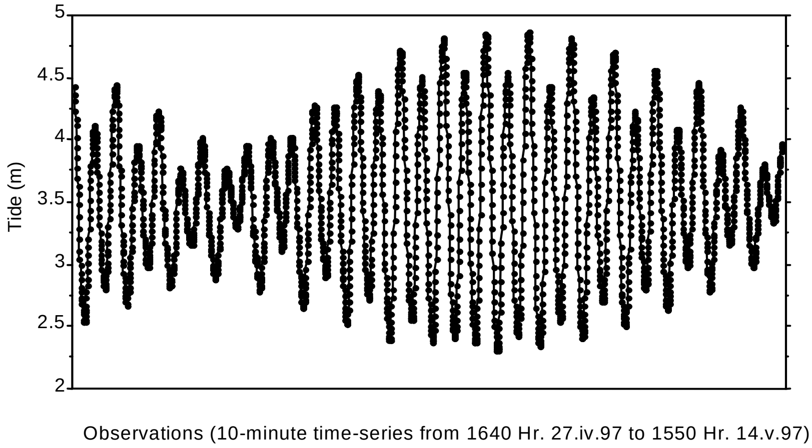


Figure 12. A perfect 17 days record of tides near the mouth cross-section of the Sg. Merbok, during MERBOK 97. A second, back-up meter, worked almost as well.

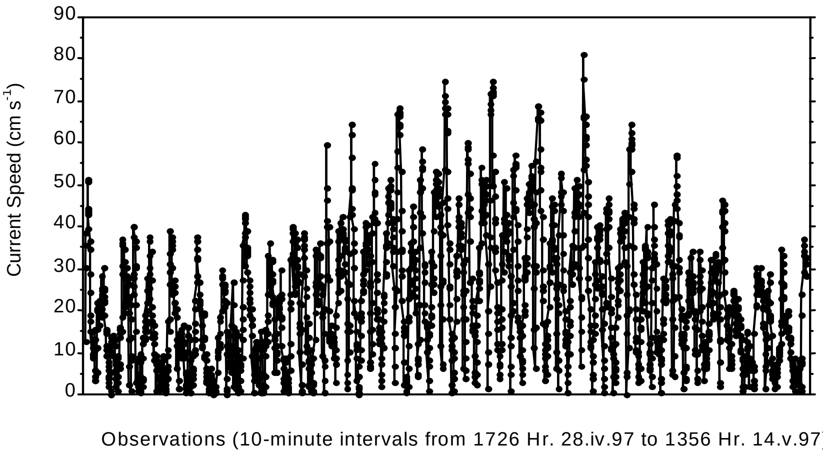


Figure 13. Current speed tracing from a General Oceanics NISKIN 6011 MK II placed at mid-depth at Station C. The winged current meter worked well for the just over 2 weeks of deployment despite biofouling. Current speed reflects the tidal amplitude.

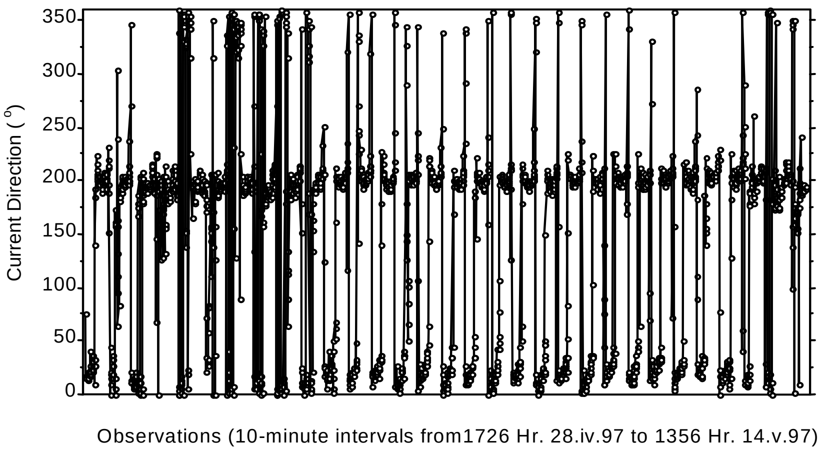


Figure 14. Current direction tracing from a General Oceanics NISKIN 6011 MK II placed at mid-depth at Station C. The winged current meter worked well for the just over 2 weeks of deployment despite heavy biofouling.

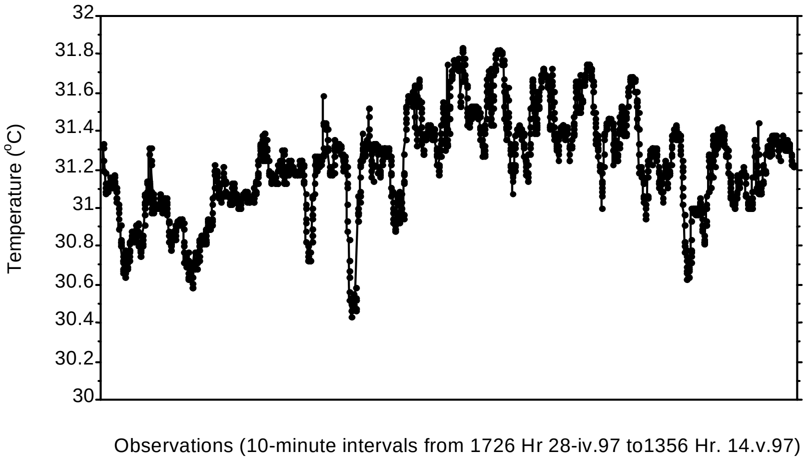


Figure 15. Temperature tracing on a General Oceanics NISKIN 6011 MK II placed at mid-depth at Station C. There was no problem with the sensor, which worked well for the just over 2 weeks of deployment despite biofouling.

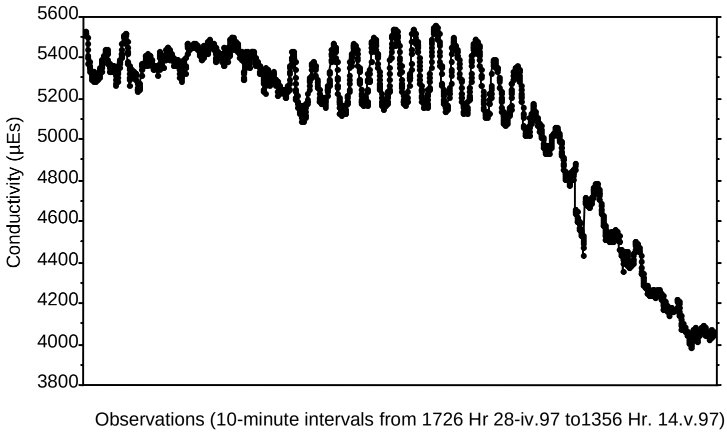


Figure 16. Tracing from the conductivity sensor on the General Oceanics NISKIN 6011 MK II placed at mid-depth at Station C. The conductivity sensor was affected by biofouling just over a week after deployment.

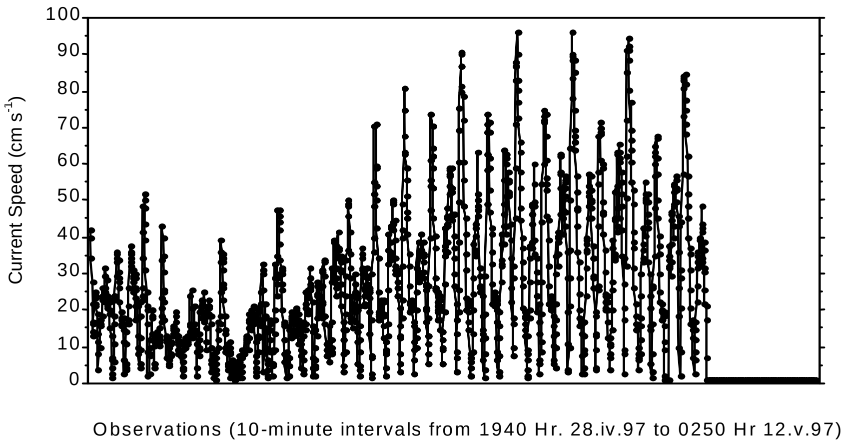


Figure 17. Current speed tracing from an AANDERAA RCM7 placed near the surface at Station C. The rotor impelled current meter failed completely after about 10 days due to rapid biofouling.

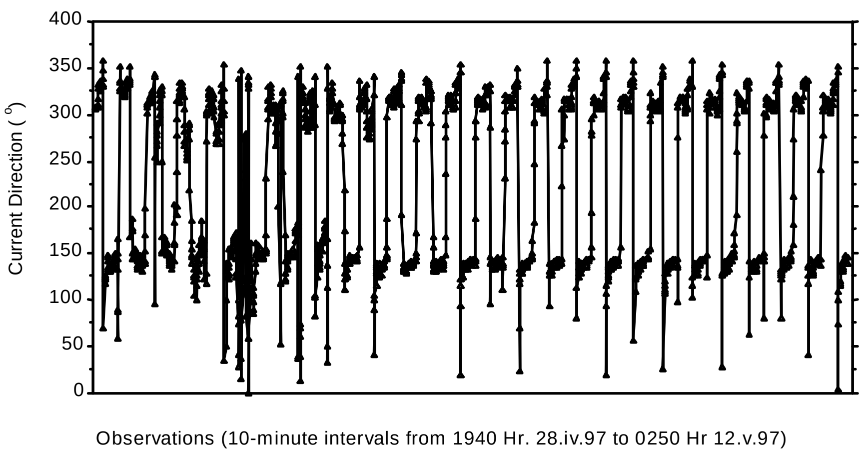


Figure 18. Current direction tracing from an AANDERAA RCM7 placed near the surface at Station C. The direction sensor was not affected by biofouling.

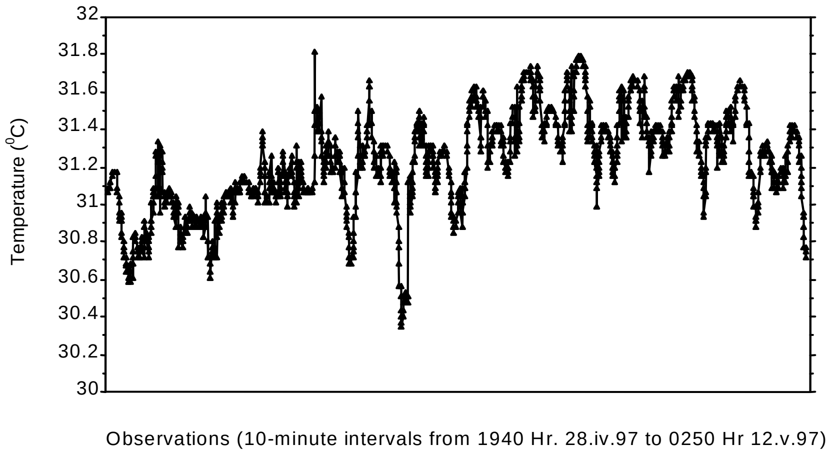


Figure 19. Temperature tracing from an AANDERAA RCM7 placed near the surface at Station C. The temperature sensor does not seem be affected by biofouling in the two weeks of deployment.

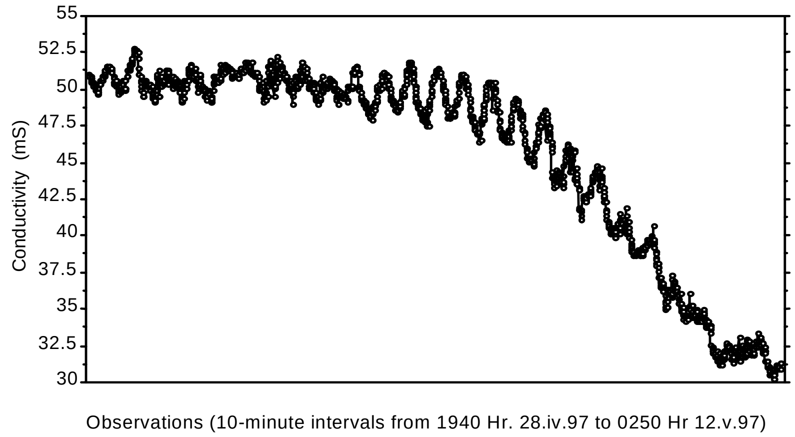


Figure 20. Conductivity tracing from an AANDERAA RCM7 placed near the surface at Station C. The conductivity sensor is affected by biofouling after only about a week in the water.

2.4.2. DISCUSSION ("MERBOK 97" FLUXES)

One of the major aims of "MERBOK 97" was to use an acoustic Doppler-effect current profiler (ADCP) for more accurate current profiling. The RDI ADCP is a 1200 kHz model (selected for its particular suitability for high resolution work in waters no more than about 30 metres deep) that can either be moored in a self-contained mode or can be mounted on a boat and operated moving along a transect. The instrument also has bottom-tracking capability so it is possible to know the velocity of the boat as well as obtain a bathymetry of the track. One problem we faced was to accurately determine the position of the ADCP at any particular time. For this we had to interface a Global Positioning System (GPS) to the ADCP via a notebook computer. Unfortunately there are no position transmitting beacons within receiving distance so we could not use the GPS in differential mode and had to accept an accuracy of no better than 50 metres.

We decided to run the ADCP on a rectangular transect continuously for 36 lunar hours during neap tide (Neap Intensive) and 24 continuous lunar hours during spring tide (Spring Intensive). The reason for running longer during neap tide is that the water stratifies during neap and there are more structures to resolve. During these periods the ADCP (which is mounted "looking down" on our boat) is continuously moved (at a constant speed) across the mouth of the estuary in a rectangular pattern. Data on current speed and direction (amongst others) are continuously collected at 1.0 metre depth intervals. During other periods the boat with the mounted ADCP is moored at Station C and set to record at 10-minute intervals (also collecting at 1.0 m depth intervals). Preparing and deploying the ADCP has been a relatively easy task but the data management and analyses are a different story. Ross Vennell has done the initial processing but, unfortunately, the group (Ross Vennell, John Simpson, Gong Wooi Khoon and Ong Jin Eong) have not yet been able to get together to get the final verdict out.

We have not been able to do the usual computations (as per Kjerfve *et al.* 1981) because (without the ADCP data) there is not enough current data as a result of the failures of some of the deployed current meters. In the meantime we are looking into improving the interpolation used in the original computations.

2.5. GENERAL DISCUSSION

In this section we compare and discuss the three methods illustrated in the previous sections, providing opportunity to evaluate the standard LOICZ method against more data-intensive methods for description of the hydrodynamics. Since we used the same data set ("BUJANG 98") for the LOICZ stoichiometric budget (LSB) method and the mixing diagram (MD) method, it is possible to compare the results of the two methods. Both rely on assumptions (eg., well-mixed conditions) that are not met by the system and the sampling regime; a multiple box model may be a more relevant compartmentation for the LOICZ approach, and potentially obviate this caveat. The comparison is shown in Table 5.

Table 5. Comparison of the "LOICZ Stoichiometric Budget" (LSB) method with the "Mixing Diagram" (MD) method: source, sink or conservative. Figures in ( ) are in mol d^{-1}.

NUTRIENT		DIP	DOP	NH_4^+	DIN	DON
Tidal State	**Method**					
Low Slack	LSB	Source (-5)	Source (-2)	-	Sink (2848)	Source (-660)
	MD	?	?	Conserv.	Conserv.	Sink
High Slack	LSB	Sink (47)	Sink (51)	-	Sink (3581)	Source (-3096)
	MD	Sink	?	Conserv.	Conserv.	W. sink

Unfortunately, even with the intensive sampling and analyses available for the system, the mixing diagram method provides only qualitative, not quantitative, results. This hampers a detailed comparison of the approaches but does provide for a comparative indication of trends that are insightful, especially in terms of the broad metabolic balance of the system.

While there is little apparent agreement between the methods for nitrogen assessment, it should be noted that the LSB methods yielded assessment values for net flux of N little different from zero. Hence, the inter-methodological analyses are likely to yield sign (+ or -) and small values of net N metabolism, and thus to be qualitatively variable around zero –as reflected in Table 5. The MD results for phosphorus are insufficient to compare methods, noting that the LSB method estimated a low net heterotrophy for the system. Use of a multiple box model may provide further insights and a greater understanding of the hydrodynamics and yield a more ready interpretation of net fluxes.

We had previously encountered problems with the mouth cross-sectional measurement method. One problem was in the inability to obtain a salt balance. What this means is that the amount of salt entering the estuary should be equal or almost equal to the amount of salt coming out of the estuary over a reasonable period of time (and we have time series measurements stretching to just over two weeks, covering a whole neap-spring tidal cycle). In one of our exercises (Simpson *et al.* 1995), we had forced a salt balance to compute the nitrogen flux but the error band for this estimate was large, suggesting that it would be necessary to measure the currents more accurately. This was the reason for the ADCP exercise described in the previous section. To date we have not been able to extract the necessary data. Also, during the ADCP measuring exercise, we may not have covered enough of the northern part of the cross-section so the whole exercise may have to be repeated at a future date.

The conclusion at this stage is that we do not have reliable cross-sectional measurements to compare with the LSB and MD methods. The flux measurement question should be further addressed with supporting sensitivity analysis on the components of the assessment in an effort to understand controlling processes and the effects of their variability; thus, a second phase of this project is needed.

3. ECONOMIC ACTIVITIES AND PROCESSES

3.1. APPROACHES

The overall objective of this project is to develop one or more integrated biogeochemical and economic models to understand and predict how changes in the coastal ecosystems will impact on the deeper (oceanic) waters. For this project two main interacting processes, biogeochemical and economical, are considered but it is realised that sociological processes are also important and will eventually have to be taken into consideration.

Basically, what needs to be considered are the biogeochemical, economical and sociological suites of processes. These are represented as three processes circles in Figure 21. The processes in each of the circles can be (and most of the time are) studied independently by natural scientists, economists and sociologists. In any system where humans are involved the processes from the different circles influence and interact (i.e., provide positive and negative feedback loops) with each other. So, in order to fully understand any system where humans are involved, it is not enough just to understand only one of the three aspects, or even to understand, separately, all three aspects. It is necessary to understand all three aspects (processes within each of the circles) as well as the interactions (arrows between the circles).

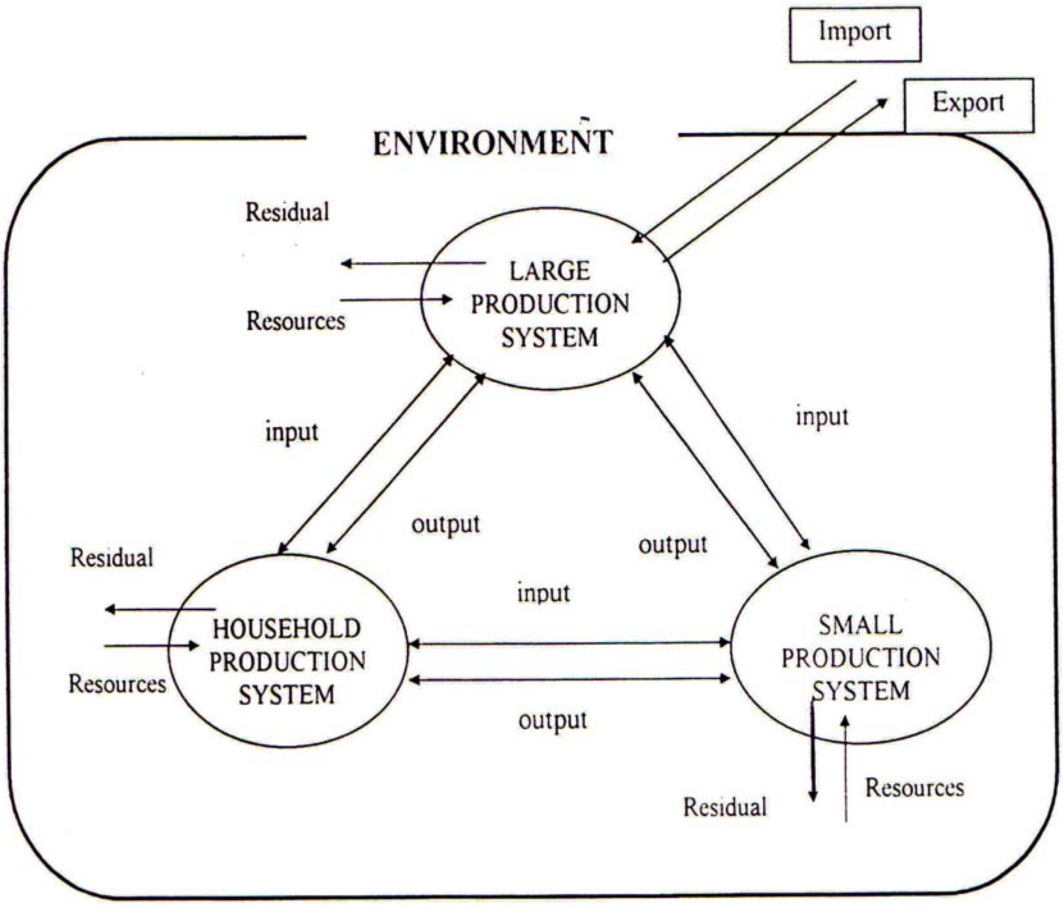


Figure 21. The biogeochemical, economical and sociological suite of processes in an ecosystem.

For this initial exercise, we will consider mainly the biogeochemical circle and the economic circle. The theme (decided by the natural scientists) is essentially the C, N, P fluxes between land and sea. In pristine systems, these fluxes are affected solely by various biogeochemical and physical process but in systems where humans intervene, the economical and sociological aspects have also to be considered. It is thus possible for natural scientists to work on their own to understand pristine systems but as soon as there is human intervention they need to work with economists and sociologists.

For this project, the natural scientists have basically started off working independently with the hope that the economists (and later on sociologists) will be able to fit in, and therein lies the problem of integration. The current paradigm is one based on pressure state response (psr) such that the socioeconomics is merely considered as the pressure on the system. This may be too simplistic and does not consider interaction between the different processes, much less encourage the interaction between natural scientists and socioeconomists. The paradigm shift that is needed is to consider the 3 circles of processes with equal weightage so that it will be easier to build bridges (these can be seen as feedback loops) between these circles. This is essentially what the Malaysian team has tried to do since the beginning of the project.

Whilst LOICZ provided adequate guidance for the biogeophysical model in the form of a "recipe book" as well as committed resource personnel, the same cannot be said for the economic model arena. The original suggestion (LOICZ 1996) was a pressure-state-response model but after much uncertainty, the teams eventually settled on the I/O Model. The I/O model provided one approach that could be adopted across a variety of sites and settings; it has use for short-term scenario analysis and could meet the overall project goals for inter-site comparisons.

The I/O model approach, which is a static method (top-down, using the National I/O Tables), was discussed and recommended at the Manila SWOL project meeting (LOICZ 1997). At the Surat Thani meeting (LOICZ 1998) it became clear that there were problems with the top-down approach. Vietnam was able to fulfil their objective but with a bottom-up approach. Malaysia was able to do likewise (although using only three instead of the stipulated 11 sectors).

3.2. BRIEF SOCIOECONOMIC PROFILE OF MERBOK

The mangrove ecosystem of Merbok sustains several types of production systems which are linked to each other and also externally, and these linkages are shown schematically in Figure 22. The internal structure of the production system i.e., the organisation of production and its operation as well as linkages between the production systems have implications on the socioeconomic activities of the population. The production systems are:

1. Large-scale production systems using modern methods such as large scale prawn and fish culture which are operated by private companies both local and foreign owned and also by government agencies - the Malaysian Fisheries Department and the Malaysian Fisheries Development Authority.

2. Small-scale production systems including cage fish-culture and pond prawn-culture owned by individual fishermen assisted by less than four workers. This type of production system also includes the production of charcoal from mangrove timber.

3. Household production systems based on household labour such as the lucrative bag-nets (pompang), bamboo traps (bubu) and stake-nets (tangkul).

3.2.1. MANGROVES

The Sg. Merbok mangroves were gazetted as a forest reserve in 1951 when some 2,600 hectare were classified as productive forest and another 1,400 hectare as unproductive forest, a total of just over 4,000 hectares. Some 25% of these forests has since be alienated (mainly for aquaculture ponds but more recently, near Sg. Petani, for housing). The forest is harvested for charcoal on a 30-year rotation and thinned for poles. The annual coupe was 100 hectares but it is not known if this has been reduced as a result of the alienation. There was enough timber to sustain 20 licensed charcoal kilns that produced a total of some 10,000 tonnes of charcoal annually. We suspect that the present annual production could be down to about 7,000 tonnes. At RM 500 per tonne the annual revenue from charcoal will still be in the region of RM 3,500,000 and at least that amount from poles giving a conservative total estimate of at least RM 7 million per annum from mangrove timber products alone.

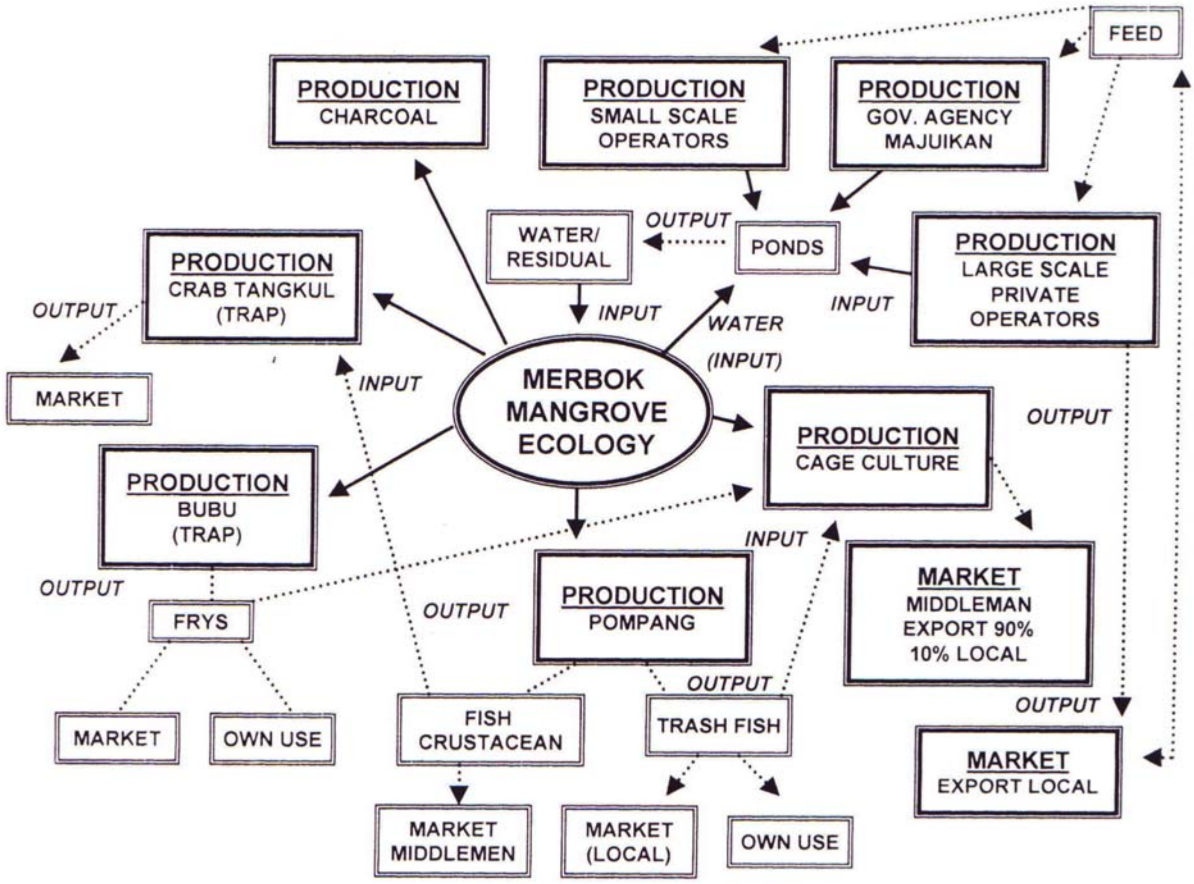


Figure 22. Production systems of the Merbok system and their linkages.

Based on 1996 data, 15 licenses were issued to charcoal kiln owners and these owners have to compete for the timber. Lim (1996) indicated that 13 of the licensees were operating at 30 percent capacity and the remaining two have sold their land and ceased operations. This trend indicates the increasing decline of the industry and based on estimates, some 600 workers were affected. The main reason for the decline of this industry is the loss of some 25% of the mangroves in the past 20 years (most of which were converted to prawn ponds) so that there was not enough mangrove timber to keep all the charcoal kilns operating at full capacity.

3.2.2. FISHERIES

As in most mangrove estuaries, fishing is a major activity here. The capture fisheries in the Merbok have been described by Khoo (1989), who listed the species composition of the bag-net ("pompang") fisheries (Table 6). Much of the catch consists of very small fish but there is a significant biomass of highly valued commercial species like pomfrets (*Pampus chinensis*), prawns (*Penaeus merguiensis* and *P. monodon*) and squid (*Loligo* spp.), making this type of fishing very lucrative. Apart from the bag-net fisheries there are other artisanal activities like push net for the shrimp *Acetes*, trapping crabs (*Scylla serrata*), trapping fish fingerlings (*Epinephalus* spp. and *Lutianus* spp.) for floating cage aquaculture and harvest of various shellfish.

The pompang fishery is based on household labour. For example, the whole village of Bakar Arang is dependent on the pompang fisheries, supplemented by small-scale cage culture, bubu and tangkul fishing. The major and most productive pompangs are at the mouth of the Sg. Merbok, which is controlled by villagers of Bakar Arang. The owners are related to each other along family lines. Pompang stakes have spread upstream at most of the major tributaries of Sg. Merbok but it appears that the pompangs here are less productive.

A pompang gate comprises two coconut trunks planted five metres apart in the river-bed and the bag-net harnessed to them. The total construction cost in 1999 was estimated to be approximately RM 1,500. The net is replaced every one and a half years. Each household owns a maximum of two gates mainly because they are constrained by the time needed to operate the net when harvesting and to clean the net after harvesting. During harvesting the operation of the net requires two people, one to manoeuvre the boat and the other to operate the net.

Pompang fishing is carried out for only 14 fishing days each month (7 days spring tide at the beginning of the lunar month and another 7 days of spring tide around the middle of the lunar month). The bag-net is set twice daily (during the day and night high tides). In order to supplement their income, the households also undertake fish cage culture. The fries for their cage culture are obtained from local fishermen or are captured from the mangrove estuary using bubu (fish trap). Feed for the fish cage culture is trash fish from pompang fishing.

The catch from pompang during each haul is estimated to average about 2 kg of pomfret (*Pampus chinensis*), 2 kg of other edible fishes, 7 kg of small prawns, 3 kg of big white prawns (*Peneaus merguiensis*) and 500 g of tiger prawns (*P. monodon*), 4 kg of squid and 10 kg of trash fish. Pomfrets fetch RM 30 per kg, large prawns fetch RM 10 per kg and tiger prawns, RM 30 per kg. A rough estimate of income from the more productive areas is between RM100-200 per fishing day. The pompang catch are sorted out by women, mainly wives and daughters of the fishermen.

The prawns and fish are sent to the local market by three local level wholesalers. The wholesalers are also related to the local fishermen.

The pompang fishing method is directly linked to the mangrove ecosystem and it is dependent on the mangrove ecosystem for its survival. Whole villages will be affected if the mangrove ecosystem is not able to function to sustain the fisheries. However, the organisation of production suggests that, at present, the system has no significant adverse impact on the mangrove system but may have adverse impact on the fisheries and mangrove system if allowed to grow unchecked.

The estuary is also the base of a very large anchovy (*Stolephorus* spp.) fishery fleet. Shoals are caught using purse seine nets and the fish are cooked on board the mother ship before being taken back to the land base to be sun-dried. This is one of Malaysia's largest mangrove-linked fisheries, in terms of biomass. The quantitative link between these tiny fish and the mangroves is not known but may be significant. Based on 1996 data, there are 40 purse seine anchovy boats e mploying about 800 workers. This fishing method generates seven anchovy industries employing 175 workers.

Table 6. Species composition of bagnet fisheries, Sg. Merbok. [from Khoo 1989]

Species	Count	Weight		Species	Count	Weight
Ambassis spp.	334	973		*Setipinna taty*	15	312
Arius venosus	20	528		*Stolephorus andhraensis*		
Caranx malabaricus	1	2		*S. heterolobus*		1,200
Chorinemus lysan	1	8		*S. indicus* ?		
Gobiidae	8	43		*Thrissocles dussumeieri*	5	56
Johnius sina	225	240		*T. hamiltoni*	3	109
J. solado	1	78		*T. mystax*	1	19
Kowala spp.	1	7		*Triacanthus* spp.	13	1
Lagocephalidae	13	614		*Trichiurus glossodon*	20	79
Leiognathus brevivostris	6	13		Tripauchenidae	1	11
Liza spp.	38	435		Other species		547
Lobotes surinamensis	1	23		Alpheids	24 70	24
Mugil spp.	6	125		*Penaeus merguiensis*	358	3,073
Opistroptherus tardoore	12	400		*P. monodon*	8	137
Osteogeniosis miltaris	5	388		*Parapeneopsis sculptilis*	7	10
Pampus chinensis	4	3,238		*Metapenaeus lysianassa*	194	139
Pellona elongata	401	568		*M. brevicornis*	24	94
P. pelagicus	?	730		*M. ensis*	178	303
Platycephalus spp.	1	4		*M. dobsoni*	104	82
Pomadasy hasta	2	97		*P. masterisis*	8	4
Rastrelliger spp.	4	7		Other prawns (juveniles)	164	15
Sardinella fimbriata	3	17	.	*Squilla* spp	1	10
Scatophagus argus	4	88		Spider crab	4	8
Sciaena russeli	1	25		*Loligo* spp.	468	1,039
Secutor ruconis	2,116	2,627		*Sepia* spp.	91	1,166
Selar kalla	27	98		Others (mixed species)	460	

3.2.3. MARICULTURE

There are different methods of aquaculture in mangrove estuaries, ranging from those that cause minimal environmental impact on the ecosystem to those that completely replace the ecosystem. The former include floating cage culture in the mangrove waterways and the seeding of mangrove mudflats with cockles (*Anadara granosa*). The latter involves the removal of mangroves and conversion to ponds.

Mangrove estuaries provide excellent shelter for the establishment of floating cages for the culture of both finfish and shellfish. Estuaries are also ideal in that water flow is good and wastes are easily flushed from the site. Like most mangrove estuaries in this region, the Merbok is used extensively for floating cage aquaculture. Most of the operations are for the culture of grouper (*Epinephalus* spp.), sea bass (*Lates calcarifer*) and snapper (*Lutianus* spp.) but there are also operations for mussels (*Perna viridis*) and oysters (*Crassostrea* spp.).

Based on 1995 figures, there were 83 floating cage culture operators in Sg. Merbok. Mukim Bukit Meriam and Merbok account for 80 percent of the total cage culture of about 8,310 m^2. Fish cage culture was started by the government through the Fishermen Association and the Regional Farmers Association. The activity then spread to individuals, for example, the pompang operators described earlier. The pompang operators mainly grew groupers (*Epinephelus* spp.) whose fry are caught in Sg. Merbok.

Fish are reared for 8-12 months. In the first month, the survival rate is about 80 % and for the next 4-5 months, it is about 90%. Fry of sea bass (*Lates calcarifer*) are imported from Thailand and cost RM 4.00-RM 4.50 per fry. These fry are fed trash fish obtained from trawlers or pompang operators.

Each operator employs an average of four workers who are paid RM20 per day and provided free food and cigarettes. The fish cage culture operators are mainly locals and employ local workers. The number of cage culture operators is increasing because of the availability of cheap feeds from trash fish at Tanjung Dawai and the suitability of Sg. Merbok for cage culture (sheltered and well flushed). Although the initial capital is high at RM 10,000 for a frame consisting of 12 sections (one section is equivalent to a 10 feet x 10 feet cage), the return is lucrative, given the high survival rate. A mature fish weighing 1200 grams fetches RM38 and a fish between 700-800 grams, between RM30-RM33. The fish is marketed locally to restaurants or exported to Taiwan and Singapore. Cage culture is an economically viable activity and has become one of the main projects for the government to increase food production and to raise the economic level of the fishers. From the environmental point, cage culture activity is presently not a threat to the Sg. Merbok mangrove ecosystem.

Ponds, dug after mangroves are felled and cleared, are used mainly for the culture of the tiger prawn (*Penaeus monodon*) and most of these are large-scale developments. They are potentially lucrative but the risks are also high (see Chan *et al.,* 1993). Initially, 307 hectares of the Merbok mangroves was excised (to the Malaysian Fisheries Developmental Authority) for aquaculture, but this has burgeoned and it is now estimated that some 25% of the mangroves in the Merbok has been converted to aquaculture ponds over the past 20 years.

Pond prawn culture is mainly organised under large-scale production systems. The first large-scale production system was carried out by government agencies: the Fisheries Department and the Fisheries Development Authority. The first project was undertaken in 1982 with 33 ponds and pond size between 0.5-2.5 hectare, with an allocation of RM 2.3 million. The second project was undertaken in 1989 with 25 operators selected from locals who were each allocated a 0.7 hectare pond. The project provided an average monthly income of RM 2,000 per participant.

In 1995, there were 24 operators operating 127 ponds but, according to the Fisheries Department, there are also illegal operators.

The other large-scale production system is undertaken by large companies from outside the area, and foreign owners. There are altogether 12 companies operating 618 hectares of ponds. The companies are given Temporary Occupational Licences by the State. The cost of starting pond prawn culture per hectare is estimated to be about RM 30,000-35,000. The companies employ one worker per one hectare of pond with a basic pay of RM 400 per month. The workers prepare the ponds, feed the prawns, check water quality and ensure security of the area. The prawns are usually grown for 4 months before harvest. The survival rate is estimated to be about 80%. A one-hectare pond produces five tonnes of prawns at a market price of RM 20-25 per kg. The gross income per hectare is estimated to be about RM 100,000.

3.2.4. RUBBER AND OIL PALM

The area for rubber in 1990 was 34,761 hectare from 47,000 hectare in 1980. Most of these are in the upper reaches of the main river (Sg. Lalang). There are only small patches of oil palm in the Merbok catchment. These are almost insignificant, compared to the total area of catchment. Only about 26,000 hectare of rubber are in the catchment.

3.2.5. RICE

Almost all the rice fields are adjacent to mangroves. In fact many of the rice fields were originally reclaimed from mangroves (mainly in the northern part or the Ban Merbok area). Many of the rice fields originally reclaimed from mangroves are however not very productive and are left idle. In 1990, for the whole district of Kuala Muda, rice acreage was 10,392 hectares from 9,796 hectares in 1980. Only about 7,500 hectares fall within the Sg. Merbok catchment. Most of the rice fields carry two crops per year.

3.3. ECONOMIC (INPUT / OUTPUT) MODEL

Every five years, Malaysia's government publishes a five-year development plan and the current phase of development planning is the Seventh Malaysia Plan, 1996-2000. Much of the work connected with its preparation is carried out by the Economic Planning Unit (EPU) of the Prime Minister's Department. To coordinate development planning with the respective state governments, branch offices are maintained throughout the country by the EPU. The five year plan contains policies and strategies for guiding development following which budgetary allocations that target development of the different sectors of the economy are made. A balanced growth strategy has always been a central feature of the country's development plan. But targeting sectors will inevitably lead to a transformation of the structure of the economy as some sectors expand at higher rates over others and become dominant over time.

Input-output analysis is a useful tool for assessing the impacts that will likely result from sectoral development targets. The model works in the following way.

The basic framework of the input-output model is given by

$$AX+Y = X$$

where AX is the input-output table. This is an n by n matrix that captures inter-industry sales in dollars among n number of industry-sectors of a given economy. The matrix records sales of only intermediate products since outputs by one industry-sector are redirected and used as inputs by another sector. The remaining output not used as intermediates are sales to satisfy final demand. Private consumption, private investment, government spending and imports together make up total final demand which is denoted in the above equation by the n by 1 vector Y. The final demand is equivalent to the gross domestic output or GDP of the economy. Thus gross output X for n industries are the dollar values for both intermediate and final sales. The technical coefficients matrix A is obtained by dividing the matrix elements by the gross output values for the respective industries. These coefficients represent inputs per dollar of gross output.

The input-output calculates the total output requirements by industries for a policy target of final demand. Since gross output is the sum of intermediate demand requirements (described by the structure of the economy AX) and final demand requirements (Y, equivalent to the GDP) which is targeted by policy, the inter-industry structure AX will eventually spin indirect and induced impacts after the following sequence of interactions,

$$AY+A_2Y+A_3Y+A_4Y+.... = X$$

which when infinitely summed mathematically converges on

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

The last equation is known in input-output literature as the Leontief inverse (Leontief 1951).

Input-output models are static in the coefficient values contained in the matrix A referred to as the model parameters. The values of final sales given in the vector Y is externally prescribed by way of policy inputs. The vector of gross output X is the resulting impacts generated conditional on the prescribed values of Y.

Thus input-output analysis attempts two things. Firstly, the Leontief inverse attempts to incorporate subsequent rounds of interactions beyond the initial direct impact stage. Time is not an element in the occurrence of the various rounds of impacts. Secondly, the working of the model requires the prescription of a set of policy inputs. In this sense, the input-output model as it is designed is used to compare the total (direct, indirect, induced) impacts arising from different policy inputs in terms of final demand targets.

Thus while the results are quantitative, interpretation is only qualitative in terms of the relative impacts from the different policy targets.

3.3.1. ECONOMIC PLANNING IN THE MERBOK

Consider the economic planning of the Muda District in which the Merbok and its hinterland is situated (Kuala Muda District Council 1991). The gross regional product (GRP), which is the sub national equivalent of the country's GDP, of the basin is about RM 1 billion in 1995 (based on 1978 prices). The sectoral composition in 1995 of the basin's economy is shown in Table 7. The GRP targeted for 2000 is also shown which will result in a number of changes to the sectoral composition.

During the five year period, the two manufacturing sectors combined are expected to expand from 39% to 49% of the total economy of Merbok. On the other hand, the various sectors in agriculture are likely to shrink from a share of 17% to only about 11% of the total economy. Changes in the contributions by the other sectors are only marginal.

To assess the impact on the local economy of the Merbok basin, the change in GRP shown in Table 7, is fed as the Y matrix into the input-output model. The resulting impacts on total output is shown in Table 8 which comprises the direct, indirect and induced impacts resulting from the sector targets contained in the Y vector specified when running the input-output model.

In developing economies such as that of Malaysia (and for that matter the Merbok basin), a portion of the flows among industries is comprised of imported intermediate products used as inputs by local industries. This means that part of the intermediate inputs used by industries in the Merbok river basin is obtained without the input-output interactions occurring in the local economy.

Table 7. Sectoral composition of the Merbok basin (RM x 1000) in 1978 constant dollars).

SECTOR	1995	%	2000	%	Change
agriculture	166,263	16.63	131,457	10.30	-34,806
fishing	29,464	2.95	2,297	0.18	-27,167
forestry	316	0.03	153	0.012	-163
mining	2,105	0.21	1,276	0.10	-828
manufac 1	38,935	3.89	61,262	4.8	22,326
manufac 2	351,468	35.15	561,564	44.00	210,096
electricity	6,314	0.63	7,147	0.56	833
water	8,418	0.84	9,572	0.75	1,154
construction	72,609	7.26	103,379	8.10	30,770
transport	28,412	2.84	31,269	2.45	2,857
other services	295,696	29.57	366,293	28.70	70,597
TOTAL	**1,000,000**	**100.00**	**1,275,669**	**100.00**	**275,669**

Thus, any input-output impacts that might occur from the imported intermediate goods should be set aside, because they do not actually occur locally. To obtain a more reasonable estimate of local impacts, therefore, it would be better to restrict running of the input-output model based only on domestic flows. The necessary adjustments are also shown in Table 8 alongside the difference which tells how much the impact on the economy has been overestimated should we neglect setting aside the imported inter-industry interactions.

From the input-output analysis, the projected increase in final demand (i.e., GRP level) by RM276 million (in 1978 constant dollars) for Merbok during the five year period will lead to an increase in gross output by RM324 million brought about by direct, indirect and induced effects. As much as RM226 million will occur within the manufacturing sectors, with smaller increases occurring among the other sectors. But these changes will also lead to significant contractions in agriculture and fishing as indicated by the negative numbers. Forestry will, however, expand by RM23 million.

Since a fair proportion of the intermediate inputs and outputs among the many industries located in Merbok are sourced from overseas, it will be necessary to net out the impacts on gross outputs which are not expected to occur locally. Taking imported inputs into consideration, the total impacts on gross output amount to RM271 million with RM205 million occurring in the manufacturing sectors. Thus there will be an over-estimate of the impacts by RM53 million had we failed to consider imports. Nearly 40% of the overestimate amounting to RM21 million is attributed to the manufacturing sector.

Table 8: Direct, indirect and induced impacts generated by I/0 model (1995-2000), (RM thousands in 1978 constant RM)

SECTOR	Total impacts	Total domestic impacts	Difference (overestimate)
agriculture	-35,762	-37,142	1,380
fishing	-25,606	-25,741	134
forestry	23,408	21,208	2,200
mining	23,849	4,715	19,134
manufacturing 1	38,812	21,134	17,678
manufacturing 2	187,294	184,306	2,989
electricity	10,935	8,251	2,684
water	1,653	1,426	227
construction	29,240	28,254	985
transport	14,236	8,322	5,914
other services	56,412	56,410	2
TOTAL	**324,471**	**271,144**	**53,327**

The indirect and induced impacts are caused by inter-industry sector linkage effects present in the production structure of the economy embedded in the input-output framework. When final demand of a particular sector is targeted to grow at a high rate, production in the sector will increase and therefore its demand for intermediate inputs from the other sectors supplying to it will also increase. Thus depending on how strong the linkages are between sectors there will also be such indirect and induced effects brought about by a targeted change in final demand.

This notion of a lead sector spinning off additional effects across the rest of the production structure prompts further investigation into the identification of likely lead sectors in the economy. The first involves looking at multipliers. Imagine if the input-output run had been based on a final demand vector Y containing the value 1 representing one dollar change for a particular sector and zero elsewhere. By pre-multiplying the $(I-A)^{-1}$ matrix with this Y vector we will obtain the resulting X matrix identical to the column representing that sector in the $(I-A)^{-1}$ matrix. This feature is caused by the procedure in matrix multiplication and the 1 in the Y vector with zero values elsewhere.

Thus the individual column sums of the $(I-A)^{-1}$ provides an indication of the strength of the sector multipliers, as if we have run over and over again the Leontief inverse with Y matrices containing a 1 in each of the sectors and zero elsewhere. The multiplier value of a sector is interpreted as the total impact on the economy that is generated as a result of a one dollar change in final demand occurring in that sector. The sector multipliers are as shown in Table 9.

A one ringgit increase in final demand (such as investment) will result in an average of RM1.37 impact on the production structure after incorporating direct, indirect and induced effects. But only RM1.14 of this amount will impact on the local economy as the rest of the impact will be felt abroad due to the import content of the inputs into local industries. The use of the multiplier figure, that is the resulting impacts from a unit increase in final demand, may be useful for picking sectors for expansion. For example manufacturing I or heavy industries have a multiplier figure of 2.02 which is well above the average. Therefore, not taking care to consider imports will result in identifying this as the sector to expand. After adjusting for imports, the local multiplier in this sector is only 1.1 which is even lower than the average.

Table 9: Sector multipliers generated from imported and domestic sectoral linkages.

Sector	Imported+domestic	Domestic only
agriculture	1.067109	1.058200
fishing	1.101060	1.060286
forestry	1.204061	1.108849
mining	1.139463	1.105261
manufac 1	2.016227	1.100567
manufac 2	1.348354	1.212876
electricity	1.544451	1.181612
water	1.593237	1.309142
construction	1.473655	1.194479
transport	1.475220	1.131054
other services	1.136830	1.069438
	1.372697	1.139251

Another useful analysis of the Leontief inverse is to calculate the values of Rasmussen's (1952) power of dispersion and sensitivity of dispersion indices. The dispersion indices are the ratios between the sector average and overall average. When backward linkages of a particular sector are strong, the sector is a large buyer of inputs from the other sectors in the economy. Thus the sector is a power sector, because should the sector expand or contract it will affect many other sectors that supply it with intermediate inputs. When forward linkages are strong, the sector is a sensitive sector because this sector sells its components to a wide variety of sectors. Thus anything that happens to any of the other sectors will indirectly affect this sensitive sector as well. The Rasmussen indices are shown in Table 10.

Figure 23 shows the index values in terms of the power of dispersion and the sensitivity of dispersion among the various sectors. Sectors located near the 45 degree line are generally well balanced in power and sensitivity. Curiously, water utilities appears to be a lead sector in the analysis. This is explained by the possibility of an expansion in water-works projects in the region during the period which must have sourced a significant amount of inputs from the rest of the economy.

The other sectors which appear high on the power index, such as manufacturing and construction are within expectation as these tend to source much inputs from other sectors. On the other hand, sectors such as electricity, transport, forestry and mining appear as sensitive sectors as these sectors tend to sell to other sectors rather than buy from them.

Table 10: Rasmussen power and sensitivity of dispersion indices.

	Power index	Sensitivity index
other agriculture	0.928856	0.898817
fishing	0.930687	0.892918
forestry	0.973314	1.020553
mining	0.970164	1.201100
electronics man	0.966044	0.964872
manufac 1	1.064626	0.886640
manufac 2	1.037183	1.151621
water	1.149125	0.899572
construction	1.048477	1.024178
transport	0.992805	1.179279
other services	0.938720	0.880450

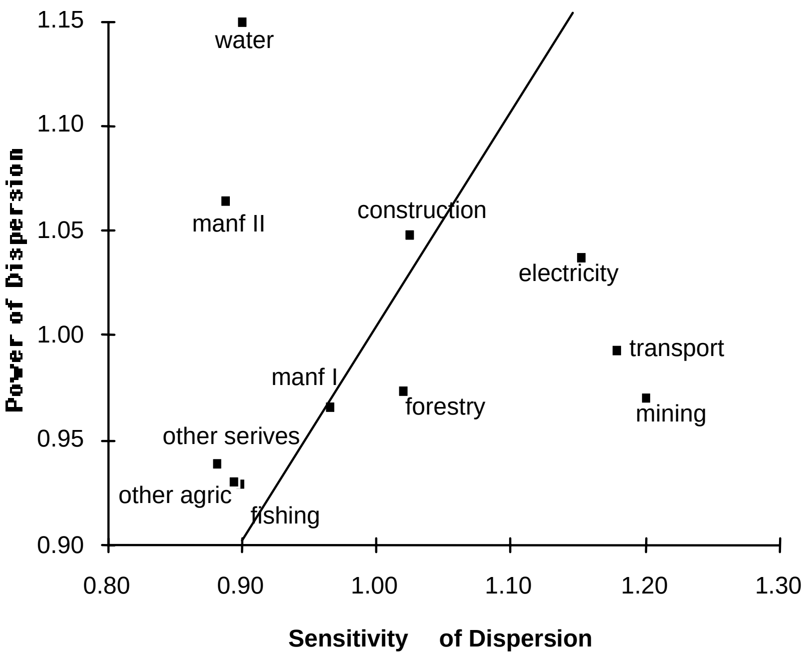


Figure 23. Power and sensitivity of dispersion plot of Table 10.

3.4. ALTERNATIVE ECONOMIC APPROACHES

The input-output model is popularly used for allocating development towards target sectors with high multiplier effects. However, many of the changes that occur to particular sectors will be the result of private sector investments in response to government incentives and other signals, that favour the expansion of some sectors in favour over others. More timely monitoring of economic changes will be necessary to gauge the extent to which the private sector is following such government leads. Typically regular interventions are made by the government to alter various economic signals to further influence the private sector towards established development priorities.

3.4.1. TRACKING OF ECONOMIC INDICATORS/INDICES

Various techniques used in monitoring the economy are discussed in Chan (1997). Tracking indicators is an effective way to closely monitor changes in the economy. These changes usually follow business cycles which have attracted much study over the timing of their turning points that occur after an expanding economy has peaked or an economy in recession has bottomed out (see Lahari and Moore 1991). A large number of variables routinely compiled as government statistics may be monitored. These variables are grouped into three different categories by performing regression analysis between each of them and the status of the economy. From the results obtained, it is possible to identify which variables form leading, coincidental or lagging indicators. All the variables in each group can then be aggregated with different weights to produce a composite index for each of the three groups.

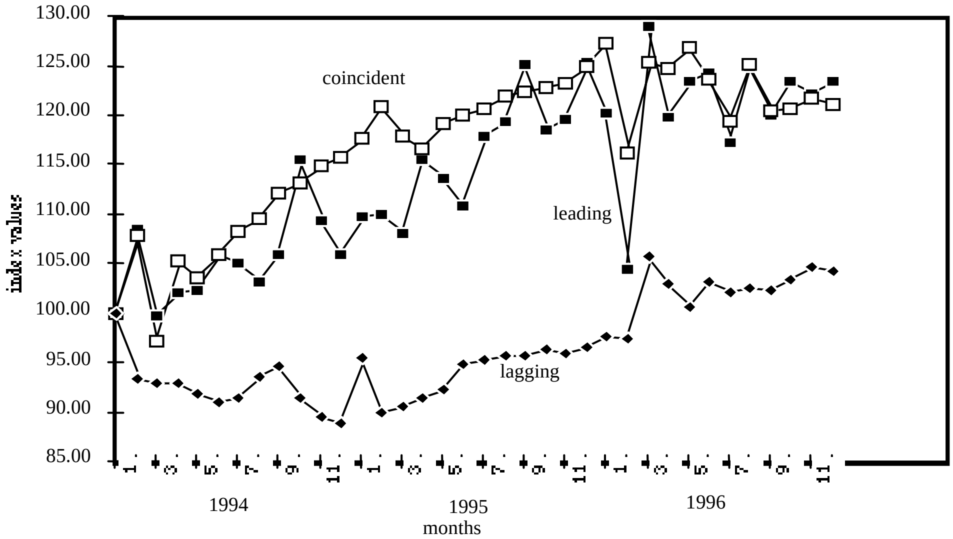


Fig.24: Leading, coincident and Lagging indices, Malaysia, 1994-1996.
Source: Produced from data in Economic Indicators, 4th. Quarter 1996, MIER

The leading index will track changes to the economy several months ahead of time and warn of possible changes at the horizon. The coincidental index will indicate changes as they occur in the economy. The lagging index will only show changes several months after they have occurred in the economy and acts to confirm that the changes experienced are real. In Figure 24, the three indices are plotted over a three-year period after their respective values are rebased to 100 in January 1994 so that they could be compared side by side. The general upward trend in all three indices could be observed for the period but seasonal and cyclical variations are clearly apparent.

During planning it is also necessary to predict the different outcomes of various plan options such that the plan that produces the best outcome could then be selected for implementation. To do so, the features of the various plans considered could be formally introduced into a causal model of the economy.

3.4.2. ECONOMETRIC MODEL

Many causal models of different sizes reflective of Malaysia's economy have been built according to a survey by the Malaysian Institute of Economic Research (MIER) (Imaoka *et al.* 1990). For example, Figure 25 shows part of MIER's annual model. In the figure the causal linkages between variables are shown, each link being represented by an equation for which parameters are to be estimated from data on Malaysia's economy. The actual model is fairly large comprising 38 exogenous variables and 58 endogenous variables which are linked together by 28 equations and 29 identities. The values of exogenous variables are data items obtained elsewhere and entered into the model so that the values of endogenous variables could be computed by the model. Identities are equations without parameters to estimate. Space does not permit a full description of the model here. Suffice that as an example we examine the causative linkage between exports and national income.

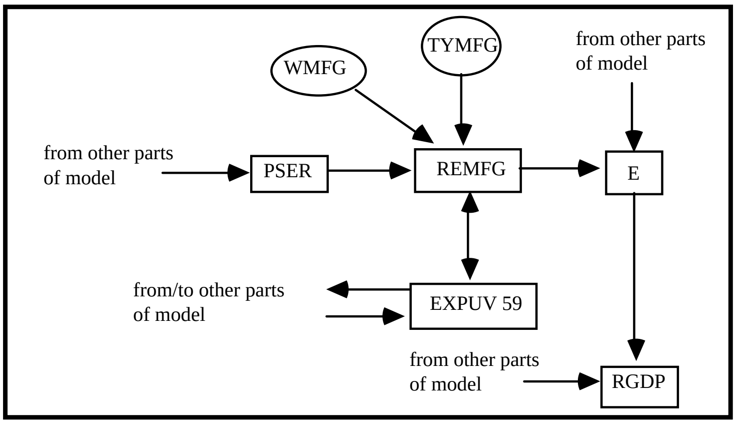


Figure 25. Forecasting national income from exports of manufactures.
Source: Adapted from MIER (1990)

According to the way the model has been specified, real exports of manufactures (REMFG), depend on their export values (EXPUV59), the nominal wage index for manufactures (WMFG), the price index for services (PSER) and the trend index for production in manufacturing (TYMFG). Data on wages and the trend index are directly fed into the model because they are exogenous. Export values and service price index, being endogenous, are computed elsewhere inside the model. Formally, according to the causal relationship established above, a regression equation is specified which links the dependent variable REMFG with the four independent variables.

$$\log REMFG = b_0 + b_1 \log EXPUV59 - b_2 \log WMFG - b_3 \log PSER + b_4\, TYMFG$$

In this equation, values of five parameters, b_0 to b_4, have to be estimated based on the values of the four independent variables either computed elsewhere or exogenously obtained. The variables were transformed into their logarithmic equivalents because a better fit was achieved by the model when logarithmic values were used. Generally, with n number of data points there are n-1 ways of drawing a regression line across these points. This means that there are that many possible parameter values to choose from. If it is possible to assume that the observations are independent of one another, a method called ordinary least squares may be used as a criterion to select, among the n-1 possibilities, the best parameter values. Another word for such estimation is econometrics. It is because of this process of estimating parameters that causal models are called econometric models.

In the model above, the resulting estimated values of the five parameters b_0 to b_4 that link the various variables together are as follows (Imaoka 1990, p.70):

$$\log REMFG = 4.7257 + 0.0268 \log EXPUV59 - 0.4881 \log WMFG - 1.7535 \log PSER + 0.0353\, TYMFG$$

Apart from computation of parameter values, regression analysis is accompanied by some test statistics. The fit of this equation is 98.4 per cent. This means that values of the four independent variables specified in the regression equation explains 98.4 per cent of the value of real exports of manufactures, REMFG. The remaining 1.6 per cent is explained by other factors not accounted for by the model. Also, the relationship between the dependent and various independent variables have t-statistics ranging from 0.24 to 6.67. This is a test of the hypothesis that the true value of each b parameter is actually zero which means to say that there is actually no relationship between REMFG and the independent variable. For the regression to make sense, therefore, this hypothesis must be rejected on the basis of the t-statistics values, which it is in this case. The Durbin-Watson statistics for testing independence was 1.832. Observations used as data in regression analysis must be independent of one another which is achieved when the data sequence is not serially correlated. In this case, independence is achieved. The value of REMFG could now be calculated by simply multiplying the values of each of the four independent variables by their parameter values and then summing these four results.

The value of real exports of manufactures computed from the above equation forms part of total exports of goods and services in $million (E in Figure 25) along with other export items. E in turn forms part of real GDP in $million, RGDP along with other items. The example used above thus demonstrates how export earnings in real terms could be estimated and incorporated in the overall forecast of Malaysia's GDP.

The approach just described is a simplified form of econometric analysis in which each equation from the overall model of many equations is estimated separately from one another. A more comprehensive approach is for all the equations to be simultaneously estimated to allow interactions among the different equations to occur.

3.4.3. DISCUSSION (ALTERNATIVE ECONOMIC MODELS)

The above two are pure economic models that are popularly used in economic planning. There was little need to address environmental issues which are usually not factored in when decisions are made. A more comprehensive approach would be to deal with both economics and the environment simultaneously using a common framework. There are versions of input-output models that contain environment coefficients embedded in them. In the next chapter an example of this is given. However, tracking environmental variables on a day to day basics alongside economic indicators to look for peaks and troughs of business cycles has never been done. Does environmental changes affect business cycles? They should, especially when an economy is dependent on agriculture of other climate sensitive sectors such as tourism. This should be interesting analysis but unfortunately difficult to carry out.

If time series environmental data are available, then causal links might be explored by linking them to relevant economic variables within an existing econometric model. This would be the ultimate model built, because many of the econometric models built are simultaneous equation models containing directional as well as feedback links. By introducing environmental variables into such a model we are actually saying that economics affect the environment the environment affects the economics. But this is still a long way off because most econometric models, even before environmental integration, suffer from statistical discrepancies. With the inclusion of environmental variables it is unlikely that a model that passes all statistical test could be quickly achieved.

"Economists were invented to make weather forecasters look good." Anon.

4. INTEGRATED MODELS

4.1. APPROACH AND BACKGROUND THEORIES

Environmental impact assessments or EIAs involve the quantification and/or qualification of possible environmental degradation of the environment resulting from interruptions by anthropogenic activities. Many perceive such interruptions by way of a pressure-state-response relationship between anthropogenic impact and the environment. The central focus is the environmental model which is popularly developed as a biogeochemical cycling system. Then analysis is extended to consider perturbations to the natural cycling phenomenon when anthropogenic impacts occur.

From a somewhat different direction, some studies consider ways by which the environment could be valued and costed as an integral part of economic accounting. The motivation here is to internalise the environment which is typically regarded as an externality, because conventional accounting has been able only to incorporate elements of the market economy within its framework. The reason is values are a function of prices which exist only when there are markets for the commodity concerned. Standing stocks of forest, clean air, river water and the sea are not traded by any formal market and thus elude valuation. Nevertheless, realising the serious oversight, many studies have sought ways to estimate economic values for such environmental aspects.

However, true ecologic-economic integration is more than merely adding a component to an existing framework. Adding economic impacts to an ecological model relegates economics to a secondary role in the analytical framework. Similarly, attempting to cost environmental variables for inclusion into an economic model plays down the environmental component. Instead true ecologic-economic integration unites two complete sets of processes that could very well stand on their own. Thus, both the ecologic and the economic processes must first be independently modelled before they can be integrated. Integration is then achieved by developing two-way feedback mechanisms that interconnect both sets of processes.

In the following, a number of possible integration approaches are explored.

Most ecologic-economic input-output frameworks do not provide true integration, because only economic input-output flows are captured in the inter-sector transaction matrix. The environment is usually introduced by way of a set of residual generation coefficients that indicate ecological impacts for each of the sectors.

However, fully integrated ecologic-economic frameworks have been suggested. These have both ecological as well as economic sectors that make up the intersectoral transaction matrix. The only problem with such an arrangement is what units of measurement to use? Input-output transactions are measured by dollar inputs per dollar output. But ecological sectors have no such money equivalents. The suggestion to measure transaction flows instead by weight in place of money values could not be accommodated as weights become totally meaningless for many economic sectors. Electronics for example fetch high values despite their light weight compared to the steel industry, and services sectors such as finance and banking have no weight equivalents.

To circumvent the measurement unit problem, some studies have attempted to adopt hybrid inter-industry transaction tables. This means that the ecologic sector to ecologic sector transactions will be measured by weight, the ecologic to economic sectors flows will be in weight per dollar, the economic to ecologic sector flows in dollars per unit weight and the traditional inter-economic sector flows measured completely in dollars.

No matter how the input-output flows are organised, one must, however, be mindful of what such models are useful for. To begin with, the input-output framework is an efficient way to capture interactions among various components, i.e. sectors, that make up a system. The cell by cell entries of the input-output matrix reveal the degree of interdependence among the sectors. This has prompted studies that examine input-output relationships to identify which are power sectors as opposed to sensitive sectors. Power sectors are those that draw large inputs from many other sectors. They are important in that any change affecting them will create indirect and induced effects throughout the other sectors that make up the system. In contrast, sensitive sectors supply large inputs to many other sectors. Thus such sectors are easily affected by changes that occur elsewhere in the other sectors.

The possible close interactions among sectors of an input-output framework have also prompted several studies that attempt to measure matrices according to their degree of connectedness. Such measures allow different input-output matrices to be compared. Matrices representing different locations could be classified according to similarities and differences in connectedness. Alternatively matrices for the same location but representing different time periods could be examined to see if there is a movement towards greater connectivity over time.

However, input-output analysis is traditionally an impact assessment tool. The Leontief inverse computed from the inter-sectoral flows captures the direct, indirect and induced impacts resulting from changes to an externally defined final demand vector normally introduced as policy instruments to assess their likely impacts.

But input-output models have one serious limitation that makes its ecologic-economic integration less worthwhile. Input-output models are static. By this is meant that the coefficients that define the inter-sectoral flows are constants. Even dynamic input-output models are static in these coefficients. The difference with dynamic input-output models is they use a set of capital coefficients to generate the impacts. On the contrary, the ecology is regarded to be highly dynamic, ever changing from hour to hour and from day to day. Energy is continuously converted as is measured by carbon fluxes, leading to biological growth through carbon uptake.

In summary, input-output models provide a convenient and efficient accounting framework. Their usefulness is limited to the ability to analyse intersectoral linkages for their connectedness and, with the introduction of a final demand vector to drive the model, the total as opposed to first round impacts could also be assessed. Input-output inter linkages are static and the model contains no internal processes.

4.1.1. THE ECOLOGIC-ECONOMIC RESIDUALS GENERATION I/O FRAMEWORK (Isard)

Based on ecological extensions of standard input-output analysis (after Victor, 1972; Cumberland and Korbach, 1973; and Isard, 1971), the direct, indirect and induced impacts of C,N,P residual outputs resulting from economic final demand (i.e., income) changes are estimated as follows:

$$V' = \{V\,(I-A)^{-1}\}\,Y$$

where Y is a 11x1 column vector indicating final demand changes by the eleven sectors and V' the 11x1 column vector of C, N, P residual generation.

The mathematics (involving matrix algebra) of this is as described by de Kok (1998).

There are thus two ways of attempting to integrate ecology into the standard input-output framework. The more straightforward approach (as described by de Kok 1998), is by pre-multiplying an ecological "residuals" vector (V), with the original Leontief inverse $(I-A)^{-1}$ Y. The product indicates ecological impacts resulting from pure economic interactions embedded in the technical coefficients matrix A and policy driven changes to the economy found in the vector Y.

The limitation with this straightforward approach is that the interactive components, given as coefficients, in the model are purely economic. Ecology is crudely brought in as a transformation device that converts standard economic impacts (i.e., the Leontief inverse) into ecological impacts.

4.1.2 SIMULTANEOUS DYNAMIC I/O MODEL (Johansen)

Johansen (1974) described an interesting way of devising rates of change in an elaborate intersectoral framework. The dynamics which drive the changes are modelled based on economic theory. Conditions such as profit maximisation, depreciation, technological production functions, input-output relationships and resource allocations among sectors are imposed as a system of simultaneous equations to form the model. Dynamics are achieved by specifying each variable as a change response with respect to another variable - in other words, as derivatives. The different variables are carefully divided between their right hand and left hand sides of the equations in such a way that the number of endogenous ones are exactly equal to the number of equations in the system. The system could then be uniquely solved by exogenously providing values for the remaining variables (see Chan 1996).

Johansen's framework, like the traditional Leontief-type input-output model, presents itself as a useful planning tool. Certain variables are externally defined policy instruments which are introduced into the model to simulate outcomes, or impacts, on a variety of variables. The implications of several policy options considered for possible implementation could then be assessed. The framework could be extended to incorporate the environment by introducing equations which deal with the economic-ecologic interactions. The notion of ecological inputs used by economic production is a convenient way to meet this aim. For example, the Cobb-Douglas (1928) type production function specified as part of the equation system could be divided between ecological and economic inputs instead of the more typical division between labour and capital inputs. Comparison of an I/O model (see Section 4.1.1) and the Johansen model for the same site would be an interesting exercise.

4.1.3. THE INTERACTIVE ECOLOGIC- ECONOMIC I/O MODEL (Miller and Blair)

There are many versions of economic-cum-energy variation of this model. The one which was built for analysis in this paper is based on Miller and Blair (1985) (see also Pearce and Turner 1990). It uses revised form of matrices we will call Z*, Y* and X* in which are contained energy flows in energy units alongside industry flows in ringgit. In addition a diagonal matrix of total energy consumption, F* is established.

The following are defined:

$$\delta = F^* (X^*)^{-1} A^*$$

$$\alpha = F^* (X^*)^{-1} (I - A)^{-1} *$$

Here, X* is a diagonalised matrix of the otherwise n x 1 vector containing both energy and non-energy sectors to facilitate matrix multiplication. The resulting matrix indicated by δ shows the direct energy intensities by sectors. The matrix α shows the total energy intensities which incorporate secondary impacts made up of indirect and induced effects.

The matrices α and δ contain values identical to the A* and $(I-A^*)^{-1}$ matrices respectively except that pre-multiplication by F* and $(X^*)^{-1}$ removes the inter-industry money flows. Such flows are irrelevant here because they should be analysed under standard input-output analysis.

Regional tables expands on the national table by recording flows between sectors and between regions in the country as well (see Miller and Blair 1985). To simplify the regional table concern is only given to flows inside the region and flows with the rest of the country as another composite region.

Incorporating the environment into the input-output framework is complicated by the need to introduce an elaborate set of environmental sectors that have indicated flows among themselves and among these environmental sectors with the various economic sectors. Furthermore there is the need to resolve the units of measurement for the environmental sectors.

With the eMergy concept, the environmental component needed on the input-output table is reduced to one sector flowing out as eMergy, E_A^+ and becomes energy, E_B^-. A sketch of the input output framework is shown in Figure 26.

Figure 26. Economic-eMergetic input-output table framework.

In Figure 26, the usual inter-industry flows within the locality are entered into A and the economic investments into the energy transformation process of the local environment goes into B. In C and D are entered economic inputs affecting the rest of the country. E contains data on eMergy inputs into economic production in the locality while F records transformation losses involved from E_A^+ to E_B^-. Again G and H are meant for interactions from the locality to the rest of the country. The remaining parts of the table contain similar inputs but this time dealing either with flows within the rest of the country or from the rest of the country into the locality.

The first step to input-output analysis is to transform the above table format into what is called a technical coefficients table by dividing the column entries by gross economic output in dollar terms. The resulting entries become input-output flows per dollar of gross output. Notice that wherever the nominators are in dollars, we obtain the usual input-output coefficients. Wherever the nominators are in eMergy terms, the coefficients become monergy values. Thus from equations described above, environmental prices of the local ecosystem can be expressed as its total eMergy divided by monergy values on the coefficients table.

Beyond such descriptive indicators, standard input-output analysis procedures can be introduced from which we obtain secondary and induced impacts based on the Leontief inverse and the inter-connectedness between input and output sectors based on Rasmussen's power and sensitivity indices.

We are currently quite far from being able to implement the above framework largely because inter industry flows of any local region is unavailable and may have to be built from scratch. But once this is done, flows for the rest of the region is a matter of subtracting out the locality from data on the national input-output table. The other problem, of course, deals with data units between market dollars and environmental measurement units which should be in eMergy or monergy terms.

4.1.4. ODUM'S "EMBODIED ENERGY" (I/O) MODEL

The survey by Faucheux and Pillet (1994) indicated three main views on energy valuation. The first involves estimating the ratio of energy to money (see Odum and Odum 1981, p.44) so that we can measure money in energy terms or vice-versa. This view is a misconception because energy does not have the same properties that money has. It will be a mistake to think that energy and money are convertible from one to the other. Money can be transformed from one form of asset into another and back again. Fluctuations in money values encountered in the conversion process is not due to transformation losses (the way it happens for energy due to thermodynamic laws) but according to changing market demand and supply conditions.

The second view concerns energy theories of value which attempts to convert labour, materials, capital and all other production factors into energy terms. The limitation of this approach is that when we lose sight of the money values for these items, we also lose sight of whatever price signals that affect how these items are brought into play within the production process. Thus while an accounting of energy within the ecosystem is a useful inventory exercise it will not help us very far when we wish to incorporate economic considerations that impact on the ecosystem.

The third view leaves energy and money as distinct entities and does not attempt to replace one by the other, but attempts to relate them. Economic activities are seen as a continuous transformation of low entropy energy sources into high entropy and in the process emit irreversible waste. Responding to this transformation of energy, composite indicators are developed that show to what extent a threshold is drawing near beyond which the ecosystem will undergo a major change. The next section will discuss details of this view.

The most effective way to make an assessment of the energy fluxes found in various forms within a local ecosystem is in terms of the solar energy that was used to produce them. All energy forms found are thus standardised in relation to solar energy, which is the embodied energy denoted as eMergy contained in the various forms of energy. The principle of this approach initiated by Odum (1983) is illustrated by Figure 27.

As E_A^+, which is the embodied energy (or eMergy), is transformed through the process of economic activities into another form of energy (E_B^-) we obtain an eMergetic balance by the ratio E_B^-/E_A^+ expressed in joules by solar joules or emjoules. This ratio defines the solar transformity of E_B^- telling us the amount of E_A^+ incorporated in E_B^-. Both the first and second laws of thermodynamics are thus taken into account with respect to energy transformation and losses. The degree of solar transformity thus serves as a qualitative description of the ecosystem being assessed. The biomass of the local ecosystem expressed in E_A^+ emjoules indicates the amount of solar energy that had gone into generating this ecosystem.

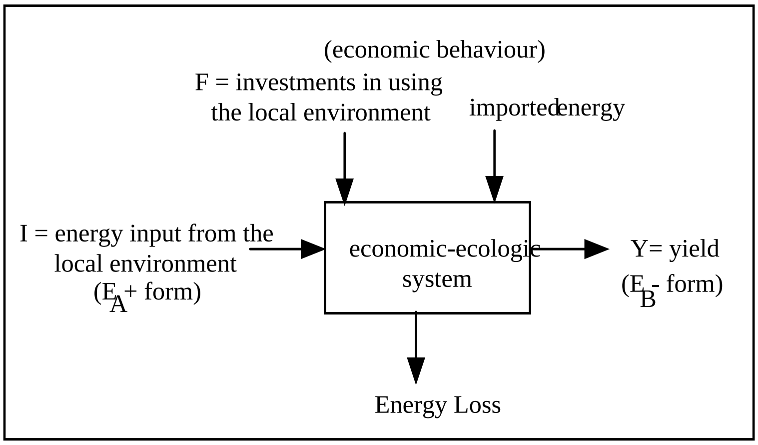


Figure 27. eMergy-energy relationship.

To attempt bridging what we know of the energy state of the ecosystem, in terms of the degree of transformity, with economic production, another term called monergy is introduced (see Pillet 1994).

monergy = [eMergy^{nation} (emjoule)] / GDP($)

This is a macroeconomic indicator which relates the total energy state of the country i.e., eMergy in emjoules against the total economic production of the country in dollars.

Our intention is to estimate the unknown ecological price for a given hectare of land, say located within our study area, for a given year. If we assert that this price, $P_I(\$)$, in proportion to the country's total income, GDP($), is exactly equal to the proportion of the energy inventory of that hectare of land to the total energy state of the country, that is:

$$P_I(\$) / GDP(\$) = eMergy^{local}(emjoule) / eMergy^{nation}(emjoule)$$

then, we can obtain an estimate of $P_I(\$)$ as follows:

$$P_I(\$) = GDP(\$) . eMergy^{local}(emjoule) / eMergy^{nation}(emjoule)$$

$$P_I(\$) = eMergylocal(emjoule) . GDP(\$) / Mergy^{nation}(emjoule)$$

$$P_I(\$) = eMergy^{local}(emjoule) . 1 / monergy$$

In other words, if we can separately estimate the monergy of the country and if we perform an energy inventory of the local ecosystem in eMergy terms, we will be able to estimate the price of the local ecosystem, $P_I(\$)$.

4.1.5. BIOECONOMIC RENEWABLE RESOURCE MODEL (Wilen)

It is the formal introduction of economic principles that makes a model an economic model. Essentially, an economic system like its biogeochemical counterpart, is a process that occurs through time as a result of the behaviour of various components that interact within the system. "Bioeconomic" models have been applied in various settings, notably in fisheries and forestry economics.

Take, for instance, the extraction of natural resources for economic purposes (Wilen 1985). Two systems, the economics and the environment collide, each forced to take the other into account. The Merbok mangroves form an example. The mangrove trees would have grown naturally undisturbed if they were not of economic value. But once some of the trees are unnaturally removed, the remaining standing stocks of mangrove will see very different biogeochemical dynamics. Thus, when modelling the mangrove ecology, this anthropogenic disturbance factor cannot be ignored.

From the purely economic perspective, mangrove extraction has to yield maximum revenues. But this cannot be achieved without taking the natural growth rates of mangroves into account. In other words, the economic model that analyses revenue maximisation has to make a reference link to the biogeochemical model of mangrove growth. Thus, as far as the Merbok mangroves are concerned, ecology and economics are not two but one system as they are interdependent on one another.

4.1.6. INTEGRATED MODEL COMPARISON

The models discussed above are essentially "weak" integration models for linking elemental ecological and economic modelling approaches. Five approaches to integrated ecologic-economic modelling have been suggested and their applicability is summarised in Table 11.

The first (here called the Isard) model is essentially the Victor-Cumberland-Isard I/O framework model which was popularly applied during the late sixties and early seventies. It was presented by Douglas McGlone at the 1997 Open Science Meeting and subsequently discussed in Bolinao for application in this SWOL project (LOICZ 1997). It uses standard input-output technology coefficients (or economic interactions) that describe flows among economic sectors but imposing a matrix containing ecologic residuals (pollutants per dollar output) to estimate direct, indirect and induced ecological impacts resulting from changes in future economic demands or incomes.

In the second (Johansen) model, the equations that establish interactions among the relevant variables are differentiated with respect to time to produce rates of change relationships. These form the simultaneous system of equations which is solved by matrix algebra because the system is specified (the number of equations exactly match the unknown variables).

Table 11. Comparison of the five integrated ecologic-economic models.

Suggested ecologic-economic model	Ecol-econ. residuals generation model (Isard)	Simultaneous ecol.-Econ. Model (Johansen)	Interactive ecol.Econ. model (Miller and Blair)	Odum's "embodied energy" model	Bioeconomic renewable resource model (Wilen)
1. Capture processes and interactions	Yes	Yes	Yes	Yes	Yes
2. Address changes through time	No	Yes	No	No	Yes
3. Ecological behaviour mechanism	Yes/No	No	Yes	Yes	Yes
4. Economic behaviour mechanism	Yes	Yes	Yes	Yes	Yes

In the third (Miller and Blair) model, the ecological aspect is incorporated in an interactive manner.

The Isard and the Miller and Blair models attempt to incorporate the ecological aspects into the I/O model. There are two ways of attempting to integrate ecology into the standard input-output framework. The more straightforward approach (as described by de Kok), is by premultiplying an ecological "residuals" vector by the original Leontief inverse $(I-A)^{-1}Y$. The product indicates ecological impacts resulting from pure economic interactions embedded in the technical coefficients matrix and policy driven changes to the economy.

The limitation with this straightforward approach is that the interactive components, given as coefficients, in the model are purely economic. Ecology is crudely brought in as a transformation device that converts standard economic impacts (i.e., the Leontief inverse) into ecological impacts.

A more complete extension of the input-output framework to incorporate ecological variables would be to expand the interactions matrix to contain both economic as well as ecological components (as in the Miller and Blair model). This way there will be coefficients that will relate economic sectors with other economic sectors, economic sectors with ecological sectors in the form of residuals production, ecological sectors with economic sectors in the form of resource utilisation, and pure ecological interactions. The problem that has to be overcome if such an interaction matrix is to be built concerns the units of measurements from which input-output coefficients will be calculated. Traditional input-output tables record dollar flows among economic sectors which is not possible with ecological sectors. Pure ecological interactions can be described using mass but what about interactions between economy and ecology? Hybrid measurements may be required.

Both the Isard and the Miller and Blair models do not capture the time component (i.e. they are static models). The second (Johansen) model captures the time component but does not capture the ecological behaviour.

Isard's model also does not formally incorporate ecological behaviour. Ecological components are introduced merely as coefficients relating economics and the ecology.

The fourth (Odum's) model, attempts to capture the flow of energy in the opposite direction each time money is made through the transformation of materials from one stage of production to the next. Thus energy and money are two sides of the same coin, any one cannot be obtained without affecting the other. Unfortunately this model is static.

The fifth (Wilen bioeconomic renewable resource) model, is a function of time. Economic returns are also timed and these are adjusted to their present values (because they are received at different points in time under different harvest scenarios) so that they can be compared for their maximum values. Here, the trade-off is faced by either (a) increasing each harvest by waiting for biomass to grow (but in the process achieving fewer harvests throughout) or (b) increasing the number of achievable harvests by harvesting frequently (but the value of each harvest is reduced accordingly).

Presently we have only been able to implement the Isard model (Sections 4.1.1 and 4.2) and one aspect of the Wilen bioeconomic renewable resource model (Sections 4.1.5 and 4.3).

4.2. IMPLEMENTATION OF THE ECOLOGIC-ECONOMIC I/O MODEL (ISARD) IN THE MERBOK MANGROVE CATCHMENT

The Input-Output Tables for Malaysia in 1978 (Malaysia, Department of Statistics 1978) and 1983 (Malaysia, Department of Statistics 1983) were used. The latest available was for the year 1987 but this table had a different format rendering it incompatable with the earlier tabulated information. Malaysia's input-output tables were based on 60 sector commodities as well as 60 sector industries, and broken down into domestic and imported inter-sectoral flows. For our evaluations, the sectors have been reduced to 11 (see Section 3).

The corresponding entries of the Leontief inverse matrix, i.e. $(I-A)^{-1}$, found in the national table were extracted to form the 11x11 inverse matrix representing the Merbok estuary. Estimations of the values making up the 11x3 V matrix (comprising carbon, nitrogen and phosphorus residuals) resulting from per ringgit output of mangrove extraction, rice cultivation, and prawn aquaculture are outlined below.

4.2.1. ESTIMATION OF C, N and P RESIDUALS

The C, N and P residuals obtained here are order of magnitude estimates (or perhaps more correctly, "best guesstimates") based on limited knowledge, assumptions and data, where available. Details of the calculations involved are shown for only some of the more important sectors.

4.2.1.1. Agriculture

Agricultural crops includes rice, rubber, oil palm and some fruit orchards. Rice is the main crop and is used here as representative of agriculture. According to the World Health Organization (1993), for one tonne of rice produced, 800 kg of putrescible material result. Presumably, the remaining 200 kgs consist of rice grains. Thus, 1 kg of rice grain produced has an accompanying 4 kg of putrescible material. We assume the same C, N, P concentrations as for mangrove litter.

Rice costs RM 2.00 per kg. Therefore, for a one ringgit output of rice, the C, N and P produced are 1.018 kg, 0.012 kg and 0.0014 kg respectively. This is an underestimate because the N and P contained in fertilisers are not included, but this may be compensated by the lower residuals from rubber and oil palm cultivation.

4.2.1.2. Fishing
Fishing include capture fisheries and cultured fisheries. At least 20% of the mangroves in the Merbok has been converted to prawn culture ponds. There is input of fish from outside the estuary (in the form of trash fish) used for feeding fish in the cage culture system within the estuary. The prawn pond activity is used as indicative of the residuals from the fishing industry.

Only the feed is considered here - an underestimate as fertilisers would contribute to the C, N, P. Twenty tonnes of dry feed would result in 10 tonnes of prawn wet weight. "Guesstimates" of the composition of the feed is 70% C, 10% N and 0.5% P.

1 kg of prawns costs RM 30. Therefore, for a ringgit output of prawns, the C, N, P produced are 0.0462 kg, 0.0066 kg and 0.00033 kg respectively. (This assumes that all the food supplied is eaten by the prawns but if there is excess food then this is an underestimate of the residuals).

4.2.1.3. Forestry
Forest harvests include those from inland forests (mainly on the lower slopes of Gunung Jerai) as well as from mangrove forests. The residuals are estimated based on the mangrove forest litter.

The C, N, P concentrations of mangrove leaf litter (Gong *et al.*, 1984) were used, namely C = 50%, N = 0.6% and P = 0.07% of dry weight. 2 tons of dry trunk converts to 1 ton of charcoal; and 0.8 ton of slash (about one-third of the tree biomass) is left behind in the forest.

1 kg of charcoal cost RM 0.50. Therefore, for a ringgit output of charcoal, the C, N, P produced is: 0.8 kg C, 0.0096 kg N and 0.0011 kg P.

4.2.1.4. Other Sectors
The other sectors are:
mining (there is very little mining activity: practically all of the mining is for sand), **manufacturing 1** (there is a relatively new light industrial estate situated at Tikam Batu which is dominated by the electronics industry so the residuals are based on this)
manufacturing 2 (this is a mainly wood-based furniture manufacturing industry so the residuals would be mainly derived from wood waste)
electricity generation (electricity comes from the national grid and relatively little is generated locally)
water supply (most of the potable and industrial water come from the Muda River which is more than enough to supply the whole of the State of Kedah)
construction (most of the construction is related to the housing industry and is concentrated around the main town of Sg. Petani)
transport (much of the public transport is serviced by buses; material transport is also mainly via roads rather than via rail), and
other services (this being small scale enterprises like stalls, eating places, vehicle servicing and cottage industries).

The C, N and P residuals are guesstimates based on the labour force contribution of each sector (Table 12) and the three sectors where better estimated are available. It is thus noted that these values are preliminary "order of magnitude" estimates.

Table 12. Allocation based on labour force, Kuala Muda District Council (1991) Structure Plan 1990 -2000.

	1995	**2000**
Agriculture	15.80	10.30
Fishery/Aquaculture	2.80	0.18
Forestry and Hunting	0.03	0.01
Mining and Quarrying	0.20	0.01
Manufacturing 1	3.70	4.80
Manufacturing 2	33.40	44.00
Electricity and Gas	0.60	0.56
Water Supply	0.80	0.75
Construction	6.90	8.10
Transport	2.70	2.45
Others	28.10	28.70

The C, N and P residuals for all the 11 sectors for the Sg. Merbok are shown in Table 13.

Table 13. C, N and P residuals for the Sg. Merbok by economic sectors.

kg/RM1 output	**C**	**N**	**P**
Agriculture	1.01819	0.01200	0.00140
Fishing	0.04620	0.00660	0.00033
Forestry	0.80000	0.09600	0.00112
Mining	0.00100	0.00010	0.00001
Manufact. 1	0.01000	0.00150	0.00070
Manufact. 2	0.08000	0.00090	0.00030
Electricity	0.00300	0.00030	0.00003
Water	0.00600	0.00060	0.00006
Construction	0.01000	0.00100	0.00010
Transport	0.00300	0.00030	0.00030
Other services	0.06000	0.00900	0.00050

4.2.2. RESULTS

As stated in Section 4.1.1, the direct, indirect and induced impacts of C,N,P residual outputs resulting from economic final demand (i.e., income) changes are estimated as follows:

$$V' = \{V (I-A)^{-1}\} Y$$

where, Y is a 11x1 column vector indicating final demand changes by the eleven sectors, and V' the 11x3 column vector of C,N,P residual generation.

Three sets of calculations were made. The first was based on the total flows between sectors using the 1983 National I/O table and the second taking into account only domestic flows (i.e., subtracting out inter-sectoral flows of imported items), also using the 1983 table (Table 14). The difference in multipliers between these two sets of calculations (Table 16) show impacts that will occur externally as opposed to impacts occurring locally. A third set of calculations was conducted based on domestic flows and an updated 1987 National I/O table. The difference in multipliers between this and the second run (shown in Table 14) shows the technological/cultural shifts which indicate whether impacts have become more or less intense for each ringgit change in the respective sectors (Table 16).

For convenience, Y was defined iteratively in the form (1,0,...,0)', (0,1,...,0)' and (0,0,1,...,0)' and signifying one ringgit change in the final demand for each sector one at a time, with no changes elsewhere. By specifying the Y vectors in this fashion, the resulting impacts (V') are called multipliers or total impacts per ringgit change in the respective sectors.

Table 14. The total and domestic generated C, N and P residuals for 1983 for the Sg. Merbok system.

	C,83(Total)	N,83(Total)	P,83(Total)	C,83Dom	N,83Dom	P,83Dom
Agriculture	1.037635	0.012253	0.001433	1.033846	0.012208	0.001431
Fishing	0.050483	0.006709	0.000341	0.048290	0.006682	0.000343
Forestry	0.820620	0.009944	0.001181	0.814166	0.009815	0.001155
Mining	0.003172	0.000179	0.000030	0.002544	0.000180	0.000025
Manufact. 1	0.026431	0.002833	0.001281	0.012390	0.001605	0.000740
Manufact. 1	0.188484	0.002261	0.000477	0.172330	0.002044	0.000443
Electricity	0.006867	0.000444	0.000066	0.004726	0.000363	0.000045
Water	0.014326	0.000963	0.000155	0.009818	0.000774	0.000094
Construction	0.038971	0.001565	0.000239	0.032441	0.001340	0.000164
Transport	0.008916	0.000488	0.000382	0.005194	0.000371	0.000329
Other services	0.070726	0.009190	0.000528	0.063125	0.009082	0.000511

Table 15. The domestic generated C, N and P residuals for 1987 for the Sg. Merbok system.

	C,87Dom	N,87Dom	P,87Dom
Agriculture	1.040822	0.012278	0.001435
Fishing	0.050483	0.006709	0.000341
Forestry	0.048915	0.006667	0.000337
Mining	0.002601	0.000187	0.000074
Manufact. 1	0.011973	0.001560	0.000720
Manufact. 1	0.174553	0.002063	0.000448
Electricity	0.004775	0.000352	0.000041
Water	0.009532	0.000746	0.000082
Construction	0.045997	0.001490	0.000176
Transport	0.006219	0.000415	0.000336
Other serv.	0.064020	0.009091	0.000514

Table 16. The difference between total and domestic generated C, N and P residuals for 1983 and the difference between the 1987 and 1983 domestic generated C, N and P residuals for the Sg. Merbok system.

	C,83Tot-Dom	N,83Tot-Dom	P,83Tot-Dom	C,87-83 Dom	N,87-83 Dom	P,87-83 Dom
Agriculture	0.003789	0.000046	0.000002	0.006976	0.000070	0.000004
Fishing	0.002194	0.000028	-0.000002	0.002194	0.000028	-0.000002
Forestry	0.006454	0.000129	0.000027	-0.765251	-0.003148	-0.000818
Mining	0.000628	-0.000001	0.000005	0.000056	0.000007	0.000049
Manufact. 1	0.014041	0.001228	0.000541	-0.000416	-0.000046	-0.000019
Manufact. 1	0.016155	0.000216	0.000035	0.002224	0.000019	0.000005
Electricity	0.002141	0.000081	0.000021	0.000049	-0.000011	-0.000005
Water	0.004508	0.000189	0.000060	-0.000286	-0.000028	-0.000012
Construction	0.006530	0.000225	0.000075	0.013556	0.000151	0.000012
Transport	0.003722	0.000117	0.000053	0.001025	0.000045	0.000007
Other services	0.007601	0.000108	0.000017	0.000895	0.000009	0.000003

In the above tables (Tables 14, 15, 16), each row shows the C, N and P impacts for a one ringgit change of final demand in the respective sectors. The various columns show results from using data based on: the 1983 total technological inverse incorporating both domestic and imported flows; the 1983 domestic flows only (Table 14); and differences between the two (Table 16). The differences show the likely over-estimation of impacts if imported flows were not to be set aside, because the inter-sectoral interactions that generate impacts by imported flows do not occur within the local vicinity. The differences between the 1987 and 1983 domestic impacts have also been included in Table 16. This shows impact changes resulting from technological transitions that occurred between 1987 and 1983. Further understanding of the characteristics of such technological transitions will help us model changes to the matrix and help overcome the inherent static nature of input-output models.

Returning to the economic planning application of input-output model described in Section 3.3.1, a Y matrix was introduced as a policy variable to assess the economic impacts on gross-output, X. By introducing the V residuals vector, the economic impacts is translated to indicate ecological impacts. Based on the same policy vector that was used, the C, N, P residual generation was produced (Table 17). Here, the Y vector that drives the impacts X may be specified as a one-sector-one-ringgit change in final demand or as an externally defined set of sector by sector final demand changes in actual ringgit. Whether one or the other is used, it is important to take note that the inter-sectoral interactions (contained in the A matrix) as well as the sectoral final demand changes (in the Y matrix) are entirely defined in pure economic terms. In other words, no ecological interactions are captured by the current model nor is the model driven by any ecological factors. The only ecological components which are found in the V vector is a set of coefficients that translates pure economic impacts into anticipated ecological impacts based on the coefficient values of V.

Table 17. The all sectors (total inverse and domestic inverse) and the difference between total inverse and domestic inverse of generated C, N and P residuals for the Sg. Merbok system.

	C	N	P
All Sectors (Total inverse)	8806	2957	115
All Sectors (domestic inverse)	4536	2649	92
Difference	4270	307	23

4.3. BIOECONOMIC RENEWABLE RESOURCE MODEL

In terms of real output, the Malaysian team was able to take a positive first step with a simple integrated economic and biological growth model. This is described in our paper "An ecologic-economic model for more optimal management of mangrove timber extraction." submitted to *Ecological Economics* (Chan *et al.* submitted).

4.4. DISCUSSION

Five integrated models were considered (see Section 4.1.6) and the first four of these can be run on the I/O framework. Unfortunately, none of these satisfies all the conditions for a good model. So far, only the first (Isard) model has been implemented but this suffers from the fact that the C, N and P residuals of each of the 11 economic sectors are at best, order of magnitude guesstimates, with limited confidence in the estimates. The model also suffers in that the ecological component is not interactive. The next logical step would be to proceed to the interactive ecologic-economic model (Miller and Blair). There is still the short-coming of it being a static model which can only be overcome if this can be combined with the Johansen simultaneous model. There is thus much conceptualising to be done.

The fifth model (Bioeconomic Renewable Resource Model) satisfies all the modelling conditions but is not based on the I/O framework. The problem with the fifth model is that it does not include the entire ecosystem; only subsections of the ecosystem. It is necessary to eventually integrate the sub-systems into a model that includes the whole ecosystem. Presently, one sub-system (mangrove charcoal production) has been implemented and it would be logical to follow this up with pond prawn production, fish cage culture production, bag-net fishery production and other production sub-systems in the Sg. Merbok. The difficult part will be to link up the various sub-systems to represent the whole ecosystem.

5. CONCLUSIONS and RECOMMENDATIONS

Mangrove and salt marsh workers have long known that determining material fluxes from coastal ecosystems is an extremely difficult task (e.g., Nixon, 1980). For this SWOL project the approach agreed between the groups was the LOICZ stoichiometric budget method. This is basically a "first-order estimation" method and whilst it may be useful in providing a first global picture (once there is data from enough sites, globally), it must be borne in mind that the method may not be universally applicable. Our group has been working on the flux problem (as part of our long term objective of closing the carbon and nutrient budgets for a mangrove ecosystem) and will continue to explore other methods and approaches that will bring increased confidence in flux estimates.

The present integrated model that has been implemented by all four SWOL project groups is the Isard Ecologic-Economic I/O Framework Model (the first of the models in our comparison Table 11). There are two major limitations to using this model; first, it does not address changes through time (i.e., it is a static model) and second, it is not interactive in terms of ecological behaviour.

Although C, N and P residuals are "guesstimated" and fed into the model (V), the output has very limited ecological significance. The second limitation may be overcome by using the Interactive Ecologic-Economic I/O Framework Model (the Miller and Blair model in our comparison Table 11) but the model will remain static and thus have little predictive value.

The Simultaneous Dynamic Model (Johansen) (the second of the models in our comparison Table 11) overcomes the static nature of the I/O approach but cannot capture the ecological behaviour. If we still want to pursue the I/O approach, we should look into the possibility of combining the Interactive Ecologic-Economic I/O Framework Model with the Simultaneous Dynamic Model, if this is possible. It should also be possible to incorporate Odum's Embodied Energy Model especially when dealing with energy and carbon. However, data for this may be difficult to obtain and both the monitoring and energy units will not remain fixed, but change through time.

The only model that fulfils all four attributes is the Bioeconomic Renewable Resource model (the fifth of the models in our comparison Table 11). We have started pursuing this line and have submitted a paper (modelling charcoal production) to Ecological Economics. We are continuing along this line to model pond prawn production, floating fish cage production, bag-net fishery production with the goal of perhaps bring all these various sub-components of the ecosystem together into an integrated ecologic-economic model of the entire ecosystem.

The biogeochemical aspect formed a major part of this project. All four SWOL groups have expended considerable effort in obtaining C, N and P budgets using the LOICZ Stoichiometric Model. One major concern about the present project is that data (which is at least a good order of magnitude more reliable than those guesstimated as C, N and P residuals for each of the economic sectors) from this aspect has not been used in the (Isard) integrated ecologic-economic model.

Finally, we note that the sociological aspect is at present almost completely lacking. The weakness in current government statistics on economic production compiled for measuring gross domestic products (GDP) of national economies is that they fail to incorporate households and informal (petty trading) sectors which are also involved in production. In certain developing economies, both of these neglected sectors can be many times larger than the formal production sectors. When attempting to address the anthropogenic activities in more pristine ecosystems that make up SWOL study sites, this absence of the informal and household sectors becomes a more critical issue, because only a small proportion of the economic activities is captured and compiled in the national accounts statistics.

Thus, when putting together input-output tables to represent anthropogenic activities in the individual SWOL sites, some effort must go into dealing with the above inherent weakness. It may amount to adjusting available data obtained from government statistical sources or through ground-up field evaluation. When doing this, be mindful that economic production in money terms that is meant to be captured and entered into the input-output table is but an outcome of social and cultural processes that interplay in the respective study sites. Figure 21 describes how the different processes connect. Religious beliefs, local traditions and preferences, among other factors, factor in through these processes and result in the quantity and quality of economic production that are observed in these study sites. We refer to these as local dynamics that work in different ways for the formal, informal and household sectors. Such dynamics also lead to not only flows within and among these three divisions of sectors in input-output fashion, but also between all these sectors collectively with economic activities and ecological processes occurring outside the ecosystems of these sites. Such interactions between the site location and the outside represent import and export flows. These external flows become critical when we begin to address the issue of long term sustainability, questioning whether the study site is actually a net contributor or net consumer of both ecological and economic resources used for production.

For the next phase of this project, the recommendations are as follows:

1. The biogeochemical study, using additional approaches, should be continued with the aim of developing a robust set of C, N and P budgets for the ecosystem. This is a vital exercise on its own (for system understanding and for management of changes due to anthropogenic external forcing), even if it cannot be integrated in the integrated models.

2. The integrated biogeochemical-socioeconomic modelling study should also be continued, first by making the ecological behaviour more interactive (using the Miller and Blair model) and then by combining with the Johansen model to add the time component. This would provide vital comparisons for assessment approaches (and additional cost-benefit of the research). It may not be possible to implement all the models but this will be a very useful conceptualisation exercise.

3. The Bioeconomic Renewable Resource Model should also be pursued by adding more sub-production systems, and eventually an attempt should be made to integrate the sub-systems into a whole ecosystem model. Here, socio economic changes and "residuals" can be linked as drivers to the biogeochemical models for system response description and scenario-building to assess land-use practices and land-use changes.

4. The sociological aspect should be very much part of any integrated model. The next phase of the study would therefore explore the social dimension identifying local social institutions and local social organisation that shapes the use of resources.

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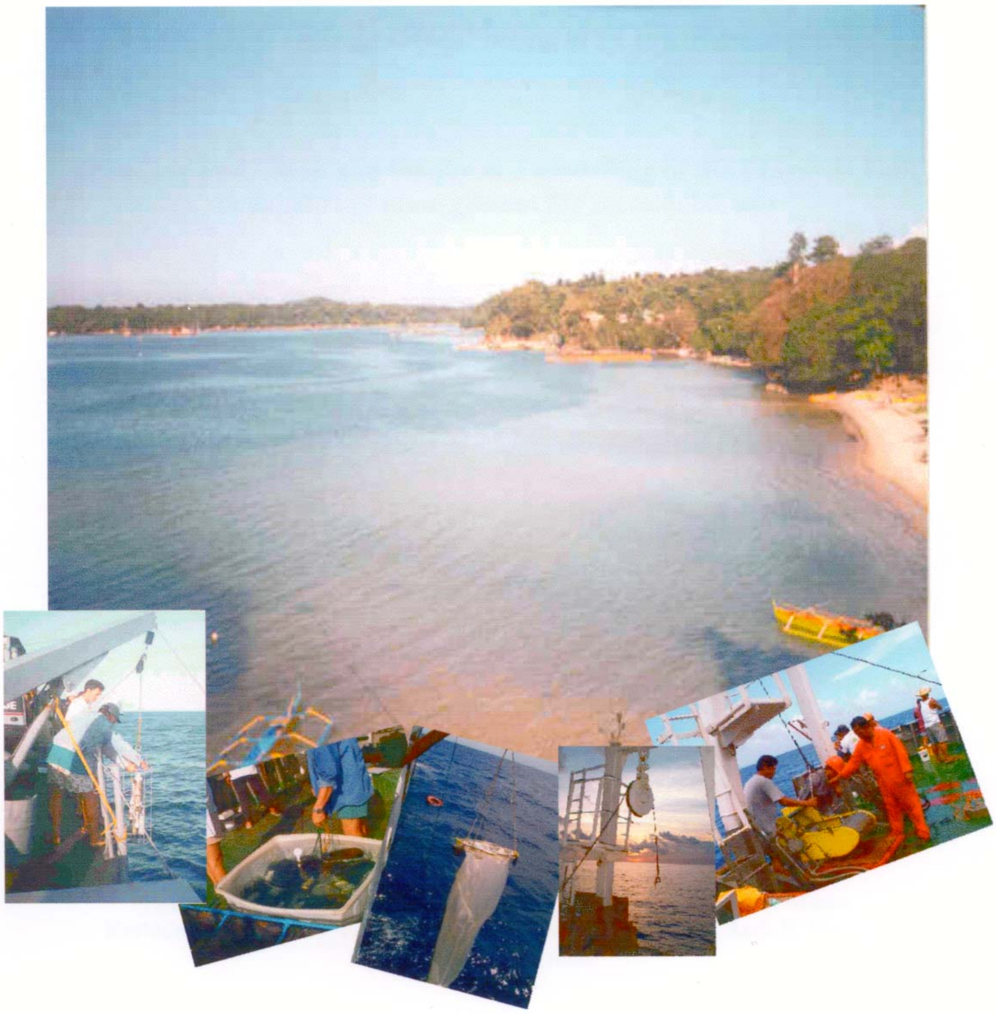
SARCS/WOTRO/LOICZ PHILIPPINES CORE RESEARCH SITE

1996-1999 FINAL REPORT

Economic Evaluation and Biophysical Modelling of the Lingayen Gulf in Support of Management for Sustainable Use



Marine Science Institute, University of the Philippines
October 2000

SARCS/WOTRO/LOICZ Philippines Core Research Site

1996-1999 Final Report

Economic Evaluation and Biophysical Modelling of Lingayen Gulf in Support of Management for Sustainable Use

Research Team

Dr Liana Talaue-McManus, *Principal Investigator*
Roberto S. Clemente, *Hydrologist*
Prof.Edgardo Gomez, *Coordinator*
Dr Wlifredo Y. Licuanan, *Marine Ecologist*
Mr Douglas McGlone, *Economic Modeller*
Dr Maria Lourdes San Diego McGlone, *Chemical Oceanographer*
Dr Fernando P. Siringan, *Marine Geologist*
Dr Cesar L. Villanoy, *Physical Oceanographer*

Research Associates

Charina Lyn. A. Amedo   Leah N. Asuncion   Jack B. Barajas
Herminia R. Caringal   Charisma G. de Castro   Vilma S. Dupra
Elizabeth Francisco   Zenon Richard P. Mateo   Daisy O. Padayao
Kathleen M. Silvano   Edwin N. Wilson

Collaborating institutions

Marine Science Institute, University of the Philippines
National Institute of Geological Sciences, University of the Philippines
Environmental Science Program, University of the Philippines
Department of Biology, De La Salle University

Marine Science Institute, University of the Philippines, Quezon City
October 2000

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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.

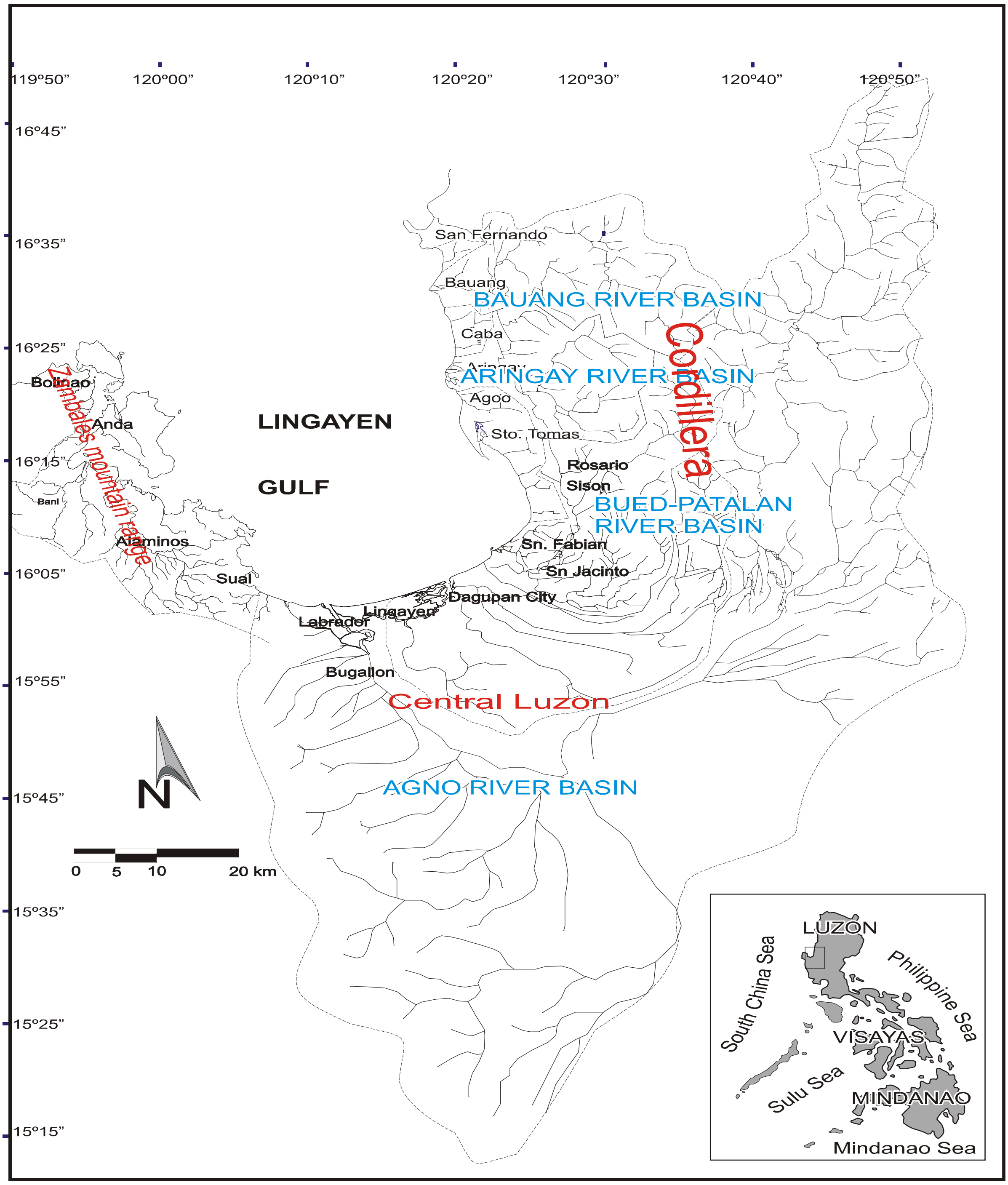


Figure 1. Watershed map of Lingayen Gulf with political boundaries.

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.

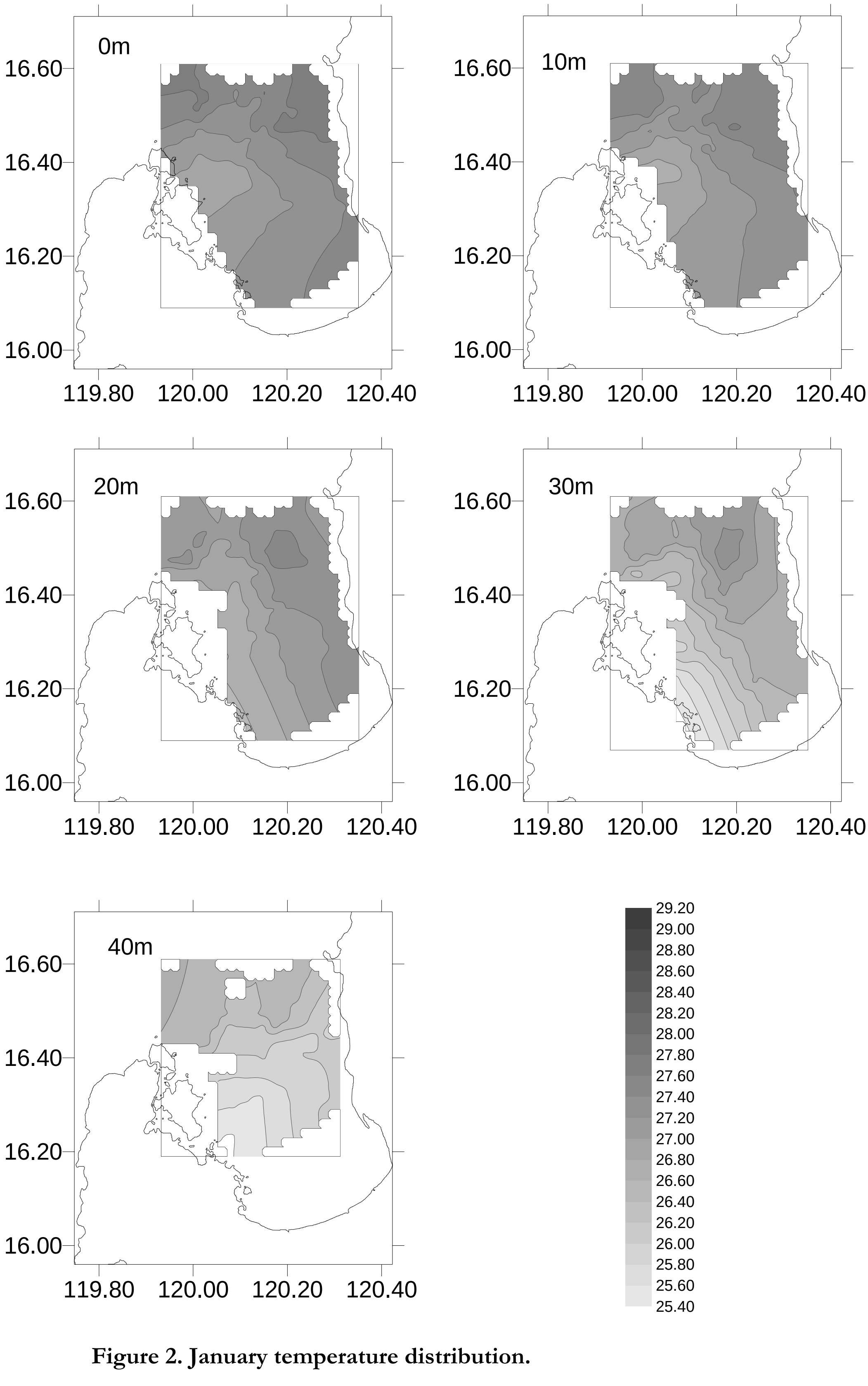


Figure 2. January temperature distribution.

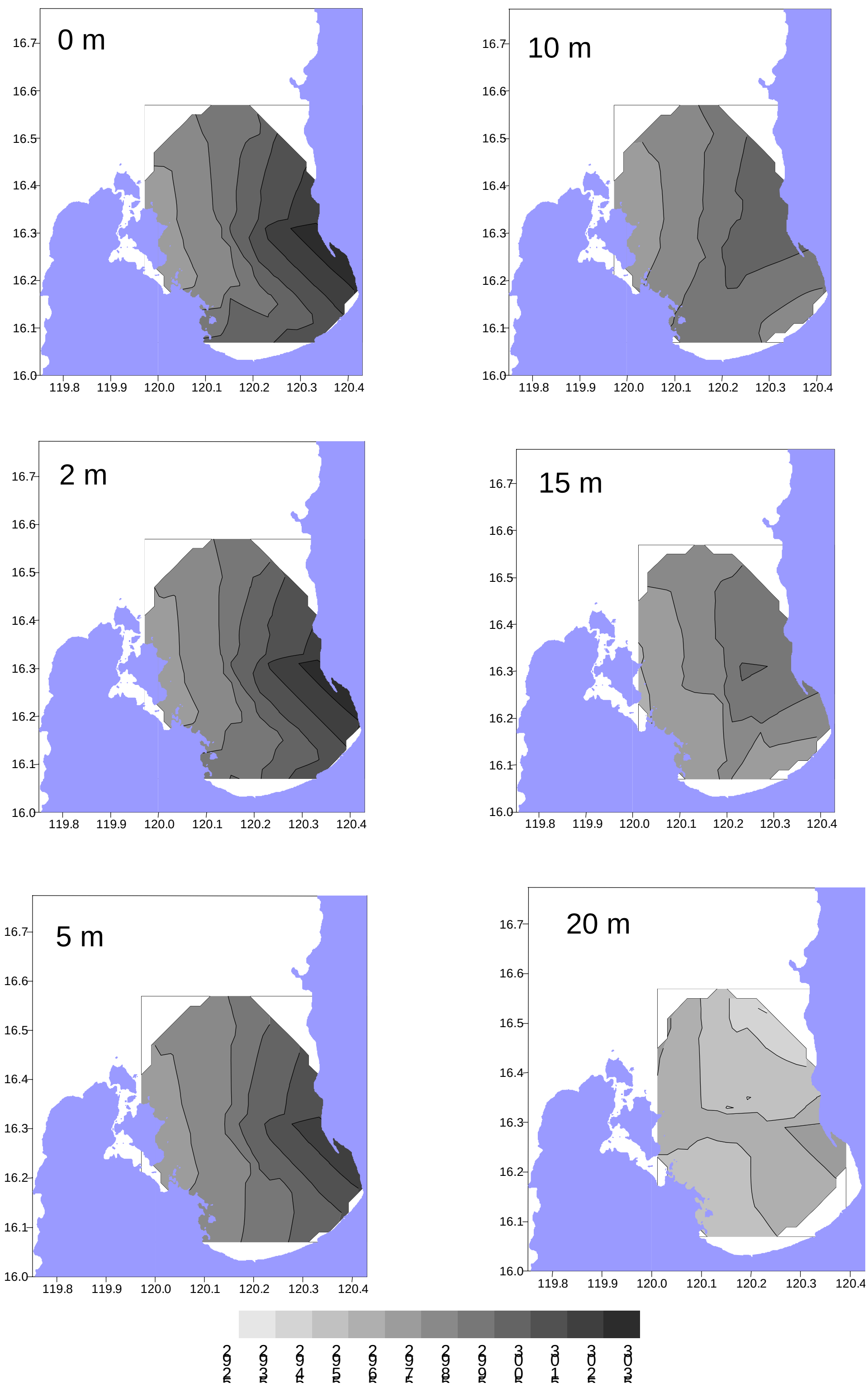


Figure 3. July temperature distribution.

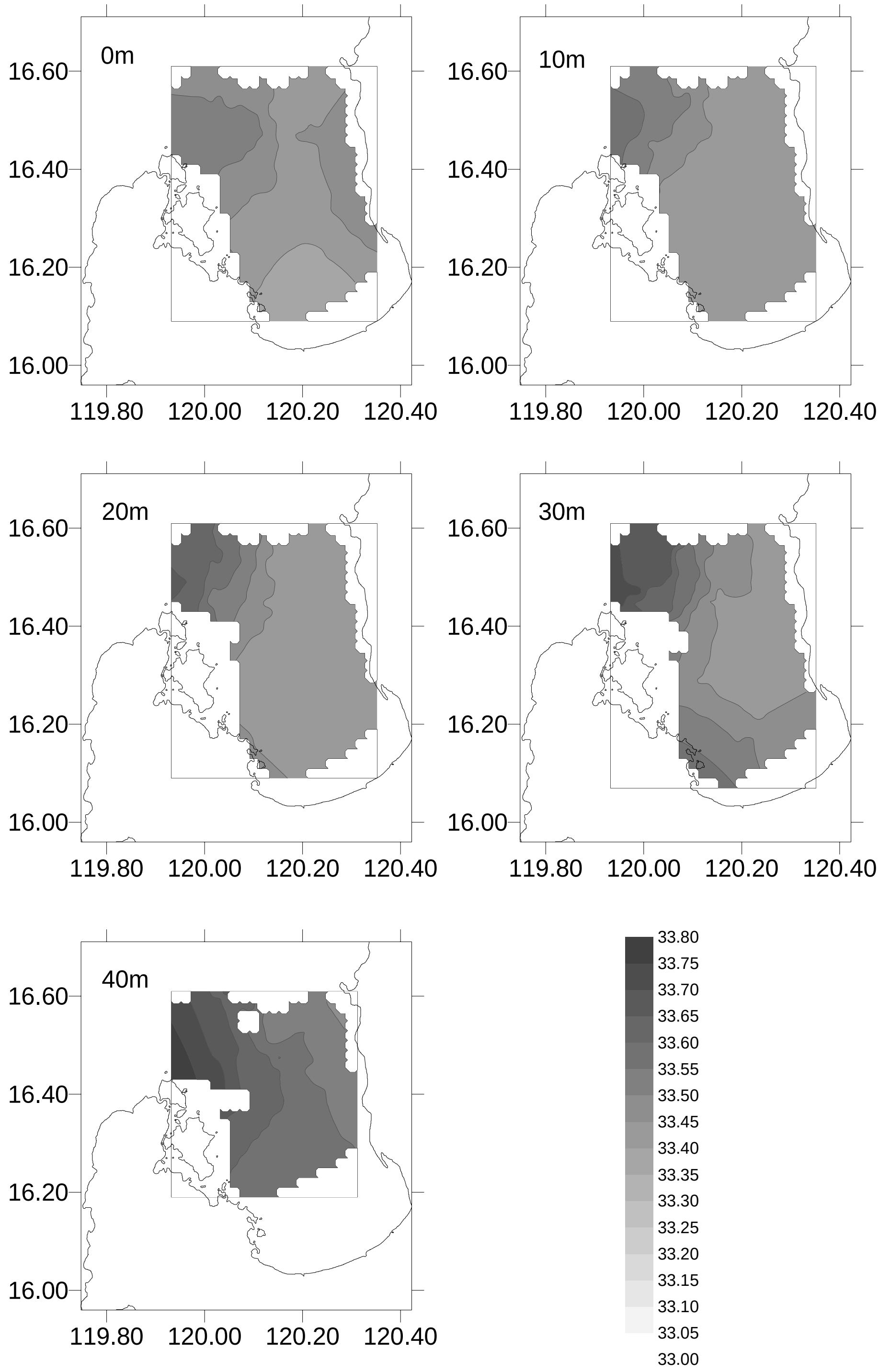


Figure 4. January salinity distribution.

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.

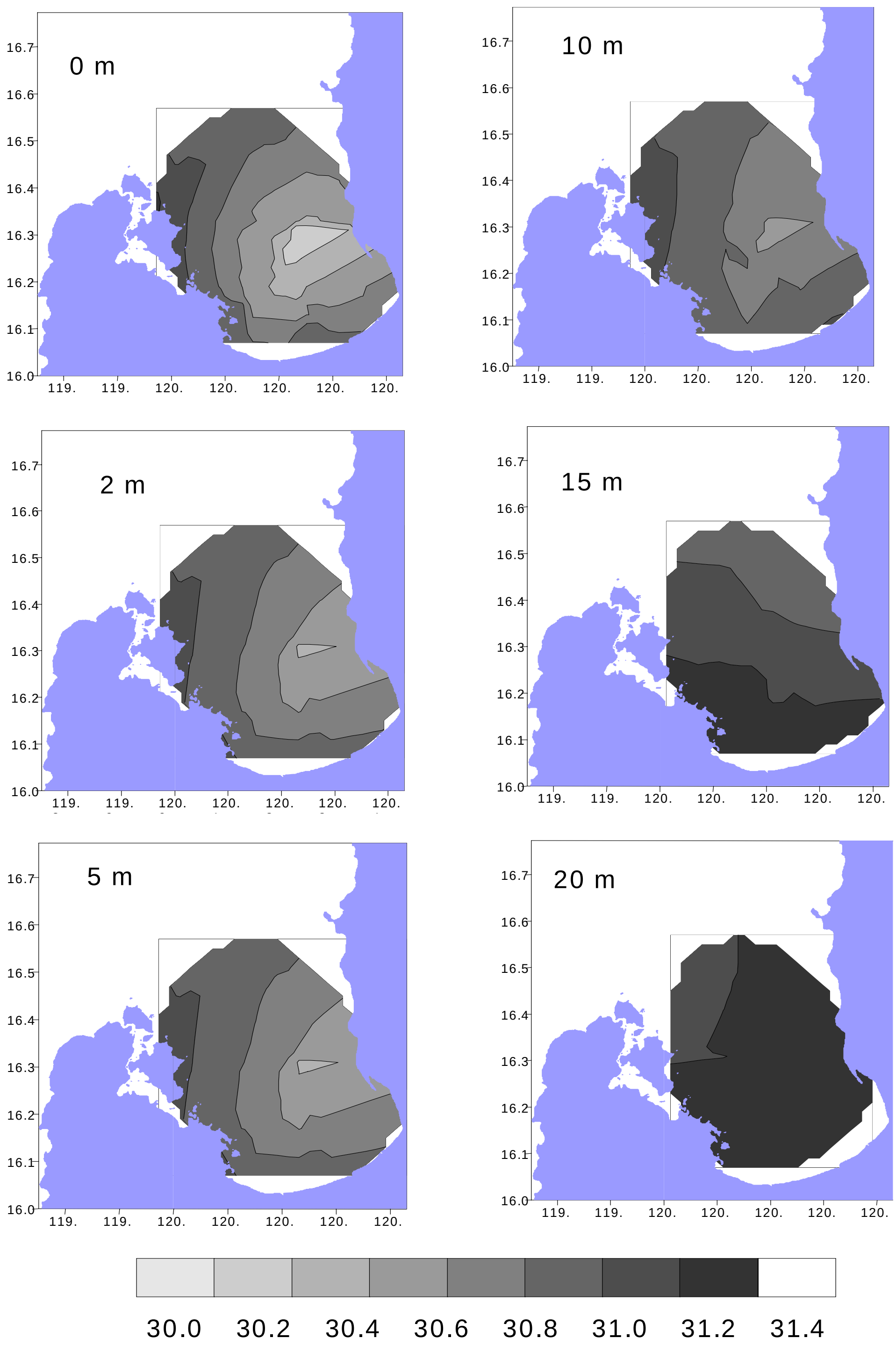


Figure 5. July salinity distribution.

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.

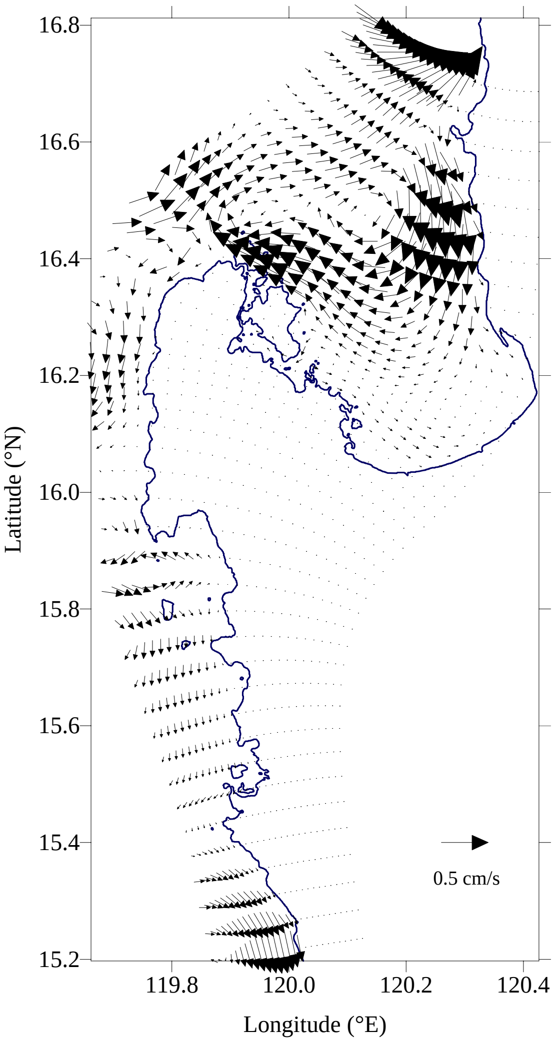


Figure 6. Velocity plot of tidal residual current velocity averaged over a spring-neap cycle.

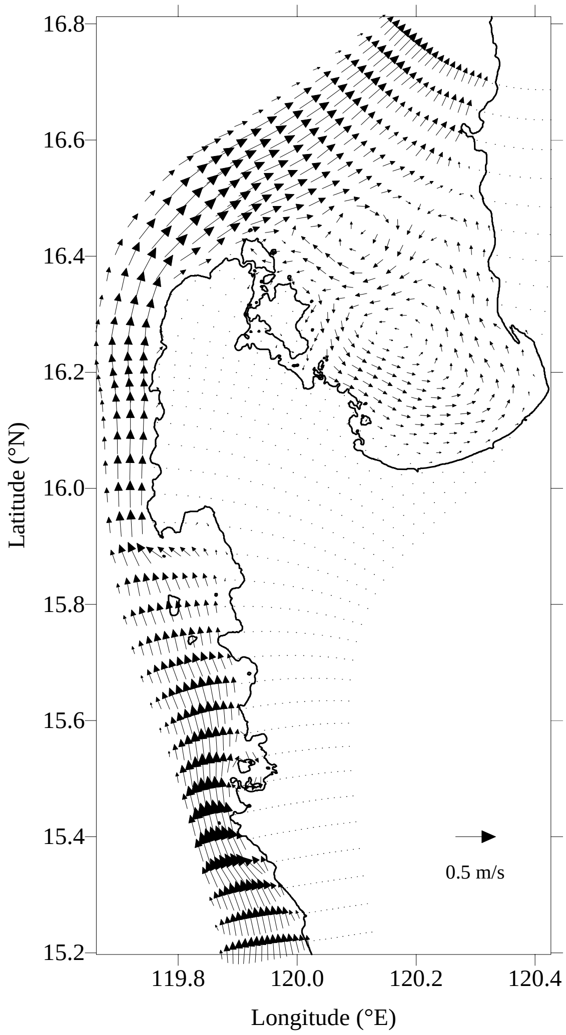


Figure 7. Velocity-averaged currents derived from model forced by northward shelf current.

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.

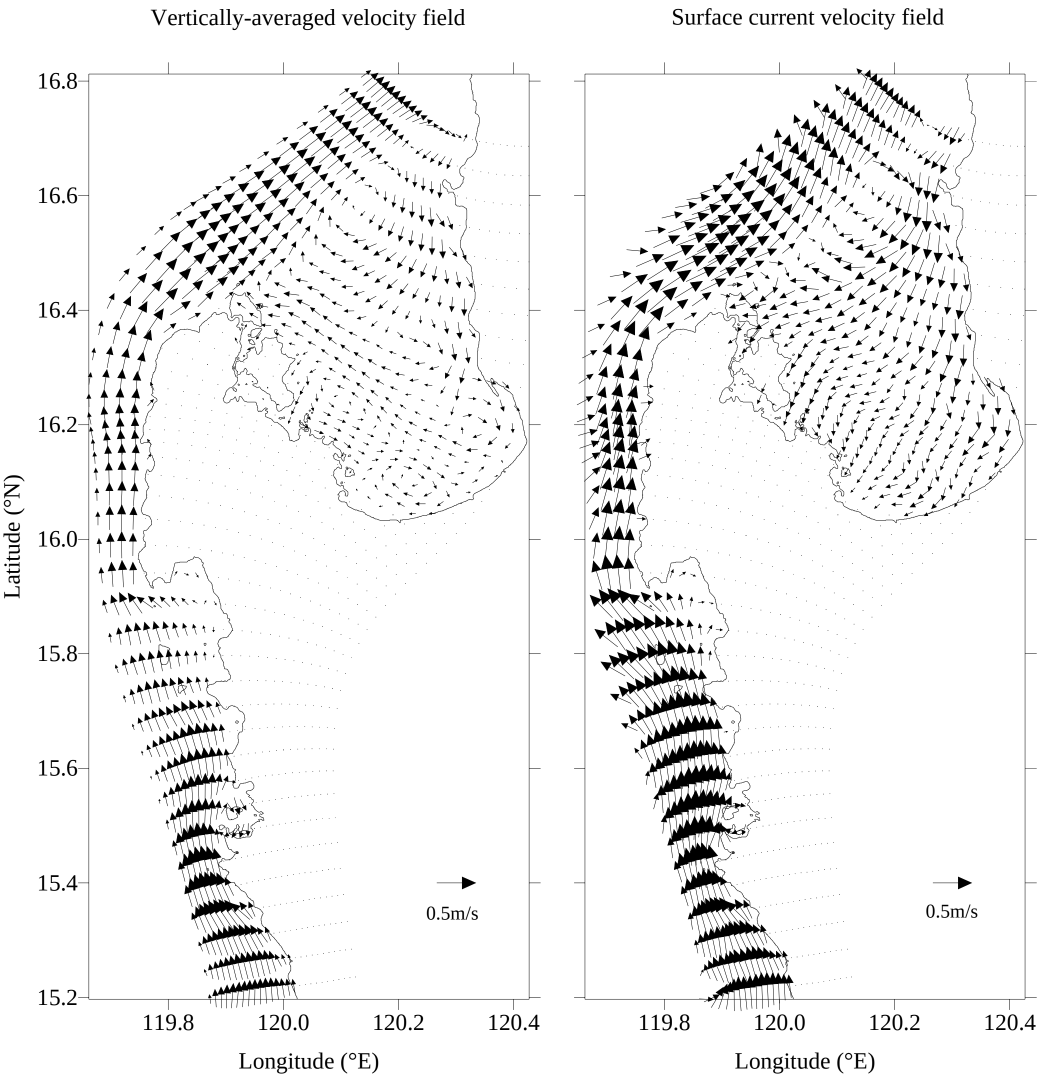


Figure 8. Vertically-averaged and surface currents from model forced coastal current and northerly wind.

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.

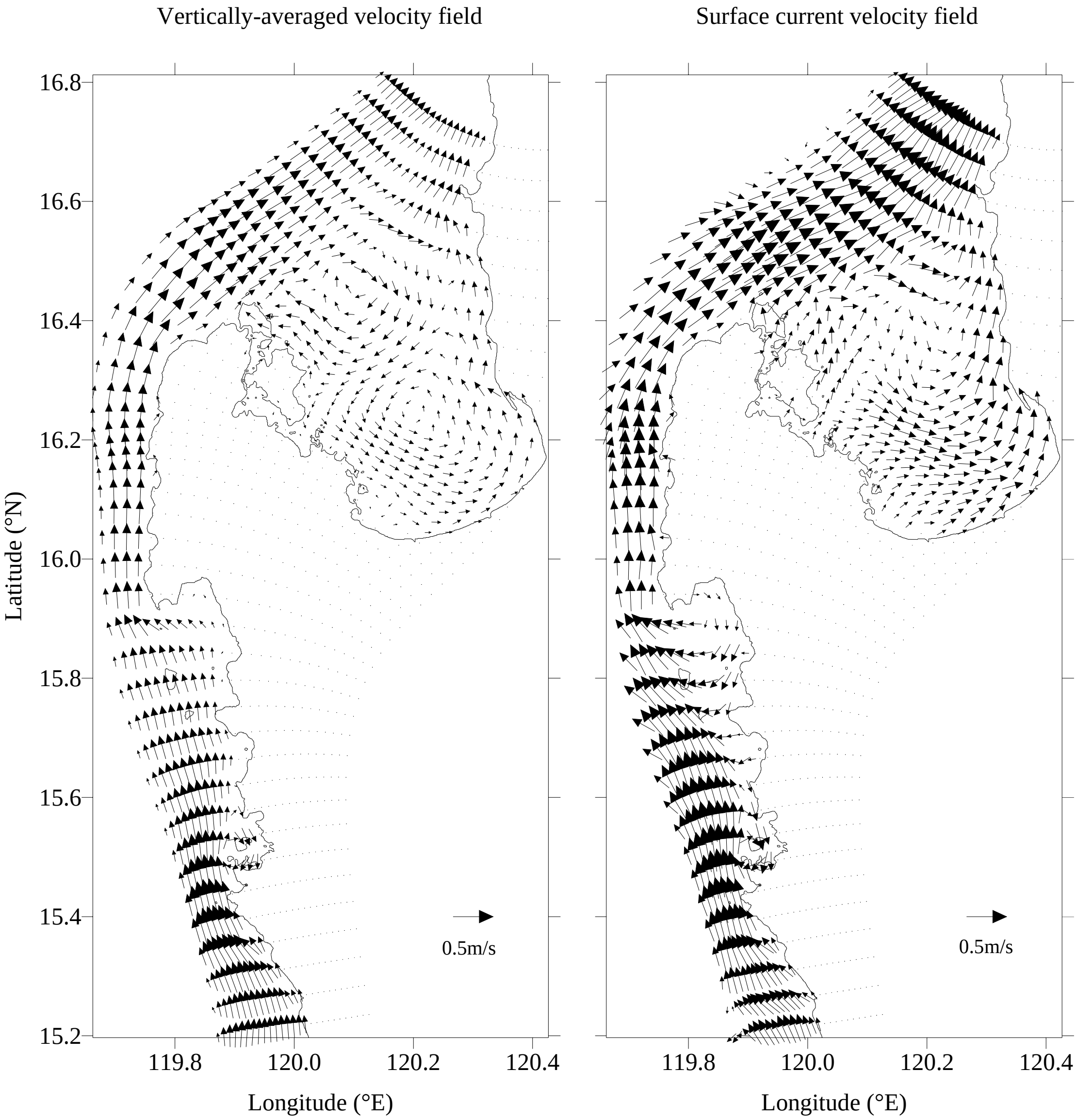


Figure 9. Vertically-averaged and surface currents from model forced coastal current and southerly wind.

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.

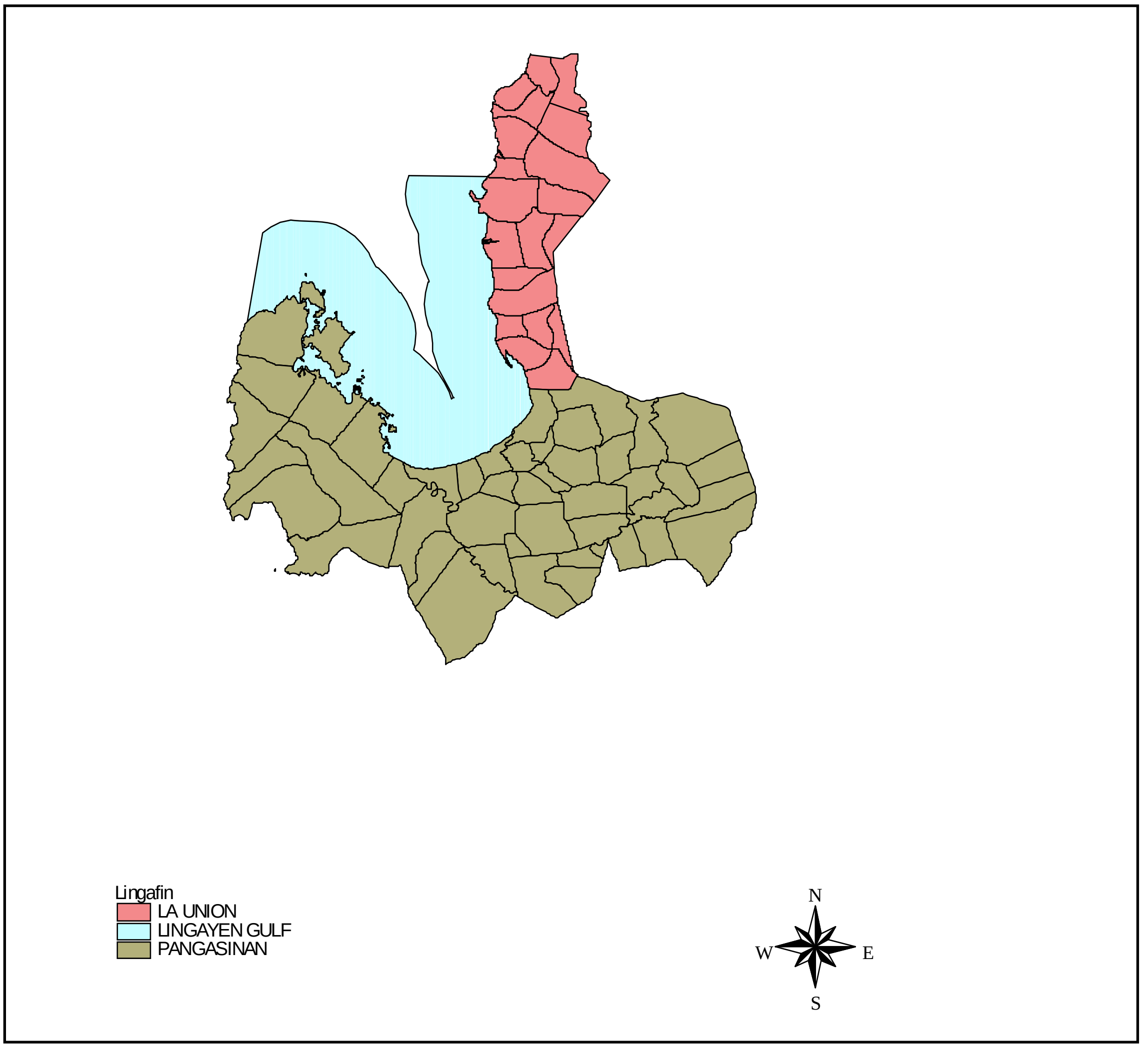
Figure 10. Political boundaries of the Agno River watershed (heavy line).

<u>1.6.2 Human Resources</u>

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 8th 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		

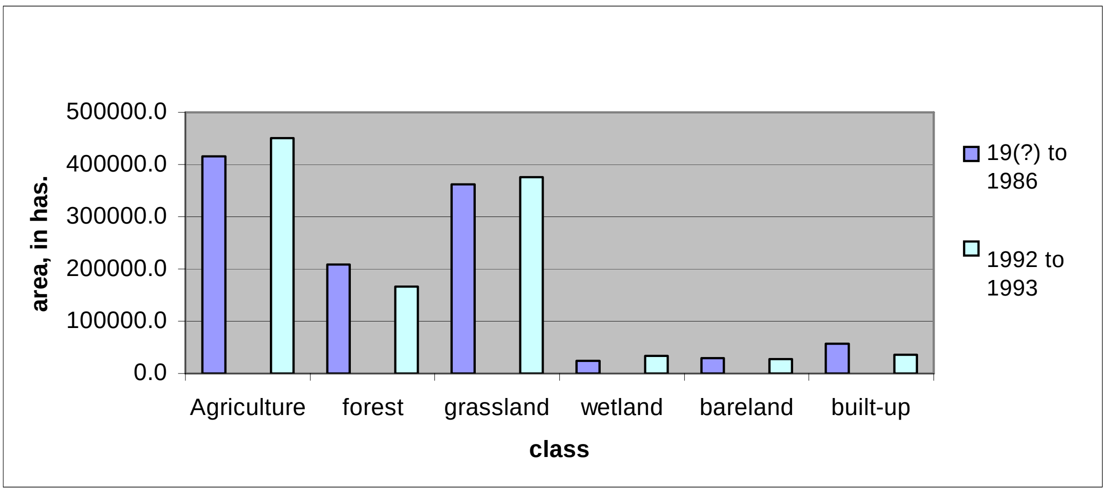


Figure 12a. Total area of land use/cover in Agno watershed.

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**

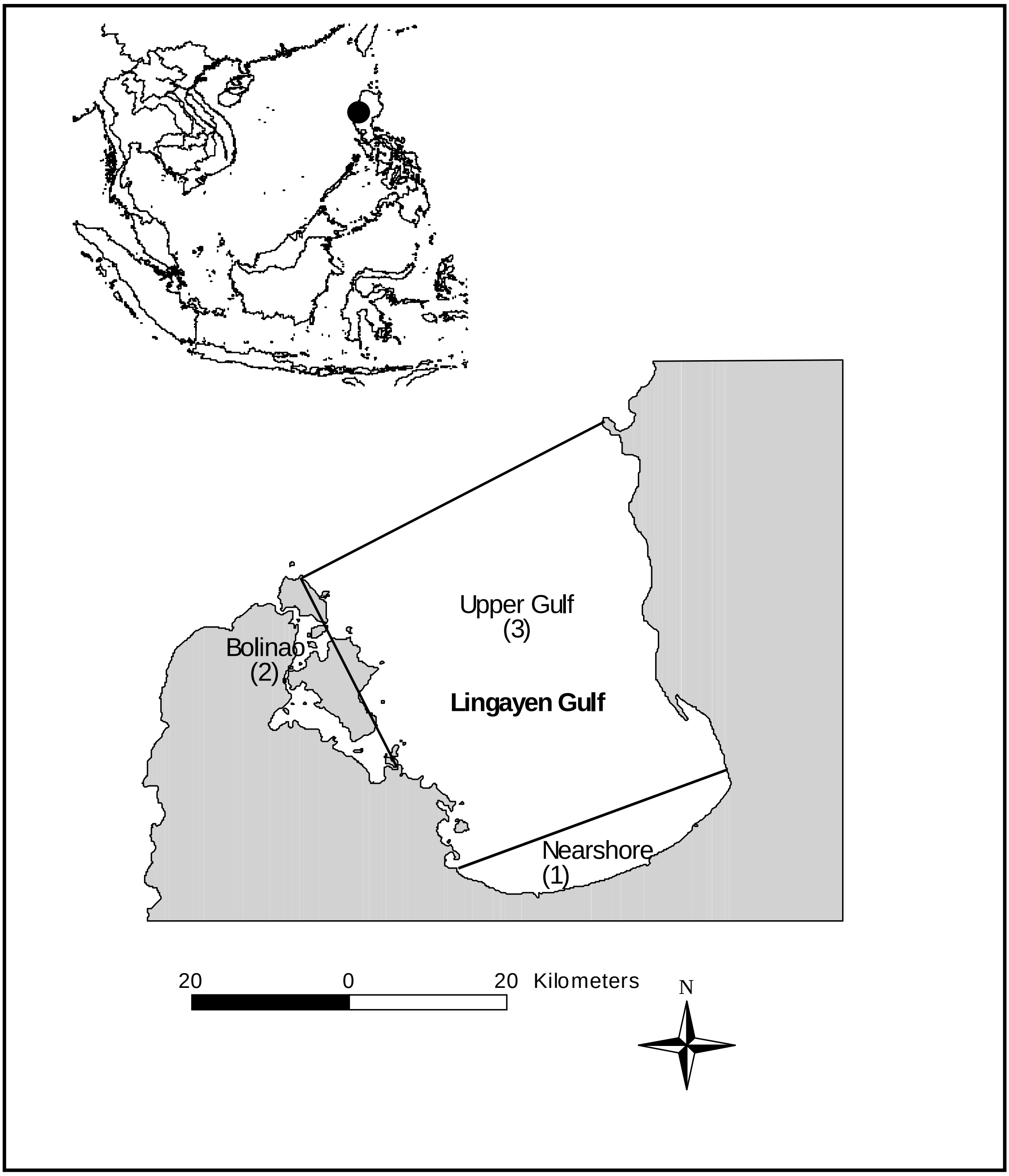


Figure 13. Map of Lingayen Gulf showing the boundaries of the budgets.

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

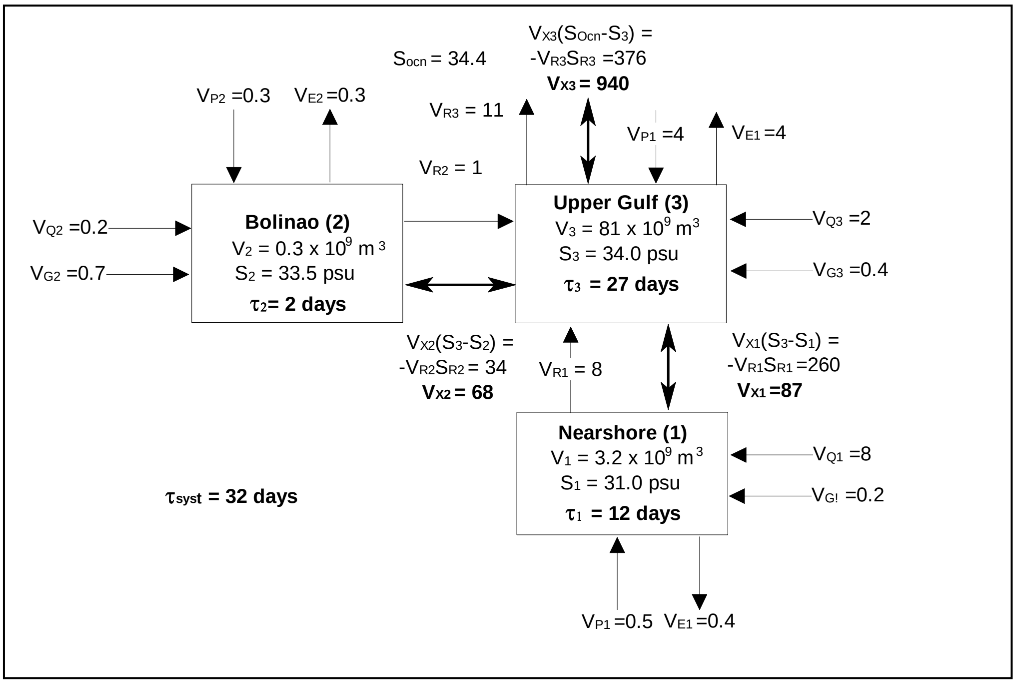


Figure 14. Water and salt balance for Lingayen Gulf. Water fluxes in 10^9 m^3 yr^{-1} and salt fluxes in 10^9 psu-m^3 yr^{-1}.

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 km², 84.5 km³)	
	10^6 moles yr^{-1}	mol m^{-2} yr^{-1}
ΔDIP	+1.2	+0.0006
ΔDIN	-210	-0.1
(*p-r*)	-147	-0.07
(*nfix-denit*)	-420	-0.2
ΔDOP	+189	+0.09
ΔDIC$_t$	-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.

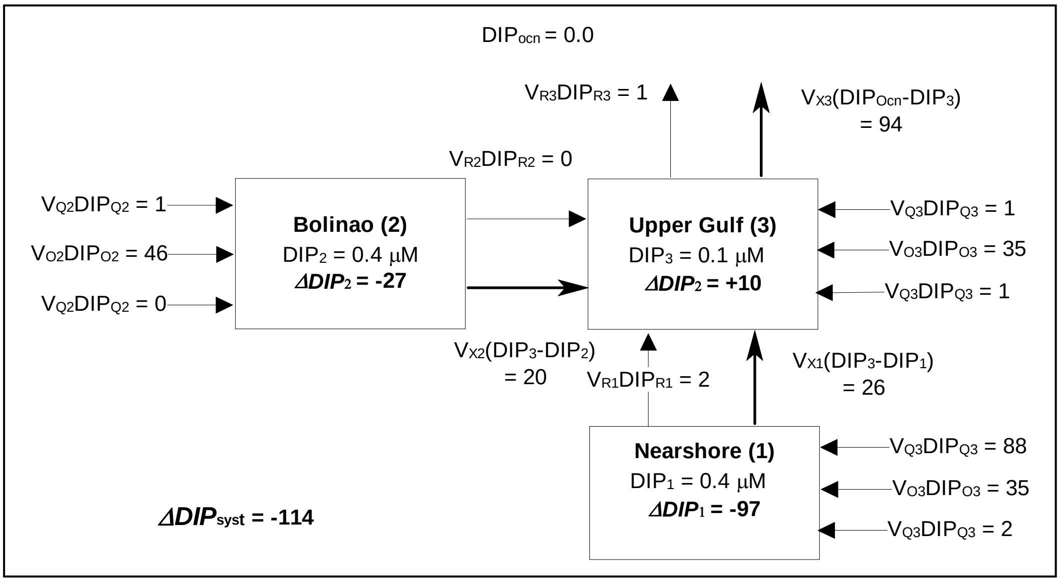


Figure 15. Dissolved inorganic phosphorus (DIP) budget for Lingayen Gulf. Fluxes in 10^6 mol yr^{-1}.

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 ($V_O DIP_O$) 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 ($V_Q DIP_Q$). 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. 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. *ΔDIP* 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 *ΔDIP* 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.

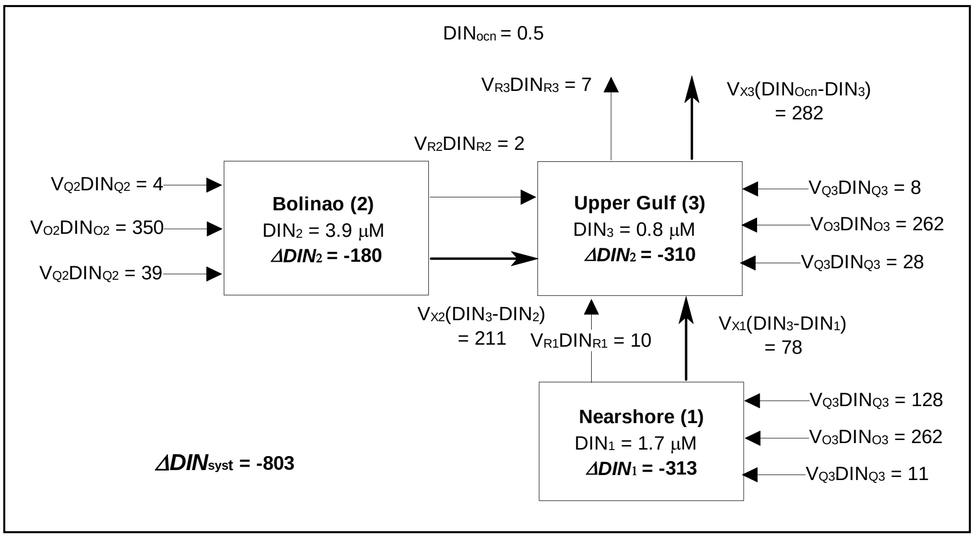


Figure 16. Dissolved inorganic nitrogen (DIN) budget for Lingayen Gulf. Fluxes in 10^6 mol yr^{-1}.

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 ($V_O DIN_O$) 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 (*ΔDIN* 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 km^2, 81 km^3*)		*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

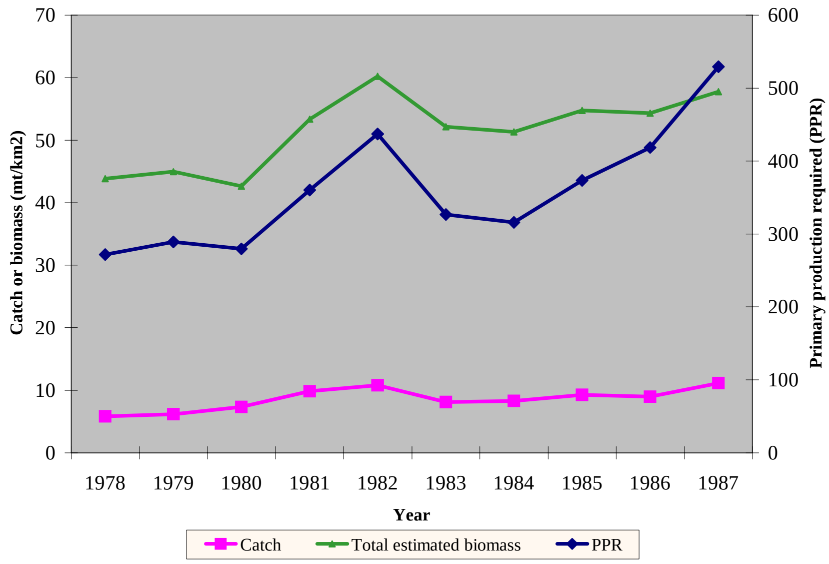


Figure 17. Comparison of raw total biomass (from catch data), total balanced biomass (balanced using ECOPATH on the same groups), and primary production required to support the latter for Lingayen Gulf.

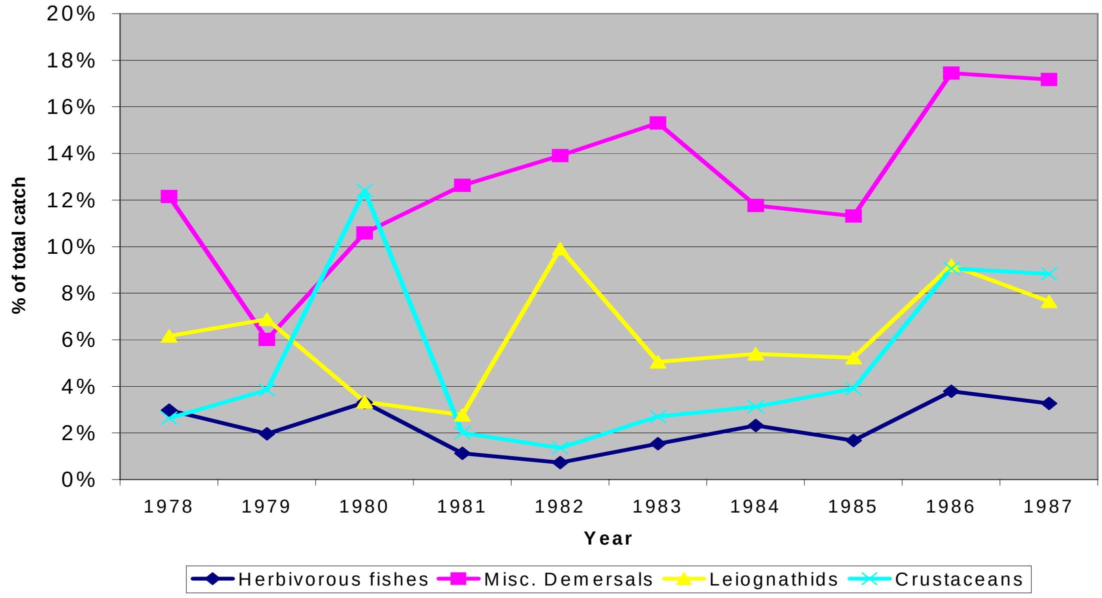


Figure 18. Catch (as a proportion of total catch) of groups lower in food web in Lingayen Gulf.

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.

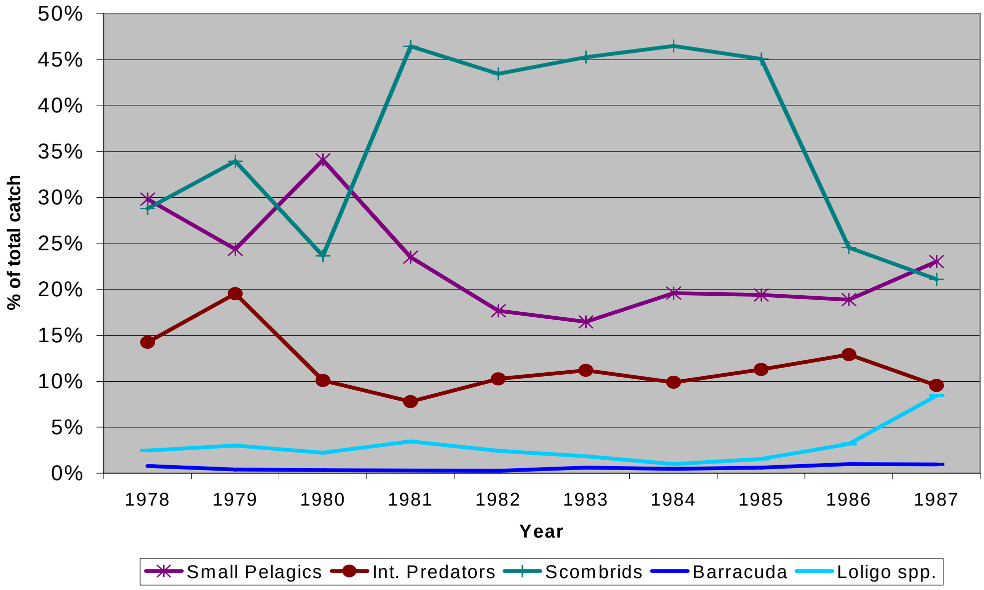


Figure 19. Catch as a proportion of total catch of groups higher in the food web in Lingayen Gulf.

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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Appendix A Land use changes within the Agno watershed (1986-1993)

Fernando Siringan and Elizabeth Francisco
National Institute of Geological Sciences,
University of the Philippines, Diliman 1101 Quezon City

Introduction

The data sets used for the determination of land use change were compiled from: the 1995 JAFTA report for the more recent land use/cover of the Agno watershed; the 1986 and an indeterminate date but presumably before 1990 Soil/Land Resources and Evaluation Project reports of the Bureau of Soils and Water Management, and the Study of Agno River Basin and Flood Control report by JICA in 1991 for the earlier data sets.

The spatial coverage for the land use/cover data includes the three provinces that can roughly fit within the Agno Watershed boundary as delineated in the JICA report. Benguet Province occupies in part the headwaters of the Agno Watershed. Pangasinan covers the central and low-lying areas, but more than half of its administrative boundary extends beyond the watershed divide to the west. Tarlac Province occupies the southern portion of the watershed but a third of its boundary also extends beyond the southeastern watershed divide. The area of the Agno Watershed is 7,460 km2 while the aggregate area of these three provinces is 1,096,458 hectares or 10,964.58 km2. The delineated area of the Agno watershed is only about seventy percent of the size of the three provinces.

Data Lineage

For the provinces of Benguet and Tarlac, the BSWM and JAFTA data were used for calculation of land use/cover change through time. The JAFTA data were generated from the image processing of the Landsat TM image using the scenes from the paths and rows, 116-48 and 116-49 captured in April 2, 1993. The BSWM data as presented in the Soils/Land Resources Evaluation Project (S/LREP) report were generated through aerial photograph interpretation and field surveys. Report for Benguet does not specify the dates and acquisition of aerial photographs, the duration of the field survey and the publication and date of the report. The LREP for Tarlac was issued in 1986 but without any reportage on the date of acquisition of the aerial photos and duration of field survey. Nevertheless, it is assumed that these data sets were generated at the latest, in 1986.

The land use/cover change data for the province of Pangasinan were entirely taken from the 1991 Study of Agno River Basin Flood Control report of JICA. The lineage of JICA data is the 1983-1987 Multi-Year Human Settlement Plan of Region I, 1987-1992 Mid-term Ilocos Region Development Plan, Regional Development Council Report of Region I, 1985 Socio-Economic Profile and the compilation of the Department of Agriculture in the provinces of Tarlac and Pangasinan. The JICA data did not provide a definition or detailed description for each land use categories but it is assumed that land use classes are similarly defined as the other data sets.

The JAFTA and BSWM employed different nomenclatures in designating land use/cover types, although certain classes have similar descriptions. For Benguet and Tarlac data sets to be comparable, similarly described or closely defined classes in both sets were grouped. Also, in order to calculate land use changes for the whole region, land use classes were reclassified to conform to the data set that has the least information resolution. Since the JICA land use categories used a more regional approach in its classification scheme, unlike the more detailed classification of BSWM and JAFTA, the JICA scheme was then used as template for reclassification but with some modifications (refer to Table A1). Note that the JICA land use/cover data do not have shrub land or brush land in its classification. It is also assumed that this category is included in the grassland class. Swamps and fishpond is grouped with the wetland class, and mining, with the bare land class. The JAFTA data included clouds and shadow classes that were present only in the Benguet. These classes were disregarded since they contributed only 0.3% of the province and 0% of the study area.

Table A1. Land use/cover nomenclatures or categories used in the various data sets

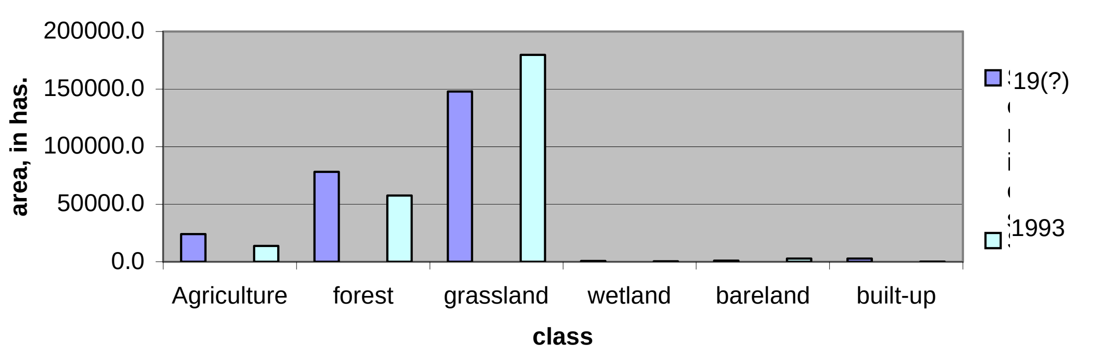
This report	BSWM (S/LREP)	JAFTA	JICA
Forest land	Forest	Old growth Mossy Residual forest Sub-marginal forest Pine forest	Forest
Agricultural land	Irrigated rice paddies, wet season rice paddies, corn, root crops, vegetables, coffee, tobacco, cotton, coconut, fruit trees, banana, maguey	Agricultural area Coconut Other plantation	Agricultural land Irrigated paddy Rain-fed paddy Others
Grassland	Shrubs, ipil-ipil, grasses, pasture lands, bamboo	Grassland Reproduction brush	Grassland
Wetland	Nipa, mangrove, rivers, fishpond, salt beds, swamp, reservoir, filling pond	Mangrove Water body	Fishpond Swamps
Bare land	Sand and gravel areas, mine pit site, riverbed, river wash	Bare/rocky land	Mining Bare land
Built-up area	Residential and commercial areas	Built-up area	Built-up/others

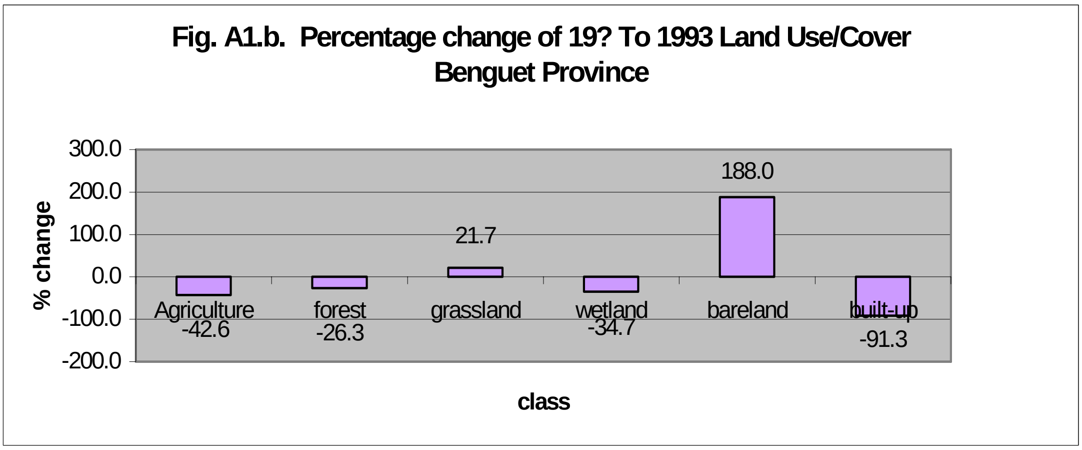
Discussion

Land use changes in the provinces of Benguet, Tarlac and Pangasinan

<u>Benguet</u>
The eastern half of Benguet occupies in part the northern headwaters of the Agno Watershed. Here, agricultural land encompasses the third most extensive land use/cover classes, which has an aggregate area of a few ten thousands of hectares. From an indeterminate date to 1993, there was a contraction of 10,275 hectares that ate up 42.6 % of the previous area. Forestland is the second most extensive area which is some ten thousands of hectares. For the inclusive years it showed the largest magnitude in area reduction of 25% of the province's original size. Grassland is the most extensive class, with areas of approximately a hundred hectares. It showed an expansion of 32,054 hectares, representing 21.7% increase from the earlier data. Wetland occupies some hundreds of hectares, which is one of the least extensive classes in the province. It decreased by 269 hectares, which is 34.7% of previous area. Bare land comprises just a few thousand hectares. In 1993, it expanded by 1,903 hectares, about twice its earlier size. Of the six land use/cover classes, built-up area suffered the greatest loss in terms of percentage change while showing the least reduction in size at 254 hectares. Built-up area is nearly wiped out with only less than 10% of its earlier area remaining as of 1993 (refer to Table A2. a and Figure A1. a, b).

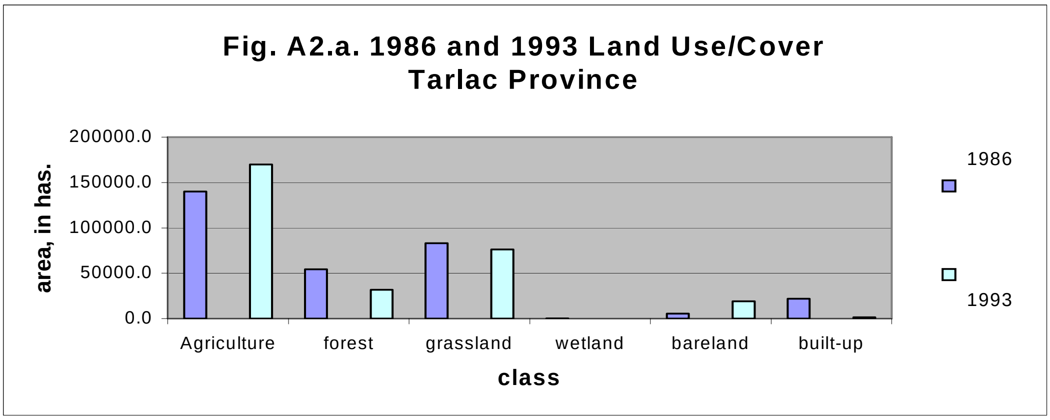
Fig. A1.a. 19(?) and 1993 Land Use/Cover, Benguet Province

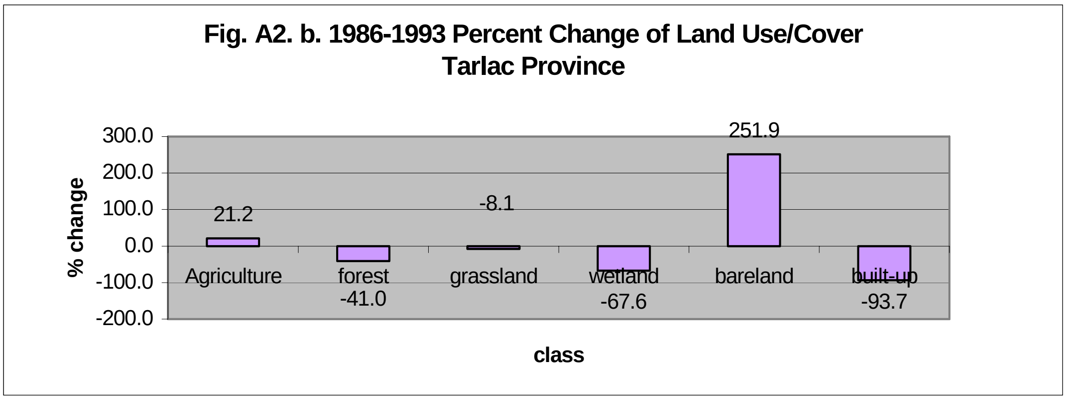




Tarlac

Tarlac Province is located on the southern section of the Agno watershed. Unlike the north, Tarlac is situated in mostly gentle terrain. Agricultural land is the largest class in the province that has total area of a few hundred thousand hectares. From 1986 to 1993, agricultural land has encroached by 29,728.2 hectares or 21.2 % of the 1986 area. Grassland also expanded, in the order of some ten thousands of hectares. By 1993, the grassland class had decreased by 6,714.5 hectares, approximately a tenth of the 1986 area. Wetland occupies the smallest area in terms of size, which is around a few hundred hectares. In a span of seven years, the wetland class contracted by 238 hectares or two thirds of its previous size. The bare land class of Tarlac experienced the highest percentage of increase from 5,387 hectares in 1986 to 18,957 hectares in 1993. The change represents 251.9% of the earlier data. The built-up class of Tarlac showed the same trend as the built-up class of Benguet province, which also showed a loss of greater than 90 percent of the previous area (refer to Table A2. b and Figure A2. a,b).





Pangasinan

Pangasinan is situated in the low-lying areas of the Agno watershed. Like Tarlac, its agricultural land use/cover class is the most extensive in the province. The sum of its areas is a few hundred thousand hectares. From 1983 to 1992, the agricultural land use/cover increased by 14,700 hectares, a modest growth of 5.8%. Forestland is the third most extensive, but showed no change in area during the period. Next to agriculture, grassland covered the largest area in the province with an aggregate size of a little more than a hundred thousand hectares. By 1992, its area was reduced to 10,900 hectares, which is less than a tenth of the 1983 size. The wetland area of Pangasinan is the largest among the three provinces because of its location in the Agno watershed. The total size is in the order of few ten thousand hectares. By 1992, the wetland class was 10,700 hectares, or almost half the 1982 area. The bare land class showed the most drastic change in the province. For a period of nine years, it suffered a 74% of earlier area. The built-up class occupies a total area of approximately few thousand hectares. By 1993 built-up area expansion is 8.8% of 1982 size (refer to Table A2. c and Figure A3. a,b).

Fig. A3.a. 1983 and 1992 Land Use/Cover Pangasinan Province

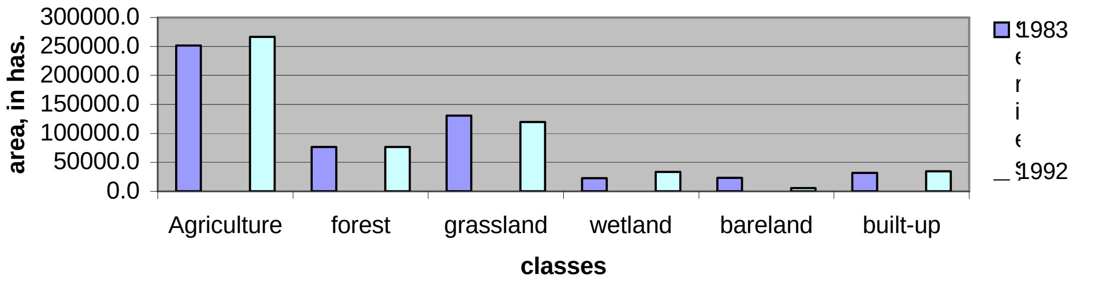


Fig. A3. b. 1983 to 1992 Percent Change in Land Use/Cover Pangasinan Province

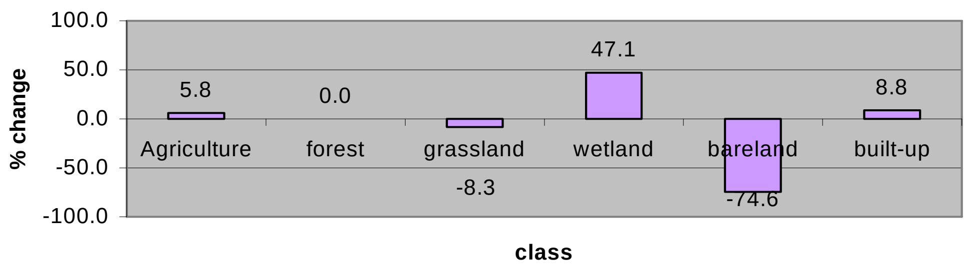


Table A2. Land use changes for the three provinces of the Agno watershed.

a. Benguet Province

Class	19(?) (area in has.)	%		1993 (area in has.)	%		Change (in has.)	% change
agriculture	24098.0	9.5		13823.0	5.4		-10275.0	-42.6
forest land	78034.0	30.6		57521.0	22.5		-20513.0	-26.3
grassland	147814.0	58.0		179868.0	70.4		32054.0	21.7
wetland	776.0	0.3		507.0	0.2		-269.0	-34.7
bare land	1012.0	0.4		2915.0	1.1		1903.0	188.0
built-up	2931.0	1.2		254.0	0.1		-2677.0	-91.3
clouds	data from survey			653.0	0.3			
shadow	and aerial photo			113.0	0.0			
total area	254665.0	100.0		255654.0	100.0			

Table A2 (cont.).
b. Tarlac Province

Class	1986 (area in has.)	%		1993 (area in has.)	%		change (in has.)	% change
agriculture	140129.8	46.0		169858.0	56.9		29728.2	21.2
forest land	54136.0	17.8		31920.0	10.7		-22216.0	-41.0
grassland	83038.5	27.2		76324.0	25.6		-6714.5	-8.1
wetland	352.0	0.1		114.0	0.0		-238.0	-67.6
Bare land	5387.0	1.8		18957.0	6.3		13570.0	251.9
Built-up	21841.7	7.2		1372.0	0.5		-20469.7	-93.7
Total area	304885.0	100.0		298545.0	100.0			

c. Pangasinan Province

Class	1983 (area in has.)	%		1992 (area in has.)	%		change (in has.)	% change
Agriculture	251800.0	46.9		266500.0	49.6		14700.0	5.8
Forest land	76500.0	14.3		76500.0	14.3		0.0	0.0
Grassland	130800.0	24.4		119900.0	22.3		-10900.0	-8.3
Wetland	22700.0	4.2		33400.0	6.2		10700.0	47.1
Bare land	23200.0	4.3		5900.0	1.1		-17300.0	-74.6
Built-up	31800.0	5.9		34600.0	6.4		2800.0	8.8
total area	536800.0	100.0		536800.0	100.0		0.0	0.0

d. Land use changes for the Agno 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			

Totals for the Provinces within the Agno watershed

The most extensive land use/cover classes within the Agno watershed are agricultural land, grassland, and forestland. Their sizes range from 200,000 to 400,000 hectares, while the land use/cover classes that occupy smaller areas are built-up, wetland and bare land. 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 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 the 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 is the forestland at 20.5%. 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 6.2%. 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, land use/cover change yielded less than 10% contraction for the Agno watershed (refer to Table A2. d and Figure A4. a,b).

Fig. A4. a. Total Area of Land Use/Cover in Agno Watershed

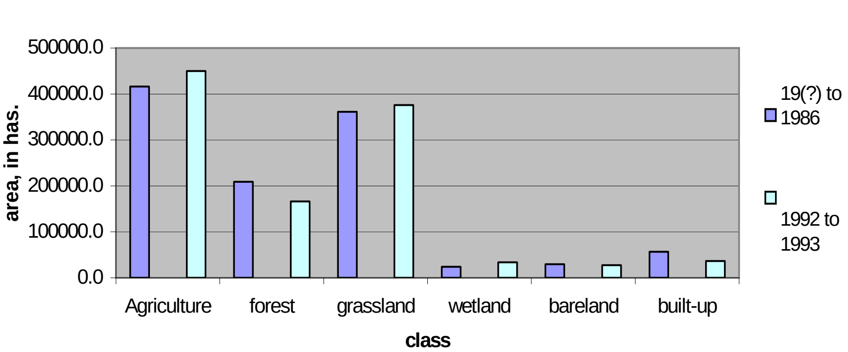


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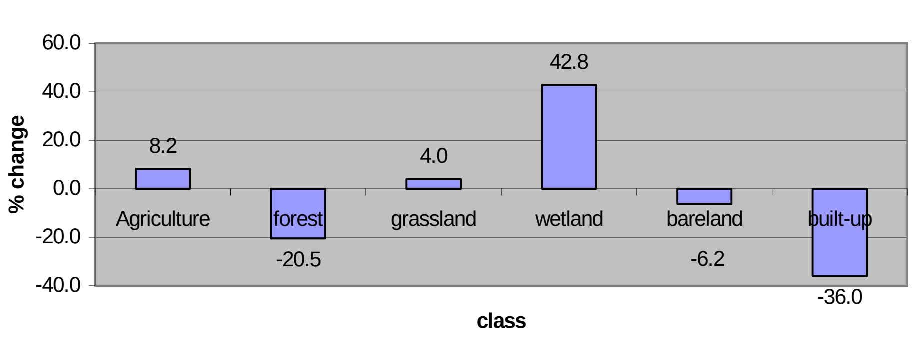
Fig. A4. b. Percent Change of Land Use/Cover in Agno Watershed



Appendix B. Economic modelling of residual generation for the Lingayen Gulf watershed

Douglas McGlone and Herminia Caringal
Marine Science Institute, University of the Philippines
Diliman 1101, Quezon City

Introduction

Political Boundaries

The Lingayen Gulf watershed crosses four provinces in three political regions (Figure 1, main report). For the study of inland influences on the coastal waters of Lingayen Gulf, emphasis is placed on the provinces and regions 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 another 37 inland municipalities, while La Union has an 13 other municipalities, five of which are coastal but north of Lingayen Gulf, and 8 of which are inland. These two provinces form an envelope around the Gulf. The furthest distance from shoreline to provincial boundary is approximately 60 km.

Pangasinan and La Union are a part of the political Region 1, which also consists of 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 the purposes of the input-output model of residual generation, data constraints require the inclusion of all of Region 1.

Human Resources

1. *Population/Demographics*
As of 1995, there were 2,775,854 people living in Pangasinan and LaUnion, with 2,178,412 in Pangasinan, and 597,442 in LaUnion. This reflects a population growth for the two provinces of 8% between 1990-95, and 23% from 1980-90. The national population growth for 1990-1995 was 13%, and 26% for 1980-1990. The two 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 two 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 8th out 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.

2. *Labor Force*
In 1995 the potential labor force (age 15 years and above) was 1,822,000, or 65.64 % 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 under-utilized labor, which is also reflected in the family income statistics. The trend in under-utilized labor is expected to continue as

population continues to grow. The manufacturing sector has lagged in labor absorption due to 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.

3. Incomes

The average family income for 1995 was P 68376 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.

Economic Activity

A. 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.

B. 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. Palay (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 head of cattle and 3.6 million head 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 that is expected to substantially increase the potential for irrigation.

C. 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 t/year (Padilla and Morales, 1997). Maximum production was 24,015 t in 1987. By 1995 it was down to 13,443 t, despite an increase in standardized aggregate effort of over 150%.

D. 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.

Land Use

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 is devoted to permanent crops, and the remaining 2% to livestock.

Approximately 23% of the land area is 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.

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, SS) 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. The model may be expanded by allowing economic activity to be represented by a regional input-output 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 alternative but related approaches to addressing the question of how economic activity affects the generation of residuals. Equations 5–7 represent the input-output (IO) modeling 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, in which "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), occurs. 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.

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 30-sector regional model based upon the 229-sector 1994 national model, adjusted with the simple location quotient method of reduction. This 30-sector model was then aggregated to the agreed upon 12-sector model. The sectors for the 30-sector model and their aggregation to 12 sectors are shown in Table B1.

Table B1. Sectoral Classification Scheme (Region 1 - Ilocos Region I/O Table)

Production Sectors			
11 Sector Regional I/O Table			30-Sector National I/O Table
Code	Description	Code	Description
1	Agriculture	01 02 03	Agricultural crops Livestock and poultry Agricultural services
2	Fishery	04	Fishery
3	Forestry	05	Forestry
4	Mining and quarrying	06	Mining & quarrying
5	Manufacturing I	07 08 09 10 11 12 13 14 15	Meat, meat products, dairy products Milled rice and corn; flour; bakery products Fish preparations Miscellaneous food manufactures Beverage industries Tobacco manufactures Textile and textile products, leather & leather products Wood and wood products; furniture and fixtures Paper and paper products; publishing and printing
6	Manufacturing II	16 17 18 19 20 21	Chemical products; rubber and plastic products Products of petroleum and coal Non-metallic mineral products Basic metals Fabricated metal products; machinery and transport equipment Miscellaneous manufactures
7	Electricity, gas & water	23	Electricity, gas and steam
8	Waterworks and supply	24	Waterworks and supply
9	Construction	22	Construction
10	Transportation, communication & storage	26	Transportation, storage and communication
11	Other Services	25 27 28 29 30	Wholesale and retail trade Finance, insurance and real estate Hotel and restaurant services Other private business, personal and community services Government services

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 B_a'. The corresponding 12 sector model (households endogenized) tables will also be provided, as 'Table B_b'.

Table B_2a is the 1994 regional 11 x 11 sector IO table for Region 1 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 Annex A).

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, labeled 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. 11 Sector transaction table (Region 1 - Ilocos Region 1994, in thousand pesos).

Code	1	2	3	4	5	6	7	8	9	10	11
1	2399734	200	20	0	321644	29426	0	0	0	0	98986
2	355	149876	0	2	24348	58	0	0	0	0	49333
3	0	0	198	3434	11515	3655	578	2	1300	1	1
4	424	26	0	0	298	250847	1719	0	225440	19	1591
5	1012232	178397	15	18169	580905	250994	746	262	357665	6455	719863
6	1590268	252689	1964	189395	307513	1675043	132909	5289	3373165	730750	1126510
7	141534	26811	47	4900	81811	303896	10479	4745	101783	38259	621418
8	4365	0	0	43	11752	181	0	0	11383	7522	85954
9	6431	11332	24	12449	24846	64531	4788	1579	309322	59068	955612
10	354229	57705	1028	12837	86840	132922	0	478	592956	60972	776879
11	743945	62340	677	49014	302584	397675	40736	2932	995823	449427	2545190
TII	15534477	1745729	19136	533221	2218032	3581592	275516	27653	7273300	2241890	18924333
CE	6193676	519231	2238	172568	262166	472340	83561	12366	1283941	618778	9740618
GOS	11275152	1638678	12941	478260	1050157	1665280	187065	16110	2433073	1077484	11945510
HOA	3087284	487122	12925	70410	201810	24	0	0	20522	270639	2350698
NHOA	8187868	1151556	16	407850	848347	1665256	187065	16110	2412551	806845	9594812
TPI	17468828	2157909	15179	650828	1312323	2137620	270626	28476	3717014	1696262	21686128
TI	23722345	2897285	19152	941071	3066379	5246848	462581	43763	9685851	3048735	57335230

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.

Table B2b. 12 Sector Transaction Table (Sector 1 - Ilocos Region 1994, in thousand pesos)

Code	DESCRIPTION	1	2	9	10	11	12	TID	
									Note:
1	Agriculture	2399734	200	0	0	98986	2390321	2850010	*TII: Total Intermediate Inputs*
2	Fishery	355	149876	0	0	49333	1753267	223972	*CE: Compensation of Employees*
3	Forestry	0	0	1300	1	1	0	20684	*GOS: Gross Operating Surplus*
4	Mining and quarrying	424	26	225440	19	1591	0	480364	*HOA: Household-Operated Activities*
5	Manufacturing I	1012232	178397	357665	6455	719863	19751759	3125703	*NHOA: Non-Household Operating Activities*
6	Manufacturing II	1590268	252689	3373165	730750	1126510	5347774	9385495	*GOS = HOA + NHOA*
7	Electricity, gas and water	141534	26811	101783	38259	621418	1329913	1335683	*TPI: Total Primary Inputs*
8	Waterworks and supply	4365	0	11383	7522	85954	238703	121200	*TPI = CE + GOS*
9	Construction	6431	11332	309322	59068	955612	75468	1449982	*TI: Total Inputs*
10	Transpo., comm., and storage	354229	57705	592956	60972	776879	4708613	2076846	*TI = TII + TPI*
11	Other Services	743945	62340	995823	449427	2545190	19915057	5590343	
12	Household sector	9280960	1006353	1304463	889417	12091316	0	25862917	
TII	Total Intermediate Inputs	15534477	1745729	7273300	2241890	18924333	55510875	52523199	
GOS	Gross Operating Surplus	8187868	1151556	2412551	806845	19189624	0	25278276	
NHOA	Non-HH Operated Activities	8187868	1151556	2412551	806845	19189624	0	25278276	
TPI	Total Primary Inputs	8187868	1151556	2412551	806845	19189624	0	25278276	
TI	Total Inputs	23722345	2897285	9685851	3048735	57335230	55510875	77801475	

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 B3a. 11 Sector Transactions Table (Region 1 - Ilocos Region 1994, in thousand pesos)

Code	PCE	GCE	GFCF	CS	E - M	TFD	TO
1	2390321	0	1983520	177951	16320543	20872335	23722345
2	1753267	0	0	0	920046	2673313	2897285
3	0	0	0	0	-1532	-1532	19152
4	0	0	0	11790	448917	460707	941071
5	19751759	0	0	166076	-19977159	-59324	3066379
6	5347774	0	1235028	21615	-10743064	-4138647	5246848
7	1329913	0	0	0	-2203015	-873102	462581
8	238703	0	0	0	-316140	-77437	43763
9	75468	0	5809729	0	2350672	8235869	9685851
10	4708613	0	229882	0	-3966606	971889	3048735
11	19915057	6704644	536392	0	-4078971	23077122	28667465
TII	55510875	6704644	9794551	377432	-21246309	51141193	
CE							
GOS	0	0	0	0	0	0	
HOA							
NHOA	0	0	0	0	0	0	
TPI	0	0	0	0	0	0	
TI	55510875	6704644	9794551	377432	-21246309	51141193	

Table B3b. 12 Sector Transaction Table (Regio 1 - Ilocos Region 1994, in thousand pesos)

Code	PCE	GCE	GFCF	CS	E - M	TFD	TO
1	2390321	0	1983520	177951	16320543	20872335	23722345
2	1753267	0	0	0	920046	2673313	2897285
3	0	0	0	0	-1532	-1532	19152
4	0	0	0	11790	448917	460707	941071
5	19751759	0	0	166076	-19977159	-59324	3066379
6	5347774	0	1235028	21615	-10743064	-4138647	5246848
7	1329913	0	0	0	-2203015	-873102	462581
8	238703	0	0	0	-316140	-77437	43763
9	75468	0	5809729	0	2350672	8235869	9685851
10	4708613	0	229882	0	-3966606	971889	3048735
11	19915057	6704644	536392	0	-4078971	23077122	28667465
12	0	0	0	0	0	0	25862917
TII	55510875	6704644	9794551	377432	-21246309	51141193	103664392
GOS	0	0	0	0	0	0	25278276
NHOA	0	0	0	0	0	0	25278276
TPI	0	0	0	0	0	0	25278276
TI	55510875	6704644	9794551	377432	-21246309	51141193	

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 its 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).

Appendix B

Table B4a. 11 Sector Technical Coefficient Matrix (Region 1 - Ilocos Region, 1994).

Code	1	2	3	4	5	6	7	8	9	10	11
1	0.101159	0.000069	0.001044	0.000000	0.104894	0.005608	0.000000	0.000000	0.000000	0.000000	0.001726
2	0.000015	0.051730	0.000000	0.000002	0.007940	0.000011	0.000000	0.000000	0.000000	0.000000	0.000860
3	0.000000	0.000000	0.010338	0.003649	0.003755	0.000697	0.001250	0.000046	0.000134	0.000000	0.000000
4	0.000018	0.000009	0.000000	0.000000	0.000097	0.047809	0.003716	0.000000	0.023275	0.000006	0.000028
5	0.042670	0.061574	0.000783	0.019307	0.189443	0.047837	0.001613	0.005987	0.036927	0.002117	0.012555
6	0.067037	0.087216	0.102548	0.201255	0.100285	0.319247	0.287320	0.120856	0.348257	0.239690	0.019648
7	0.005966	0.009254	0.002454	0.005207	0.026680	0.057920	0.022653	0.108425	0.010508	0.012549	0.010838
8	0.000184	0.000000	0.000000	0.000046	0.003833	0.000034	0.000000	0.000000	0.001175	0.002467	0.001499
9	0.000271	0.003911	0.001253	0.013229	0.008103	0.012299	0.010351	0.036081	0.031935	0.019375	0.016667
10	0.014932	0.019917	0.053676	0.013641	0.028320	0.025334	0.000000	0.010922	0.061219	0.019999	0.013550
11	0.031361	0.021517	0.035349	0.052083	0.098678	0.075793	0.088062	0.066997	0.102812	0.147414	0.044391

Table B4b. 12 Sector Technical Coefficient Table (Region 1 - Ilocos Region 1994, in thousand pesos)

Code	DESCRIPTION	1	2	3	4	5	6	7	8	9	10	11	12
1	Agriculture	0.101159	0.000069	0.001044	0.000000	0.104894	0.005608	0.000000	0.000000	0.000000	0.000000	0.001726	0.043060
2	Fishery	0.000015	0.051730	0.000000	0.000002	0.007940	0.000011	0.000000	0.000000	0.000000	0.000000	0.000860	0.031584
3	Forestry	0.000000	0.000000	0.010338	0.003649	0.003755	0.000697	0.001250	0.000046	0.000134	0.000000	0.000000	0.000000
4	Mining and quarrying	0.000018	0.000009	0.000000	0.000000	0.000097	0.047809	0.003716	0.000000	0.023275	0.000006	0.000028	0.000000
5	Manufacturing I	0.042670	0.061574	0.000783	0.019307	0.189443	0.047837	0.001613	0.005987	0.036927	0.002117	0.012555	0.355818
6	Manufacturing II	0.067037	0.087216	0.102548	0.201255	0.100285	0.319247	0.287320	0.120856	0.348257	0.239690	0.019648	0.096337
7	Electricity, gas and water	0.005966	0.009254	0.002454	0.005207	0.026680	0.057920	0.022653	0.108425	0.010508	0.012549	0.010838	0.023958
8	Waterworks and supply	0.000184	0.000000	0.000000	0.000046	0.003833	0.000034	0.000000	0.000000	0.001175	0.002467	0.001499	0.004300
9	Construction	0.000271	0.003911	0.001253	0.013229	0.008103	0.012299	0.010351	0.036081	0.031935	0.019375	0.016667	0.001360
10	Transpo., comm. and storage	0.014932	0.019917	0.053676	0.013641	0.028320	0.025334	0.000000	0.010922	0.061219	0.019999	0.013550	0.084823
11	Other Services	0.031361	0.021517	0.035349	0.052083	0.098678	0.075793	0.088062	0.066997	0.102812	0.147414	0.044391	0.358760
12	Household sector	0.391233	0.347343	0.791719	0.258193	0.151311	0.090028	0.180641	0.282567	0.134677	0.291733	0.210888	0.000000

Table B5a. 11 x 11 Leontief Inverse Matrix (Total Output Multiplier)

Code	DESCRIPTION	1	2	3	4	5	6	7	8	9	10	11
1	Agriculture	1.121608	0.012182	0.004162	0.007904	0.149256	0.021981	0.007342	0.005284	0.014830	0.006836	0.004898
2	Fishery	0.000653	1.055385	0.000182	0.000494	0.010729	0.001009	0.000429	0.000348	0.000940	0.000467	0.001142
3	Forestry	0.000413	0.000546	1.010691	0.004213	0.005095	0.001914	0.001906	0.000575	0.001197	0.000553	0.000159
4	Mining and quarrying	0.007055	0.008956	0.009374	1.017096	0.013339	0.076906	0.027394	0.014770	0.054623	0.020823	0.003389
5	Manufacturing I	0.068988	0.093112	0.014265	0.047644	1.262035	0.100809	0.034797	0.028560	0.090313	0.032897	0.021345
6	Manufacturing II	0.143308	0.180460	0.191563	0.344837	0.262828	1.587392	0.480639	0.276711	0.627618	0.416990	0.059267
7	Electricity, gas and water	0.018380	0.024532	0.016000	0.028933	0.054464	0.100187	1.054924	0.130362	0.054843	0.042033	0.016553
8	Waterworks and supply	0.000633	0.000537	0.000323	0.000481	0.005278	0.000844	0.000438	1.000407	0.002113	0.003046	0.001743
9	Construction	0.004575	0.009330	0.006566	0.021242	0.018920	0.026940	0.020930	0.045125	1.048246	0.030721	0.019846
10	Transportation, communication and storage	0.024068	0.030516	0.062252	0.027488	0.049845	0.049399	0.017364	0.023884	0.088096	1.037362	0.018222
11	Other Services	0.061656	0.056609	0.066511	0.097357	0.172335	0.161129	0.145705	0.116594	0.194205	0.205278	1.060329
TOM	Total Output Multiplier	1.465	1.485	1.397	1.620	2.042	2.164	1.824	1.669	2.220	1.440	

Table B5b. 12 x 12 Leontief Inverse Matrix (Total Output Multiplier)

Code	DESCRIPTION	1	2	3	4	5	6	7	8	9	10	11	12
1	Agriculture	1.197679	0.079294	0.138001	0.061491	0.203582	0.062275	0.052399	0.064370	0.063039	0.070612	0.043342	0.155672
2	Fishery	0.027619	1.079175	0.047625	0.019489	0.029987	0.015293	0.016401	0.021293	0.018029	0.023074	0.014769	0.055182
3	Forestry	0.001974	0.001923	1.013439	0.005313	0.006210	0.002741	0.002831	0.001788	0.002187	0.001862	0.000948	0.003196
4	Mining and quarrying	0.018857	0.019369	0.030140	1.025410	0.021768	0.083158	0.034385	0.023938	0.062102	0.030718	0.009353	0.024153
5	Manufacturing I	0.409252	0.393299	0.612923	0.287339	1.505037	0.281044	0.236337	0.292850	0.305950	0.318165	0.193308	0.696315
6	Manufacturing II	0.378036	0.387541	0.604542	0.510188	0.430460	1.711726	0.619669	0.459028	0.776373	0.613780	0.177894	0.480346
7	Elect., gas and water	0.065546	0.066143	0.098984	0.062159	0.088148	0.125171	1.082861	0.166997	0.084734	0.081576	0.040390	0.096521
8	Waterworks and supply	0.005779	0.005077	0.009378	0.004106	0.008953	0.003570	0.003487	1.004405	0.005375	0.007360	0.004344	0.010531
9	Construction	0.020056	0.022988	0.033802	0.032147	0.029976	0.035140	0.030099	0.057150	1.058057	0.043700	0.027670	0.031680
10	Transpo., comm.& storage	0.109571	0.105949	0.212686	0.087720	0.110908	0.094690	0.068007	0.090296	0.142282	1.109046	0.061434	0.174973
11	Other Services	0.407030	0.361304	0.674161	0.340652	0.418986	0.344071	0.350271	0.384853	0.413080	0.494831	1.234874	0.706772
12	Household sector	0.714532	0.630372	1.257144	0.503344	0.510287	0.378482	0.423220	0.554991	0.452823	0.599046	0.361110	1.462215
TOM	Total Output Multiplier	3.356	3.152	4.733	2.940	3.364	3.137	2.920	3.122	3.384	3.394	2.170	3.898

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 due to 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 modeling 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 Annex B. The residual coefficient matrices for the various models are given in Tables B6a-b.

Table B6a. 11 x 11 Residual Coefficient Matrix

Description	1	2	3	4	5	6	7	8	9	10	11
N	0.000413	0.000021	0	0	0.000023	0	0	0	0	0	0.000012
P	0.000234	0.000019	0	0	0.000000	0	0	0	0	0	0.000005
SS	0.1157700	0.000023	0	0	0.000208	0	0	0	0	0	0.0023111
C	0.000000	0.000003	0	0	0.000223	0	0	0	0	0	0

Table B6b. 12 x 12 Residual Coefficient Matrix

Description	1	2	3	4	5	6	7	8	9	10	11	12
N	0.000413	0.000021	0	0	0.000023	0	0	0	0	0	0.000012	0.000088
P	0.000234	0.000019	0	0	0	0	0	0	0	0	0.000005	0.0001145
SS	0.115770	0.000023	0	0.022030	0.000208	0	0	0	0	0	0.002311	0
C	0	0.000003	0	0	0.000223	0	0	0	0	0	0	0.0010139

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.

Table B7. Residual Multiplier for 12 Sector I/O Model

Description	1	2	3	4	5	6	7	8	9	10	11	12
N	0.000573	0.000125	0.000192	0.000081	0.000170	0.000070	0.000069	0.000088	0.000079	0.000096	0.000070	0.000220
P	0.000365	0.000113	0.000181	0.000074	0.000109	0.000060	0.000063	0.000081	0.000069	0.000088	0.000058	0.000209
SS	0.140097	0.010548	0.018327	0.030556	0.025330	0.009896	0.007683	0.008930	0.009685	0.010062	0.008118	0.020334
C	0.000816	0.000730	0.001411	0.000574	0.000853	0.000446	0.000482	0.000628	0.000527	0.000678	0.000409	0.001638

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.

Table B8. Estimation of total material concentrations in Lingayen Gulf and those contributed by economic activities.

Material	Ambient concentration	Concentration derived from economic activities (% contribution)[3]
DIN	0.81[1] µmol/L	0.33 □ mol/L (41)
DIP	0.12[1] µmol/L	0.04 □ mol/L (33)
TSS	2.5± 4.5 mg/L 6.3 mg/L[2]	2.6 mg/L (37-100)

1 San Diego-McGlone, et. al., 1998
2 Siringan, et. al., 1998
3 McGlone & Caringal, 1998

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.

12-Sector Model

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.

Table B9. Changes in the total final demand (ΔY) 12 Sector Regional Model, 1994 (in thousand pesos)

Code	Description	Scenarios	
		1	2
1	Agriculture	3696402.80	3696402.80
2	Fishery	0.00	184009.20
3	Forestry	0.00	306.40
4	Mining and quarrying	0.00	92141.40
5	Manufacturing I	0.00	3962216.60
6	Manufacturing II	0.00	1897284.20
7	Electricity, gas and water	0.00	440603.00
8	Waterworks and supply	0.00	63228.00
9	Construction	0.00	1632080.20
10	Transportation, communication and storage	0.00	747344.80
11	Other services	0.00	632413.00
12	Household	0.00	0.00

Results

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.

Table B10. Induced changes in total output (Δx) (in thousand pesos)

Code	Initial X	Scenarios			
		1		2	
		ΔX	□%	ΔX	□%
1	23722345	4427104.603		5582417.598	
2	2897285	102089.450		514890.217	
3	19152	7297.831		45178.466	
4	941071	69704.380		558673.958	
5	3066379	1512760.299		9090308.156	
6	5246848	1397374.316		8609449.000	
7	462581	242285.253		1559430.644	
8	43763	21363.099		146986.036	
9	9685851	74134.871		2060646.255	
10	3048735	405017.947		2187334.982	
11	28667465	1504548.147		5919144.825	
12	25862917	2641199.414		7180584.346	

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 B10 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 mt, (13.9%), phosphorus by 1349 mt (11.1%), suspended solids by 517856 mt (18.3%), and carbon by 3015 mt (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.

Table B11. Induced changes in residual generation, ΔR (in metric tons)

		IO Model			
#	Initial R	Scenario 1		Scenario 2	
		ΔR	□%	ΔR	□%
N	15189	2116.829	13.90	3236.472	21.30
P	12117	1349.224	11.10	2170.397	17.90
SS	2833967	517855.724	18.30	674166.894	23.80
C	56975	3015.140	4.75	9306.558	16.30
		Rapid Assessment Method			
#	Initial R	Scenario 1		Scenario 2	
		ΔR	□%	ΔR	□%
N	15189	1525	10.0	1630	10.7
P	12117	866	7.1	873	7.2
SS	2833967	427933	15.1	432253	15.3
C	56975	0	0.0	883	1.5

In 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.

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Appendix C Sediment load partitioning of the Agno River and changes in the shoreline position

Fernando P. Siringan and Zenon Richard P. Mateo
National Institute of Geological Sciences University of the Philippines, Diliman, Quezon City

Introduction

The Agno River, the fifth largest river in the Philippines, is the largest river in terms of drainage area and discharge that empty into Lingayen Gulf. Its water discharge accounts for almost 70% of the total fresh water input into the gulf (Table C1). The Agno River originates from the slopes of Mt. Data in the Cordillera Mountains at an elevation of 2090 m, where it drains Cretaceous to Paleocene igneous basement rocks, and marine siliciclastic and carbonate rocks. Several mining districts are located within these upper reaches of the Agno River. Two major hydroelectric dams, Binga and Ambuklao (Figure C1), have been in operation since 1950 and 1956 respectively, and a third, the San Roque Dam, is presently being constructed. As the river descends following a southerly course, it exhibits a braided channel pattern. It then transforms into a southwest-directed meandering river as it crosses the Central Luzon Alluvial Plain. From the confluence with the Tarlac River emanating from the south, the Agno River then veers northward while draining the eastern flanks of the ophiolite Zambales Mountain Range. Historically, this last reach exhibited meandering channel patterns, but it has been transformed into single and relatively straight channels due to river control works since the early 1970's.

Our primary aim in this report is to come up with initial estimates of the partitioning into suspended, bed, and dissolved components of the Agno River's sediment load as it reaches the coast. We used the changes in shoreline position to estimate the bed load delivered to the coast. Secondary data were used in estimating the likely magnitudes of suspended and dissolved loads.

Table C1: 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).

Data and Methods

Shoreline and Volumetric Changes
Estimation of the Agno River's bed load input into Lingayen Gulf is based on the changes of shoreline position and offshore profile. The oldest shoreline data is from a 1940 reconnaissance survey published in a 1944 topographic map. Another topographic map published in 1955 derived its coastal outline from a set of aerial photographs taken in 1950. The latest topographic map has data from 1977. The 1989 and 1991 shoreline data were taken from aerial photographs and a Synthetic Aperture Radar image, respectively. These shoreline data sets were enlarged or reduced to a scale of 1:50,000 and were either traced manually or with the aid of an Aero Sketchmaster into the 1977 topographic map which served as the base map. Data for the offshore region was derived from the series of 1902-1903 hydrographic surveys contained in NAMRIA Bathymetric Chart #4209 (1980). We acquired the 1997 to 1998 bathymetric data by making spot water depth measurements with a depth meter operating at a frequency of 455 Khz. Positions were established using a hand held GPS unit.

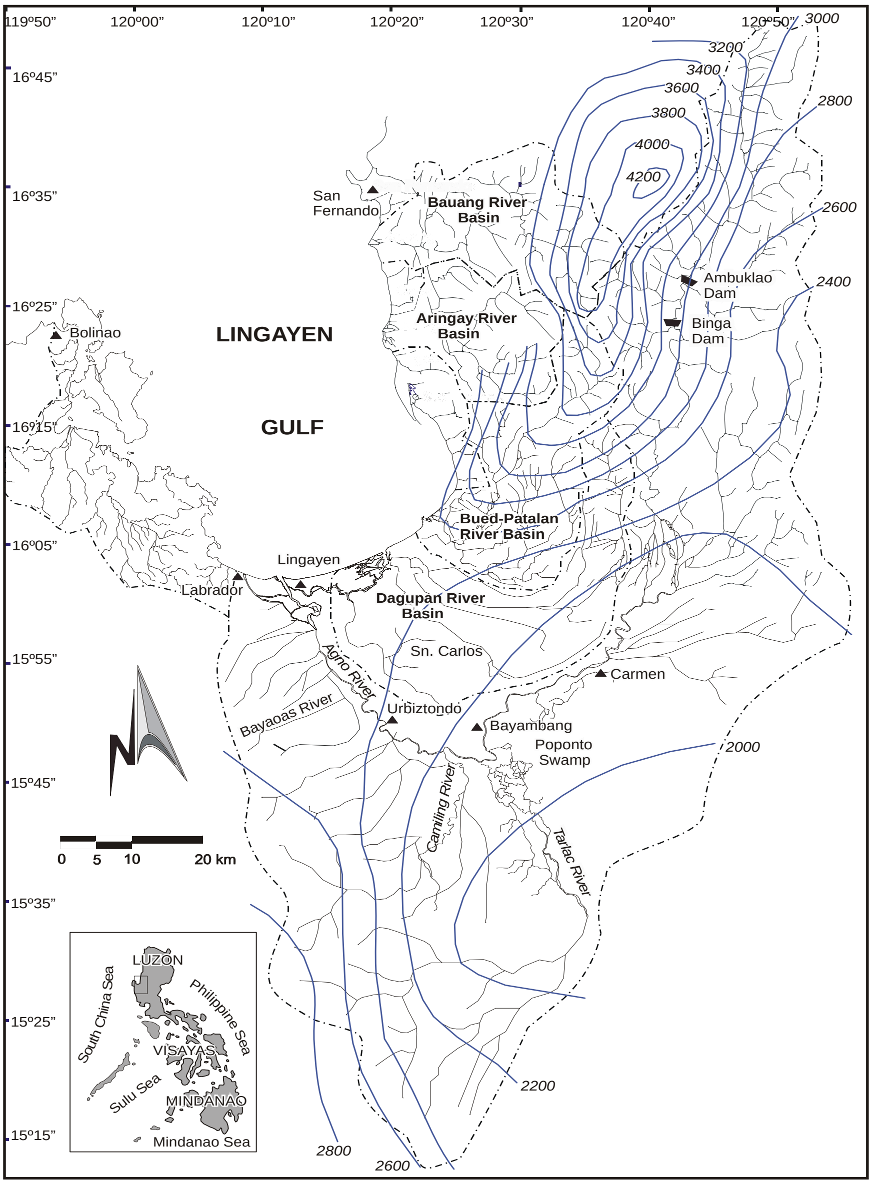

Figure C1. Watershed map of Lingayen Gulf showing the different river basins and isohyetal lines in intervals of 200 mm. From David et al. (1997); JICA (1991)

To facilitate the computation of volume, the shorelines and isobaths defining the present deltaic and non-deltaic shorefaces were digitized. The total area that was eroded or prograded along the Agno Labrador and Agno Lingayen deltas were then computed using AutoCad. The x,y,z coordinate of data points were also extracted using a written Visual Basic programming tool in preparation for input in a generic mapping software. From the grid data, the volume was calculated using SURFER. The closure depth, derived from the lower limit of the predominance (50%) of sand in the surface sediment and from the average depth of occurrence of sand as reflected in the borehole data from adjacent coastal plains, was set at 15 m. This depth was set to delimit the offshore transport of the bedload. Final outputs are 1950 and 1991 surface maps and volumetric change of Agno-Lingayen Delta.

We assumed that the sediment eroded from the adjacent Agno-Labrador delta to the east was transported and subsequently accreted, 100%, to the western flank of the Agno Lingayen delta. This is based on the predominance of eastward longshore currents along the coastline west of the Agno Lingayen delta. An additional assumption is that no sediment is lost to or gained from the coastal area east of the delta.

Estimation of Suspended and Dissolved Sediment Discharge

To estimate the magnitudes of suspended and dissolved loads of the Agno River, secondary data generated by the Bureau of Soils and EIA reports were used. Several stations were reoccupied during the above studies (Figure C1). We wanted to use a station downstream but, except for Bocboc in San Carlos City where only one measurement of SS was made, the rest of the stations were situated right at the mouths of the Agno-Lingayen and Agno-Labrador channels. We did not include these stations because of the influence of seawater in the measured concentrations. The only other station that is close to the coast where several measurements were done is in Bayambang, Pangasinan, 9 kilometers upstream of the Agno–Tarlac River confluence or 54 km from the river mouth. We multiplied the measured concentrations with the mean annual discharge of $9x10^9$ m^3/yr measured at Urbiztondo for the period 1959–1970. Note that this yearly mean is 34% higher than the yearly average reported by NWRC (1976) and which is used in Table C1. Water discharge values at the site and time of measurement are unavailable.

Results and Discussion

Shoreline Changes

From 1950 to 1964, the shoreline within the Agno–Lingayen River mouth prograded by a maximum of 300 m (Figure C2; Table C2A). This progradation also marks the shift of this river mouth from a linear shoreline to a deltaic shoreline. The prograded area is $1.5x10^6$ m^2. This area of progradation together with the change of shoreline character, from linear to deltaic, would require sediment input amounting to $69.2x10^6$ m^3. Erosion ensued from 1964 to 1977. Progradation resumed from 1977 to 1991. The maximum net progradation from 1950 to 1991 was 1050 m. The net prograded area is $3.6x10^6$ m^2 which would require a total sediment input of $179.1x10^6$ m^3.

The Agno-Labrador delta, in the 51 years from 1940 to 1991, underwent continuous shoreline retreat of as much as 910 m (Figure C2; Table C2B). This caused erosion of $1.9x10^6$ m^2 in delta plain area. To compensate for this, a corresponding amount of $1.61x10^6$ m^3 was taken out from this delta. The most drastic event occurred during the first 10 years (1940 to 1950) when the shoreline retreated by as much as 333 m, eroding $0.8x10^6$ m^2 of the former delta plain and causing removal of $23.5x10^6$ m^3 of materials.

However, within the next 14 years (1950–1964), the shoreline retreated by only 139 m accompanied by a decrease of only $0.2x10^6$ m^2 and $8.4x10^6$ m^3 in delta area and volume, respectively. Farther reduction in the seaward extent of the delta occurred from 1964 to 1977 when the shoreline moved 222 m landward, removing $0.4x10^6$ m^2 of land surface which correspond to a decrease of $6.6x10^6$ m^2 in the delta volume. In 1989, the shoreline again receded by 277 m from its position in 1977. Likewise, the area decreased by $0.5x10^6$ m^2 and the volume by $1.1x10^6$ m^3. From 1989 to 1991, there was no detectable change in the shoreline position.

Bed Load Calculated from Shoreline Changes

From 1950 to 1991, the volume of net progradation, which includes the eroded volume during the period 1964–1977, in the Agno Lingayen Delta is $179.1x10^6$ m^3 (Table C2A).

Table C2A: Changes in the Agno-Lingayen (Limahong Channel) Delta

Year interval	Period (no. of years)	Maximum shoreline advance (+) retreat (-) (m)	Rate of advance (+) or retreat (-) (m/year)	Net change in area: increase (+) or decrease (-) (x 10^6 m^2)	Volume Change (x 10^6 m^3)
1950 – 1964	14	+ 590	42	1.5	69.2
1964 – 1977	13	- 410	32	- 0.6	-45.2
1977 – 1989	12	+ 820	68	2.6	55.0
1989 - 1991	2	+ 60	30	0.1	9.7
Total		**1060**		**3.6**	***179.1**

- In this total, we treated the 1964-1977 volume change as a positive change. What had eroded was accounted for as sediment input.

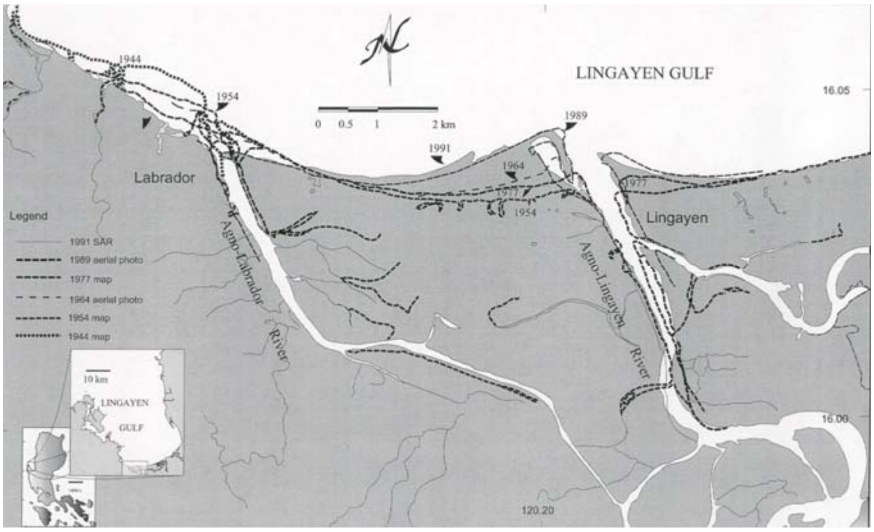

Figure C2. Shoreline change map of the Agno-Lingayen and Agno-Labrador deltas.
Sources: 1944, 1954 maps were published by the US Army Corps of Engineers; 1964 data from SRMP ERA (1997); 1977 topographic map and 1991 SAR image from the Philippines National Mapping and Resoirce Information Authority (NAMIRA).

Table C2B: Changes in the Agno-Labrador delta.

Year interval	Period (no. of years)	Maximum shoreline advance (+) retreat (-) (m)	Rate of advance (+) or retreat (-) (m/year)	Net change in area: increase (+) or decrease (-) ($x10^6$ m^2)	Volume Change (x 10^6 m^3)
1940 - 1950	10	-333	-33.3	- 0.8	- 23.5
1950 - 1964	14	-139	-9.93	- 0.2	- 8.4
1964 - 1977	13	-222	-17.1	- 0.4	- 6.6
1977 - 1989	12	-277	-23.1	- 0.5	- 1.1
1989 - 1991	2	0	0	0	0
Total		**971**		**1.9**	**20.6**

During the same period, the net eroded volume in Agno Labrador is 16.1x10^6 m^3. Assuming that all of the sediment eroded along Agno Labrador was transported to Agno Lingayen, the required sediment input would be 163x10^6 m^3 within the 41-year period, or equivalent to a yearly input of 5.6x10^6 using a bulk density of 1.4 tons/m^3.

Not all of these would be bed load. The closure depth of 15 m, as defined earlier is the depth where the sand concentration of the surface sediment drops to below 50%. If we assume that only half of the prograded volume is bed load, fine sand and coarser, then the required input would be approximately 2.8x10^6 tons/year.

Suspended and Dissolved Loads Based on Secondary Field Measurements
Table C3 shows the magnitudes of measured concentrations of suspended and (SS) dissolved (DS) loads of Agno River at Bayambang. The tabulation shows the possible range of suspended and dissolved loads delivered to Lingayen Gulf. The suspended load ranges from a low 1.3x10^6 tons/yr during dry period, to a high of 13.3x10^6 tons/yr during the middle of the rainy season. The mean is 4.1x10^6 tons/yr. For the dissolved load, the low value is 1.4x10^6 tons/yr during the rainy season while the high value is 4x10^6 tons/yr., also during the rainy season. The mean is 2.1x10^6 tons/yr. Overall, the measurements indicate that the likely magnitude of suspended and dissolved loads delivered to Lingayen Gulf is in the order of 10^6 tons/yr. and that the dissolved load could be half of the suspended load. However, at the Bayambang station, the input from the western sub-basins are still unaccounted for. Thus, it is more likely that the actual amounts of suspended and dissolved loads delivered to the coast are higher.

Table C3. Suspended and dissolved loads from secondary data.

Station	SS (mg/l)	DS (mg/l)	SS (x 10^6 tons/yr)	DS (x 10^6 tons/yr)
Bureau of Soils (Aug.75- Nov.76)				
Wet (Bayambang)	514	184*	4.6	1.7
Dry (Bayambang)	140	225*	1.3	2.0
Bureau of Soils (June 1981)				
Bayambang (Poblacion)	480		4.3	
Bayambang (Wawa)	298		2.7	
Bocboc (San Carlos City)	235		2.1	
NPCC (Bayambang)	300	200*	2.7	1.8
1984 SRMP EIA				
Aug	240	440	2.2	4.0
Sept	1480	160	13.3	1.4
Oct	620	200	5.6	1.8
Dec.	360	200	3.2	1.8
Feb.	340	290	3.1	2.6
*derived from (total solids - suspended sediments)		**Mean**	**4.1**	**2.1**

Sediment Partitioning

JICA (1991) estimates that the total amount of sediment delivered by the Agno River to the coast is 6.3x10^6 m^3/yr. Using 1.6 tons/m^3 as bulk density of watershed materials, the above sediment delivery would be equal to 10.1x10^6 tons/yr. The progradation of the Agno-Lingayen delta would account for at least 28% of the above. If some of the bed load material is from the eastern flanks of Agno-Lingayen delta, this percentage may go lower. Based on the secondary field measurements the suspended load may account for 41% while the dissolved load may account for 21%.

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Appendix D Hydrologic and physico-chemical modelling of the watersheds draining into Lingayen Gulf

Roberto S. Clemente and Edwin N. Wilson
Environmental Science Program, College of Science,
University of the Philippines, Diliman, 1101 Quezon City

Introduction

There is a growing concern and evidence that Lingayen Gulf is being threatened by the influx of toxic and hazardous substances from the surrounding watersheds and coastal communities. In addition, surface and subsurface inflow of freshwater into the gulf has been reported (Villanoy, 1998). Because of these environmental concerns, there is now an increasing need to evaluate the transport of water and solutes from the different land management units that drain into the gulf. Specifically the migration of nutrients, e.g., nitrogen and phosphorus, and sediments from the upland watersheds and agricultural production areas need to be assessed to establish seasonal and long term impacts on the gulf.

This module therefore comprises a new component of the overall conceptual framework that integrates the biophysical and economic assessment of the interactions among population, human activities, and the environment. The methodologies under this module are aimed to characterize the hydrology, i.e., both quantity and quality, of the watersheds that drain into Lingayen Gulf. This module covers the results of the study, which are:

1. validation of groundwater flow to the gulf as computed by Siringan et. al. (1998) using measured piezometric heads and specific hydraulic conductivities.
2. calculations of water balance in the watershed based on rainfall, evapotranspiration and surface runoff with infiltration or groundwater recharge as the residual value.
3. Simulation of runoff, sediment, and nutrient transport to assess the inputs from the watershed with respect to water quantity and quality.

Methodology

This component consists of field surveys, groundwater sampling, computation of groundwater flow, water balance calculations and simulation of runoff, sediment, and nutrient transport from the watersheds to Lingayen Gulf. The watershed area draining into the gulf was classified or subdivided into land use criteria and topographic features. Generally, these are the inputs to the runoff/erosion model including the slope, soil and management practices for each land management unit. Also, from groundwater flow computations as done by Siringan, et. al. (1998), a representative subsection covering the wells sampled for water depths and hydraulic gradients were considered in the analysis. This is to study the effect of spatial variability in hydraulic conductivity (K) on ground water flow that was not reflected in the previous computation of discharge for each whole block.

A. <u>Field surveys and groundwater sampling</u>

Site visits to the study area were undertaken on 16 February and 22-23 March 1999 to gather representative well data within the blocks initially delineated by Siringan et. al. (1998). The first site visit in Sual and Bugallon areas of Pangasinan and the second visit along the coastal communities in La Union involved measurements of well depths and interviews with well owners concerning well profile and history. Details of the interview and well characterization are presented in Table D1.

Table D1 ***In situ*** **open wells data taken in Pangasinan and La Union on February 16, 1999 and from March 22 to March 23, 1999.**

Place	Location	Ground Elevation	Groundwater Elevation	Soil Profile
Putot, Bauang, La Union (Station 20)	16^{0} 33’ 38” N 120^{0} 20’ 20” E	15.0m	10.38m	Sand with pebbles
Dili Norte, Bauang, La Union (Station 19)	16^{0} 33’ 32” N 120^{0} 19’ 30” E	10.0m	7.0m	Sand with pebbles
Calumbaya, Bauang, La Union (Station 18)	16^{0} 30’ 58” N 120^{0} 19’ 53” E	15.0m	6.06m	Sand with gravel
Parian Este, Bauang, La Union (Station 17)	16^{0} 30’ 31” N 120^{0} 19’ 14” E	4.0m	1.25m	Sand with gravel
Parian Este, Bauang, La Union (Station 17-A)	16^{0} 30’ 20” N 120^{0} 19’ 14” E	4.0m	4.25m	Sand with gravel
Santiago Norte, Caba, La Union (Station 16)	16^{0} 25’ 57” N 120^{0} 20’ 04” E	3.0m	0.81m	Sandy
Lasud, Caba, La Union (Station 15)	16^{0} 25’ 57” N 120^{0} 20’ 25” E	5.0m	2.53m	Sandy
Lasud, Caba, La Union (Station 15-A)	16^{0} 25’ 57” N 120^{0} 20’ 45” E	15.0m	3.3m	-
----------, Aringay, La Union (Station 14)	16^{0} 24’ 15” N 120^{0} 20’ 00“ E	1.5m	0.12m	Sand with grit
Sta. Lucia, Aringay, La Union (Station 13)	16^{0} 23’ 50” N 120^{0} 21’ 02” E	10.0m	7.0m	Sand with grit
Sta. Rita West, Agoo, La Union (Station 12)	16^{0} 21’ 22” N 120^{0} 20’ 30” E	1.5m	0.15m	Sandy
Sta. Rita Norte, Agoo, La Union (Station 11)	16^{0} 21’ 22” N 120^{0} 21’ 25” E	10.0m	3.95m	Sand with grit
Ambitacay, Sto. Tomas La Union (Station 10)	16^{0} 17’ 53” N 120^{0} 23’ 47” E	30.0m	26.75m	Clayey
Ambitacay, Sto. Tomas La Union (Station 10-A)	16^{0} 17’ 56” N 120^{0} 23’ 55” E	32.0m	30.87m	Clayey
Namboangan, Sto. Tomas La Union (Station 9)	16^{0} 17’ 39” N 120^{0} 22’ 40” E	5.0m	3.0m	Sandy
Amlang. Sto. Tomas, La Union (Station 8)	16^{0} 14’ 11” N 120^{0} 25’ 48” E	20.0m	15.7m	Sand with grit
Damortis, Sto. Tomas, La Union (Station 7)	16^{0} 13’ 15” N 120^{0} 24’ 29” E	10.0m	1.66m	Sand with grit
Bulasi, San Fabian, Pangasinan (Station 6)	16^{0} 05’ 01” N 120^{0} 25’ 15” E	3.0m	1.5m	Sandy
Lobong, San Jacinto, Pangasinan (Station 5)	16^{0} 05’ 11” N 120^{0} 29’ 28” E	40.0m	34.0m	Clayey
Quintong, San Carlos City, Pangasinan (Station 4)	15^{0} 57’ 47” N 120^{0} 19’ 08” E	4.0m	1.6m	Sandy
Cawaya Kiling, Urbiztondo, Pangasinan (Station 3)	15^{0} 51’ 40” N 120^{0} 19’ 20” E	6.0m	3.48m	Sandy
Abanon, Urbiztondo, Pangasinan (Station 3-A)	15^{0} 52’ 05” N 120^{0} 19’ 33” E	6.0m	2.76m	Sand with pebbles
Estanza, Lingayen, Pangasinan (Station 2)	16^{0} 01’10” N 120^{0} 10’ 27” E	2.0m	0.24m	Sandy
Pangasinan (Station 2-A)	16^{0} 02’ 00” N 120^{0} 11’ 02” E	1.5m	0.08m	Sandy
Buenlog, Bugallon, Pangasinan (Station 2-B)	15^{0} 58’ 55” N 120^{0} 11’ 27” E	6.0m	4.24m	Sand with pebbles
Cabayawasan, Bugallon, Pangasinan (Station 2-C)	15^{0} 57’ 13” N 120^{0} 13’ 28” E	5.0m	3.32m	Sand with grit
Laguit Padilla, Bugallon, Pangasinan (Station 1)	15^{0} 57’ 01” N 120^{0} 10’ 53” E	13.0m	11.95m	Sand with pebbles
Laguit Padilla, Bigallon, Pangasinan(Station 1-A)	-do-	11.0m	11.83m	Sand with pebbles

B. Groundwater discharge

The open wells inspected were each designated a station number, the locations of the stations, the groundwater surface elevation, and the soil profile characterization. This is presented in Figure D1 (marked Figure 10).

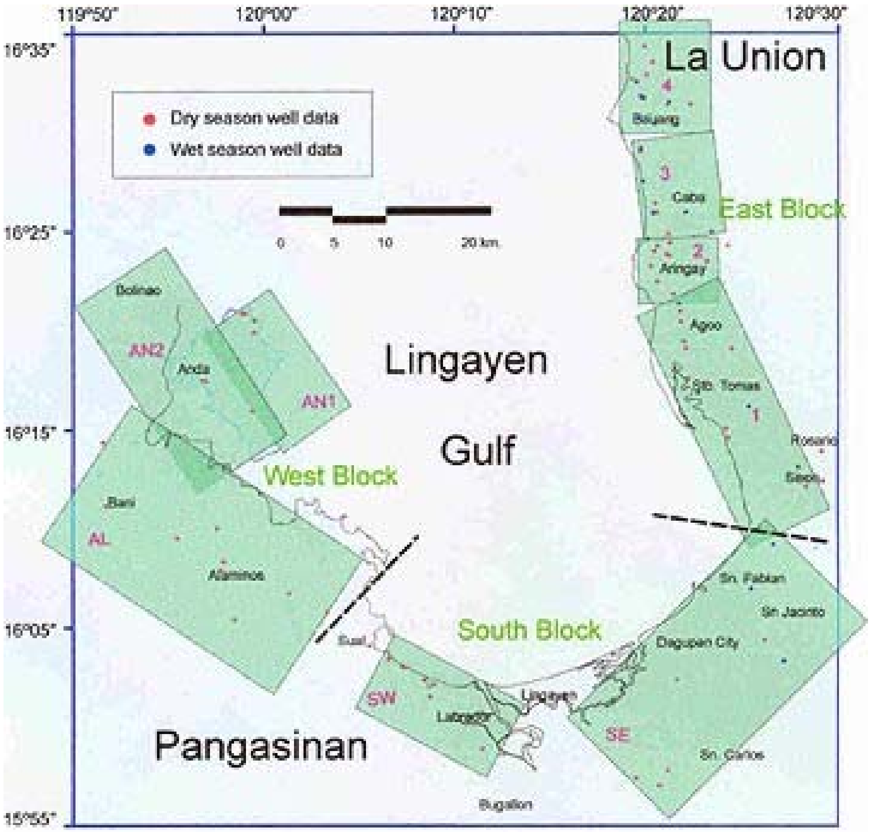

Figure 10: Map showing the distribution of wells utilized in the calculation for the groundwater outflow into Lingayen Gulf. Also shown are the pertinent zonations established.

Table D2 shows the groundwater discharge along the coasts of Lingayen Gulf that is within the watershed area. By definition, a watershed area is a land based ecosystem with a defined area (may be composed of several smaller or sub-watersheds), with a specific climate characteristics, water and other resources and in turn is capable of making available and sustaining life support systems for plants, animals and people (Clemente et al.,1998). Each soil profile where a well is located and sampled was designated a corresponding hydraulic conductivity (Bedient and Huber, 1992; Maidment, 1993). The groundwater flow then is computed using the Darcy's Law (Shaw, 1994) as:

$$Q = -K\,A\,i,$$

where: Q = groundwater discharge (m^3/day)
K = hydraulic conductivity (m/day)
A = cross-sectional area of flow, (L x W)
L = length of coastline (m)
W = width of flow or highest hydraulic head (m)
i = hydraulic gradient, (h1-h2) / d
h2 = highest hydraulic head (m)
h1 = lowest hydraulic head (m)
d = distance from h1 to h2 (m)

Table D2. Groundwater discharge along the coastal towns of Lingayen Gulf computed by using different hydraulic conductivities.

Soil Profile	Hydraulic Conductivity (K)
Sand with pebbles	10 +2 m/day or 1000 m/day
Sand with gravel	10 +2 m/day or 1000 m/day
Sand with grits	10 +2 m/day or 1000 m/day
Sand	10 m/day or 10 m/day
Sand with grits to sandy	10 m/day or 10 m/day
Sand with pebbles to sandy	10 +1 m/day or 100 m/day
Clayey to sandy	10 –3 m/day or 0.01 m/day

Segment	Hydraulic Conductivity (m/day)	Highest hydraulic head (h1) (m)	Lowest hydraulic head (h2) (m)	Distance between h1 and h2 (m)	Approximate length of coast (m)	Vertical section of flow (m)	m^3/day	m^3/year
4	1000	10.38	7	1500	5,937.86	10.38	138,884.1703	50,692,722.14344
4	1000	6.06	1.25	1450	5,937.86	6.06	119,365.7283	43,568,490.81968
3	10	3.3	0.81	1150	9185.438	3.3	656.3195	239,556.62241
2	1000	7	0.12	2000	7252.2187	7	174,633.4263	63,741,200.59804
1	10	3.95	0.15	1650	11758.244	3.95	1,069.6439	390,420.02116
1	0.01	30.87	3	2300	11758.244	30.87	43.9833	16,053.92001
1	1000	15.7	1.66	2450	11758.244	15.7	1,057,896.4116	386,132,190.23579
SE	0.01	34	1.5	10300	7201.8856	34	7.7263	2,820.09758
SE	100	2.76	1.6	10250	7201.8856	2.76	224.9518	82,107.39787
					Total		**1,492,782.3612**	**544,865,561.8559**
SW [a]	56.16	0.39	0.09	172.93	11,801.34	0.39	448.4086091	163,669.14
AN1[a]	56.16	7.72	1.7	1025.915	30372.86	7.72	77270.76276	28,203,828.41
AN2 [a]	56.16	19.09	5.85	350.4459	44150.523	19.09	1788281.508	652,722,750.46
A1 [a]	56.16	7.87	1.95	3618.3108	44319.474	7.87	32048.8364	11,697,825.28
					Total		**1,898,049.52**	**692,788,073.29**
				Grand Total			**3,390,831.88**	**1,237,653,635.15**

[a] - adopted from Siringan et al. (1998) hydraulic conductivity of 0.00065m/sec or 56.16 m/day.
Reference: Maidment (1993)

Using the blocks delineated by Siringan et al. (1998) in Figure D1 (= Figure 10) as the basis for groundwater discharge validation, this study subdivided Block 4 into two equal subsections, Blocks 3 and 2 were maintained as is, Block 1 was also subdivided into three equal subsections and SE Block into two. Other blocks (SW, AN1, AN2, and Al) and its corresponding computed groundwater discharge were used as is in the computation of total groundwater discharge.

C. <u>Water balance</u>

Daily water balance at the soil surface and unsaturated zone were estimated using the following equation;

$$P = Ro + AET + I$$

where: P = rainfall depth (cm)
Ro = runoff depth (cm)
AET = actual evapotranspiration (cm)
I = infiltration or recharge to groundwater (cm)

This is also the equation used by JICA (1992) in a study to estimate the groundwater recharge in Metro Manila.

However, unlike in the JICA approach where runoff is approximated to be a certain fraction of rainfall, this component was estimated using the US SCS equation which is written as:

$$Qt = ((Rt - 0.2\ St)2 / (Rt + 0.8\ St))$$

where St = retention parameter

$$= 2540/CN - 25.4$$

where CN = curve number, a factor from soil hydrologic tables (Schwab et al., 1987) which reflects the runoff potential of a watershed. The results of the water balance calculations are summarized in Tables D3-6.

In a study by Siringan et al. (1998), freshwater inflows into Lingayen Gulf coming from the watershed were the stream flow and the subsurface discharge. Stream flow was computed based on river discharge while subsurface flow was computed using the modified Darcy's Law (Q=-KAi). In this module however, the whole watershed area of 7485.6 km^2 or 748,560 hectares (Siringan et al. 1998) was divided according to its effective land use such as agricultural, grassland or shrubland, forest or wooded , wetland, bareland, and built-up areas. Agricultural area is further subdivided into irrigated rice paddies, unirrigated rice paddies and orchard or fruit trees (LREP-Pangasinan, 1980 and LREP- La Union, 1986). Water balance was calculated for each land-use unit to reflect the effect of farming practices, crop characteristics and soil properties on watershed hydrology.

Runoff depth for built-up areas is computed as 60% of the rainfall (MWSS, 1992 as cited by McGlone and Caringal, 1998). Runoff volumetric rate is also considered as river or stream flow (Clemente et al. 1998) which amounted to 7.03×10^9 m^3 average per year (Table D6). Siringan et al. (1998) calculated the river discharge in the watershed as 9.88×10^9 m^3 per year. The difference in the volume can be attributed to the different approach in the calculations. Siringan et.al.(1998) calculated the river discharge while in this study climatological data such as precipitation and pan evaporation in the watershed from 1990 to 1998 were used as inputs to the Runoff Submodel of PESTFADE (Clemente, 1991; Clemente, et al., 1993; Clemente et al., 1998). Within the land use classification, grassland or shrubland registered the highest runoff in both provinces of Pangasinan and La Union. This could be attributed also to its areal extent.

The results of water balance calculation (Table D6 and Figure D2) are summarized in Table D5 (ground water recharge or infiltration), Table D3 (surface runoff), and Table D4 (actual evapotranspiration).

Table 3. Computations for surface runoff (m^3/yr) from the watershed area draining into Lingayen Gulf.

Land Use	Area	1990	1991	1992	1993	1994	1995	1996	1997
Pangasinan	(ha)								
Agricultural areas									
Irrigated	35,226	309,892,738.70	101,823,782.44	279,579,779.37	143,650,261.90	133,775,847.24	129,331,836.29	198,230,528.84	163,113,780.52
Unirrigated	170,839	1,863,284,596.13	704,518,510.29	1,718,038,986.72	930,058,647.70	829,347,128.43	828,777,402.74	1,226,016,171.59	1,076,958,902.18
Orchard/fruit trees	31,990	348,904,373.30	131,922,729.26	321,706,795.20	174,155,644.44	155,297,178.27	155,190,495.81	229,574,378.97	201,663,058.67
Grassland/ Shrubland	209,009	2,828,238,724.94	1,219,915,305.98	2,650,163,056.94	1,510,277,055.03	1,313,223,866.85	1,358,359,732.44	1,909,749,237.72	1,769,762,513.36
Forest or wooded areas	42,197	371,218,528.78	121,974,057.44	334,906,828.77	172,077,729.56	160,249,231.42	154,925,779.14	237,459,082.08	195,392,953.97
Wetland areas	19,445	48,786,979.99	5,655,074.62	33,098,345.64	14,225,276.45	18,287,331.23	20,821,219.88	25,176,209.95	10,867,010.68
Bareland areas	9,849	43,242,083.75	8,644,967.63	34,639,445.15	15,301,606.86	17,320,610.89	17,013,674.75	24,943,180.35	15,146,009.97
Built-up areas	19,375	333,416,625.00	214,225,500.00	316,095,375.00	148,168,834.65	128,480,887.68	221,595,750.00	185,902,431.05	173,917,652.80
Total	537,930	6,146,984,650.59	2,508,679,927.66	5,688,228,612.79	3,107,915,056.59	2,755,982,082.01	2,886,015,891.05	4,037,051,220.55	3,606,821,882.15
La Union									
Agricultural Areas									
Irrigated	5,280	46,449,601.44	15,262,294.08	41,906,013.60	21,531,635.60	20,051,566.64	19,385,456.64	29,712,632.50	24,449,008.15
Unirrigated	3,559	38,816,838.53	14,676,867.57	35,791,012.32	19,375,427.90	17,277,357.22	17,265,488.42	25,540,957.01	22,435,724.47
Orchard/fruit trees	3,447	37,595,291.49	14,214,993.68	34,664,686.56	18,765,692.60	16,733,647.19	16,722,151.89	24,737,195.51	21,729,683.13
Grassland/ Shrubland	41,448	560,860,243.68	241,918,049.47	525,546,547.68	299,498,889.41	260,421,813.57	269,372,582.95	378,717,119.38	350,956,737.05
Forest or wooded areas	8,372	73,650,769.56	24,199,985.99	66,446,429.14	34,140,691.33	31,793,885.00	30,737,697.54	47,112,530.16	38,766,495.50
Wetland areas	558	1,400,006.93	162,279.85	949,800.82	408,213.13	524,779.16	597,492.45	722,464.65	311,843.25
Bareland areas	2,120	9,307,870.60	1,860,831.70	7,456,150.24	3,293,675.15	3,728,266.33	3,662,198.24	5,369,026.53	3,260,182.88
Built-up areas	2,962	50,971,873.20	32,750,241.60	48,323,845.20	22,651,669.07	19,641,826.55	33,876,986.40	28,420,283.91	26,588,081.94
Total	67,746	819,052,495.43	345,045,543.94	761,084,485.56	419,665,894.18	370,173,141.67	391,620,054.53	540,332,209.65	488,497,756.37
Benguet									
Forest or wooded areas	142,884	2,090,575,811.52	2,572,047,739.80	2,590,098,275.52	1,505,830,770.12	2,429,074,257.27	546,432,710.04	2,004,543,417.61	767,994,851.61
Grand Total	**748,560**	**9,056,612,957.54**	**5,425,773,211.40**	**9,039,411,373.87**	**5,033,411,720.89**	**5,555,229,480.95**	**3,824,068,655.62**	**6,581,926,847.81**	**4,863,314,490.13**

Note: Average yearly runoff volume = 7,032,867,085.92 m^3

Table 4 Computations for evapotranspiration (m^3/yr) in the watershed area of Lingayen Gulf.

Land Use	Area (ha)	1990	1991	1992	1993	1994	1995	1996	1997	1998
Pangasinan										
Agricultural Areas										
Irrigated	35,226	450,751,896.00	429,582,831.30	408,862,545.84	414,045,699.48	410,128,744.41	401,274,160.92	403,224,448.41	449,007,328.35	439,167,227.06
Unirrigated	#####	1,758,794,338.56	1,639,033,636.98	1,573,442,064.83	1,629,526,446.63	1,617,053,491.24	1,583,652,758.35	1,592,526,136.01	1,739,427,175.33	,721,011,568.24
Orchard/fruit trees	31,990	275,491,002.15	262,172,765.40	249,713,300.20	253,148,386.14	250,979,624.35	245,171,999.80	246,714,877.50	273,802,569.95	268,836,687.07
Grassland/Shrubland	#####	2,215,311,472.08	2,108,215,260.48	2,008,024,706.24	2,035,647,335.68	2,018,207,624.72	1,971,506,653.76	1,983,913,428.00	2,201,734,247.44	2,161,801,991.14
Forest or wooded Areas	42,197	363,391,491.65	345,823,825.62	329,388,938.06	333,920,051.92	331,059,306.31	323,398,651.94	325,433,813.25	361,164,333.99	354,613,994.51
Wetland Areas	19,445	257,624,860.50	245,170,338.00	233,518,894.00	236,731,208.00	234,703,094.50	229,272,106.00	230,714,925.00	256,045,926.50	251,402,091.05
Bareland Areas	9,849	104,390,732.88	99,344,105.28	94,622,888.64	95,924,532.48	95,102,731.92	92,902,071.36	93,486,708.00	103,750,941.84	101,869,239.18
Built-up Areas	19,375	258,324,937.50	246,213,625.00	234,916,062.50	235,879,000.00	233,858,187.50	231,077,875.00	229,884,375.00	255,124,187.50	250,497,069.38
TOTAL	#####	5,684,080,731.32	5,375,556,388.06	5,132,469,400.31	5,234,822,660.33	5,191,092,804.95	5,078,256,277.13	5,105,898,711.17	5,640,056,710.90	5,549,199,867.63
La Union										
Agricultural Areas										
Irrigated	5,280	67,562,880.00	64,389,864.00	61,284,115.20	62,061,014.20	61,473,904.80	60,146,697.60	60,439,024.80	67,301,388.00	65,826,462.24
Unirrigated	3,559	36,640,047.36	34,145,134.98	32,778,283.23	33,947,076.63	33,687,234.04	32,991,413.95	33,176,090.46	36,236,581.33	35,852,938.56
Orchard/fruit trees	3,447	29,684,822.90	28,249,750.62	26,907,213.06	27,277,351.92	27,043,662.56	26,417,876.94	26,584,125.75	29,502,890.24	28,967,804.32
Grassland/Shrubland	41,448	439,312,325.76	418,074,370.56	398,205,857.28	403,683,624.96	400,225,203.84	390,964,062.72	393,424,416.00	436,619,863.68	428,701,007.75
Forest or wooded Areas	8,372	72,097,864.02	68,612,391.12	65,351,664.56	66,250,649.92	65,683,070.18	64,163,175.44	64,566,957.00	71,655,989.86	70,356,384.63
Wetland Areas	558	7,392,886.20	7,035,487.20	6,701,133.60	6,793,315.20	6,735,115.80	6,579,266.40	6,620,670.00	7,347,576.60	7,214,315.60
Bareland Areas	2,120	22,470,134.40	21,383,846.40	20,367,603.20	20,647,782.40	20,470,889.60	19,997,196.80	20,123,040.00	22,332,419.20	21,927,382.18
Built-up Areas	2,962	39,492,049.80	37,640,503.60	35,913,361.40	36,060,572.80	35,751,363.20	35,326,589.20	35,144,130.00	39,002,727.40	38,295,345.52
TOTAL	67,746	714,653,010.44	679,531,348.48	647,509,231.53	656,721,388.03	651,070,444.02	636,586,279.05	640,078,454.01	709,999,436.31	697,141,640.80
Benguet										
Forest or wooded Areas	142,884	470,088,360.00	470,088,360.00	470,088,360.00	474,374,880.00	759,342,729.60	470,088,360.00	640,120,320.00	1,222,944,870.42	1,222,944,870.42
Grand Total	**748,560**	**6,868,822,101.76**	**6,525,176,096.54**	**6,250,066,991.84**	**6,365,918,928.36**	**6,601,505,978.57**	**6,184,930,916.18- -**	**6,388,097,485.18**	**7,573,001,017.63**	**7,469,286,378.85**

Average yearly AET = 6,691,645,099.43 m^3

Table 5. Computations for groundwater recharge (m³/yr) in the watershed area of Lingayen Gulf as calculated from the water balance.

Parameters							Ground Water Recharge/Infiltration								
Land Use	**Area** (ha)	**Kco**	**BD**	**CN**	**Slope %**	**LS**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**
Pangasinan															
Agricultural Areas															
Irrigated	35,226	1	1.35	75	2	0.73	310,296,217.30	186,675,396.26	337,585,376.79	151,156,774.52	124,438,029.47	210,161,556.79	206,735,018.09	202,374,391.55	291,115,272.89
Unirrigated	170,839	0.7	1.25	80	8	7.005	1,571,768,343.31	1,139,000,867.74	1,684,566,501.45	878,208,302.90	794,927,826.25	1,180,143,169.91	1,101,016,695.66	1,133,753,035.85	1,482,447,615.33
Orchard/fruit trees	31,990	0.7	1.25	80	8	7.005	348,164,604.55	258,020,655.34	360,352,634.60	216,430,776.24	200,669,495.18	272,355,214.39	257,657,280.93	264,207,105.50	331,018,487.59
Grassland/Shrubland	209,009	0.8	1.35	85	20	13.83	1,310,741,420.98	932,517,898.54	1,429,617,379.82	659,962,492.12	634,097,608.10	1,065,383,874.80	901,630,110.02	861,209,315.88	1,255,890,582.98
Forest or wooded Areas	42,197	0.7	1.4	75	40	38.24	548,263,173.57	392,387,961.94	564,776,252.18	343,132,374.37	309,294,811.05	409,036,281.92	405,232,728.74	19,121,660.35	520,186,739.24
Wetland Areas	19,445	1	1.35	50	0.01	0.325	284,755,049.52	145,560,912.38	299,757,275.36	140,335,168.18	115,939,451.35	158,815,579.13	190,235,568.67	182,694,369.79	286,441,378.25
Bareland Areas	9,849	0.8	1.5	60	0.01	0.325	151,796,481.38	92,782,792.09	157,609,489.21	86,965,291.14	74,441,686.85	97,198,874.89	107,535,764.81	108,831,617.43	146,768,105.94
Built-up Areas	19,375	1	1.1	86	2	0.73	(2,702,812.50)	(65,479,750.00)	13,324,187.50	5,835,248.56	5,262,715.00	(45,236,750.00)	28,733,938.94	18,946,963.73	55,700,567.46
TOTAL	537,930						4,523,082,478.11	3,081,466,734.29	4,847,589,096.91	2,482,026,428.03	2,259,071,623.25	3,347,857,801.83	3,198,777,105.86	3,191,138,460.08	4,369,568,749.68
La Union															
Agricultural Areas															
Irrigated	5,280	1	1.25	75	2	0.942	46,510,078.56	27,980,641.92	50,600,431.20	22,656,781.06	18,651,927.43	31,500,965.76	30,987,364.32	30,333,753.12	43,635,060.49
Unirrigated	3,559	0.7	1.25	80	2	0.942	32,743,832.11	23,728,212.46	35,093,697.45	18,295,256.69	16,560,317.81	24,585,308.63	22,936,907.97	23,618,887.11	30,883,059.86
Orchard/fruit trees	3,447	0.7	1.25	80	2	0.942	37,515,579.62	27,802,350.70	38,828,869.38	23,320,940.47	21,622,624.25	29,346,934.17	27,763,196.23	28,468,955.69	35,668,043.97
Grassland/Shrubland	41,448	0.8	1.3	85	40	71.41	259,929,526.56	184,925,059.97	283,503,491.04	130,875,346.87	125,746,152.85	211,273,346.33	178,799,787.57	170,784,051.04	249,052,207.72
Forest or wooded Areas	8,372	0.7	1.3	75	50	111.4	108,776,910.42	77,850,842.89	112,053,150.30	68,078,399.84	61,364,934.90	81,153,915.02	80,399,279.69	83,154,881.64	103,206,469.20
Wetland Areas	558	1	1.35	50	0.01	0.325	8,171,422.87	4,177,062.95	8,601,931.58	4,027,103.30	3,327,035.94	4,557,423.15	5,459,061.32	5,242,656.64	8,219,814.30
Bareland Areas	2,120	0.8	1.65	60	2	3.32	32,674,235.00	19,971,521.90	33,925,486.56	18,719,303.20	16,023,593.88	20,922,084.96	23,147,103.40	23,426,036.04	31,591,875.78
Built-up Areas	2,962	1	1.1	86	2	0.942	(413,199.00)	(10,010,375.20)	2,036,967.40	892,077.74	804,550.29	(6,915,677.60)	4,392,770.43	2,896,562.92	8,515,359.01
TOTAL	67,746						525,908,386.14	356,425,317.59	564,644,024.91	286,865,209.17	264,101,137.35	396,424,300.42	373,885,470.93	367,925,784.20	510,771,890.33
Benguet															
Forest/wooded areas	142,884	0.7	1.3	75	50	111.4	3,686,407,200.00	2,900,545,200.00	3,414,927,600.00	2,443,316,400.00	2,451,500,981.27	2,100,394,800.00	3,014,852,400.00	1,743,048,488.66	1,970,776,723.52
Grand Total	748,560						8,735,398,064.25	6,338,437,251.88	8,827,160,721.20	5,212,208,037.20	4,974,673,741.87	5,844,676,902.25	6,587,514,976.79	5,302,112,732.94	6,851,117,363.53

Note: Kco - Crop Coefficient CN - Curve Number

BD - Bulk Density in g/cm3 slope %- slope of the topography

Note: Average yearly groundwater recharge = 6,519,255,532.50 ^{m3}

Table 6 Computations for water balance in the Lingayen Gulf watershed area using the formula: Infiltration = Rainfall - Runoff - AET[a].

	Area	1990	1991	1992	1993	1994	1995	1996	1997	1998
Rainfall	(ha)									
Pangasinan /La Union	605,676	18,413.761.752	12,346,705,260	17,641,524,852	12,188,016,663	11,491,494,097	12,736,760,604	13,897,332,910	14,004,440,535	22,768,573,866
Benguet	142,884	6,247,071,372	5,942,681,300	6,475,114,236	4,423,522,023	5,639,915,105	3,116,915,870	5,658,206,400	3,733,987,706	5,467,884,912
Total	**748,560**	**24,660,833,124**	**18,289,386,560**	**24,116,639,088**	**16,611,538,686**	**17,131,409,201**	**15,853,676,474**	**19,555,539,310**	**17,738.428.241**	**28,236,458,778**
Runoff										
Pangasinan/ La Union/		9,056,612,958	5,425,773,211	9,039,411,374	5,033,411,721	5,555,229,481	3,824,068,656	6,581,926,848	4,863,314,490	13,916,055,035
Benguet										
AET										
Pangasinan/ La Union/		6,868,822,102	6,525,176,097	6,250,066,992	6,365,918,928	6,601,505,979	6,184,930,916	6,386,097,485	7,573,001,018	7,469,286,379
Benguet										
Infiltration/ Groundwater Recharge										
Pangasinan/ La Union/		8,735,398,064	6,338,437,252	8,827,160,722	5,212,208,037	4,974,673,742	5,844,676,902	6,587,514,977	5,302,112,733	6,851,117,364
Benguet										
Total	**748,560**	**24,660,833,124**	**18,289,386,560**	**24,116,639,088**	**16,611,538,686**	**17,131,409,201**	**15,853,676,474**	**19,555,539,310**	**17,738.428.241**	**28,236,458,778**

[a] - in m^3/year

Mean:

Rainfall - 20,243,767,717.99 m^3

Runoff - 7,032,867,085.92 m^3

AET - 6,691,645,099.43 m^3

Infiltration - 6,519,255,532.5 m^3

Parameters used in the calculation such as pan and crop coefficients, bulk density, etc. are derived from literature (Israelsen and Hansen, 1962; Jensen, 1973, LREP-Pangasinan, 1980; LREP-La Union, 1986; Seckler, 1993).

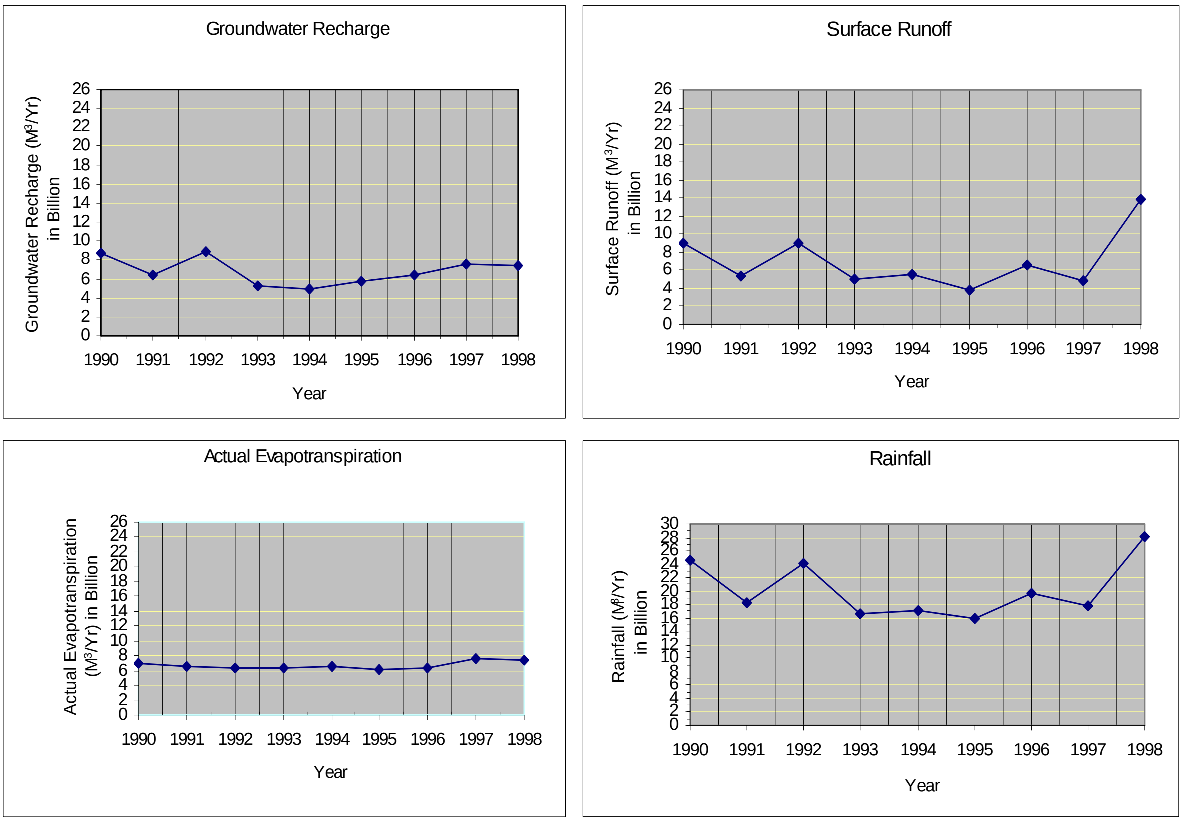

Figure D2. Overall water balance in the watershed areas draining into Lingayen Gulf.

D. <u>Simulation of runoff, sediment, and nutrient transport</u>

A pesticide transport model called PESTFADE model was modified and applied to assess nutrient and sediment transport from the land based production systems into the gulf. PESTFADE, which stands for PESTicide Fate and Dynamics in the Environment is a one dimensional computer model which was developed and validated in Canada (Clemente, 1991; Clemente et al., 1993; Clemente et al., 1998), and recently applied in the Philippines (Clemente et al., 1998). The model simulates the combined effects of runoff, leaching, sorption, degradation, and volatilization on the fate and transport of pesticides in agricultural soils. PESTFADE is an integration of the models and submodels describing water flow, runoff/erosion, heat flow, and solute transport.

In this study, the RUNOFF submodel of PESTFADE was enhanced so it could assess the fate and behavior of nutrients, e.g. phosphorus and nitrogen, at the soil surface as affected by rainfall, soil bulk density, soil erodibility factors and Curve Number (which represents different tillage practices). As a result, Best Management Practices (BMPs) can be evaluated to minimize pollution and sedimentation of surface waters.

Because of the varying land use and cropping practices in the Lingayen Gulf area, the whole watershed surrounding the gulf was categorized into three subareas namely: agro-forest, agro-industrial and flood plain. Details of this classification are presented in Figure D3. This scheme will enable a modular or distributed approach in modeling runoff/erosion based on specific soil properties associated with each land management unit. However, for modelling nutrient transport, it limited the study to major land use for agriculture, e.g., orchard and rice, as they are treated with fertilizers. Since rainfall data with duration is only available during the years 1994, 1995 and 1996, only during these periods where the simulation of nutrient and sediment transport were done. Also, only phosphorus transport was assessed in this phase of the study because of time and data constraints. This is the first attempt to modify the model to incorporate phosphorus transport. Although the relationships for phosphorus partitioning in the adsorbed and dissolved phases have been derived from existing models, some of the constants are not readily measurable or available at the site so it is not possible to validate the modified model predictions. Another limitation is that plant uptake of phosphorus occurs at the crop rootzone and this requires modifications of the leaching/infiltration submodels of PESTFADE which can not be done at this time. So, in modifying the PESTFADE model to simulate phosphorus transport, the following background and methodology explained the various mechanisms incorporated in the model.

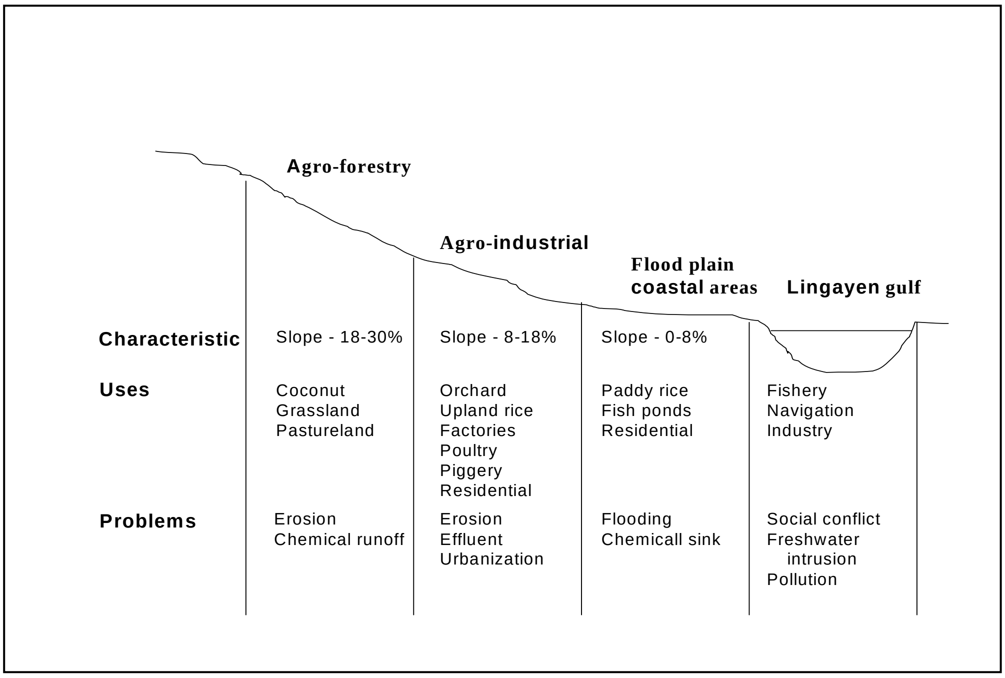

Figure D3. Transect of the Lingayen Gulf basin showing watershed land use classification.

Phosphorus Transport in Agricultural Watersheds

In the soil, water and overland flow systems, phosphorus can exist in two forms: phosphorus in solution (dissolved phosphorus) and in soil or sediments (particulate phosphorus). Also, in these flow regimes, phosphorus which occurs as orthophosphate anion (PO_4^{-3}) exists in organic and inorganic forms. Since overland flow and sediment yield from agricultural watersheds vary spatially and temporally, the description of areal and seasonal variations in phosphorus transport is very important (Coote et al., 1982).

Low solubility and high adsorptivity are two of the most important properties of phosphorus in the soil water systems. So much of the phosphorus from fertilizers are strongly adsorbed at soil particles, only around 10% is used by plants. Therefore, the bulk of phosphorus inputs to surface water bodies is likely due to phosphorus transported with sediment. That is why in the Great Lakes basin, 75% of the total phosphorus load comes from Ontario Agricultural watersheds (Miller et al., 1982).

This finding supported the need to assess nutrient transport from the watersheds surrounding the Lingayen Gulf. In modifying the model, it was envisioned to adopt a modeling approach that has been used in existing models, e.g., CREAMS-Knisel, 1980; GAMESP-Rousseau, 1985. Since this has been tested under different climate and watershed conditions, the dissipation of phosphorus is based on the partitioning of phosphorus in particulate and dissolved forms which are mathematically defined below.

Particulate phosphorus

Phosphorus adsorbed in sediments and carried by overland runoff (POS) (g/ha) is a function of sediment yield, SL (kg/ha), phosphorus level in surface soil, PO (g/g) and phosphorus enrichment ratio, PER. It is written as:

$$POS = SL * PO * PER$$

The enrichment ratio (PER) is the ratio of sediment PO content to bulk soil PO content and Menzel (1980) indicated that enrichment ratios for cropland range from 2.5 to 7.5. In this study, an average PER value of 5.0 was used.

The phosphorus in dissolved phase (POW, *u*g/l) was modeled using the following equation:

$$POW = K * PO * DI * BD * t^{\alpha} * WS^{\beta} / V$$

Where K, α, and β are soil constants (Sharpley et al., 1985), PO is phosphorus in soil surface, DI is depth of interaction (10 mm), BD is bulk density (g/cm^3), WS is soil water ratio, and V depth of runoff (mm). However, because of the unavailability of some of the constants required in the equation, another approach was used based on Clemente et al. (1993) and Haith (1980). It is written as:

$$POW = (Runoff / Rain) * DT$$

$$DT = (1.0 / (1.0 + (\theta / Kd * BD))) * Pr$$

Where θ is available moisture, Pr is phosphorus available at soil surface (g/ha), and Kd is sorption coefficient. It should be noted that POS and POW are being computed every runoff event and the remaining phosphorus (PR) is being updated everytime there is partitioning in phosphorus through the adsorbed and dissolved phase. An initial and one time application of phosphorus amounting to 30 lbs/acre was used in the simulation.

The main input data/parameters consist of daily rainfall events and their duration that is currently available from the climatological data base in the gauging station close to the site, other soil and watershed factors, and constants. Details of the input data used in the simulation is presented in Table D5.

Results of the study

<u>Groundwater Discharge</u>
Using the hydraulic conductivity of Maidment (1993), the total groundwater discharge amounts to 1.24x10^9 m^3 per year (Table D2). While using another hydraulic conductivity by Bedient and Huber (1992), the total groundwater discharge is 1.17x10^9 m^3 per year (Table D2A). The derived amounts were computed from actual well measurement conducted during the dry season. Siringan et al. (1998) computed dry season groundwater discharge at 1.27x10^9 m^3 per year. The reasons for the discrepancies in the results can be attributed to the source(s) of data used in the computations and the selection of hydraulic conductivities. In this study, primary data collected from the site were used.

<u>Water Balance</u>
Table D3 presents the runoff volume. The highest is in 1998 with a volume of 13.9x10^9 m^3 and the lowest is in 1995 with 3.8x10^9 m^3 as shown in Figure D2. The high runoff in 1998 can be attributed to higher rainfall intensities during this year. Direct relationships between runoff and rainfall is commonly demonstrated during high rainfall events of short duration which result to higher surface runoff. Mean discharge for the nine year period from 1992-1998 is 7.03x109 m^3.

In Table D4 and Figure D2, the highest AET is recorded in 1997 with a volume of 7.57x 10^9 m^3 while the lowest is in 1995 at 6.18x10^9 m^3. Mean AET is 6.69x10^9 m^3. Within the land use area, grassland or shrubland (includes pastureland), Pangasinan and La Union registered the highest AET. This is mainly attributed to the larger area of the grassland and shrubland (accounting to about 28% of the total watershed) which resulted in higher volume of water lost through ET.

Table D5 shows the residual value in the water balance which comprises the infiltration or groundwater recharge. It can be seen that the highest recharge was obtained in 1992 with 8.8x10^9 m^3 while 1994 is the lowest with 4.97x10^9 m^3. Mean groundwater recharge is 6.52x10^9 m^3. Looking at the rainfall and runoff data for 1992, it was found that during this year the rainfall events were not as intense as the other years that resulted in more time for the water to infiltrate into the ground water.

Pangasinan and La Union registered the highest rainfall in 1998 amounting to 375.92 cm with a volume of 2.28x10^{10} m^3. The lowest was in 1994 with a rainfall of 189.73 cm and a volume of 1.15x10^{10} m^3. Benguet on the other hand had the highest rainfall in 1992 which amounted to 453.17 cm with a volume of 6.48x10^9 m^3 while the lowest was 218.14 cm which occurred in 1995 with a volume of 3.12x10^9 m^3. Details are shown in Table D6. 1998 registered the highest total volume of rainfall at 2.82x10^{10} m^3 while 1995 was the lowest at 1.59x10^{10} m^3. The nine-year mean is 2.02x10^{10} m^3. Figure D4 shows the percentage distribution among the different components of the water balance.

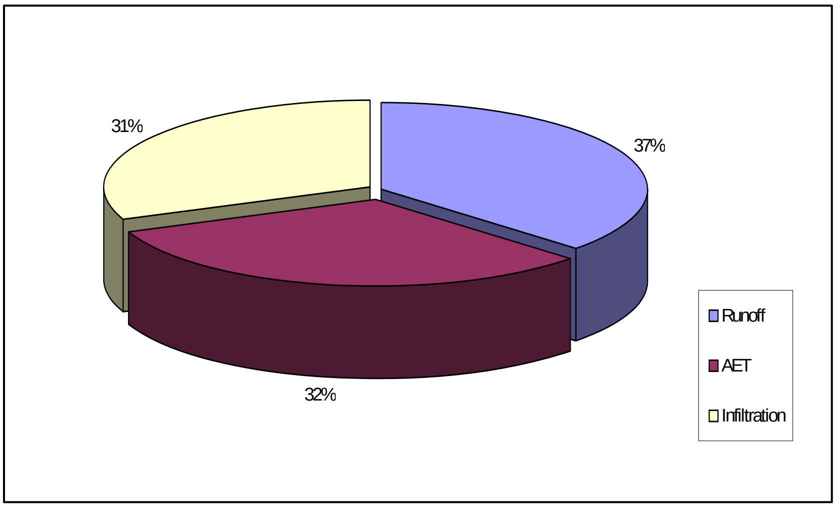

Figure D4. Average water balance distribution for the nine year period 1990-1998 in the watershed area of Lingayen Gulf.

<u>Sediment and phosphorus transport</u>

From the preliminary runs for sediment and phosphorus transport at the soil surface, initial results indicate that there were considerable soil loss obtained at the orchard and upland rice farming systems with maximum loss of 345.6 tons/ha-yr, which translate into 2.8 cm of top soil lost every year (Table D8). This is very close to the soil loss obtained by Clemente et al. (1998) for pineapple plantation at the Siniloan watershed that amounted to 322 tons/ha-yr. This high soil loss can be attributed to the steeper slope in these land use units that resulted in higher runoff rates. The environmental implication is that this eroded soil eventually found its way to surface water systems when carried by running water. Because this happens every runoff causing rainfall event, the problem of sedimentation of receiving water courses (e.g., Lingayen Gulf) can worsen over time especially if accumulation of sediments is not controlled.

For phosphorus transport, good correspondence with findings in literature was also obtained. For instance the loss of 0.58 kg/ha/yr in runoff from a row crop obtained by Nelson and Logan (1983) is quite comparable with the total loss of 7.7 mg/l (i.e. 0.96 kg/ha-yr) for the orchard and upland areas in Pangasinan (Table D7). Although some values obtained are higher than this, this can be attributed to the different practices in the watershed as well as varying soil properties that cause high runoff and thus, high phosphorus partitioning in the dissolved phase. For the particulate part, simulation results are also comparable with the data reported in literature. For instance, a value of 119 mg/l was obtained by the model for upland rice in 1995 (Table D7) which translates into around 10 kg/ha-yr. Although this is quite higher than the 0.5 kg/ha-yr of particulate phosphorus found by Nelson and Logan (1983), the discrepancy can be due to differences in climate and soil characteristics in the two studies. However, the high percentage of phosphorus being partitioned in the adsorbed phase (around 90%, as simulated by the model) has also been reported by various researches (Nelson et al., 1980). This confirms that phosphorus has high affinity for solid phases thus downward movement is considered very slow. Results of the simulation are presented in Table D7.

Table D7. Phosphorus partitioning in adsorbed and dissolved phases.

Year	Land Use	Place	PQT	PXT	PTOT	PR
1994	Irrigated Rice	La Union	7.22	210.35	217.57	6.95
		Pangasinan	6.64	189.66	196.30	10.66
	Upland Rice	La Union	8.70	215.90	224.60	2.68
		Pangasinan	7.71	220.48	228.19	0.01
	Orchard	La Union	8.73	215.77	224.50	2.77
		Pangasinan	7.71	220.48	228.19	0.01
1995	Irrigated Rice	La Union	12.04	133.23	145.27	73.69
		Pangasinan	10.56	126.19	136.75	69.99
	Upland Rice	La Union	12.47	119.99	132.46	82.36
		Pangasinan	13.88	183.09	196.97	25.60
	Orchard	La Union	24.19	162.85	187.04	36.12
		Pangasinan	14.25	183.48	197.73	27.41
1996	Irrigated Rice	La Union	24.31	145.03	169.34	96.98
		Pangasinan	21.57	125.74	147.32	99.16
	Upland Rice	La Union	25.65	136.77	162.43	109.55
		Pangasinan	23.86	173.68	197.54	38.66
	Orchard	La Union	40.27	156.83	197.10	47.01
		Pangasinan	24.24	173.45	197.69	40.24

PQT - dissolved phase concentration mg/l

PXT - adsorbed phase concentration mg/l

PTOT- total of PQT and PXT

PR - phosphorus remaining over time

Conclusion

This module is part of the overall framework for studying the biophysical and chemical interactions affecting Lingayen Gulf. The three objectives of the module consist of: (1) validation of groundwater flow to the gulf, (2) calculations of water balance in the watershed based on rainfall, evapotranspiration, and surface runoff with infiltration or groundwater recharge as the residual value, and (3) simulation of runoff, sediment, and nutrient transport to assess the inputs from the watershed with respect to water quantity and quality. The methodologies for accomplishing these objectives have been described in detail and the sources of information and data for the modelling aspect have also been presented.

Results of the study indicate that ground water flow estimated by Siringan et al. (1998) was comparable with the calculated ground water discharges using measured data. Although this should be expected considering that both methodologies used the modified Darcy's Law in the calculation of discharge, it is still recommended that detailed characterization of the hydraulic properties of the areas surrounding the gulf should be adopted in future studies to reflect the effect of spatial variability.

Table 8 Soil Loss from the different land use units in Pangasinan and La Union.

Place	Land Use	Soil Loss in tons/ha-yr			Depth of soil loss (cm) per year		
		1994	1995	1996	1994	1995	1996
La Union	Irrigated Rice	28.94	46.53	47.11	0.23	0.37	0.38
	Unirrigated Rice	36.35	58.09	58.42	0.29	0.46	0.47
	Orchard	36.21	57.87	58.19	0.29	0.46	0.47

Pangasinan	Irrigated Rice	28.15	45.28	45.84	0.21	0.34	0.34
	Unirrigated Rice	215.05	343.71	345.64	1.7	2.7	2.8
	Orchard	175.88	281.11	282.69	1.4	2.2	2.3

The study also indicated that the watersheds in Pangasinan, La Union and Benguet contribute a large amount of freshwater into the gulf. This was established from the water balance accounting using a modified version of the runoff component of the PESTFADE model. Specifically, the percentage distribution among the components of the water balance provided 37%, 32% and 31% for surface runoff, actual evapotranspiration and groundwater recharge or infiltration respectively for the nine year study period. This suggests that the different agricultural and land use units in the watershed surrounding the gulf do not consume much of the rainfall through evapotranspiration nor controlled surface runoff. In effect, freshwater loading to the gulf through overland flows and recharge to ground water has been observed. Since infiltration is around 31% of the total rainfall or $6.52x10^9m^3$, groundwater depletion or seawater intrusion will not be a major concern in the near future, despite the numerous private wells in the area being used for domestic and agricultural purposes.

For sediment transport, results indicate that the upland rice and orchard plantations were susceptible to runoff and erosion. Specifically, a total soil loss of 345.6 tons/ha-yr and 282.7tons/ha-yr was obtained from the two land use units. This was attributed to the larger slope length and the low infiltration capacity of these upland areas.

For the nutrient transport part, it was only possible to consider phosphorus partitioning in the adsorbed and dissolved phases at the soil surface. Results indicated that a high percentage of phosphorus (exceeding 90%) was partitioned into the adsorbed phase which demonstrated the high affinity of this nutrient to solid particles. However, high runoff during the rainy season, loss of phosphorus at the soil surface in both phases can be considerably high which is a cause for concern since the surface water system downstream of the watershed (i.e., Lingayen Gulf) is the receiving end of the chemical residues carried by runoff.

Remedial measures are therefore required to alleviate the potential problem of surface water contamination by sediments and chemical residues from the watershed. Conservation practices such as terracing and increased vegetation can reduce the momentum and impact of rainfall on the soil surface and can therefore be regarded as remedial measures for controlling runoff and soil erosion. However, controlling runoff at the soil surface can have a major effect on the subsurface transport of nutrients. Less runoff means that more water and dissolved nutrients are available for leaching and this has a serious implication on the underlying ground water.

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Appendix E Circulation in Lingayen Gulf inferred from temperature and salinity

Cesar Villanoy
Marine Science Institute, University of the Philippines
Diliman, Quezon City 1101, Philippines

Introduction

The exchange of water masses between the coastal and open oceans plays 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.

Temperature and salinity distributions in Lingayen Gulf were obtained from conductivity-temperature-depth (CTD) surveys conducted in February 1997, April 1997, April 1998 and July 1999. Data from previous surveys (April 1993 and January 1994) were also included in the analysis. The CTD data were objectively interpolated into a 2.5km x 2.5km grid using a 20 km covariance scale based on the method by Carter and Robinson (1987). This procedure was done for each 5 m interval and interpolated data with less than 10% standard error were included in the objectively analyzed data set. The vertical density profiles were calculated to ensure that no spurious density inversions were produced in the interpolation procedure.

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 – 5, main report). 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 are important. The salinity distributions (Figures 4 and 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 indicates 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 gulf salinity is reduced, subsurface groundwater discharge from the western and eastern sides of the gulf is evident.

Tidal Circulation:

The circulation in Lingayen Gulf is influenced by three main driving forces; the tidal component, local wind-driven forcing and the interaction with remotely forced alongshore currents along the western Luzon Shelf. Characterization of the tidal circulation patterns was inferred from the results of a tidal model based on the two-dimensional, vertically-integrated version of the Princeton Ocean Model (Blumberg and Mellor, 1986). The model makes use of a curvi-linear grid extending from Zambales to the northern part of La Union (Figure E1). This type of grid was used to conveniently allow the incorporation of alongshore shelf currents off the western coast of Luzon. The western open boundary roughly coincides with the 1000m isobath.

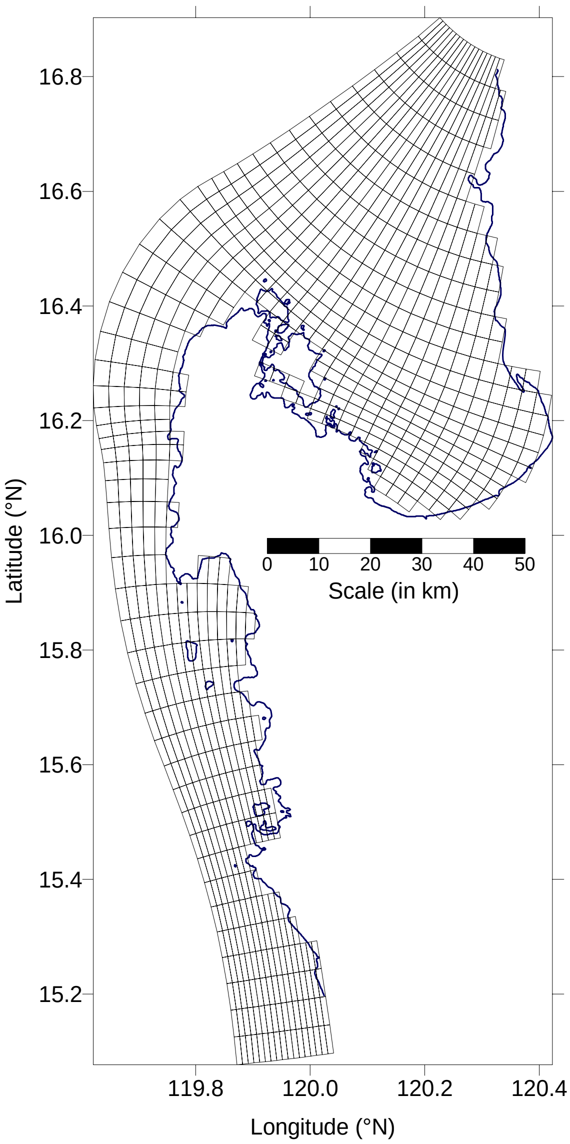

Figure E1. Curvi-linear grid used in the Lingayen Gulf model.

Tidal forcing was prescribed by allowing the sea level at the open boundaries to oscillate at tidal frequencies. The offshore tidal characteristics were obtained from the global tide model of Matsumoto et al. (1996) for two diurnal (O_1 and K_1) and two semidiurnal (M_2 and S_2) tidal components. The amplitudes of the tidal elevations all increase towards the south but the propagation direction is perpendicular to the coast for the diurnal components and parallel to the coast for the semidiurnal components.

The model, initially run in 2-dimensional mode with purely tidal forcing, was integrated for a period of 16 days, including a one-day spin-up time. Hourly vertically integrated velocities were stored and the amplitudes and phases of the tidal current velocities were extracted using harmonic analysis and were used to produce the tidal ellipses shown in Figure E2. The oscillation of the tidal currents occur mainly in the alongshore direction except inside the Gulf where tidal flow is simply in and out of the Gulf. Near the head of the Gulf, the main axis of the ellipses is oriented perpendicular to the coast. In the northern half of the bay, the orientation of the ellipses show that flow across the Gulf mouth occurs at the eastern part (La Union side) for the O_1, K_1 and M_2 components. The S_2 component is the weakest of the four components considered in the simulations. An interesting feature of the tidal circulation is where the alongshore flow outside the gulf meets the flow from the interior of the Gulf. This occurs northeast of Cabarruyan Island and is also where the tidal currents exhibit a higher degree of rotation, particularly for the M_2 component.

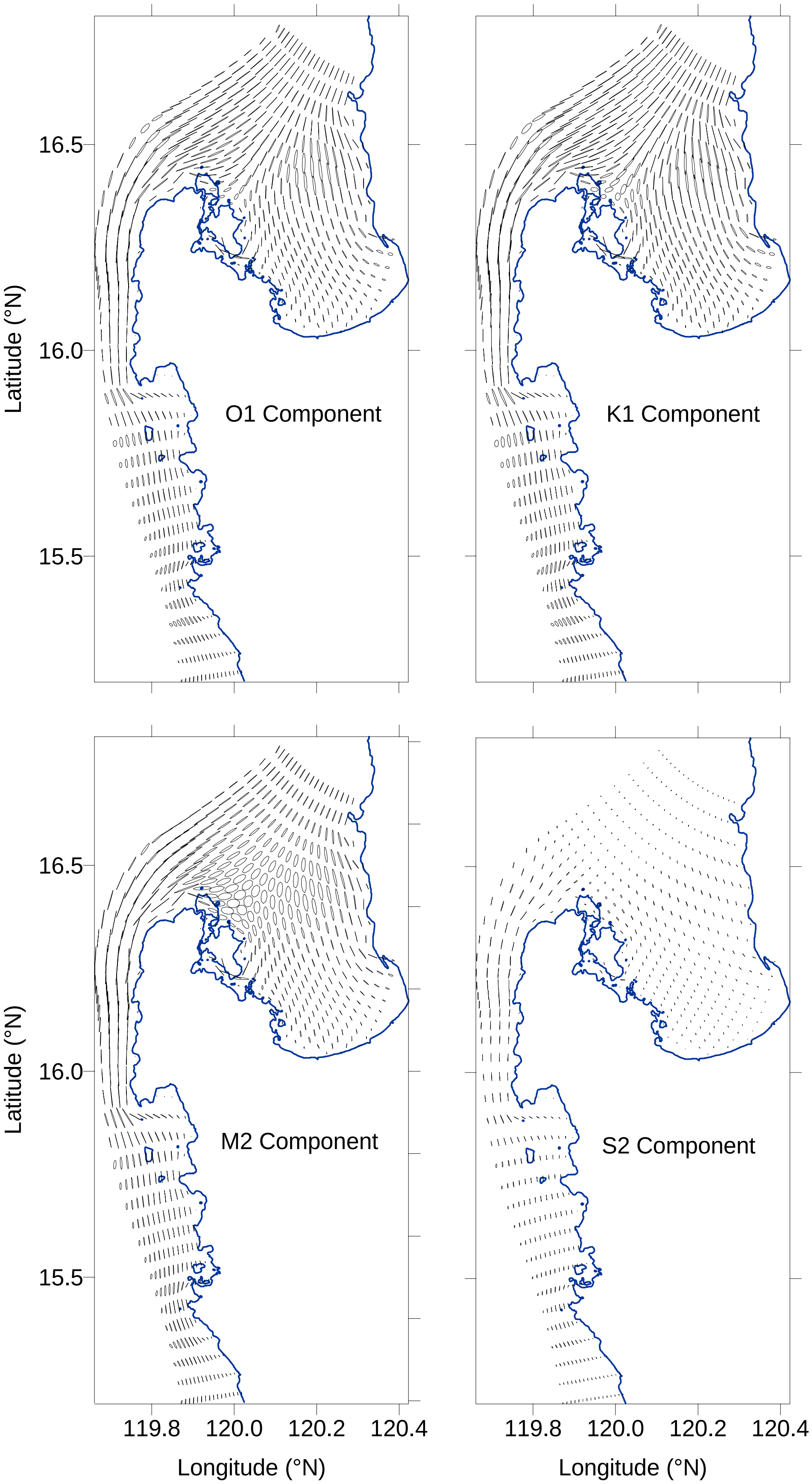

Figure E2. Tidal ellipses for the dominant diurnal and semi-diurnal components.

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, main report). 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.

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 modeling 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 lahar discharged from rivers in Zambales during the eruption of Mount Pinatubo shows a net northward transport off the coast of Zambales.

Previous circulation models of the Lingayen Gulf circulation extended only to the mouth and processes outside the mouth were not considered (e.g. Balotro, 1992). The distribution of temperature and salinity across the mouth, however, suggests that interaction with shelf processes cannot be neglected. Numerical experiments were conducted using the curvi-linear grid described above and applying the full 3-dimensional version of the Princeton Ocean Model (POM). The model was initialized with a horizontally uniform temperature and salinity profile of the adjacent area of the South China Sea. At the northern and southern cross-shelf open boundaries of the model, transport northward of about $0.8x10^6$ m^3s^{-1} was prescribed.

The result for the coastal current forced model is shown in Figure 7 (main report). The velocity component normal to the eastern boundary was set to zero to constrain the prescribed current to flow in the alongshore direction. Since the outer boundary generally coincides with the 1000m isobath, this assumption can be argued using the conservation of potential vorticity. The transport through the southern boundary was assumed to be equal to the transport in the northern boundary but the difference in velocities is accounted for by the difference in their cross-sectional area. The narrower shelf west of Zambales results in stronger currents compared to the broader shelf area to the north. 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 which 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 Figure 8 and 9 (main report) 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.

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.

Summary

The circulation in Lingayen Gulf is influenced by conditions outside the gulf mouth. Outside the gulf, particularly along the narrow western shelf extending from Zambales to La Union, the prevailing current is a northward coastal current which is forced remotely by the basin-wide gyre circulation of the South China Sea. As it flows past the Cape of Bolinao, the current loops southward and enters the northern half of the gulf before turning back to exit on the other side of the gulf mouth. The significantly steep slope of isotherms across the gulf mouth manifests this feature. Penetration into the gulf is limited to the northern half, based on the decrease in isothermal slopes towards the gulf head. Local wind forcing is not strong enough to reverse the coastal current outside the gulf, thus the net transport along the western Luzon shelf is northward throughout the year. However, wind forcing can produce seasonally reversing recirculating gyres in the southern half of the gulf.

The tidal component of the flow influences the gulf circulation in a similar manner because the main axis of the tidal currents over the shelf is alongshore. Residual currents show a similar loop feature. This feature has implications on the flushing of the bay as it forms a barrier that can reduce mixing and transport from the southern part of the bay. Consequently, most of the flow in and out of the gulf occurs on the eastern and western edges of the bay mouth.

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 than 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.

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Appendix F N and P Budgets for Lingayen Gulf, Philippines

Maria Lourdes San Diego-McGlone, Vilma Dupra, Daisy Padayao, and Judycel Abalos
Marine Science Institute, University of the Philippines,
Quezon City 1101, Philippines

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 85×10^9 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 10×10^9 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 $8x10^9$ 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, $-1x10^9$ 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.

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_RS_R) from the three boxes indicate advective export. Exchange of gulf water with ocean water must replace this exported salt by $V_{X1}(S_3\text{-}S_1)$ = +260 x 10^9 psu-m^3 yr^{-1} from the nearshore box to the upper gulf box, $V_{X2}(S_3\text{-}S_2)$ = +34 x 10^9 psu-m^3 yr^{-1} from the Bolinao box to the upper gulf box, and $V_{X3}(S_{Ocn}\text{-}S_3)$ = +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 (main report)). 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.

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

<u>N and P Balance - Multiple-box Model</u>

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. *ΔDIP* 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 *ΔDIP* 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_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 (*ΔDIN* 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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Appendix G Primary production and fisheries in Lingayen Gulf, northern Philippines: biological oceanography component

Liana Talaue-McManus[1], Wilfredo Licuanan[2], Leah Asuncion[1],*
Kathleen Silvano[1], Merliza Bonga[1] and Charisma de Castro[1,]
[1]Marine Science Institute, University of the Philippines, Diliman, Quezon City 1101
[2]Marine Biological Station, De La Salle University 2410 Taft Avenue, Manila 1004

Introduction

One of the goals of the SARCS/WOTRO/LOICZ project is to understand the biogeochemical processes that occur in the coastal zone of the South East Asian Region. Among the major processes of interest is the cycling of carbon as a biogenic material. This paper looks at the production of carbon in Lingayen Gulf, northern Philippines and how this interacts with the harvest of carbon in the form of fish biomass. It aims to provide estimates of carbon production by various producers and using these, determine the extent of fisheries exploitation in Lingayen Gulf. It also examines the interactions between primary production and the trophic composition of the catch.

Until recently, fisheries management has often been based on single species models of exploited stocks, originally developed for the high latitude marine ecosystems (Pauly 1979). Unfortunately, the kinds of data needed for these models (e.g., age at catch) are frequently unavailable in less industrialized countries. More important is the fact that much more species are exploited in tropical areas, for example 341 species from trawls in eastern peninsular Malaysia, 173 from the Visayas Seas in the Philippines (various references in Pauly 1979), and thus interactions among various species and stocks complicate any analysis. The realization that fisheries cannot be considered or assessed properly in isolation of its support systems, as had been the norm in the past as fisheries biology, oceanography, and ecology have gone in their own ways (Larkin 1996), has led to the development of even more complicated multi-species models and simulations (see Larkin and Gazey 1982). These trends have meant developing countries face greater challenges in understanding the dynamics of their fishery in the face of the demands of their rapidly increasing population.

A promising approach in assessing condition of multi-species fisheries (via assessment of primary production required to support the system) is the use trophic balance models such as those implemented in ECOPATH models (Christensen and Pauly 1992). Such approaches divide the system into a series of functional or species groups with similar diets, production, and consumption patterns; and seek to balance the energy / nutrient budgets under an equilibrium assumption. Thus, steady-state biomasses of each of the living groups in the system could be computed, which could then be the basis for estimates of carrying capacity, and sustainable yield. Although designed mainly for biotic/living components of the system, nutrient levels and other physical factors could be included indirectly through their effect on productivity levels. The applicability of this approach is explored in this work.

Methods

Carbon 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. Data on chlorophyll a were obtained from four cruises conducted in Lingayen Gulf in February and April 1997, April 1998 and July 1999. For the first three cruises, samples for chlorophyll a analysis were filtered unto GFC glass fiber filters, frozen and later analyzed using a spectrophotometer following the method given by Parsons et al. (1984). In the last cruise, chlorophyll a was estimated using a fluorescence sensor inside a Nu-shuttle housing as well as by the spectrophotometric method. Nu-shuttle values were approx. 40% that estimated by spectrophotometry.

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).

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% glutaraldehyde final concentration. To determine growth rates, samples were incubated *in situ* by suspending the bottles at different depths (1, 5 and 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 um 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 under blue light excitation were provided by Agawin (pers. comm.). The latter were subtracted from the total counts to obtain numbers 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 μm3 (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).

Primary production required. The primary production required (PPR) was estimated using two methods. The first was computed by ECOPATH 3.0 (see www.ecopath.org) 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 to estimate PPR relied on the basic equation of Pauly and Christensen (1995), which incorporated the parameters for weighted mean trophic level and biomass of the harvested groups. As in the ECOPATH 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 (ECOPATH) analyses. 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 analyses.

Results

Carbon Production. Production of carbon in Lingayen Gulf by various components is presented in Table G1. Phytoplankton accounted for 29%, bacterioplankton, 42%; while corals and macrophytes contributed 29%. Of that produced by bacterioplankton, heterotrophic bacteria accounted for 99% while autotrophic bacteria contributed only 1%. This validates the heterotrophic condition of the upper Gulf as indicated in the biogeochemical budgets done for the Gulf (McGlone et al. 1999).

Table G1. System carbon production by component in Lingayen Gulf.

Primary producer	Production (t C km^{-2} yr^{-1})	Area (km^2)	Areal production (t C yr^{-1})	Percent contribution (%)
Phytoplankton (McManus et al., this study)				
• Open Gulf	93.5	1,900	177,678.5	
• Bolinao	166.8	200	33,350.0	
Sub-total	100.5	2,100	211,028.5	29
Bacterioplankton (McManus et al., this study; Agawin et al., manuscript)				
• Heterotrophic Bacteria	146.0	2,100	306,684.0	
• Autotrophic Bacteria	1.7	2,100	3612.0	
Sub-total	147.8	2,100	310,296.0	42
Benthic producers				
• Seagrasses (Fortes, 1990)	511.0	60	30,660.0	
• Seaweeds (Westlake,1963)	118.00	14	1,652.0	
• Corals (Westlake, 1963				
• Reef flat	4,120.0	10 (MGB-DENR & Nikko 1995; McManus, pers.comm)	41,612.0	
• Reef slope	4,120.0	34.8 (MGB-DENR & Nikko , 1995; McManus, pers.comm)	143,376.0	
• Subtotal	103.5	2,100.0	217,300.0	29
Total Primary Production	351.8	2,100.0	738,624.5	100

The empirically derived phytoplankton production was compared to that estimated using nutrient budgets which were based on the Redfield elemental ratio for phytoplankton (McGlone et al. 1999) (Table G2). Between these two estimates, an average of 86.2 t C km^{-2} yr^{-1} net phytoplankton production was obtained.

The amount of fish catch was converted to equivalent phytoplankton production using two methods as indicated in Table G2. The mean estimate of harvested biomass in terms of phytoplankton was 57.6 t C km^{-2} yr^{-1}.

Table G2. Net phytoplankton production and fisheries harvest in Lingayen Gulf.

Parameter	Value
1. Net phytoplankton production in Lingayen Gulf (McManus et al, this study)	100.5 t C km^{-2} yr^{-1}
2. Net phytoplankton production = (p-r) =+ 6 mol m^{-2} yr^{-1} (McGlone et al., this study)	72.0 t C km^{-2} yr^{-1}
3. Average of Estimates (1) and (2)	86.2 t C km^{-2} yr^{-1}
4. Mean harvested fish biomass in equivalent phytoplankton production required estimated by ECOPATH (9:1 wet weight to dry weight ratio)	40.0 t C km^{-2} yr^{-1}
5. Mean harvested fish biomass in equivalent phytoplankton production required estimated by fish carbon and weighted trophic level for 1978-1987 catch data (Pauly and Christensen 1995; Parsons et al,1984 and McManus et al., this study)	75.2 t C km^{-2} yr^{-1}
6. Average of Estimates (4) and (5)	57.6 t C km^{-2} yr^{-1}
7. Index of exploitation = Mean harvested phytoplankton production / Mean net Phytoplankton production; 8. Optimal exploitation = 0.50 (Modified after Gulland, 1971)	0.67

A comparison of the per year PPR computations relative to the catch is shown in Figure 17 (main report). Computed PPR (averaging around 360 mt 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 PPR.

There was an overall increase in the catch of all groups in the ten-year period from 1978 to 1987 (Figures 18 and 19, main report). 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.

Discussion

The ratio of harvested biomass to net phytoplankton production was used to determine the level of exploitation rate (see Table G2). At 67% exploitation rate, the Lingayen Gulf can be considered overexploited using catch data for the period 1978-1987. As a consequence, there seems 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 as the predators are depleted. Proportional catch of groups higher in the food web such as of small pelagics and intermediate predators declined (Figure 18 main report), 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, main report) 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. One can then argue that 67% exploitation rate may be limited by the fact that the phytoplankton used to support the fisheries is not just those found within the Gulf. For small and big pelagics, the feeding grounds can include areas within their migration routes, e.g. portions of the South China Sea. Thus, it is not sufficient to establish a state of overfishing purely on the basis of trophic dynamics. In the case of Lingayen Gulf however, Silvestre et al. (1991) also concluded that the fisheries showed biological overfishing with a high yield to biomass ratio of 5.2 using empirical data from 1987 to 1988.

Trophic cascades have been described for a number of marine systems involving fisheries, pollution, eutrophication, and species introductions (Larkin 1996). The Gulf of Thailand situation has often been used to illustrate shifts in dominance due to stock interactions as a result of fishing (Gulland 1976 in Pauly 1979). Here, catches of rays have decreased as those of squids (and now, "trash fish") increased. Note though that contrary to expectations, small, short-lived prey species in the Gulf of Thailand have been shown to decrease faster than their predators because of the combined effects of fishery and predatory mortality (Pauly 1979).

The present analysis suggests that there may be trophic interactions involved in the changes in the relative compositions of the catch. However, interactions other than trophic ones may also be involved. A possibility is fishing selection driven by market demand, and strong differences in system boundaries of the modeled groups. Hence, primary data collection, and not just analysis of secondary data is required. There is a need for further disaggregation of the species groups as the data allows. Individual species may stand to benefit from disaggregation to size or age classes in recognition of ontogenetic shifts in diet, consumption, and mortality patterns. Differences in ranges of the species (e.g., pelagic fishes versus demersal fishes) also must be considered, something that can be addressed in the ECOSPACE module also being tested in the Alpha version of ECOPATH used in this analysis.

ECOPATH models have the advantage of requiring relatively little input compared to other models available for fisheries assessment and modeling. However, it only gives a static picture of the trophic structure of the ecosystem modeled, showing the levels of trophic flow needed to this current structure given observed growth and mortality patterns (Walters et al., 1997). The addition of the ECOSIM module to ECOPATH allowed for more dynamic simulations needed in examining various scenarios such as of changes in fishing patterns or policies (see Walters et al. 1997) in a multi-species setting that is more realistic for tropical situations. This module requires little additional data above the inputs to ECOPATH to perform temporal analyses. Although ECOPATH and ECOSIM are still data intensive, parameter inputs are becoming more widely available (see Christensen and Pauly 1992, 1993; and Fishbase: Froese and Pauly 1997). Numbers adopted for similar systems and situations could be used as initial inputs and the preliminary models derived from them could then serve to help prioritize which inputs require refinement and additional data collection.

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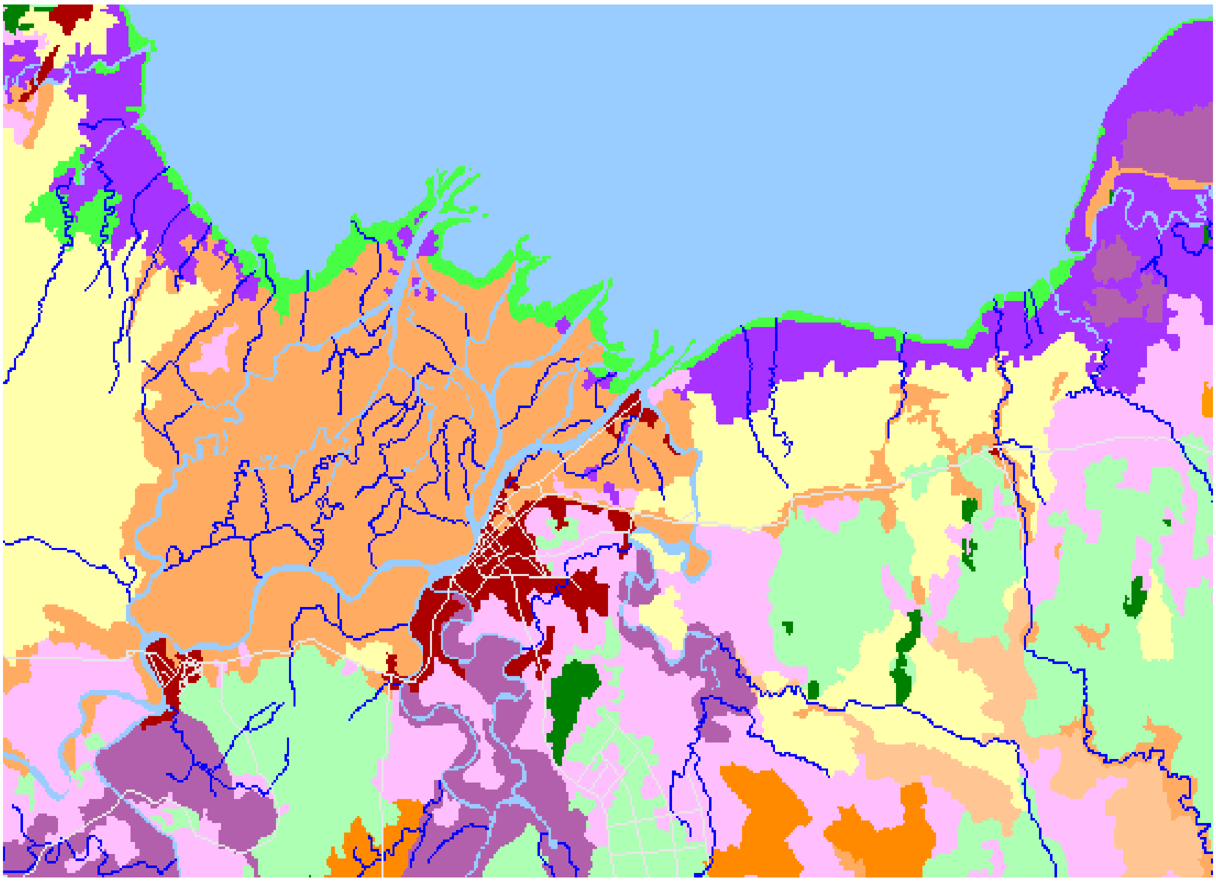
SARCS/WOTRO/LOICZ/Thailand Core Research Site

1997-1999 Final Report

Economic Evaluation and Biogeochemical Modelling of Bandon Bay, Suratthani, Thailand



Chulalongkorn University, Bangkok

December 1999 and December 2000

SARCS/WOTRO/LOICZ/Thailand Core Research Site

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Economic Evaluation and Biogeochemical Modelling of Bandon Bay, Suratthani, Thailand

Research Team:

Dr. Gullaya Wattayakorn
Dr. Charit Tingsabadh
Dr. Ajcharaporn Piumsomboon
Mrs. Nittharatana Paphavasit
Dr. Sanit Aksornkoae
Dr. Suthawan Sathirathai
Ms. Panyanee Prapong
Mr. Suwat Thananuparppaisarn

Research Associates:

Mr. Narumitr Sawangphol
Mr. Damrongsak Noichareon
Mr. Sompop Leongkangwankid
Ms. Itchika Phromthong
Ms. On-anong Reungsapanek
Mr. Somsak Kraisribandit.

Chulalongkorn University, Bangkok

December, 1999
(Appendix revised December, 2000)

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PART I SYNTHESIS REPORT

1. INTRODUCTION

1.1 Background

The coastal ecosystems of Thailand, like many of the coastal ecosystems of the world, are in decline from direct and indirect disturbances as a result of population growth. Generally, the main causes of the problems are human activities induced by economic gain and development, which fail to recognize adverse environmental impacts and non-market value losses. Among the most productive coastal areas in the southern part of Thailand, Bandon Bay in Suratthani Province is one example of this heavy utilization of coastal resources. Bandon Bay is an important fishing ground for pelagic and demersal fishes in Thailand. However, a number of problems such as decreasing water volume due to rapid siltation, reduction in mangrove coverage, excessive fishing effort, the use of nets with very fine mesh and deteriorating water quality, have been hindering the ecological role of Bandon Bay and the surrounding mangroves as nursery grounds and feeding areas for juvenile fish and shellfishes.

To maintain the nourish coastal resources in parallel to the economic development of this area, we need to know how the coastal ecosystem of Bandon Bay responses and interacts with the economic development of the area. First, the nature of the coastal ecosystem and the socio-economics of the population in the area must be determined. Then the linkage between the coastal ecosystem and socio-economic data can be performed. This report assesses the anthropogenic drivers of change in the coastal zone of Bandon Bay from an integrated socio-economic and biogeochemical perspective. The nature of the coastal ecosystem of Bandon Bay, based on the trophic relationships and productions of the aquatic living resources in the bay, were also studied. This synthesis report, PART I, covers the results obtained in the 3-year practical study between 1997 and 1999.

1.2 Objectives

The overall objective of the research project is to develop a model of the effects of conversion of mangrove ecosystems, particularly to shrimp farming, on different biogeochemical aspects including forest structure; carbon, nutrient and sediment fluxes; fishery production and trophodynamic status for Bandon Bay; and on economic evaluation encompassing an assessment of Total Economic Value, including option and bequest values. The study aims to use techniques of economic valuation to assess the relation between shrimp-farming, mangrove forest removal and oyster farming in terms of carbon flows. Physical/chemical water quality parameters are key factors that drive the biological/system responses. They are measured in order to interpret the forcing factors that affect the ecological response. This interpretation is required to formulate and evaluate management responses.

1.3 Site description

1.3.1 Physical setting

Bandon Bay (9^{o} 12’ N and 99^{o} 40’ E) is located in Suratthani Province, southern Thailand. It covers the area from Chaiya District on the west side to Don Sak District on the east side, approximately 1070 km^2 (Figure 1.1). The bay is exposed to monsoon weather with northeast winds from October to April while southwest winds prevail from May to November. Therefore there are two pronounced seasons in the area: the dry condition, from January to May with scarce rainfall and high evaporation rate, and the wet season from June to December with higher rainfall and lower evaporation rate. From January to March, surface current circulation is counter-clockwise while from April to December, the surface current flows clockwise from Chumporn Province to Suratthani and Don Sak.

The inner bay, from Chaiya District to Kanchanadit District (Figure 1.1), covers an area of 480 km^2 with 80 km of coastline. The area of the mangrove swamps surrounded the bay is about 20 km^2. The coastal area has a gradual slope and the water is shallow. A large band of mudflats extends along the coast to about 2 km offshore, resulting from high sedimentation in the bay area. Water depths vary from below 1 m to 5 m near the mouth of the bay, with a mean depth of 2.9 m with respect to mean sea level. The system is a mixed tidal type with principally semidiurnal tides. Tidal amplitudes range from about 0.70 m at neap tides to about 1.90 m at spring tides. The average tidal range is 1.0 meter. The volume of the inner bay is estimated to be $1,392 \times 10^6$ m^3.

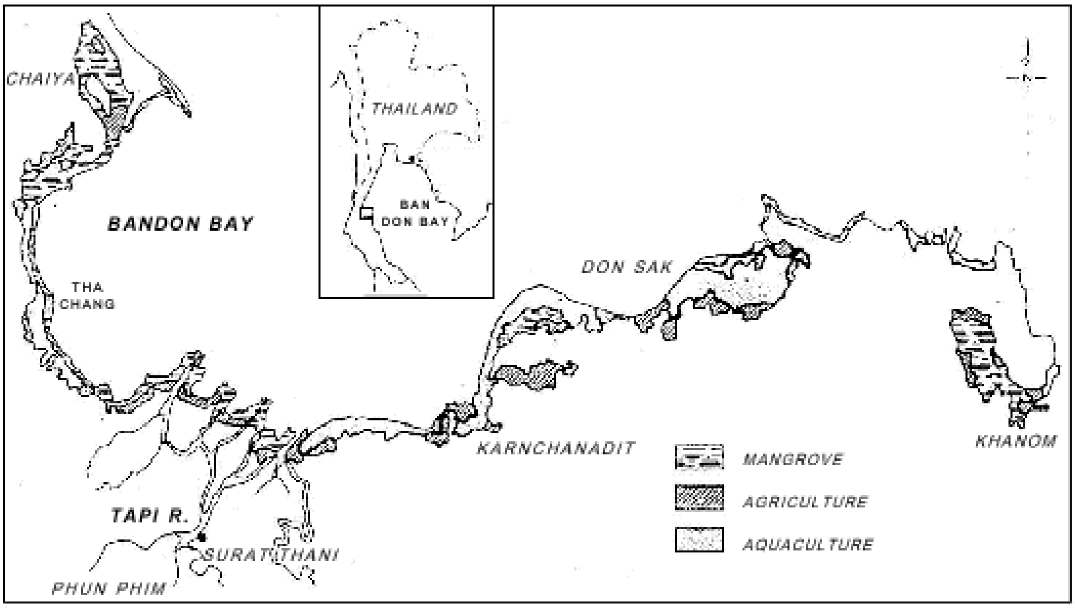

Figure 1.1 Map of the study area.

Meteorological data for Bandon Bay in 1997-1998 is based on the data compiled from the Suratthani Weather Stations and is shown in Figure 1.2. The wet season starts in May and lasts until December, with monthly rainfall ranging from 77 mm to 412 mm. The highest rainfall recorded during the study was in August. The dry condition, from January to April, is characterized by lower rainfall (< 50 mm) and higher evaporation rate. The average rainfall is 4.48 mm day^{-1} and average evaporation is 4.46 mm day^{-1}. Relative humidity is 81% (range from 61-95%). Annual rainfall for 1997 was 1500 mm, which is less than the mean annual rainfall for 1951-1996 (1690 mm).

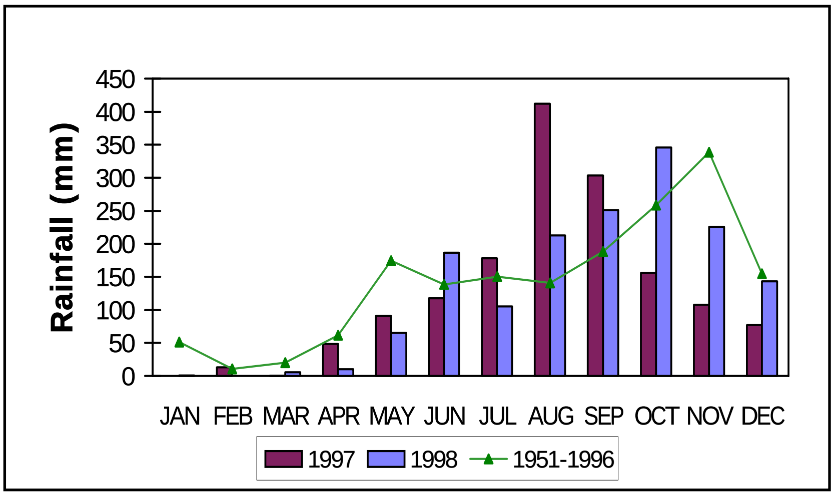

Figure 1.2 Monthly rainfall in mm for Suratthani in 1997-1998.

Bandon Bay receives most of the surface freshwater runoff from the Tapi-Phumduang River watershed (latitude 7° 58.2' N – 9° 31.0' N, longitude 97° 28.4' E – 99° 46.0' E), which is situated between the Nakorn Si Thammarat mountain range and the Phuket mountain range in Southern Thailand. The watershed consists of two catchment areas with an approximate area of 11,585 km². It has two major river basins, namely the Tapi River basin and the Phumduang River basin, with an area of 5,460 km² and 6,125 km², respectively. The Tapi River, approximately 230 km long, originates in the Nakorn Si Thammarat Range, while the Phumduang River originates in the Phuket Range. The two rivers join to become one at Phunphin District (30 km west of Suratthani), and flow through Muang District and Municipality then empties into Bandon Bay which is connected to the Gulf of Thailand.

Further upstream, a rockfill dam with clay core (Chiew Larn Multipurpose Dam), 94 meters high, was constructed across the Klong Saeng River, a tributary of the Phumduang River. The river is dammed and used to irrigate the agricultural land, so discharge is strongly regulated. The annual volume of water released from the Chiew Larn Dam to the lower basin depends on demand for salinity control, irrigation, navigation, industry and domestic consumption. However, the discharge hydrographic of the Tapi-Phumduang River still exhibits a periodic variation with a cycle of one year (Figure 1.3). Annual runoff in the Tapi-Phumduang river system normally amounts to more than 10 billion m³. The hydrological characteristics of the Tapi and Phumduang rivers in 1997 are summarized in Table 1.1. The ratio of the maximum and minimum discharges appears to be high, which implies that monthly discharges fluctuate according to seasonal precipitation.

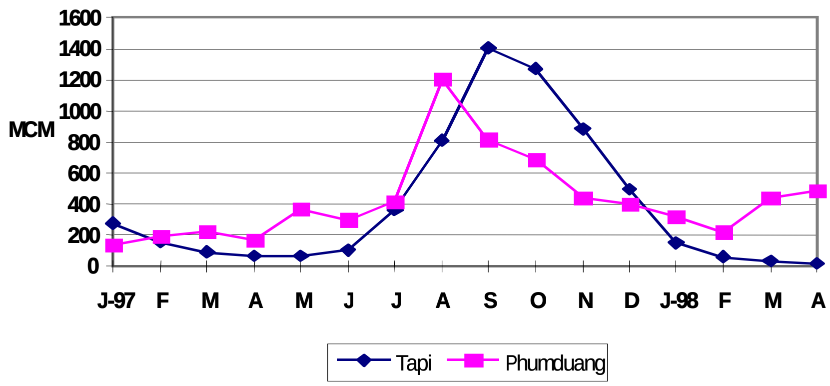

Figure 1.3 Monthly discharge of Tapi and Phumduang rivers into Bandon Bay in 1997-1998. (Source: Royal Irrigation Department)

Table 1.1 Hydrological characteristics of Tapi and Phumduang rivers in 1997.

River	Drainage Area (km²)	Discharge (m³/s)			Ratio Maximum/ Minimum	Annual Runoff (million m³)
		Mean	Minimum	Maximum		
Tapi	5,200	135.4	14.4	803.9	56	4280
Phumduang	3,012	120.9	14.5	1253.4	86	3830

Source: Royal Irrigation Department

1.3.2 Ecological characteristics

1.3.2.1 Coastal habitats

Bandon Bay is among one of the productive coastal area in the southern part of Thailand. However it is also an example of the heavy utilization of coastal resources. The mangrove forests along the coast of Bandon Bay, covering the provinces of Chumporn, Suratthani and Nakhon Si Thammarat, are quite productive and extensive. Seagrass beds surrounding Samui, Ang Thong and Phangan islands are important nursery grounds for marine resources. These two productive natural resource habitats coupled with the nutrient discharges from the Tapi and Phumduang Rivers into the bay provide a rich and continuous supply of biogenic carbon for marine resources.

Riverine forests are common in the extensive mangrove forests of Bandon Bay. Riverine mangrove forests are recognized as most productive, partly due to seasonal flooding by freshwater from upland areas. The mangrove forests along the coast of Bandon Bay are estimated to cover 25,570 ha. The species composition of mangrove communities of Bandon Bay was observed at Muang District, Chumporn Province, Chaiya District and Don Sak District, Suratthani Province and Khanom District, Nakhon Si Thammarat (Aksornkoae, 1994). The dominant species at Chaiya District were *Rhizophora apiculata, Sonneratia alba, Avicennia alba, Xylocarpus pranatum*, *Excoecaria agallocha, Ceriops decandra* and *Nypa fruticans*. At Don Sak District, the dominant species are *R. mucronata, R. apiculata A. officinalis, X. molluscensis, E. agallocha* and *Phoenix* sp.

Five species of seagrasses were recorded from the seagrass beds at Koh Samui, Suratthani Province by Nateekanjanalarp and Sudara (1991): *Halodule uninervis, Halophila ovalis, Halophila ovata, Halophila decipiens* and *Enhalus acorides*. The seagrass biomass was estimated in the range of 0.004 - 1111.5 g dry wt m^{-2}.

The mangrove forests and seagrass beds in Suratthani have played significant roles as food sources, habitat, shelter and nursery grounds for numerous associated fauna. A study of macrofauna in the soft bottom community was carried out under the ASEAN-Australian Coastal Living Resources Project (1994) during May-June 1988. A total of 20 species belong to 6 families and 10 genera of shrimps were reported. The family Penaeidae was the most diverse consisting of 13 species. Three economically important genera, namely *Metapenaeopsis, Metapenaeus* and *Parapenaeopsis*, made up approximately 82% of the total density. The results agreed well with Boonyubol and Chaitiamvong (1994). *Metapenaeopsis, Metapenaeus* and *Parapenaeopsis* were dominant in this area. Boonyubol (1996) has studied the seasonal changes in shrimp larvae, *P. merguiensis* in Don Sak River, Suratthani. She found that the highest abundance of post-larvae was recorded during March, with two other peaks during September and November. Juvenile stages were detected throughout the year with the highest peaks in January, April, May and November. Chaitiamvong (1997) investigated the shrimp community in Don Sak area. Sergestid, caridean and penaeid shrimps in particular *P. merguiensis* were dominant in the mangrove forests. Shrimps of the genus *Metapenaeus, M. affinis* and *M. ensis* were more abundant in the estuarine area. Monkolprasit (1994) investigated the fish community in the Bandon Bay mangrove forests. She recorded 56 species in 26 families with the family Engraulidae the dominant group. *Stolephorus indicus, Engraulis kammalensis* and *E. baelama* were the three most dominant species. She concluded from her study that the mangrove forests in Bandon Bay played an important roles as feeding grounds for fishes. She found that approximately 56% of fishes that come in feed on zooplankton benthos and fishes. Detritivorous and herbivorous fishes were also recorded.

Copepods, mysidaceans, ostracods, tanaidaceans and brachyuran zoea were the dominant groups in the zooplankton community in Suratthani seagrass beds. (Nateekanjanalarp and Sudara 1991). Amphipods, polychaetes and molluscs were the three major groups of benthic fauna associated in the seagrass beds. Nekton in the seagrass beds can be divided into two groups: permanent residents such as caridean shrimps and gobiid fishes, and seasonal residents such as brachyuran crabs and economically important fishes including *Siganus spp.*; *Epinephelus tauvina, Psammoperca waigiensis* and *Gerres sp.*

Tookwinas *et al.* (1992) conducted an investigation on the potential for aquaculture in Suratthani Province. for 1988-1990. Their study revealed that the coastal environment was in an appropriate condition for aquaculture. Phytoplankton density was in the range of 4,533-62,128 cells/liter. The dominant genera of phytoplankton were *Thalassiothrix, Rhizosolenia, Nitzschia, Chaetoceros* and *Guinardia*. Zooplankton density recorded was in the range 118-897 cells/liter with shrimp larvae representing 5-10% of the total zooplankton. The benthic community recorded was in the range of 73.8 – 1,138 individuals/m^2. Stations inside Bandon Bay itself recorded the highest phytoplankton, zooplankton and benthic production.

1.3.2.2 Marine fisheries in Bandon Bay

Captured fisheries

Most of the fisheries in Bandon Bay are small-scale fisheries. The major fishing gears are gill net or drift net for catching crabs and threadfins, trammel net for catching shrimps, push net and other trawls. Penaeid shrimps largely *P. merguiensis*, *P. monodon*, *P. semisulcatus*, *P. latisulcatus* and *Metapenaeus spp*. are the important target species. Other invertebrates such as mantis shrimp, swimming crabs and squids are also caught. Bandon Bay has been declared by the Department of Fisheries as a conservation zone due to its importance as spawning and nursery grounds for penaeid shrimps, anchovies, club mackerel and mollusc species. The fish larvae survey by the Department of Fisheries revealed more than 42 families of fish larvae in the area with the dominant families Gobiidae, Leiognathidae, Clupeidae, Callionymidae and Engraulidae. Monkolprasit (1994) found that of the 56 fish species recorded from Bandon Bay mangrove forest, fishes in the family Engraulidae were the dominant group. Fish eggs and larvae were most abundant between March and May. The important demersal fishes in the area were Sciaenidae, Cynoglossidae, Engraulidae and Clupeidae. Rattanachote (1994) reported that the commercially important mullets in Bandon Bay were *Liza subvirides* and *Valamugil cunnesius.*

Bandon Bay is very productive in terms of benthic production. The benthic fauna serve as important linkages in the marine food chain as the aquatic food resources for large predatory fishes and crustaceans. A total of 40 species from nine families and 26 genera of brachyurans were reported from the area. Three major families were Portunidae, Goneplacidae and Leucosiidae. Although many of these were small-sized crabs, they served as food resources for large predatory fishes, crustaceans and squids (Aryuthaka *et al.* 1991). The results corresponded to those reported by Charoenruay *et al.* (1983) and Sanguansin (1986). Other important benthic aquatic food resources as revealed from the ASEAN-Australian Coastal Living Resources Project (1994) were polychaetes of predominantly families Terebellidae, Eunicidae and Nereidae. There were 29 families recorded in the area. Dominant echinoderms were brittle stars *Ophiocnemis marmorata*; sea urchins *Temnoplereus toreumaticus* and sea cucumber *Acaudina* spp. Jivalak *et al.* (1991) found 60 species of molluscs in this area. Five commercial bivalves were found namely, *Paphia undulata, Anadara spp.*, *Scpharca sp., Modiolus senhausii* and *Placuna placentra. Paphia undulata* was the most abundant with a density of 81.51 individual/m^2 and biomass of 68.86 gm^{-2}. This findings corresponded to Chareonruay *et al.* (1983). They reported a total of 203 species of benthic organisms collected by dredges from Chong Angthong area adjacent to Bandon Bay. Of the total, 23 species were echinoderms, 60 were molluscs, 59 were decapod crustaceans, 31 were polychaetes and 30 were other organisms.

The fisheries resources in the Bandon Bay have been heavily exploited. Excessive fishing efforts and the capture of undersize fish were evidenced. Commercial fish and trash fish make up the commercial catches from small and medium-size trawlers. The commercial component of the catch from push net was also dominated by "small" and "large" shrimps. Fish and squid components were largely treated as by catch and seldom marketed. Lohsawatdikul and Eiamsaard (1991) reported the mean catch rate for push net boats in Bandon Bay at about 316 kg/boat/day with a "commercial" to "trash" fish ratio of 4:6. The "commercial" component of catches was composed largely of shrimps and swimming crabs, while the "trash fish" component was composed of more than 60 % "true trash fish" and less than 40 % undersize individuals of commercially important organisms. When compared with the push net catch survey in Tha Chang, Suratthani Province conducted by Eiamsaard *et al.* (1985), the catch rate was 187 kg/boat/day, with 57% "trash fish". Of this "trash", 47% were juveniles of commercially important organisms. This implied that over a quarter (27%) push net landing consisted of undersize fish of commercial importance. These two statistics indicate that approximately a quarter of the total landing was composed of undersize fish indicating a tremendous rate of over-fishing. There have been concerns on the destructive nature of push net operation in the shallow area especially in the bay, which are important spawning grounds for many commercial species Klinrod *et al.* (1993) reported the catch rate, species composition and size of marine invertebrates from push net and shrimp gill net from Don Sak area. They conducted monthly surveys from

1987 to 1991. The catch composition from the push nets revealed 41-63% "trash fish", 7-13% large shrimps, 18-38% small shrimps, other invertebrates 5-12% and commercial fish 0.1-0.9%. Large shrimps, mainly *P. merguiensis* and *Metapenaeus spp.* contributed approximately 58-74% of the catch from shrimp gill nets. Small shrimps made up approximately 2-8%, other invertebrates 19-28% and commercial fish 3-14%. The maximum catch rate for push net and shrimp gill net were 29.4 kg/hr (1990) and 1.66 kg/hr (1989).

Figure 1.4 shows the decline in fishery production of Suratthani within the past ten years (1986-1995). Most of the fish production is trash fish resulting from excessive fishing effort, capture of undersize fish and the destructive nature of push net. Coupled with the degradation of mangrove forest, this further reduced the fishery production. However, the ratio of food fish to trash fish has slightly improved from the year 1992 onward partly due to strict fishery regulation. As revealed from the Department of Fisheries data, the catch rate for demersal fish and shellfish in Suratthani were 1.16 kg/hr and 0.34 kg/hr in 1993. These catch rates changed slightly over time.

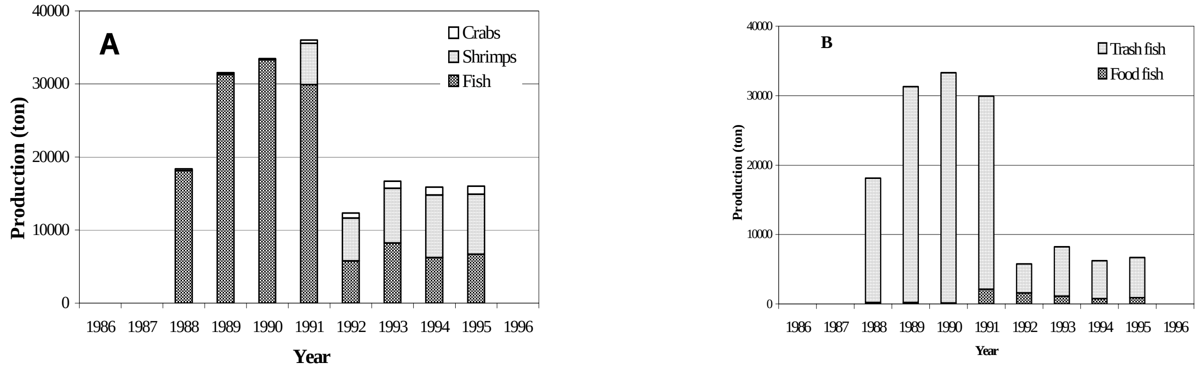

Figure 1.4. Fisheries production in Suratthani Province
A. Production of major fishery species. B. Composition of fishes landed.

Cultured fisheries

Coastal aquaculture in Bandon Bay has expanded rapidly. Shrimp culture is the dominant aquaculture activity. Other aquaculture activities are cockle (*Anadara granosa*, culture, oysters of two major species, *Crassotrea belcheri* and *C. lugubris* and fish culture. Kanchanadit District is the largest potential area for shrimp farms. The area for shrimp farms was 241 ha in 1979 (Haemaprasit and Paw 1988). The rate of increase in shrimp farm area were 6.6 and 13.5 fold respectively as compared with the original area in 1979. Table 1.2 and Figure 1.5 show the variations in mangrove coverage shrimp farm area and shrimp production in Suratthani Province from the period 1986–1996. The shrimp production increased several fold from 1986–1990 due to the increase in shrimp culture. The high shrimp production is maintained through the increase in the area of intensive shrimp farming. Boonprakob (1983) had once predicted the expansion of shrimp farms in Suratthani to its fullest capacity of 3,200 ha. Within two years, the shrimp farms at Bandon Bay had already expanded to its full prediction. However, the expansion of shrimp farm area continued to increase further to 9,642 ha in 1992 and to 13,780 ha in 1996, of which only 6,946 ha are productive. The shrimp culture technology has shifted from traditional and semi-intensive to intensive farming. The high rate of shrimp production maintained due to the ratio of traditional farms : semi-intensive : intensive farms in 1996 was 2.68 : 1.00 : 3:28 as compared to the ratio in 1989 of 4.11:3.45:1: 00. as in Figure 1.6.

Table 1.2 Variation in mangrove coverage and shrimp production in Suratthani Province.

Year	Mangrove coverage (ha)	Shrimp farm area (ha)	Total shrimp production (ton)	Shrimp production /area (ton/ha)
1986	4336.36	3740.57	2146	0.574
1987	4161.30	4915.79	2828	0.575
1988	3986.72	6728.74	3268	0.486
1989	3812.79	8270.28	9828	1.188
1990	3021.70	9025.10	14400	1.596
1991	2230.77	9596.11	18748	1.954
1992	2716.60	9642.11	20047	2.079
1993	3202.43	8771.17	25414	2.897
1994	3192.23	8136.03	25858	3.178
1995	3182.02	6655.55	22221	3.339
1996	3171.82	6946.07	21226	3.056

Fish culture and cage fish culture are other important aquaculture activities in Suratthani. Fish culture, mainly sea bass and groupers, have increased from 1990 to 1994. Total fish production from fish ponds and fish cages has increased from 14 tons to 32 tons. During the same period, the area under oyster culture has increased from 301 ha to 640 ha, and oyster production has increased from 492 tons to 10,295 tons. Cockle culture, mostly in Chaiya and Tha Chang districts, has also increased in area from 395 ha to 1,158 ha. However, the production recorded in 1990 and 1991 were 3,997 and 10,799 tons respectively with a major decline in 1994 to 4,509 tons.

1.3.2.3 Changes in mangrove forests and fisheries production

Declining fishery production in Thai waters is generally due to over-fishing, pollution and coastal habitat degradation. These three major factors seem inseparable. Several studies in Thailand demonstrated that decrease in mangrove area correlated well in time with the decrease in coastal fishery production. As with other mangrove forests of Thailand, coastal development and conversion of mangrove forests to aquaculture, in particular shrimp farming, were the two major forces of the loss of mangrove areas in Bandon Bay. The depletion of mangrove forests in Bandon Bay during 1961-1979 was due to coastal development with the highest rate of depletion of approximately 77 %. The overall depletion was 87 % from 25,600 ha in 1961 to 4,336 ha in 1986 and 3,171 ha in 1996. The rate of depletion during 1979-1989 was 35 %. The lowest rate of mangrove depletion, during 1989-1996, was 17 %.

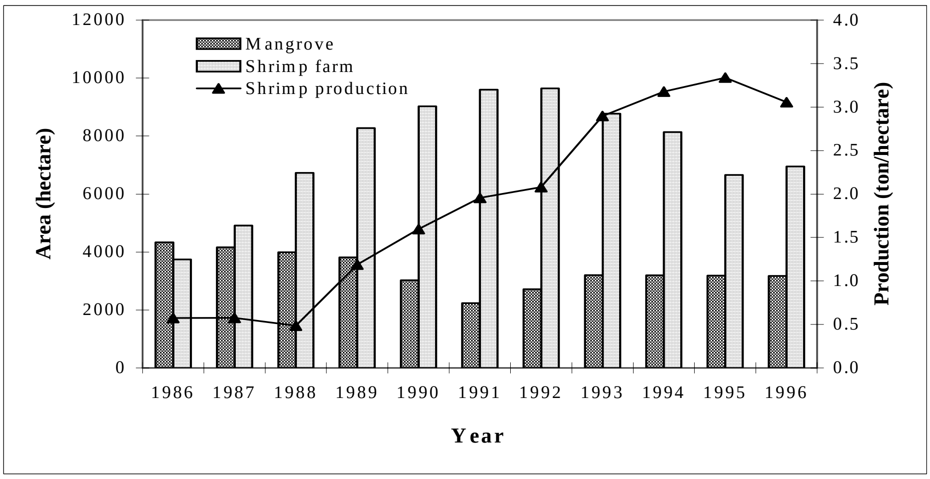

Figure 1.5 Variations in mangrove coverage, shrimp farm area and shrimp production in Suratthani Province.

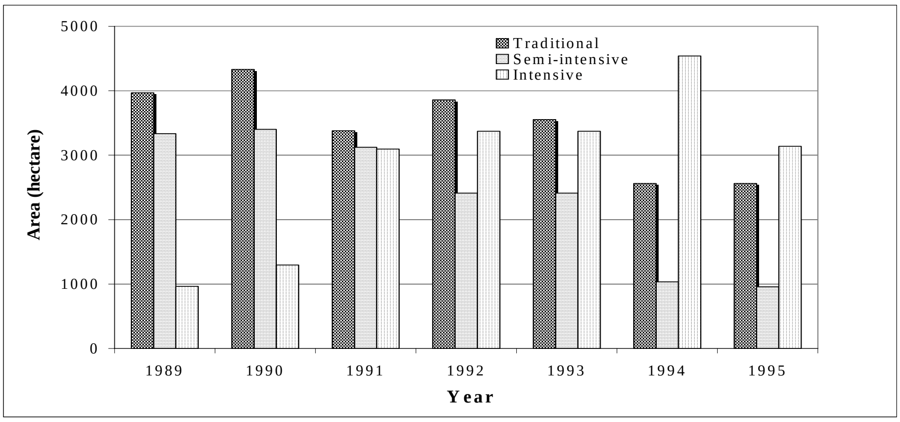

Figure 1.6 Shrimp farming technologies used in Suratthani Province.

In 1983, Boonprakob had predicted the expansion of shrimp farms in Suratthani to its fullest capacity of 3,200 ha. Within two years, the shrimp farms in Bandon Bay had already expanded to its full prediction of 3,262 ha in 1985 (Haemaprasit and Paw 1988). At the time of prediction in 1983, the shrimp farms area was 1,592 ha increased tremendously from the original 242 ha in 1979. However the expansion continued to 13,780 ha in 1996. Of this, the shrimp farm on the previous mangrove area comprised about 54% of the total shrimp area in this province. Coastal development is another major force for the loss of mangrove area. The total population has grown steadily over the years adding the demands for the natural resources.

As revealed from the fisheries statistics of Suratthani within the period of 1986 -1995, there was some correlation between the decreasing mangrove forests with the decrease in fishery production as in Figures 1.4 and 1.5. Over-fishing coupled with the degradation of mangrove forests were the major pressures for the reduction in fishery production. Figure 1.7 shows the oyster farm expansion in the Bandon Bay. The oyster farm expansion was quite rapid.

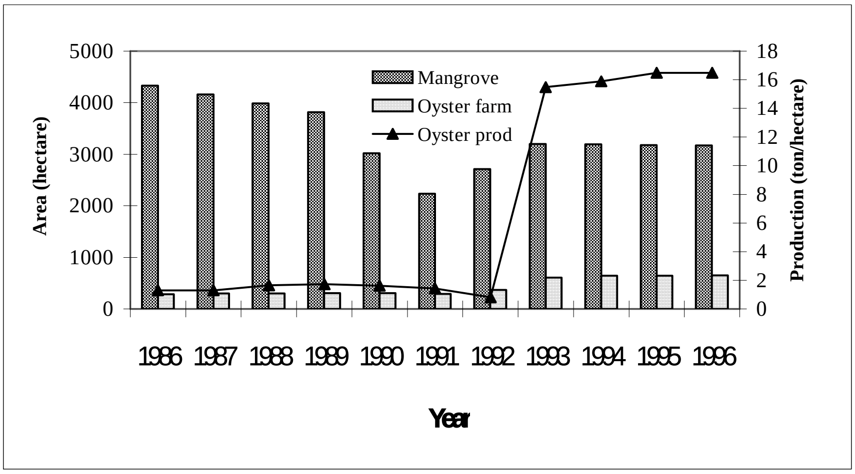

Figure 1.7 Oyster farming and production in Suratthani Province

The area for oyster culture had increased more than two-fold from 1986-1996. Oyster production jumped from 1.30 ton/hectare in 1986 to 16.5 ton/hectare. Recent studies in southern Thailand found that there were increased mollusc harvests in areas adjacent to major shrimp farming areas (Office of the Environmental Policy and Planning 1994). This could explain the increased oyster production in Suratthani during 1986–1996 apart from the rapid expansion of oyster farms.

It is always a major problem where waste production from aquaculture in particular shrimp farm area exceeds the capacity of the receiving environment to dilute or assimilate the waste materials. Self-pollution of shrimp culture areas by pond effluents and the major crash of the shrimp industry are apparent in Thailand particularly in Samut Sakhon, Samut Songkhram, Suratthani and Nakhon Si Thammarat provinces, and in Taiwan, the Philippines and Indonesia. The potential impacts from the discharges of shrimp pond effluents are the depletion of dissolved oxygen due to discharge of effluent with high biochemical oxygen demand and the breakdown of dissolved and particulate organic matter and other waste materials. There is urgent need for the development of a model to predict the carrying capacity of coastal areas for shrimp farms. This model will link the number and intensity of farms in a given coastal area with the ability of the area to assimilate waste materials. This model should take into account the physical and chemical processes of the area especially the chemical budgets, the biogeochemical processes of certain chemical compounds, tidal cycles and range, retention time and hydrology. At present, only a few studies on the carrying capacity of the receiving bay or estuaries have been carried out in Thailand such as in Khung Kraben Bay, Chanthaburi Province. However the model has not yet been implemented in the coastal management. This situation is similar to Suratthani that the expansion of coastal aquaculture in the area was quite rapid and without direction. This could easily lead to the accumulation of waste products that far exceed the carrying capacity of the receiving aquatic environment.

Table 1.3 shows our calculations using the equations proposed by Preedalumpabutr and Chaiyakum (1994) on the correlation between the total ammonia and BOD and the shrimp farm areas. The total ammonia and BOD loading are extremely high. Existing discharged loading from shrimp ponds has not been calculated. Many of the shrimp farms are along the coast, so most of the waste is discharged directly into the sea, but some is discharged into the river. For exact estimation, locations have to be considered as well as area and generated rate. Since 1990, according to Thailand National Water Quality Classification for Seawater, the water in Bandon Bay is unsuitable for aquaculture. The nutrient budget in this study revealed the average ammonia concentration in the bay was 0.10 mg/1 in April 1997, 0.07 mg/1 in October 1997, and 0.08 mg/1 in April 1998. These values are lower than the calculated values assuming that the shrimp farm area remained the same as in 1996. Thus the integrated model of carrying capacity in Bandon Bay should be further developed for the resource management.

Table 1.3 Predicted total ammonia concentration and BOD in water released from shrimp farms in Suratthani Province.

Year	Shrimp farm area (ha)	Total ammonia concentration (mg/l)	BOD (mg/l)
1986	3740.57	1.11	5.91
1987	4915.79	1.53	7.06
1988	6728.74	2.18	8.83
1989	8270.28	2.73	10.33
1990	9025.10	3.00	11.07
1991	9596.11	3.21	11.62
1992	9642.11	3.22	11.67
1993	8771017	2.91	10.82
1994	8136.03	2.69	10.20
1995	6655.55	2.16	8.75
1996	6946.07	2.26	9.04

1.3.3 Economy and society

Population

Suratthani province has an area of 12,890 km^2. The 1997 population of the province was approximately 861,200, of which 149,800 were in the urban community and 711,400 were in the rural area of the basin. In the basin area, Muang Suratthani district has the largest number of population (17.2%). The followings included Phunphin district (10.5%) and Nasarn district (7.8%).

Table 1.4 Population distribution in 1997.

District	Area (sq. km.)	Municipal Area	Population	Urban Population	Number of Households
Muang Suratthani	231.31	68.97	40,169	107,888	54,050
Kanchanadit	873.53		91,011		22,663
Koh Samui	227.25		34,792		12,397
Kiriratnikom	1,347.37		37,578		8,186
Chaiya	1,004.63		42,905		10,314
Don Sak	458		33,473		9,081
Tha Chang	1,160.42		28,819		6,577
Tha Chana	683.08		43,125		10,825
Ban Nasan	835.06	67.13	47,827	19,390	15,337
Panom	703.22		28,515		6,576
Phra Saeng	1,328.06		52,148		11,815
Punpin	1,201.16	14.1	67,724	22,520	22,444
Wiangsra	420.39		56,678		13,235
Koh pangan	193		9,029		3,218
Kiansa	580		35,503		8,191
Ban Ta Khun	1,300		13,211		3,572
Ban Nadoem	206		20,974		5,013
Chaiburi	112		18,552		4,381
Vipavadee	529.25		9,402		2,403
Total	**13,393.73**		**711,435**	**149,798**	**230,278**

Source: National Statistical Office

Land Use

The province is well endowed with natural resources, with forest covering about 25 % of the area, while the coastal zone has mangrove forest. The sea provides a livelihood for fishermen and aquaculturists, while the offshore islands have become well known internationally as tourist destinations. The rich natural resources of the province provide the raw materials for industries which have developed in the area.

Land use in 1998 (Table 1.5) is largely agricultural and forest. Agricultural land is mainly land for rubber and oil palm plantations. Most of the land is rolling foothills suitable for upland crops and tree cultivation. Flat areas suitable for rice cultivation are limited. However, a large area is still under forest, and is now protected by law as national parks, wildlife sanctuaries and non-hunting areas. A small amount of land is used for urban centres and industry.

Coastal development is a major cause of the loss of mangrove area. The total population of Suratthani has grown steadily from 588,400 in 1980 to 816,400 in 1990, and to 861,200 in 1997. The coastal resources of Bandon Bay are heavily utilized for economic development, particularly land reclamation and development for agriculture, aquaculture and human settlement. Comparison of land use in the Bandon Bay coastal area between the year 1993 and 1998 is shown in Table 1.6. In the past five years, a lot of the mangrove forest and inundated area in the coastal zone has been converted to shrimp farms and/or other uses. Land for rubber and oil palm plantations, as well as rice fields has increased whereas that for coconut plantations (or mixed orchards) has decreased in area.

Table 1.5 Classification of land cover/land use in Bandon Bay coastal area in 1998 (Sawangphol and Wattayakorn, 1999).

Categories	% Image	Area (km^2)	Area (rai)*
Forest	0.48	14.11	8,818.75
Mangroves	0.58	16.96	10,600.0
Rubber Plantation	24.83	730.29	456,431.25
Coconut Plantation	4.41	129.81	81,131.25
Oil Palm Plantation	3.44	101.24	63,275.0
Paddy Field	9.11	267.89	167,431.25
Shrimp Farm	3.72	109.50	68,437.7
Urban Area	1.21	35.67	22,293.75
Shrubs	0.54	15.89	9,931.25
Inundated Area	1.22	35.77	22,356.25
Others	7.33	215.59	134,743.75
Water bodies	38.03	1,118.53	699,081.25
Clouds	5.10	150.0	93,750.0
TOTAL	**100.00**	**2,941.24**	**1,838,273.44**

Table 1.6 Comparison of land use between the years 1993 and 1998.

Categories	Area (km^2)		Area Change	
	1993*	1998^	km^2	km^2/year
Forest	6.86	5.83	-1.03	-0.21
Mangroves	23.32	16.07	-7.25	-1.45
Rubber Plantation	168.04	363.35	+195.31	+39.06
Coconut Plantation	**161.14	110.31	-50.83	-10.17
Oil Palm Plantation	0.65	42.10	+41.45	+8.29
Paddy Field	140.82	188.30	+47.48	+9.50
Shrimp Farm	64.56	80.88	+16.32	+3.26
Urban Area	19.10	26.77	+7.67	+1.53
Inundated Area	61.47	20.50	-40.97	-8.19

* from Siripong et al., 1996;
^ normalized to the same study area as that of Siripong *et al.* (1996)

Production
The main products of the province are: rubber, oil palm, fruit, fishery products, canned seafood, and tourism. The gross provincial product for 1994 is shown in Table 1.7

Table 1.7 Gross Provincial Products in 1994.

Sector	**Current Prices (Baht)**	**% Share**	**Constant Prices (Baht)**		**% Growth**
	1994		**1989**	**1994**	
Agriculture	13,389,171	37.64	8,665,187	12,010,134	6.53
Crops	9,138,789	25.69	6,501,716	8,753,855	5.95
Livestock	584,431	1.64	420,307	589,878	6.78
Fishery	2,285,042	6.42	778,488	1,541,236	13.66
Forestry	0	0.00	57,418	0	-100.00
Agric. Services	44,097	0.12	44,784	34,302	-5.33
Agric. Processing	1,336,812	3.76	862,474	1,090,863	4.70
Mining and Quarrying	666,666	1.87	392,801	384,885	-0.41
manufacturing	2,728,564	7.67	1,901,190	2,228,548	3.18
Construction	2,270,185	6.38	715,854	1,476,789	14.48
Electricity and Water Supply	830,443	2.33	364,530	643,102	11.35
Transportation and Communication	1,829,373	5.14	794,954	1,539,903	13.22
Wholesale and retail trade	4,472,944	12.57	2,495,807	3,318,153	5.70
Banking and Insurance	2,268,615	6.38	551,373	1,701,362	22.54
Ownership of dwelling	1,224,930	3.44	656,647	828,333	4.65
Public administration	1,747,087	4.91	718,024	955,115	5.71
Other services	4,143,827	11.65	1,778,276	2,409,640	6.08
Total	**35,571,805**	**100.00**	**19,034,643**	**27,495,964**	**7.36**

2 BIOGEOCHEMICAL PROCESSES

2.1 Approaches

Knowledge of the exchange of water and materials through the mouths of estuaries is crucial to an understanding of functioning of both estuaries and the coastal zone. This study examines the fluxes of carbon, nitrogen and phosphorus from Bandon Bay into the Gulf of Thailand in order to gain an initial understanding of the biogeochemical processes occurring in the system. In assessing the C, N and P fluxes, three approaches have been taken: the LOICZ biogeochemical flux model, the single cross-section hydrodynamic budgeting and the mixing diagram approach. Nutrient flux estimates from the three approaches will be compared and discussed.

2.2 Water, carbon and nutrient budgets

Water samples were collected at twenty-five stations in Bandon Bay and ten stations in Tapi Estuary (Figure 2.1), during April and October of 1997 and 1998. Samples were taken at two depths, near surface and near bottom, as applicable. Nutrient analysis was performed in duplicates for each sample. As quality control, at least five samples were replicated five times for each of the nutrient parameters. Data in April were collected to represent the dry season and October to characterize the wet season of the study area.

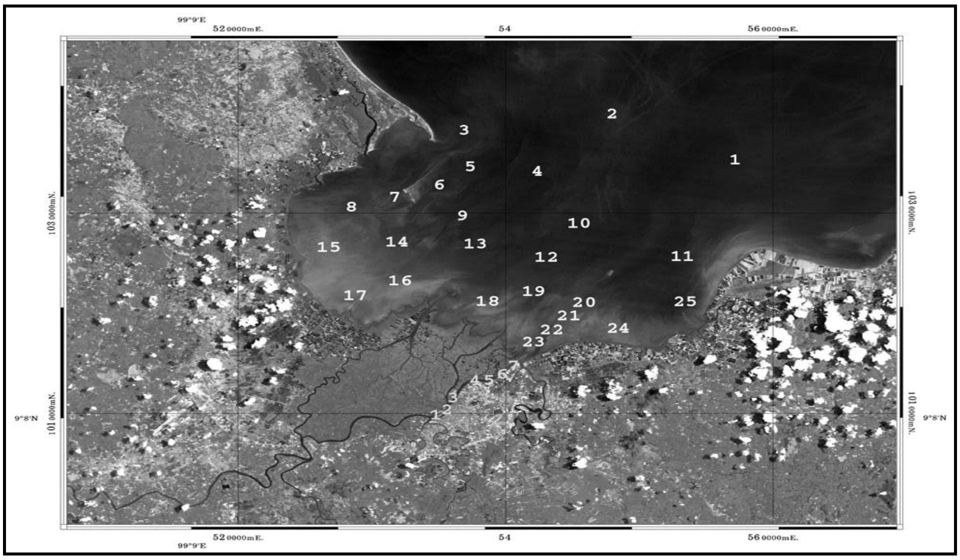

Figure 2.1. Sampling stations in Bandon Bay, 1997 – 1998.

The LOICZ Biogeochemical Modelling Guidelines (Gordon *et al.* 1996) were used to calculate the stoichiometrically linked water-salt-nutrient budgets. River flow (V_Q) data were obtained from measurements carried out by the Royal Irrigation Department. Rainfall and evaporation data were obtained from the weather stations in Suratthani. Extensive pumping of groundwater for domestic and industrial consumptions in the area has caused saline intrusion into groundwater aquifers in the Tapi-Phumduang River Basin, hence groundwater inflow (V_G) to the system can be assumed to be zero. The water volume of sewage and industrial effluents is small relative to freshwater input and is assumed negligible. Organic loads from sewage, industrial wastes, and agricultural wastes (V_O) were estimated using data from the Pollution Control Department (1998), assuming 50% BOD assimilation rates. Salinity in precipitation and wastes is assumed to be zero. The system has been divided into two boxes: Tapi Estuary and Bandon Bay. For the purposes of the budgetary analysis, both basins are treated as well-mixed systems.

Results and Discussion

Figure 2.2 shows the salinity structures in Bandon Bay during the wet and dry seasons. Average salinity in the bay ranged from 17 psu in the wet season to 20 psu in the dry season. In the sea, salinity ranged from 29 psu in the wet season to 32 psu in the dry season. Salinity in the estuary ranged from 0 to 23 psu in the dry season, 0 to 14 psu in the wet season. A longitudinal transect in Tapi Estuary revealed that the estuary was vertically well-mixed at the head of the estuary but slightly stratified towards the mouth (Figure 2.3). In the wet season, the entire estuary showed near freshwater conditions at the surface.

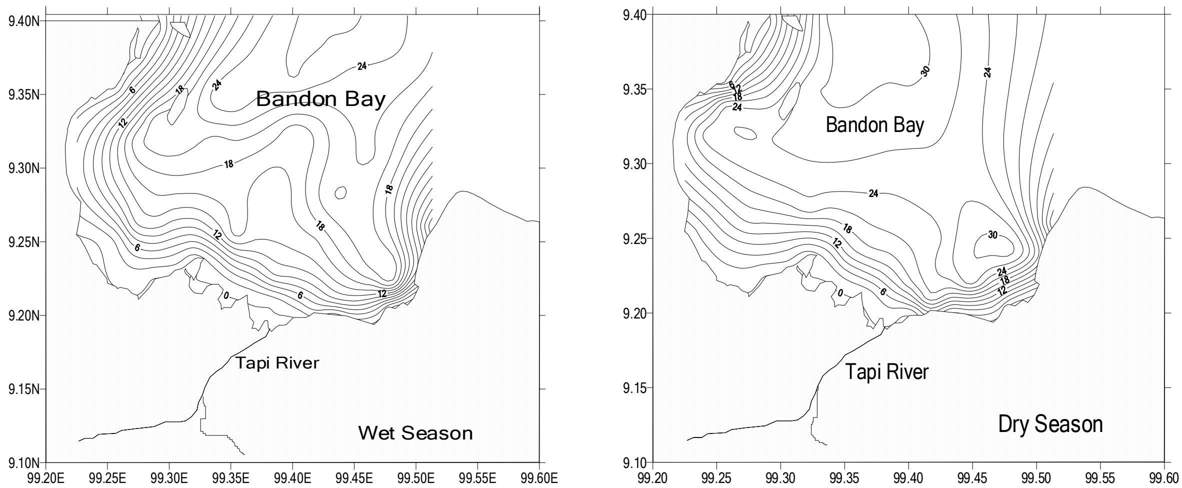

Figure 2.2 Salinity distribution in Bandon Bay.

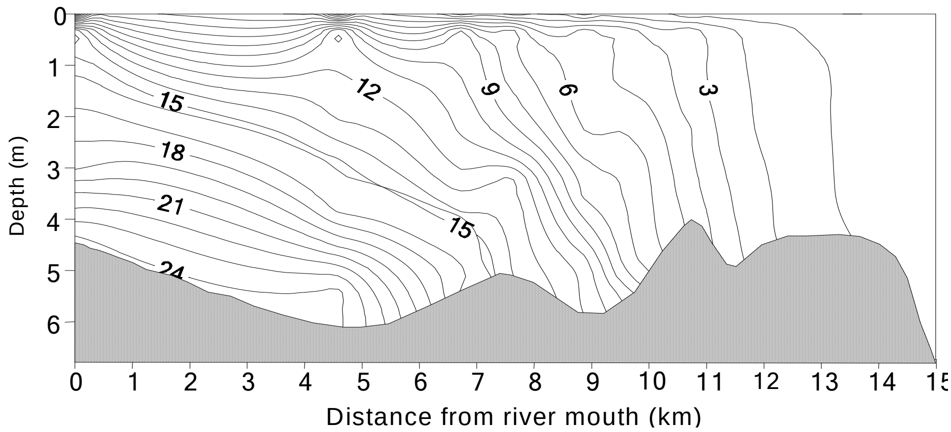

Figure 2.3. Longitudinal distribution of salinity in Tapi estuary in the dry season.

Major sources of wastewater discharge into the bay are communities, industrial factories and fishery ports and aquaculture activities along the Tapi-Phumduang river. Waste-load estimates of the economic activities are given in Table 2.1. Contribution of non-point agriculture runoff and livestock are also important during the wet season. Total N and P inflows were obtained by conversion of BOD loading, using the stoichiometric relationships of C:N:P ratios in organic waste materials (San Diego-McGlone 1999). A factor of 0.5 (PO_4 /TP) and 0.27 (DIN/TN) was used to determined the inorganic fraction (DIP) and (DIN) of the wastes from the estimated TP and TN.

Following the LOICZ Biogeochemical Guidelines (Gordon et al. 1996), the exchange time of water in the bay can be calculated as the total volume of the bay divided by the sum of V_X , mixing between bay and ocean, plus the absolute value of residual flow $|V_R|$. The water exchange time of the Tapi River estuary is estimated to be 1 to 7 days, and that for Bandon Bay is 12 to 77 days (Table 2.2 and Figure 2.4). It can be seen that the water exchange rate in Bandon Bay is faster in the wet season than in the dry season. Tides seem to be the main force driving water exchange with the adjacent Gulf of Thailand during the low flow period (April 1997).

Table 2.1. Estimated BOD generated and discharged by various economic activities.
(Pollution Control Department, 1998)

BOD generated (kg/day)			BOD discharged (kg/day)			
	1995	1996		1996	1997	1998
Domestic	1360	1430	Domestic	715	744	773
Industry	173	727	Industry	145	148	151
Shrimp farm	12	12	Shrimp farm	12	12	12
Agriculture	814	828	Agriculture	-	-	-
Total, kg/d	2359	2997	Total, kg/d	872	904	937
			Total, kmol/d	73	75	78

Table 2.2. Water circulation, residual flow (V_R), water exchange rates (V_X) and water exchange time as calculated from the water and salt budgets for Bandon Bay. The subscript "Q" indicates river; "P" is precipitation and "E" is evaporation.

Date	V_Q 10^6 m^3 d^{-1}	V_P 10^6 m^3 d^{-1}	V_E * 10^6 m^3 d^{-1}	V_R * 10^6 m^3 d^{-1}	V_X 10^6 m^3 d^{-1}	Water exchange time, days	
						Estuary	Bay
Apr-97	6	2	-2	-6	12	7	77
Oct-97	58	0	-2	-56	112	1	8
Apr-98	26	0	-2	-24	67	2	15
Oct-98	24	11	-2	-33	86	2	12

* the minus sign for V_E and V_R indicates an output from the system

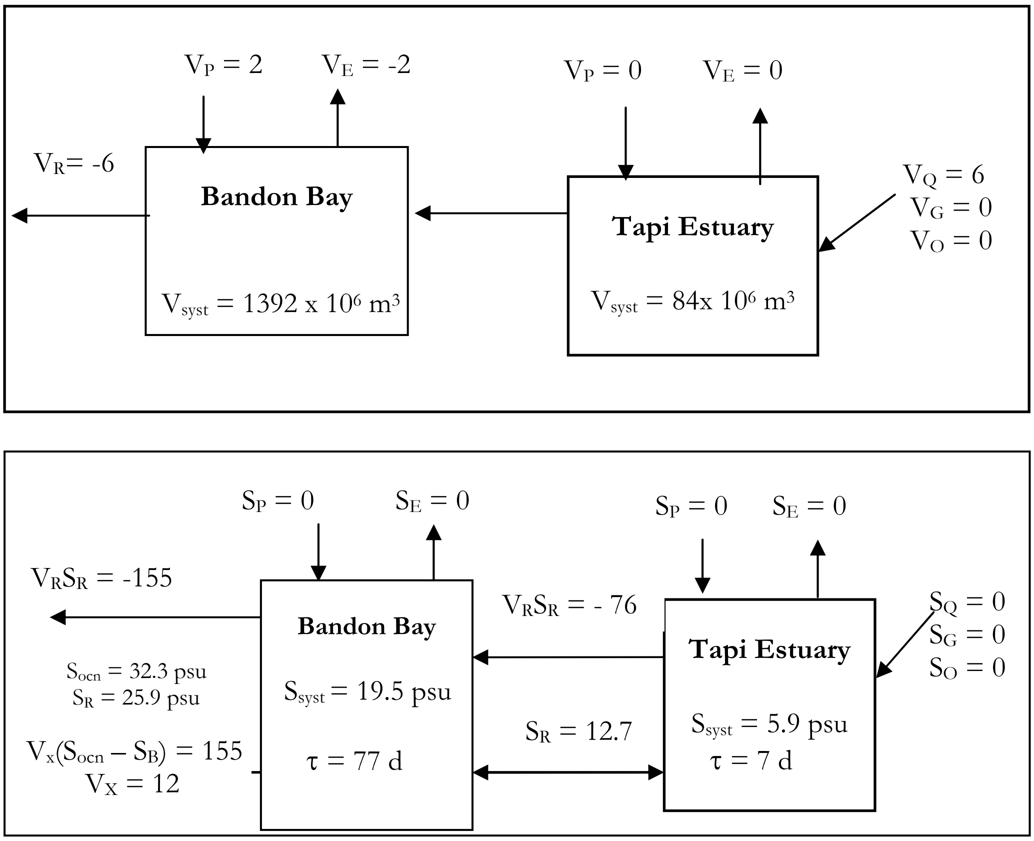

Figure 2.4. Water and salt budgets for Bandon Bay

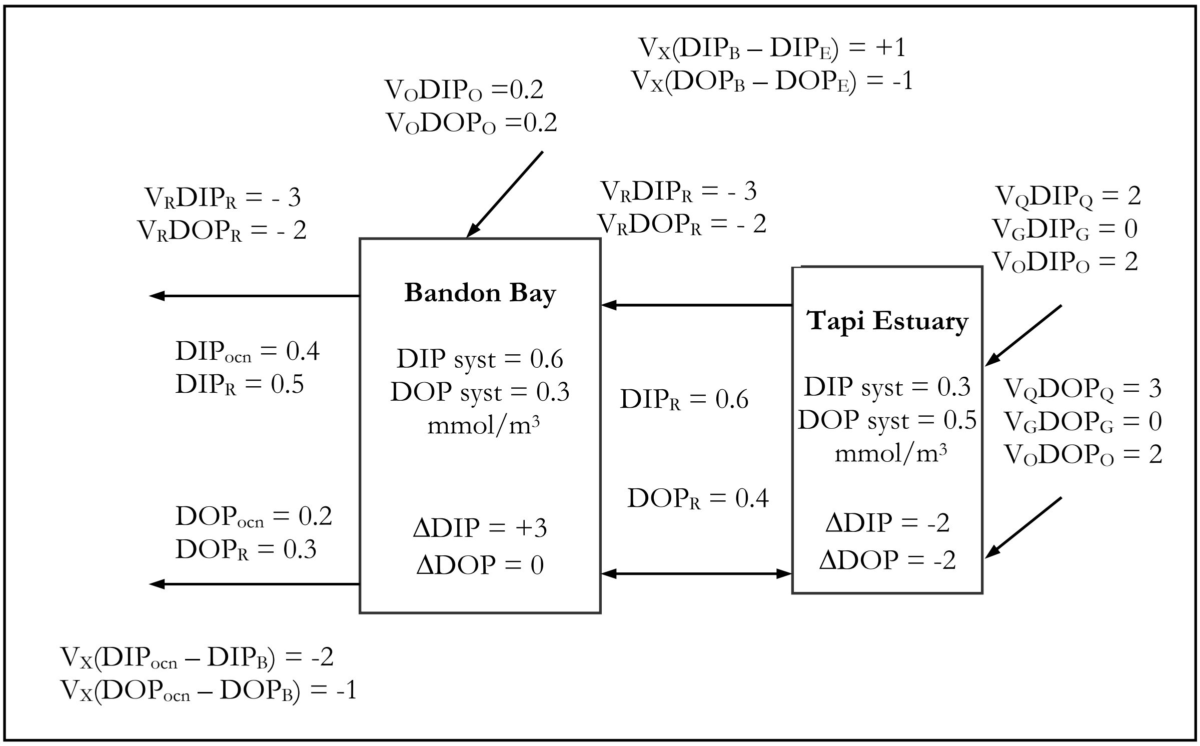

Figure 2.4 Phosphorus budgets, Bandon Bay and Tapi Estuary, wet and dry seasons 1997. Fluxes in 10^3 mol d^{-1}.

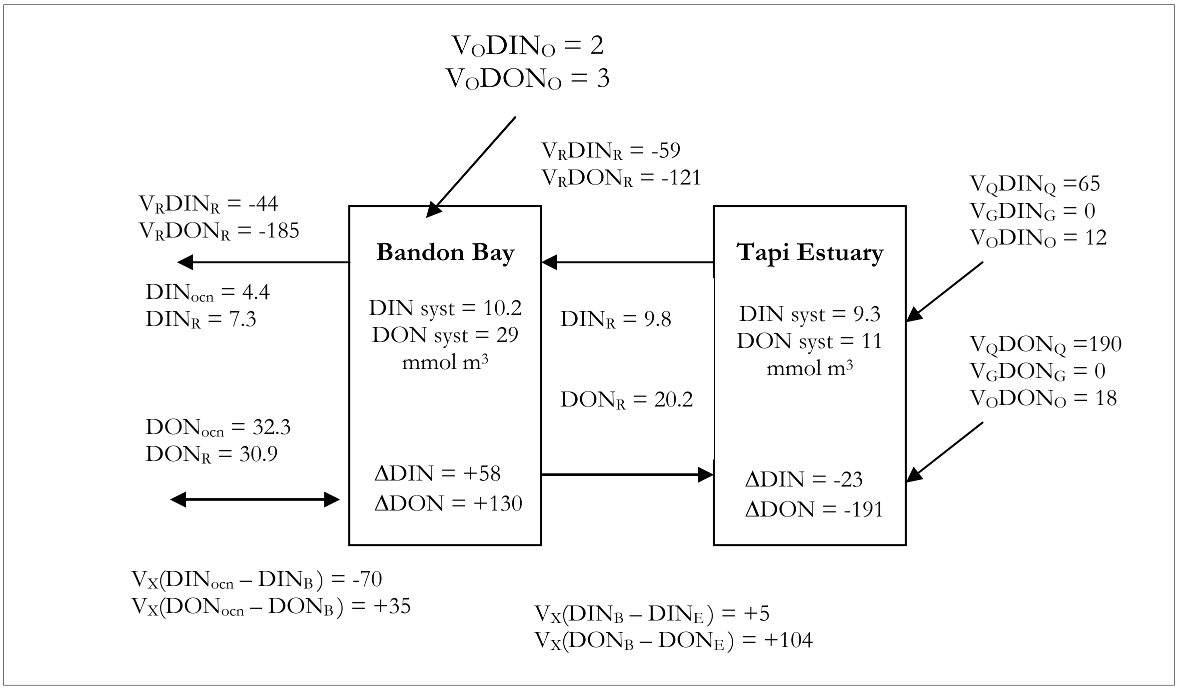

Figure 2.5 Nitrogen budgets, Bandon Bay and Tapi Estuary, wet and dry seasons 1997. Fluxes in 10^3 mol d^{-1}.

Budgets of non-conservative materials for the system are summarized in Figures 2.5 – 2.6 and Table 2.3.

Figure 2.5 shows the phosphorus budgets for the 1997 dry season. The Tapi estuary appears to be a net sink for both DIP and DOP during this period. However, DIP is slightly exported from Bandon Bay to the Upper Gulf of Thailand at a rate of 5 kmol/day. DOP is also exported to the Gulf at a rate of 3 kmol/day during this period.

Figure 2.6 presents the nitrogen budgets for the 1997 dry season. The Tapi estuary is a net sink for DIN (ammonium and nitrate) and DON, and Bandon Bay is a net source for DIN (ammonium) and DON. ΔDIN is exported from Bandon Bay to the upper Gulf of Thailand at a rate of 114 kmol/day and ΔDON at a rate of 150 kmol/day.

For the other periods of study, the results are presented in Table 2.3. In general, it can be seen that there is some variability for all the nutrients. ΔDIP for Bandon Bay ranged from -0.02 to 0.01 mmolm² d^{-1} with a mean of ~ 0 mmolm² d^{-1} ; ΔDOP ranged from -0.06 to 0.03 mmolm² d^{-1} with a mean of -0.01 mmolm² d^{-1}. ΔDIN for ranged from 0.02 to 1.8 mmolm² d^{-1} with a mean of 0.52 mmolm² d^{-1}; ΔNH_4 ranged from 0.14 to 1.7 mmolm² d^{-1} with a mean of 0.60 mmolm² d^{-1}; ΔNO_3 ranged from -0.37 to 0.10 mmolm² d^{-1} with a mean of -0.08 mmolm² d^{-1} and ΔDON NO_3 ranged from -1.3 to 0.27 mmolm² d^{-1} with a mean of -0.46 mmolm² d^{-1}.

Table 2. 3. Summary of non-conservative carbon, nitrogen and phosphorus fluxes (mmol m^{-2} d^{-1}).

	April 1997		**October 1997**		**April 1998**		**October 1998**	
	Tapi	Bandon	Tapi	Bandon	Tapi	Bandon	Tapi	Bandon
ΔDIP	-0.12	0.005	-0.65	-0.02	0.10	0.002	0.07	0.01
ΔDOP	-0.17	0	0.57	-0.06	-0.17	-0.001	-0.53	0.03
ΔNH_4	-1.75	0.14	-6.53	0.39	0.17	0.18	-19.4	1.7
ΔNO_3	-0.17	-0.02	3.10	-0.37	1.1	-0.04	-10.2	0.1
ΔDIN	-1.92	0.12	-3.43	0.02	1.3	0.14	-29.6	1.8
ΔDON	-15.9	0.27	-23.7	-0.51	3.9	-0.28	-44.2	-1.3
ΔTA*	0	-13.3	725.6	-74.6	766.7	-42.1	333.3	49.6
ΔDIC	350.0	-34.2	-62.8	-249.7	483.3	-193.7	100.0	-172.8
ΔDOC#	-10.7	-0.03	-10.0	-0.22	-10.8	-0.02	-13.1	-0.15

* flux is in meq m^{-2} d^{-1}
# flux is in mol m^{-2} d^{-1}

	Average dry season		**Average wet season**		**Annual fluxes (mol m^{-2} yr^{-1})**			
	mmol m^{-2} d^{-1}		mmol m^{-2} d^{-1}		1997		1998	
	Tapi	Bandon	Tapi	Bandon	Tapi	Bandon	Tapi	Bandon
ΔDIP	-0.01	0.0035	-0.29	-0.005	-0.157	-0.004	0.030	0.002
ΔDOP	-0.17	-0.0005	0.02	-0.015	0.096	-0.013	-0.139	0.006
ΔNH_4	-0.79	0.16	-13.0	1.04	-1.662	0.105	-4.126	0.391
ΔNO_3	0.465	-0.03	-3.55	-0.13	0.638	-0.082	-2.017	0.015
ΔDIN	-0.31	0.13	-16.515	0.91	-1.024	0.022	-6.138	0.406
ΔDON	-6.0	-0.005	-33.9	-0.90	-7.473	-0.068	-8.870	-0.320
ΔTA*	383.3	-27.7	529.45	-12.5	155.278	-17.973	187.098	4.257
ΔDIC	416.6	-113.9	18.6	-211.25	39.411	-58.600	94.378	-66.228
ΔDOC#	-10.75	-0.025	-11.55	-0.18	-3.756	-0.052	-4.434	-0.035

* flux is in meq m^{-2} d^{-1}
# flux is in mol m^{-2} d^{-1}

Table 2.3 indicates that most nutrients are trapped in the estuarine section of the Tapi River and in Bandon Bay. In general, DIP is in a steady state within the bay (average value of ΔDIP~0), while DOP is consumed in the system. The dissolved phosphorus source (ΔDIP values are positive) is interpreted to be the result of net organic oxidation and/or desorption from sediments. On the other hand, DIP can also be removed by uptake by phytoplankton and/or adsorption to particles which will later on be buried in the sediments. The Bandon Bay system appears to be very active in consuming dissolved organic phosphorus and generating DIP which, in turn is consumed by phytoplankton at about the same rate, hence ΔDIP ~ 0.

In general, there is a release of NH_4, and uptake of NO_3 within the estuary-bay system. This appears to represent net respiration of organic matter, with nitrification of released NH_4 . Because of the longer water residence time in the dry season (low flow conditions), decomposition of organic matter can take place better than in the high flow condition, where adsorption of phosphate seems to be the dominant process (ΔDIP values are negative).

The removal of DIP and DIN with NH_4 release reflects nitrogen recycling. Some nitrogen and phosphorus were, of course, lost by being bound into refractory organic matter in the sediments (adsorption to particles). By contrast with DIP, the system was a much bigger source of DIN (ΔDIN = 0.02– 1.8 mmol $m^{-2} d^{-1}$) and most of it come from NH_4 .

Removal of DON, DOP and DOC in the system may be due to sedimentation of organic matter since in the coastal zone a large fraction of organic matter falls to the bottom where it is partly accumulated and buried and partly decomposed. Some of the nutrients will be returned to the water column; some will be lost through the internal sinks (denitrification for nitrogen and adsorption for phosphorus).

Stoichiometric calculations of aspects of net system metabolism

The internal sink of nitrogen may be attributed either to denitrification, or to burial of organic matter. Phosphorus may be lost through burial as either organic or adsorbed inorganic P. According to the LOICZ interpretation, nitrogen fixation-denitrification (*nfix-denit*) is given by: ΔN_{obs} - 16xΔP (assumed to be phytoplankton with a Redfield N:P ratio of 16:1) From Table 2.4, Bandon Bay is slightly net nitrifying in 1997 and become slightly net denitrifying in 1998, while the Tapi estuary is strongly net denitrifying system in both 1997 and 1998. The presence of benthic algae on the mud flats, as well as mangrove fringe around the bay, could account for nitrogen fixation in Bandon Bay.

Net ecosystem metabolism (NEM = *p-r*) can be estimated in a similar way, as the negative of the non-conservative DIP flux multiplied by the C:P ratio of the reacting organic matter. Assuming the bulk of the reacting organic matter is phytoplankton, then the C:P ratio is 106:1. Thus:

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

The C:N:P ratio of the particulate materials (terrigenous organic detritus) entering the Tapi River estuary during 1997 survey was found to be 324:27:1 (substantially higher C:P and N:P ratios than Redfield ratio). Using this C:N:P ratio, the new (*p-r*) and (*nfix-denit*) were estimated (Table 2.4). The magnitude of the new (*p-r*) and (*nfix-denit*) in the estuary are different, but not the qualitative conclusion. From the (*p-r*) calculated for the 4 sets of data shown in Table 2.4, Bandon Bay appears to be slightly autotrophic and the Tapi estuary is strongly autotrophic in 1997. However, both systems turn to be net heterotrophic in 1998.

Table 2. 4. Stoichiometric calculations of aspect of net system metabolism for Bandon Bay (flux is in mmol $m^{-2} d^{-1}$).

	April 1997		**October 1997**		**April 1998**		**October 1998**	
	Tapi	Bandon	Tapi	Bandon	Tapi	Bandon	Tapi	Bandon
(p-r)[1]	17.7	-0.7	70.7	2.0	-8.8	-0.2	-9.0	-1.1
Nfix-denit[2]	-12.5	0.3	-25.7	0.7	6.5	-0.1	-67.0	-0.1
(p-r)[3]	54.0	-2.0	216.0	6.1	-27.0	-0.7	-27.0	-3.4
Nfix-denit[4]	-8.8	0.2	-24.8	1.6	7.4	-0.1	-63.0	-1.0

[1] based on particle C:P of 106 ; [2] based on particle N:P of 16
[3] based on particle C:P of 324 ; [4] based on particle N:P of 27

	Average dry season		**Average wet season**		**Annual fluxes ($mol.m^{-2}.yr^{-1}$)**			
					1997		**1998**	
	Tapi	Bandon	Tapi	Bandon	Tapi	Bandon	Tapi	Bandon
(p-r)[1]	4.45	-0.45	30.85	0.45	17.80	0.32	-3.25	-0.27
Nfix-denit[2]	-3	0.1	-46.35	0.3	-7.39	0.20	-13.36	-0.04
(p-r)[3]	13.5	-1.35	94.5	1.35	54.38	1.00	-9.86	-0.83
Nfix-denit[4]	-0.7	0.05	-43.9	0.3	-6.64	0.37	-12.36	-0.23

[1] based on particle C:P of 106 ; [2] based on particle N:P of 16
[3] based on particle C:P of 324 ; [4] based on particle N:P of 27

The overall net production of organic matter by the bay-estuarine ecosystem is the total gross (*p-r*). This net production either accumulates within the system (as sediment accretion) or is exported by tidal action and by movement of large organisms, i.e. birds and nekton.

The net export fluxes from the bay to the Gulf of Thailand are presented in Table 2.5. These fluxes were calculated using LOICZ guidelines as

$$V_R . (C_1 + C_2)/2 + V_x . (C_1 - C_2)$$

where C_1 is the Bay centre concentration, and C_2 is the adjacent seawater concentration.

Table 2. 5. Net export fluxes of C, N and P (kmol/day).

	Apr-97		**Oct-97**		**Apr-98**		**Oct-98**	
	Tapi	**Bandon**	**Tapi**	**Bandon**	**Tapi**	**Bandon**	**Tapi**	**Bandon**
DIP	2.3	5	17.4	9.6	16.2	17.5	7.6	13.5
DOP	3.4	3	37.8	11.2	2.6	2.4	17.2	33.7
DIN	54	114.2	722.1	733.2	359.4	428.2	973.2	1849.3
NH_4	19	88.0	354.0	543.2	253.7	339.6	746	1577.7
NO_3	35.8	26.9	368.0	190.4	106.8	89.6	227.2	271.6
DON	17	150.0	457.3	217.8	827.0	693.0	1,183.6	586.2
TA	7.2	0.8	66.6	30.8	53.4	33.2	18.4	42.2
DIC	7.2	(9.2)	5.0	(114.8)	26.6	(66.4)	20.4	(62.6)
DOC	0.6	6.9	101.1	44.8	18.2	27.8	41.7	16.5

*Note: ( ) = import

	Average dry season		Average wet season		Annual fluxes (x 10^6 mol.year^{-1})			
	kmol.day^{-1}		kmol.day^{-1}		1997		1998	
	Tapi	Bandon	Tapi	Bandon	Tapi	Bandon	Tapi	Bandon
DIP	9.2	11.2	12.5	11.5	4.1	2.8	4.1	5.5
DOP	3.0	2.7	27.5	22.4	8.6	2.8	4.1	7.6
DIN	206.7	271.2	847.6	1,291.2	162.7	174.1	262.5	460.4
NH4	136.3	213.8	550.0	1,060.4	78.6	129.5	197.9	388.9
NO3	71.3	58.25	297.6	231.0	84.2	44.8	64.7	71.6
DON	422.0	421.5	820.4	402.0	100.4	69.3	378.2	230.1
TA	30.3	17.0	42.5	36.5	15.3	6.7	12.0	14.0
DIC	16.9	(37.8)	12.7	(88.7)	2.2	(26.0)	8.4	(23.4)
DOC	9.4	17.3	71.4	30.6	21.7	10.6	11.7	7.7

*Note: ( ) = import

Comparison was made between flux estimates with and without wastewater input (Table 2.6) and between the one- and two-box models (Table 2.7). When waste flux was included in the budget calculation, it is evident that waste is the major source of organic carbon to the estuary-bay system, and that most of it remains trapped in sediments, hence none of the organic carbon is exported to the coastal waters in the dissolved form. The two-box model clearly shows that most of the organic matter (DOC, DON and DOP) remains trapped in the estuarine section of the Tapi River.

Table 2.6. Comparison of C, N and P flux estimates (mmol m^{-2} d^{-1}) with and without wastewater flux (one-box model).

	April 1997		October 1997		April 1998	
	No waste input	With waste input	No waste input	With waste input	No waste input	With waste input
ΔDIP	0.005	0.001	-0.025	-0.028	0.003	0
ΔDOP	0.001	-0.004	-0.04	-0.04	-0.001	-0.004
ΔNH_4	0.10	0.08	0.25	0.23	0.18	0.16
ΔNO_3	-0.01	-0.02	-0.25	-0.26	-0.005	-0.01
ΔDIN	0.09	0.06	0	-0.03	0.175	0.15
ΔDON	-0.09	-0.13	-1.04	-1.08	-0.17	-0.21
ΔTA*	-12.3	-12.30	-38.0	-38.0	-23.9	-23.9
ΔDIC	-22.3	-22.30	-241.8	-241.8	-1.0	-1.0
ΔDOC	10.6	-256.07	4.7	-297.4	38.3	-238.0

* flux is in meq m^{-2} d^{-1}

Table 2.7. Comparison of C, N and P flux estimates (mmol m^{-2} d^{-1}) using the one- and two-box models (with waste flux).

	April 1997		October 1997		April 1998	
	1-box	2-box	1-box	2-box	1-box	2-box
ΔDIP	0.001	0.005	-0.03	-0.02	0	0.002
ΔDOP	-0.004	0	-0.04	-0.06	-0.004	-0.001
ΔNH_4	0.08	0.14	0.23	0.39	0.16	0.18
ΔNO_3	-0.02	-0.02	-0.26	-0.37	-0.01	-0.04
ΔDIN	0.06	0.12	-0.03	0.02	0.15	0.14
ΔDON	-0.13	0.27	-1.1	-0.51	-0.21	-0.28
ΔTA*	-12.30	-13.3	-38.0	-74.6	-23.9	-42.1
ΔDIC	-22.30	-34.2	-241.8	-249.7	-1.0	-193.7
ΔDOC	-256.07	-29.3	-297.4	-216.4	-238.0	-22.5

* flux is in meq m^{-2} d^{-1}

2.3 Time series measurements of estuarine material fluxes

Water and material exchanges between the Tapi River estuary and Bandon Bay were also calculated for the major tidal river cross-section of the Tapi estuarine system from our hydrographic tidal cycle measurements. These daily material fluxes were calculated by multiplying velocity (measured by a current meter at three depths), cross-sectional area, and concentration at hourly intervals (Kjerfve and McKellar 1980) for four tidal cycles in 1997-1998. Lateral homogeneity was assumed since only one station was sampled. Two sets of observations, taken in the Tapi River estuary during 1997 corresponding to a period of dry (April) to high (October) river flow, are presented here. Results of nutrient flux estimations are presented in Table 2.7.

Table 2.8 Net constituent fluxes (kg/day) from the Tapi estuary. Positive values are exports, negative imports.

Net flux	April 1997	October 1997
Water (m^3/day)	-2.71×10^6	-8.46×10^5
Salt (Kg/day)	$+2.86 \times 10^7$	$+1.93 \times 10^7$
Ammonia	-841.38	+165.51
Nitrate plus nitrite	-447.81	-302.81
DIN	-1.29×10^3	-1.38×10^2
DON	-760	no data
DIP	-36.4	+62.3
DOP	-192	-159
DOC	-58.82	+264.7
Silicate	-2.95×10^3	$+7.82 \times 10^3$
Part. Phosphorus	-74.2	+379
Part. Nitrogen	-2.22×10^4	No data
Part. Carbon	-544.32	No data
Suspended sediments	-2.42×10^6	$+5.84 \times 10^5$

Dissolved and particulate nutrients were imported with flooding water as it traverses the mudflats in Bandon Bay and into the Tapi estuary during the dry season. However, in the wet season dissolved ammonia, phosphate and silicate were exported to coastal waters. Import of nutrients, particularly nitrate and nitrite, is probably due to denitrification occurring in the anaerobic mudflats in Bandon Bay, which was found to occur during the dry season (Wattayakorn *et al.* 1998). This phenomenon was also found in the Rhode River (Jordan *et al.* 1983). Some of these nutrients (i.e. phosphate and ammonium) may be released from pore water by either diffusion or seepage (Nixon 1980). Ammonium in sediment is readily exchangeable with other cations, so the high concentrations of sodium in saline soils tend to swamp the cation exchange sites, displacing NH_4. The ion is readily mobile and susceptible to being leached by heavy rain or flowing seawater. These nutrients were imported with flooding water as it traverses the mudflats in Bandon Bay, into the Tapi estuary during the dry season. Conversely, substantial freshwater input of nutrients may result in tidal export of ammonia, phosphate and silicate in the wet season.

2.4 Mixing diagrams

It is technically difficult and very costly to attempt to measure the flux of mass through a given cross-section of an estuary. In addition, nutrients may not behave conservatively within the estuary. Particular nutrient forms may be gained or lost by chemical reactions, by biological uptake or metabolic activity and/or adsorption on or desorption from suspended matter. Estuarine scientists have sometimes attempted to avoid the mass-balance problems in estuarine nutrient dynamic studies by relating non-conservative parameters to salinity or chlorinity. In the absence of biogeochemical processes occurring within an estuary or export to the atmosphere, the composition of a particular element within that estuary will be a linear function of its concentration in the river and the ocean. Chloride (or salinity) is the usual reference or conservative property upon which variations of other elements are measured (Liss 1976).

Nutrient data from the Tapi estuary were analyzed using a conservative mixing model to assess nutrient distribution and variability during the dry and wet season of 1997. The study shows that most nutrients behaved in a non-conservative manner during estuarine mixing (Figure 2.6). Variation of ammonia with salinity suggests the presence of an internal source of ammonia in the estuary. This could be a result of decomposition of organic matter within the system. Other sources, such as regeneration from sediments or the result of discharges from food processing plants and municipal wastes are also possible.

Mixing curves of nitrate (nitrate means sum of nitrate-N and nitrite-N) in the dry season showed that nitrate is removed from the water column at low salinity. This removal is generally takes as immobilization of nitrate by other geochemical processes (i.e. adsorption onto solid particles and thus removal of nitrate from the soluble phase). In the wet season, nitrate showed an increase in concentration followed by a gradual decrease downstream. The estuary, therefore, acts as a sink for nitrate in the dry season and as a source in the wet season.

Phosphate concentration in the estuary increased at low salinity region but gradually decreased towards the mouth during the dry season. The increase is probably due to either high input of phosphate from sewage, or desorption of phosphate during resuspension of sediments during early estuarine mixing. The removal of phosphate towards the mouth is probably due to uptake by phytoplankton. Mixing curve of phosphate in the wet season shows a distinct lack of variation. This behaviour is strongly indicative of buffering mechanism, as reported in Columbia River estuary by Steffansson and Richards (1963).

Mixing curves of silicate showed similar patterns to those of nitrate for both seasons, indicating that the system acts as a sink in the dry season and a source in the wet season. Utilization of nutrients by diatom growth is usually restricted by high turbidity. However the mixing diagram indicates biological uptake of silicate in the dry season.

2.5 Discussion

The LOICZ guidelines for constructing nutrient budgets assume an estuary or embayment which is well-mixed, both vertically and horizontally, and at steady-state. Errors might be incurred in neglecting spatial and temporal variation, as well as in treating an estuary with a two-layer circulation (particularly in the wet season) as a single box system. However, the technique is simple for assessing the biogeochemical function of estuaries including denitrification and nutrient retention rates. In estimating the C, N and P fluxes, it is not necessary to investigate all of these materials. Normally, P will be the usual parameter to be investigated, and it is often sufficient to make a detailed study of the P budget and calculate the others from their stoichiometric relationships to P. The mathematics involved is relatively straightforward and the method has been shown to give good results in a number of habitats, including our Bandon Bay system.

The mouth cross-section computation method of Kjerfve and McKellar (1980) was used to determine the discharge over each tidal cycle; these data were then used to calculate the volume of water at any time over the tidal cycle. By subtracting the volumes of water across the mouth of the estuary at successive time intervals, volume discharge was determined. Nutrient flux was then computed. Since most of the material in solution or suspension probably sloshes back and forth through the tidal channel, on average only a small fraction of the maximum instantaneous flux is likely to be added or lost from the system. Thus, it is difficult to determine net transport direction with any certainty. Furthermore, it is assumed that the variability of the cross-sectional concentrations is minimal, so that the one water sample can be used to represent the cross-sectional concentration. That will no doubt limit this technique to well-mixed estuaries. Hence, flux estimation for the dry season better fits with the other two approaches than does that of the wet season.

The mixing diagram approach has been used by estuarine chemists to characterize behaviour of an element along the estuarine salinity gradient, using salinity as a mixing index. Deviations of the parameters from linearity indicate non-conservative behavior in that there is a net loss or gain in the estuary. Although the approach appears straightforward, in many cases it has proved difficult to apply, and to interpret the results obtained. These curves do not provide insight into dynamic estuarine processes which may be occurring. A linear response of a nutrient along the salinity gradient does not necessarily mean that the substance is not participating in biogeochemical processes within the system; it means only that losses and gains are balanced and the estuary is in a steady-state with respect to that particular substance. However, the technique is also very easy to carry out and give some information which characterizes the role of the coastal zone as a source or sink for C, N and P.

Our studies have shown that the three approaches give similar results on fluxes of nutrients imported or exported in the Bandon Bay system, though not totally so. Some discrepancies obtained from the various methods are probably due to the difficulty in assessment of magnitudes and directions of net material transport between estuaries and the coastal ocean with large tidal variability. The ability to determine the flux of the medium containing the nutrients of interest, including spatial and temporal variability, sets the lower limit on the accuracy of the nutrient flux calculations. In addition, a properly preserved, adequate number of water samples must be taken so that the spatial and temporal variability with respect to nutrient concentrations is well documented. The difficulties outlined above, coupled with the inherent variability of results from estuaries, in common with most environmental data, mean that there is a limit to the sensitivity of each approach. In general, the dry season results are more comparable between the different approaches adopted than the wet season condition.

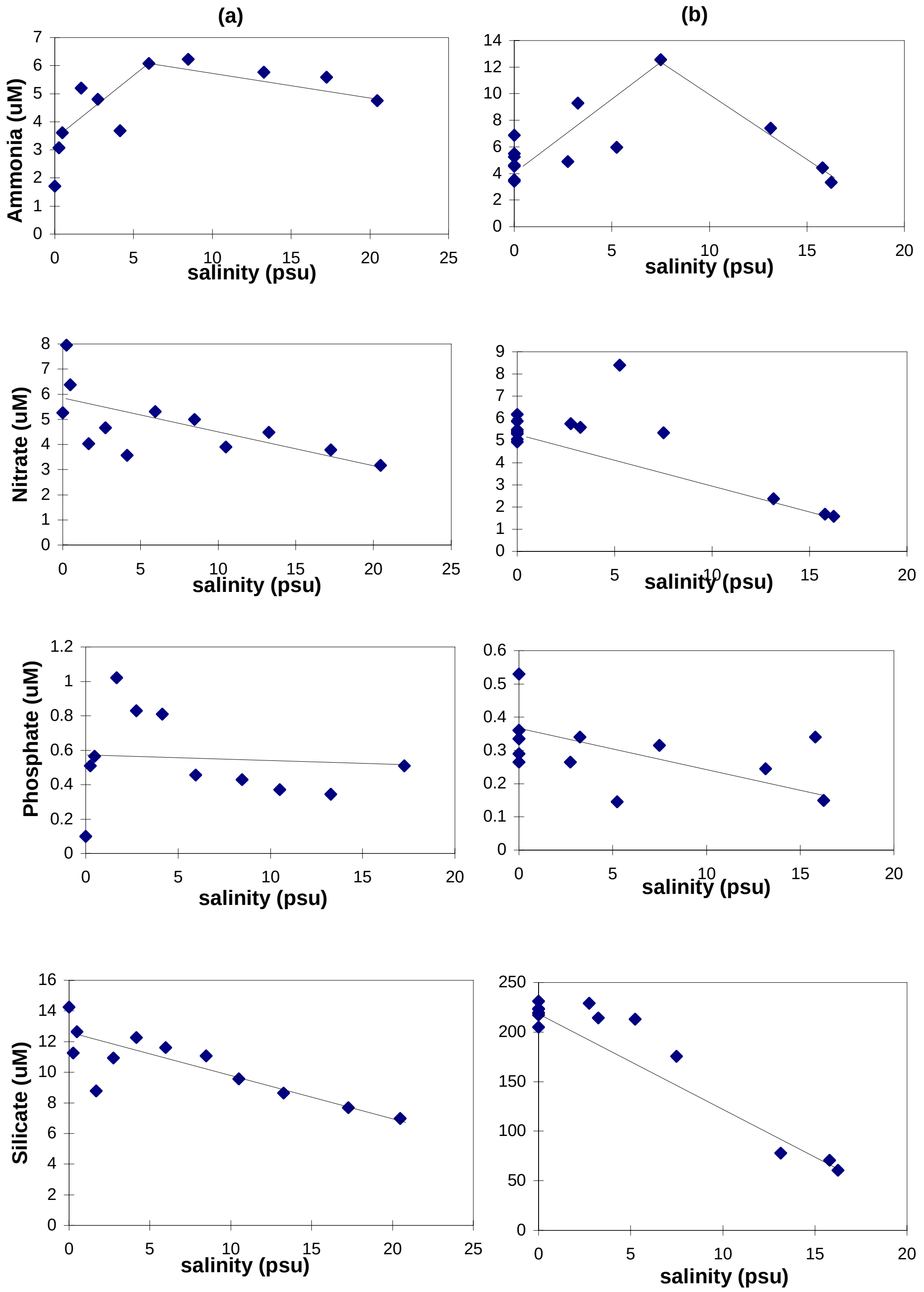

Figure 2.6 Relationship between dissolved nutrients and salinity (a) dry season (b) wet season.

3 PRODUCTION OF ORGANIC CARBON AND FISHERY PRODUCTION

Bandon Bay is one of the most productive coastal ecosystems in Thailand, with mangrove forest along the shoreline and the Tapi riverine system. Offshore to the bay are coral reef and seagrass communities. The bay also offers various types of habitat for economically important fishes and marine invertebrates such as clams and oysters. This makes the bay a suitable place for aquaculture activities. However, heavy utilization of both living and non-living resources due to urban and agricultural activities is now threatening the ecosystem and the socio-economics of Bandon Bay. Thus, it is important to understand the nature of the bay as well as the interaction and responses of both biotic and abiotic components of the economic development of the area in order to maintain the ecological and economical importance of Bandon Bay. This part of the project aims to elucidate the trophic relationships among the living inhabitants of the bay as well as to examine the response of these components to the changes in abiotic components of the system.

Nutrients and dissolved organic compounds from river runoff and various anthropogenic sources are incorporated into primary producer, phytoplankton, along the Tapi River estuary and in Bandon Bay. The assessment of this assimilation process was reported in term of primary production calculated from the relationship between primary production and chlorophyll_a biomass proposed by Shemshura *et al.* (1991) and the assumed season day of 270 days (Cushing 1969). The composition and abundance of the pelagic organisms in the bay as well as the standing crop of primary producer was investigated for three separate time periods during 1997-1998. Study of the plankton community was conducted by mean of net samplings. Quantitative measurement of extractable chlorophyll_a was performed based on the spectrophotometric method of Parson *et al.* (1984). Carbon production by phytoplankton was estimated from the chlorophyll biomass using the equation proposed by Shemshura *et al.* (1991) and fishery production was calculated based on the modification equation of Nixon (1988). Secondary data on the biotic components of both pelagic and benthic environments were also included to derive the conceptual model of trophic relationship among the organisms in the bay ecosystem.

Biomass of chlorophyll_a was measured directly in April and October 1997 and April 1998. Areal primary production was calculated from the conversion ratio of 9 between carbon and wet weight. In 1997, production was higher in rainy season (October 1997) than in the dry season (Table 3.1). Primary production in Bandon Bay reported from this study, 0.30 - 0.66 g C m^{-2} d^{-1}, was lower than those of 2.05 to 6.49 g C m^{-2} d^{-1} in Chong Arg tong and upper west of the Gulf of Thailand during 1968-1984 (Lursinsarp 1980; Lursinsarp 1983; Lursinsarp 1987; Lursinsarp and Thochalee 1985). This discrepancy is due to the offshore nature and the greater depths (more than 20 metres) of those areas in comparison to Bandon Bay.

Production of primary producer is then transferred to organisms in higher trophic levels via the grazing food chain. Thus, fishery production in this area is supported by carbon production of phytoplankton. Fishery production (Table 3.2) is estimated from primary production based on the relationship proposed by Nixon (1988) and modified by S.V. Smith and W. Boynton (Smith, personal communication), using a regression equation. Detrital materials derived from non-consumed primary production and decaying matter from flora and fauna in the bay are also calculated based on Pauly *et al.* (1993).

The estimated fish production from this study is comparable to the demersal fish catch of 319 ton yr^{-1} in 1993 (Department of Fisheries 1993) since annual fish catch is usually less than total standing stock and the production calculated here includes pelagic fishes as well.

Table 3.1 Primary production in the Tapi River estuary and in Bandon Bay during 1997-1998.

Area	Period of study	Primary production (gC m^{-2} yr^{-1})	Areal production (ton ww yr^{-1})
Tapi estuary	April 1997	114	491,776
	October 1997	164	708,554
	April 1998	93	402,955
Bandon Bay	April 1997	81	351,238
	October 1997	178	770,747
	April 1998	174	751,683

Table 3.2 Fishery production and detrital biomass derived from phytoplankton production.

Area	Period of study	Fishery production (ton ww yr^{-1})	Detrital biomass (ton C yr^{-1})
Tapi estuary	April 1997	758	397
	October 1997	1360	462
	April 1998	551	366
Bandon Bay	April 1997	443	346
	October 1997	1556	479
	April 1998	1495	474

As well as the grazing food chain (Figure 3.1) starting with primary production from pelagic producers, the detrital food chain is also of ecological importance in this area. Phytodetritus and detrital materials from pelagic animals, and litter falls from mangrove forest along the shoreline all form an important food source for the benthic community in the Tapi River estuary and in Bandon Bay.

Plankton Communities in Bandon Bay

Biomass of chlorophyll_a was measured directly in April and October 1997 and April 1998. Total chlorophyll_a biomass was minimized, 2.27 mg m^{-3}, in fresh water area in October 1997 while the maximum chlorophyll content of 14.23 mg.m^{-3} was found in the estuary in the same month. Most of the chlorophyll_a content found in Bandon Bay and the adjacent estuary and freshwater region was in fractions smaller than 20 microns. This result indicates the important role of pico- and nanoplankton as major producers in the pelagic food web. Among the microphytoplankton studied, diatoms dominated the population of net phytoplankton in the bay for the whole study period, while chlorophytes dominated in the freshwater region. In the estuary, the major component of primary producer varied. Chlorophytes, diatoms and dinoflagellates were found in higher densities than other phytoplankton in both the dry season and the wet season of 1997. In April 1998, the dominant phytoplankton group in the estuary was diatoms.

Copepods formed the dominant group of zooplankton in Bandon Bay with a density of more than 30,000.00 ind.m^{-3}. The second most abundant zooplankton in this area was the nauplius larvae of crustaceans. Mollusc larvae and decapod larvae were found in abundance in the bay area but not in freshwater or the estuary. The holoplanktonic hemichordates and arrow worms are the true inhabitants of the marine waters, since they are always found in greater abundance in the bay than in the estuary or the freshwater region.

Discussion

Primary production and fish production estimated for Bandon Bay are not very high in comparison with other coastal ecosystems in the region. This is due to the topographic nature of the bay - the average depth is only 2.9 m. Fishery statistics indicate over-fishing and decline in capture fishery in parallel with the decline in mangrove coverage. Pollution from excess waste and chemical compounds may also affect the fishery production in the area. However, the production of cultured oysters in the bay tends to increase with the increase in shrimp-farming area.

The changes in carbon and nutrient loading are the major processes in understanding the dynamics of the ecosystem and the socio-economy of Bandon Bay. The depletion of mangrove decreases nutrient input in the form of litter falls into the bay system, but on the other hand, nutrient loading from domestic, agricultural and aquacultural activities can promote fishery production of oysters and clams in the bay. The problem of whether the increase in carbon and nutrient concentrations is supporting or trampling the system production and socio-economy depends on the carrying capacity of the bay which has not yet been fully investigated.

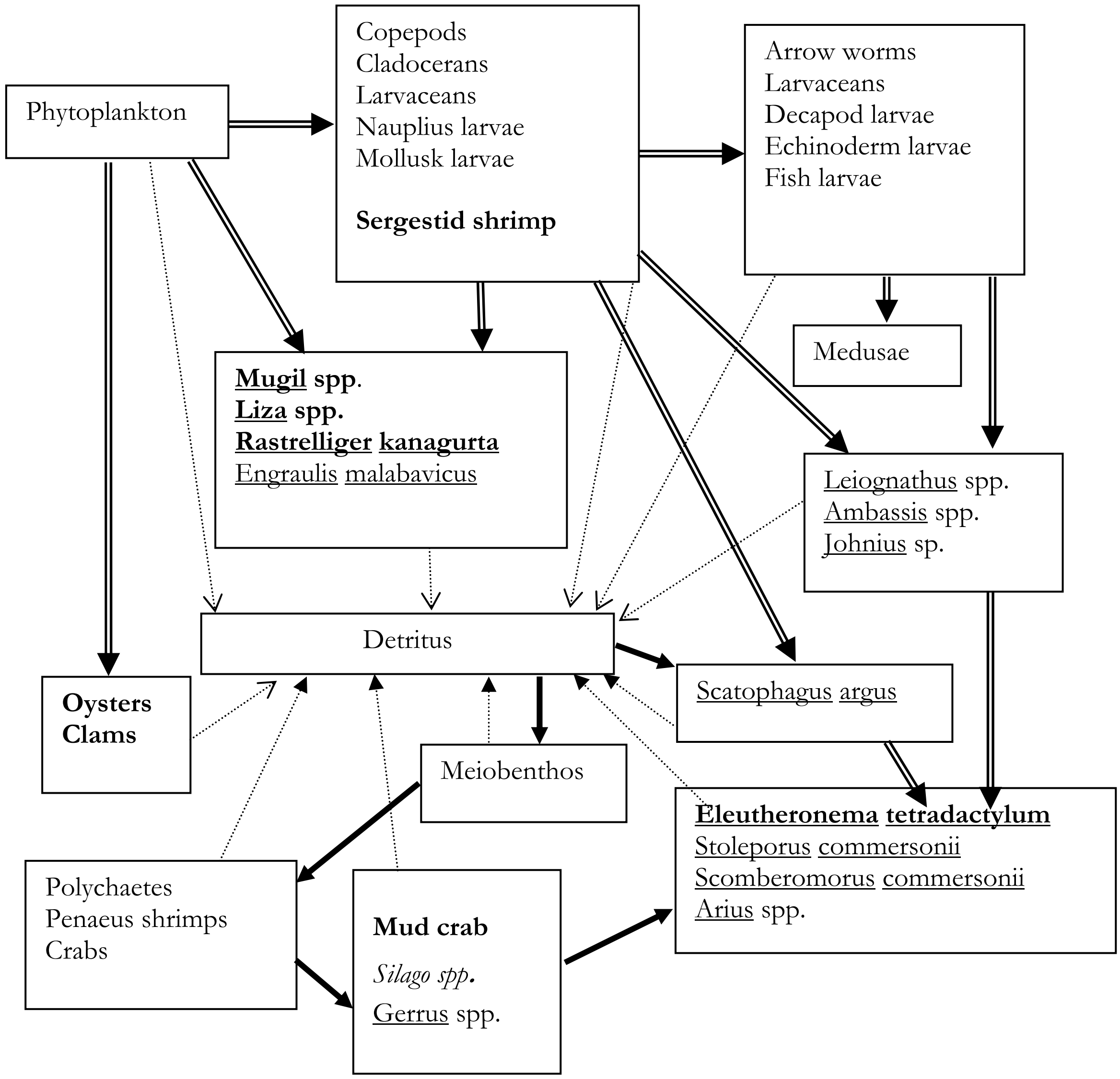

Figure 3.1 Trophic relationship in Bandon Bay ecosystem.
(Heavy letters denote commercial species)

4. ECONOMIC ACTIVITIES AND PROCESSES

4.1 Economic Profile

4.1.1 Shrimp Farming

The area of Suratthani province that borders on Bandon Bay has seen the most rapid changes over the last 30 years. The area was extensively converted from mangrove forests to shrimp farms, between 1973 when the mangrove area was 5,059 ha to 2,332 ha in 1993, and by 1998 the area of mangrove was 1,607. According to DOF source, the area under shrimp farm in 1993 was 8,666 ha, of which 42% was under intensive shrimp culture, while the remaining 40% was under extensive and 17% semi-intensive methods. However, there was a gradual movement toward intensive methods and now more than half of the shrimp farms are intensive.

The economic and financial return to intensive shrimp farming is shown in Table 4.1

In terms of financial return, a net profit of 18,327 Baht per crop can be earned from 1 rai of shrimp farm (6.25 rai equals 1 hectare), based on a total cost of 101,967 Baht, or a gross receipt of 120,294 Baht, which gives a profit rate of 18% over cost. Thus, shrimp farming becomes an attractive investment financially and attracted a lot of investors to take up shrimp farming especially in mangrove areas where access to seawater is possible at low cost. In terms of value added, namely the value net of material inputs used in the activity, but includes labour cost, profit and taxes, intensive shrimp farming produces 44,372 Baht per rai per crop.

Assuming that two crops of shrimps can be grown in one year, the value added from shrimp farming is 88,744 Baht per rai per year , or about 567 USD (at 25 Baht per USD in 1993 prices). Focussing only on the farming of black tiger prawns, the value added from the activity for the year 1993 was 1,006.2 million Baht.

4.1.2 Mariculture

The Bandon Bay area is a productive area for oysters and clams. The estuarine area is put under a concession system in which farmers have to rent land from the provincial authorities to farm the shellfish. There is an organized cooperative of shellfish farmers, which represents a large part of the farmers in the Bandon Bay area.

The financial returns to farming of oysters and clams are shown in Tables 4.2 and 4.3.

On a per rai basis, the financial return to oyster farming is 163,710 Baht per rai, and value added is 166,110 Baht per rai. This is due to the high price of oysters, which are sold in pieces.

The financial return for clam is 11,910 Baht per rai, and value added is 13,310 Baht per rai. Taking the areas of oyster and clam farming to be 7,300 and 34,000 rais respectively, the total value added from oyster and clam farming is estimated at 1,212 and 452 million Baht, or 1,665.1 million Baht in total.

Table 4.1 Cost structure of shrimp-farming

Shrimp cost-1990 per rai per crop (Midas,1995)			
Item	Cash	Non-cash	Total
Young shrimp	9,587		9,587
Feed	49,914		49,914
Gasoline,oil and electricity	7,993		7,993
Pond clearing, reparing pond and machine	6,245		6,245
Family labour		3,602	3,602
Hired labour	3,294		3,294
Others	2,183		2,183
Total variable cost	79,216	3,602	82,818
Land tax and land rent	832		832
Interest expense	3,639		3,639
Opportunity cost of land		5,301	5,301
Depreciation		9,377	9,377
Total fixed cost	4,471	14,678	19,149
Total cost	83,687	18,280	101,967
Yield per rai (kg)			957.92
Farm price (Baht/kg)			125.58
Value of production (Baht/rai)			120,294.30
Net income per rai			18,327.32
Value added analysis			
Material inputs:			
Young shrimp	9,587		9,587
Feed	49,914		49,914
Gasoline,oil and electricity	7,993		7,993
Pond clearing, reparing pond and machine	6,245		6,245
Others	2,183		2,183
Total material costs	75,922	0	75,922
Value added (Baht/rai)			44,372.32
Share of value added in gross output			36.89%
Value added per kg of shrimp			46.32

Source: cost data from Midas(1995): Volume 3, Annex 9, table 1.4.10
Yield and price data from Statistics of Shrimp Culture 1993, Fishery Department, (1995)

4.1.3 Fishery

Capture fishery is practiced in Bandon Bay by fishermen using pushnets. A study of catch per unit effort was conducted in 1988. The result of the study shows that the CPUE was 316 kg/boat/day. The catch consists of shrimps and crabs, accounting for 38% by weight, while the remaining 62% is trash fish. (Lohsawatdikul and Eiamsaard, 1991).

Table 4.2 Total value of oyster culture in the Bandon Bay area

Type of Culture Activity	Oysters				
	Unit	Quantity	Unit price	Total	Per rai
Area of culture (rai)	Rai	20			
Cost					
Bamboo fence	Stems	200	9	1,800	90
PVC pipe, cement block	Pieces/rai	4,000	25	2,000,000	
Plot preparation	Baht/piece	4,000	8	640,000	32,000
Fuel for boat	Month	12	3,000	36,000	1,800
Guarding labour	Month	12	4,000	48,000	2,400
Total Cost				2,725,800	136,290
Yield	Pieces/pole	8		600,000	30,000
Price per piece	Baht/piece	10			
Gross income				6,000,000	300,000
Net Profit				3,274,200	163,710
Rate of return over cost				120.12%	120.12%
Total value added					166,110
Total area of culture(rai)		7,300			
Total value added (million Baht)				1,212.60	
Weight of oyster (pieces per kg)					7
Value per kg of oyster					70
Value added per kg of oyster					38.75
Total values from aquaculture				1,617.54	
% Value added of oyster					55.37%

4.1.4 Mangrove Utilization

A study of mangrove utilization was reported in 1998, based on fieldwork conducted in 1996-1997 (Sathirathai, 1997). The study finds that local people collect products from the mangrove area, ranging from fish, crab and shrimp, to honey as well as the wood for domestic uses. The mean value of the mangrove use by the local people is 36,984 Baht per household. For the village studied, which has a rather degraded mangrove forest, the mean value per rai of mangrove was 562 Baht/rai, compared to a typical value of mangrove forest with charcoal production of 4,237.16 Baht/rai. The degraded mangrove was a result of shrimp farming on the coastal strip, which blocked the tidal flow of the seawater to the mangrove area.

The mangrove bordering the Bandon Bay also plays an important role in supplying the bay with nutrients. This aspect of mangrove use and the impact of mangrove forest loss will be discussed in later section.

Table 4.3 Total value of clam culture in the Bandon Bay area.

		Clams			Per rai
Type of Culture Activity	**Unit**	**Quantity**	**Unit price**	**Total**	
Area of culture(rai)	rai	20			
Cost					
bamboo fence	stems	200	9	1,800	90
Seedlings (200/kg)	ton/rai	1	15,000	300,000	15,000
sowing labour	Baht/ton	1	400	8,000	400
Fuel for boat	month	8	3,000	24,000	1,200
Guarding labour	month	8	3,500	28,000	1,400
Total Cost				361,800	18,090
Yield per rai (kg)	kg	4,000		80,000	4,000
Price per Kg	Baht/kg	7.5			
Gross income				600,000	30,000
Net Income				238,200	11,910
Rate of return over cost				65.84%	65.84%
Total area of culture(rai)		34,000			
Total value added (million Baht)				404.94	

4.1.5 Industrial development and urbanization

Suratthani province which is located upstream to the Bandon Bay is a small urban centre which is growing rapidly. In 1997, the urban centre already has a population of 107,888. In addition, the districts surrounding the bay and upstream altogether account for a population of 711,435. The major industries in the area are agriculture with rubber and oil palm are the main crops. Rubber is processed into rubber sheets and blocks for exports, and some products are also made. The rubber wood is used to support a local wood processing plant, which produces wood chip and particleboard for export. Oil palm is grown in upland areas and is used to produce crude palm oil, which is then exported to Bangkok for further refining. There is also small-scale industries serving the local population.

4.1.6 Tourism and other services

The major service industry of Suratthani is the tourism industry, due to the location of Koh Samui, which has been developed into an internationally known beach resort, attracting nearly 700,000 visitors a year. Little of this traffic remain in the Suratthani town, however, as the tourists are furried across the sea to the island as soon as they arrive.

4.2 Integrated modelling of Bandon Bay

4.2.1 Approach to modelling economy and ecology interaction

The approach for modeling the linkage between economy and ecology of Bandon Bay is based on de Kok (1998). This approach views the link in the form of flows of materials between the two systems. The economy takes nutrients from the ecosystem for producing goods, and in exchange the economy discharges wastes into the ecosystem.

The main links in the Bandon Bay area are:

- Uptake of nutrients:
  Oyster and clam production takes up the nutrients from the bay
  Fishery also removes nutrients from the bay.
  Conversion of mangrove to shrimp farms removes nutrient supply from the bay.
- Input of nutrients:
  Mangrove forest provides nutrients to the bay.
  Economic activities, including shrimp farms, discharge waste into the bay.

The value of nutrients in the bay can be estimated from the value of goods produced. In this analysis, we use the value of oyster as a proxy for the value of a ton of carbon.

4.2.2 Construction of I/O model

Construction of the Input-Output table for 1997
We ran the input-output model and integrated the emission data, based on previous studies and WHO (1993), for the economic activities into the input-output tables.

The basic data for the input-output table is obtained from the NESDB IO table for 1990. This is a 180x180 sector table for the whole country. The table is modified to reflect the sectors present in Suratthani, by means of matching with secondary data pertaining to specific economic activities. The industries are then grouped into sectors for analysis. For each sector, the column percentage is calculated, giving the input structure for the sector.

The derived input structure is applied to the value-added for the sector, in order to obtain the flow values for the transaction table. By matching the row sum and the column sum, the value of the final demand vector is obtained.

The IO table can be used to estimate the value of gross output by sector.
For the present study, the estimate of gross output is prepared using the projected final demand and the Leontief inverse. The IO table and the projected gross output estimates are shown in Table 4.4

4.2.3 Estimation of emission coefficients

The approach to estimating the emission coefficient is a mixed strategy. In principle, emission can be measured directly at the same time as production, and the coefficients can then be directly calculated. However, for the IO table, there are certain limitations: the production data are aggregated over different sectors, and are in monetary units, not physical. Thus there is the problem of conversion and aggregation over many industries and products to derive the emission for each sector.

Available data are obtained from various studies, which are reported in different units. These have been converted to emission per monetary units.

Using these output and emission coefficients, it is possible to estimate the value of total emission for a one year period corresponding to the rate of production of goods. The result of the analysis is shown in Table 4.5.

4.2.4 Estimation of carbon utilization

In this section, we focus on identifying the value of carbon in the Bandon Bay area, as set out in the approach toward integrating the biogeochemical with the socioeconomic analyses applied to Bandon Bay area. The LOICZ project began with the question of how much is the contribution of anthropogenic discharges to the stock of nutrients in Bandon Bay. We look at this question by estimating the flow of BOD from economic activities using the input-output table method. The result shows that the flow of organic carbon contained in BOD is estimated to be 10,642 ton Carbon per year (Table 4.6.1)

Shrimp farm wastes are considered to be a source of pollution. According to the estimate of the total shrimp farm waste from around Bandon Bay, the amount is 3,189 ton C/year (Table 4.6.2)

Anthropogenic emissions can be compared to natural discharges. One natural source of discharges is mangrove forest. This produces a steady flow of nutrients in the form of leaf fall and detrital matters to the water. The total amount of TOC from mangrove around Bandon Bay is estimated to be 19,006 ton C/year (Table 4.6.3).

The nutrient inputs contribute to the primary production in the bay area. It has been estimated elsewhere in the study that primary production in the bay area is 144 ton C/km^2. Based on this value, the total primary production, in terms of the standing stock of plankton biomass, in the bay area is 69,120 ton C.

A question may be raised at this point about the relationship between land-based nutrient inputs and primary production. Our approach is as follows:

We first assume that the nutrients which are important to primary production are N and P. These are used to produce phytoplankton. However, since there is a relationship between C, N and P, the amount of carbon associated with the primary production can be estimated. This amount of carbon can then be compared with the carbon that is contained in the nutrient inputs. Based on this estimation, the proportion of annual anthropogenic carbon input to the primary production is about 15% of the total primary production in the bay area (Table 4.6.5).

Table 4.4 Input Output table, final demand and gross output estimate for Suratthani, 1997.

Description	GPP or VA(97)	Share of Final Demand (90)	Final Demand from GPP(97)	Inverse(I-A)										Gross Output (97)
Agricutlture	14,901,911	0.27	9,674,151	1.07	0.02	0.16	0.29	0.00	0.05	0.00	0.07	0.04	0.01	12,182,218
Fishery	1,317,175	0.04	1,454,073	0.01	1.02	0.09	0.00	0.00	0.00	0.00	0.03	0.00	0.00	2,246,337
Manuf. I	2,561,235	0.19	6,812,666	0.00	0.00	1.14	0.01	0.00	0.01	0.00	0.07	0.00	0.00	8,101,072
Manuf. II	281,813	0.02	839,054	0.02	0.06	0.02	1.04	0.00	0.14	0.01	0.04	0.13	0.01	2,231,265
Utilities	858,550	0.02	572,600	0.00	0.00	0.01	0.01	1.10	0.01	0.01	0.03	0.01	0.02	1,035,234
Construction	2,436,322	0.10	3,682,094	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.01	3,774,140
Trade	4,073,446	0.08	2,755,145	0.04	0.04	0.09	0.04	0.01	0.07	1.01	0.09	0.03	0.02	4,619,934
RestHotel	2,620,224	0.09	3,372,740	0.00	0.00	0.01	0.00	0.00	0.01	0.02	1.01	0.01	0.01	3,581,947
TransCom	2,615,589	0.05	1,851,215	0.01	0.01	0.03	0.03	0.02	0.06	0.02	0.02	1.05	0.01	2,671,751
Other services	3,996,782	0.13	4,649,309	0.02	0.02	0.03	0.02	0.02	0.03	0.09	0.03	0.03	1.03	5,745,697
Total	35,663,047	1.00	35,663,047											46,189,593

Table 4.5 Estimation of emission.

Sector	Output (VA - based)	Coefficient	Total discharge	
	mB	ton/mB	ton/year	%share (total human=100)
Agriculture	12,182	0.1075	1,309.7	20.92%
Fishery	2,246	0.0537	120.7	1.93%
Manufacturing I	8,101	0.2150	1,741.8	27.82%
Manufacturing II	2,231	0.1075	239.8	3.83%
Utilities	1,035	0.2150	222.5	3.56%
Construction	3,774	0.1075	405.7	6.48%
Trade	4,620	0.0708	327.5	5.23%
RestHotel	3,582	0.0708	253.9	4.06%
TransCom	2,672	0.1075	287.2	4.59%
Other services	5,746	0.0708	407.3	6.51%
Total from production			**5316.5**	**84.92%**
Domestic household	679672	0.0013	943.8	15.08%
Total from Human activity			**6,260.4**	**100.00%**

We turn now to the use of primary production in the bay area. As described earlier, a major economic activity in the Bandon Bay is shellfish culture, particularly of oysters and clams. The primary production on the bay's ecosystem supports this activity. The economic value of oyster culture provides a measure of the value of carbon in the bay's ecosystem. According to the biological study component, the conversion from primary production to fishery production in the bay area occurs at the rate of 0.84%, based on total primary production of 69,120 ton Carbon and fishery production of 582 ton Carbon. This estimate is used to obtain the estimate of the value of carbon required to support 1 kg of oyster, namely approximately 6 kg of TOC. Since we also have the estimate of the value added of 1 kg of oysters, the value of 1 kg of carbon in primary production can be calculated to be 6,530 Baht (Table 4.6.2).

Table 4.6 The Value Flows of Carbon in Bandon Bay.

4.6.1	**Emission from Anthopogenic Sources**			
	Value added from Suratthani Economy in 1997	mB	35,663	
	Total emission of BOD	Ton/yr	6,260	
	Total carbon emission from BOD (1.7 factor)	Ton C/yr	10,642	
	Rate of carbon emission per value added	Ton C/mB	0.2984	
4.6.2	**Carbon Uptake from Oyster farming**			
	No of oyster by weight	Pieces/kg	7	
	Price of oyster	Baht/piece	10	
	Price of oyster	Baht/kg	70	
	% value added of oyster		55.37%	
	Value added of oyster	Baht/kg	38.75	
	Carbon content of oyster	% dry weight	5.00%	
	Carbon content of oyster	g.C/kg	50	
	Ratio of primary production to organic carbon in oyster	%	0.84%	
	Carbon as primary production for oyster production	g.C/kg C oyster	5,935.08	
	Value of carbon in oyster production	Baht/kg C	6.53	
	Value of carbon in oyster production	Baht/t C PP	6,530.48	
4.6.3	**Mangrove Input of nutrients**			
	Managrove input of organic carbon per km² (Wattayakorn *et al.* 1990)	Ton.C/km²/yr	1,118	
	Mangrove Input of nutrients from coastal area around	Ton.C/yr	19,006	

	Bandon Bay			
	Mangrove Input of nutrients per km^2 of Bay area	Ton.C/km^2/yr	39.59	
4.6.4	**Carbon Input from Shrimp Farm Waste**			
	Shrimp farm BOD discharge	mg/L	11.6	
	Area of Shrimp farm	Km^2	80.88	
	Volume of shrimp farm waste water	Million.cu. m	80.88	
	Total BOD from shrimp farm	Ton BOD/crop	938.21	
	Total BOD from shrimp farm per year (2 crops)	Ton BOD/yr	1,876.42	
	Total Carbon from shrimp farm into Bandon Bay (ton BOD x 1.7)	Ton .C/yr	3,189.91	
	Area of Bandon Bay	Km^2	480	
	Rate of shrimp farm discharge per area of Bay	Ton C/km^2/yr	6.64	
4.6.5	**Carbon Balance in Bandon Bay**		**Total**	**per km^2**
	Area of Bay (km^2)	480		
	Input			
	Waste from economic activities		10,642	22.17
	Shrimp farm waste		3,189.91	6.64
	Mangrove nutrient cycling		19,006	39.59
	Total from Land		32,837.91	68.41
	Primary production: standing stock of plankton biomass		69,120	144
	Uptake			0
	Fishery (Including oyster)		582.3	1.21
	Ratio of fishery to primary production		0.84%	
4.6.6	**Impact of Shrimp farm conversion of mangrove**			
	Shrimp farm area from mangrove conversion	Km^2	80.88	
	Loss of carbon from mangrove conversion	Ton .C/yr	90,423.84	
	Input of carbon from Shrimp farm waste	Ton. C/yr	3189.91	
	Net loss of carbon from conversion of mangrove to shrimp farms	Ton.C/yr	87,233.93	
	Loss of primary production due to mangrove conversion to shrimp farm**	Ton.C/yr	87,233.93	
	Unit value of carbon as primary production in Bay	Bath/ton.C	6,530.49	
	Value of Loss of nutrients	Million.Baht	569.68	
	Value of Loss of nutrients per area of shrimp farm	mB/km^2	7.04	
	Value of Loss of nutrients per rai of shrimp farm	Baht/rai	11,269.64	

** Assume 1:1 conversion of nutrients to primary production

4.2.5 Discussion

(1) Economic value of carbon in Bandon Bay: trade-off between mangrove and shrimp farming
Having calculated the monetary value of carbon in the bay, in terms of oyster value added, we are now in a position to consider the question of the trade-off between mangrove conversion due to shrimp farming. It is known that conversion of mangrove forest to other uses will reduce the flow of nutrients to the natural ecosystem and will lead to reduction in the rate of primary production. Our calculation (Table 4.6.6) shows that for the study area of Bandon Bay, the net loss of carbon input to the bay due to mangrove to shrimp farm conversion may be estimated at approximately 87,233 tons Carbon/year. This is based on the total area of shrimp farm of 80.88 .km^2, and applying the rate of nutrient input from mangrove forest to the whole of shrimp farm area under the assumption that this would have been converted from mangroves, and deducting the carbon input to the bay ecosystem from shrimp farm waste.

The economic question is what is the value of this loss. For the specific study site, it may be hypothesized that an additional input of carbon nutrient would be used for oyster production, which generates by far the highest value in monetary terms from among alternative uses, and is therefore an appropriate measure of opportunity cost of carbon in the Bandon Bay ecosystem. Using this line of reasoning, and assuming a 1:1 correspondence between carbon nutrient input and primary production, we can thus consider the amount of the loss of carbon from mangrove conversion in terms of the loss of primary production that would have supported the associated quantity of oysters. As shown above, the monetary value associated with 1 ton of primary production for oysters is 6,530 Baht/ton Carbon. Thus, the total loss of value added from mangrove conversion to shrimp farm in the Bandon Bay area is 569 million Baht. On a per area basis, this is 7 million Baht per km^2, or approximately 11,269 Baht per rai. This can be considered as the external cost of mangrove conversion to shrimp farm, specifically for the Bandon Bay area.

(2) Implications for resource management
What is the significance of this result? According to the Polluter Pays Principle, the person causing environmental damage should be responsible for the cost of damage. In this sense, it is suggested that the shrimp farmer who establishes his farm on mangrove should be responsible for the damage, defined as the loss of nutrients, which would otherwise have been used to support oyster production. This can be imposed in the form of a tax on shrimp farms located in mangrove areas at the rate of the estimated damage, namely around 12,000 Baht per rai. In relation to the net income from shrimp farming, the farmer would still be able to make a profit of around 7,000 Baht per rai. This would reduce the financial rate of return on investment in shrimp farming. The tax would reduce the incentive to destroy mangrove area for shrimp farming in the Bandon Bay area, where mangrove serves a valuable function of supplying nutrients to the ecosystem of the bay to support farming of shellfish, especially oysters.

A more general implication of the result is that the approach provides a way of assessing the monetary value of the loss of natural capital, such as the mangrove forest, in terms of the net value of the use of that capital as input into a productive process. The government could regulate access to mangrove areas for shrimp farming purpose by using the tax as a market based instrument to reach a more optimal use of land resources in the coastal area.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

5.1.1 Nutrient budgets
The following conclusions can be drawn from the nutrient budget study:

- According to the LOICZ Biogeochemical Modelling Guidelines (Gordon *et al.* 1996), most nutrients are trapped in the estuarine section of the Tapi River and Bandon Bay.
- Bandon Bay is slightly net heterotrophic in low flow conditions. However, on a two-year average basis, Bandon Bay is in balance metabolically, whereas the Tapi River estuary is strongly autotrophic.
- In general, Bandon Bay is slightly net nitrifying while the Tapi estuary is strongly net denitrifying.
- The inclusion of waste flux in the budget calculations indicate that sewage is the major source of organic carbon to the Tapi estuary-Bandon bay system. The two-box model clearly shows that most of the organic matter (DOC, DON and DOP) remains trapped in the estuarine section of the Tapi River.
- The discrepancies obtained from the various methods adopted is attributed to the large tidal variability which makes the assessment of magnitudes and directions of net material transport between estuaries and the coastal ocean rather difficult. This coupled with the inherent variability of results from estuaries, in common with most environmental data, mean that there is a limit to the sensitivity of each approach.
- In general, more agreeable results are obtained with the low flow condition than at the high flow condition.

5.1.2 Carbon production and fisheries

- Primary production and fish production estimated for Bandon Bay are not as high as initially expected in comparison with other coastal ecosystems in the region. This probably is due to the reduction of water volume in the bay resulting from heavy siltation during the past decade.

- Fishery statistics indicates over-fishing and declining in capture fishery in parallel to the declining in mangrove coverage. Pollution from excess waste and chemical compounds may also affect the fishery production in the area.

5.1.3 Human dimensions and the ecology of Bandon Bay

The main conclusions from the study fall under three headings

- impact of human activities upstream from the bay,
- human use values from the bay area, and
- management issues.

Impact of human activities upstream from the bay

Human activities impact on Bandon Bay in terms of emissions and uptake of nutrients. The study calculates that input of BOD is 6,240 ton/year, or 10,642 ton Carbon/year. Shrimp culture adds approximately 3,000 ton Carbon/year from shrimp farm waste discharge. However, the main impact is due to the removal of mangrove forest fringing the bay area, which results in the loss of approximately 87,000 ton Carbon/year.

Human use values from the bay area

Bandon Bay provides a rich breeding ground for marine aquatic life, and is being used for culture of oysters and clams which have a high market value, estimated at around 1,200 million Baht per year in terms of value added.

Management issues

The resources of Bandon Bay have competing uses. We have focused on the trade-off between land-based shrimp farming in mangrove areas and aquaculture in the bay area. The removal of mangrove for shrimp farms results in the loss of supply of nutrients to the bay and thus affects the growth of aquatic life in the bay's ecology. This loss is calculated in terms of the market value of oysters to be around 12,000 Baht per rai of shrimp farm. It is proposed that this external cost of shrimp farming be internalised by imposition of a tax of the same amount on shrimp farmers.

5.2 Recommendations

- The biogeochemical study should be continued with the refinement of the model to better estimate residual and exchange fluxes, as well as the net ecological production of the Bandon Bay system. In addition, it would be useful to select more sites which have variability in socio-economic, and other parameters and compare sites.
- Studies concerning trophic models and waste loading into the bay are necessary in order to elucidate the interaction between anthropogenic activities and coastal ecosystems as well as fishery potential in Bandon Bay. The carrying capacity of the bay also needs to be estimated. Introduction of the transport model may help in better understanding the link between the terrestrial and marine environments in this area.
- The input-output model was adopted as an economic representation of the Suratthani economy. In addition to the usual reservations about input-output tables, there are some limitations of the present A matrix. The sectors have been selected on *a priori* grounds, so they may not truly correspond to the actual set of economic activities in the study area. The sector totals were obtained from the national table, so they should be regarded as a blown-up version of the economy of the study area. This was not so serious since we were interested in the coefficients, which was calculated on a per unit basis. However, there was a problem of proportions of the various sectors, which may not correspond exactly with the national totals. This aspect needs to be furthered considered.

- Another limitation of the economic study is that it only considers one aspect of the use value of the Bandon Bay ecology, namely the relationship between shrimp farming and oyster farming, which is mediated through the ecological processes occurring in the bay. However, the processes have been considered only in terms of inputs and outputs of organic carbon that can be quantified as annual flows. The analysis undertaken provides only a snapshot of the processes that occur in Bandon Bay during one period. There is a need to model the situation in Bandon Bay as a dynamic process, whereby the relevant links, from land-based discharges of nutrients to primary production and conversion of marketable value of biomass is produced, can be fully specified and quantified.

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Appendix A. Integrated modelling of Bandon Bay: socio-economic aspects

Charit Tingsabadh
Centre for Ecological Economics
Chulalongkorn University
Bangkok, Thailand
Email: charit98@yahoo.com

1. Introduction

This report is part of the Integrated Biogeochemical and Socioeconomic Modelling Project supported by the SARCS/WOTRO/LOICZ Project which was undertaken in four countries, namely Philippines, Malaysia, Vietnam and Thailand. The overall objective of the project was to explore the approaches toward integrated modelling of the biogeophysical and socio-economic processes through an intensive case study. For Thailand, the Bandon Bay area in Suratthani Province, Southern Thailand was selected as the site for the case study.

For the socio-economic study, the objectives of the study are:

- To present a description of the social and economic setting of Bandon Bay
- To examine the human uses of the ecosystems present in the study area
- To estimate the amount of the anthropogenic contribution of the Carbon, nitrogen and phosphorus fluxes in Bandon Bay
- To estimate the values of the ecosystem in economic terms

1.1 Methodology

A number of methodological approaches are used to achieve the objectives of the study. These are:

- A review of secondary data sources relating to the socioeconomic condition of the province
- An economic analysis of specific activities present in Bandon Bay
- Construction of an input-output table of Suratthani province for the estimation of the anthropogenic CNP fluxes
- An economic valuation of ecological variables relating to ecosystem-based production activities

1.2 Data Sources

The data sources for the study are:

- Publications for the Suratthani province
- The Thailand National Input-Output Table for 1990
- The WHO Data book for emission
- Field trips were made with the science team in 1998-99
- Comments from the SWOL Meetings were taken into consideration in the completion of the Final Report.

1.3 Organization of the Report

The report is divided into six parts. Part 2 gives the overview of the socio-economic setting of the study area. It looks at the growth of economic activities in particular, and identifies important production activities, which are dependent on the resource endowment based on the ecosystem attributes of the study area.

Part 3 describes the methods and results of the estimation of anthropogenic CNP fluxes using the input-output table constructed for the provincial economy.

Part 4 assesses the economic returns from resource use in the Bandon Bay area. In particular, the economic returns to shrimp farming and mariculture of oysters and clams in the Bay area are estimated.

Part 5 provides an estimate of the values of ecosystem inputs into economic activities. The analysis in this chapter looks at the trade-off between shrimp farming in mangrove areas and the culture of oyster which utilizes the natural flows of nutrients into the Bay area to support the growth of the oysters. The focus of the analysis is the value of the carbon flows relating to these two activities.

Part 6 summarizes the results and outlines a number of issues for further study.

2. Description of the study area

Suratthani province is located in the upper southern region of Thailand. It has an area of 12,890 km^2 and a population of approximately 861,200 in 1997. The province is well endowed with natural resources, with forest covering about 25% of the area, while the coastal zone has mangrove forest. The sea provides a livelihood for fishermen and aquaculturists, while the offshore islands have become well known internationally as tourist destinations. The rich natural resources of the province provide the raw materials for industries which have developed in the area.

2.1 Population

The 1997 population of the province is distributed into 19 districts, and three urban centres as shown in Table A2.1.

2.2 Land Use

Land use in Suratthani province in 1994 was largely agricultural and forest. Agricultural land is mainly land for rubber and oil palm plantations. Most of the land area is rolling foothills suitable for upland crops and tree cultivation. The lowland areas suitable for rice cultivation is limited. However, a large area is still under forest, and it is now protected by law as national parks, wildlife sanctuaries and non-hunting areas. One part of the protected forest was used for the construction of a hydroelectric dam and the reservoir A small amount of land is used for urban centres and industry. See Table A2.2.

In the last ten years, a lot of the mangrove forest in the coastal zone has been converted to shrimp farms. The loss of the mangrove has raised concerns about the ecological and economic damage, and the remaining mangrove areas is now closely guarded by the local communities and the provincial administration.

2.3 Mangrove forests and changes through time

The depletion of mangrove forests in Bandon Bay during 1961-1979 was due to coastal development with the highest rate of depletion of about 77%. Conversion to aquaculture in particular shrimp ponds was not likely the major pressure. The area for shrimp farms was 241.60 ha in 1979 (Haemaprasit and Paw, 1988). However the shrimp farming steadily increased in the area to 1592.32 ha in 1983 (Boonpakob, 1983) and to 3,262.0 ha in 1985 (Haemaprasit and Paw, 1988). The rates of increase in shrimp farm areas were 6.59 and 13.50 folds respectively as compared to the original area in 1979. Boonpakob (1983) had predicted the expansion of shrimp farms in Suratthani to its fullest capacity of 3,200 ha. Within two years, the shrimp farms in Ban Don Bay had already expanded to its full prediction. However, the expansion of shrimp farm area continued to 6,115.20 ha in 1993 and to 13,780.52 ha in 1996. Of this, shrimp farms on the previous mangrove area comprised about 54% of the total shrimp area in this province.

Coastal development is the other major force for the loss of mangrove area. The total population has grown steadily over the years from 588,400 in 1980 to 816,400 in 1990, with the projected population of 926,000 by the year 2000. The coastal resources of Ban Don Bay are heavily utilized for economic development, particularly tourism and aquaculture. Table A2.3 shows the comparison for the land use zonation in the mangrove area between the year 1993 and 1996 in Suratthani Province.

2.4 Production

The main products of the province are: rubber, oil palm, fruit, fishery products, canned seafood, and tourism. The gross provincial product for 1994 is shown in Table A2.4.

2.5 Future trends

Given its rich natural resource base, Suratthani has a high potential to continue to develop its economy. The main concerns are to make that development will be sustainable with proper balance between using resources for the present and the future. In this regard, the main issues may be briefly described:

- Forest and Agriculture: the preservation of forest area to maintain the ecological balance and the functions is crucial. Conversion of forest to other tree crops such as fruit tree and rubber plantations will be damaging to the ecological balance of the area.

- Mangrove and Shrimp farm: the need to maintain the mangrove forest as nursery ground for marine life has to be balanced against the use of the area for shrimp farming. Shrimp farms can be sustainable, but need to be highly managed. The mangrove areas need to be preserved to support its various ecological functions.

- Urbanization and Industrialization : with the increasing development of urban activities, based on tourism, and industrialization, based on processing of agricultural raw materials, there is a need to ensure that the wastes from urban centres and industries do not pollute the natural water sources. In particular, the aquaculture in the Ban Don Bay area is highly sensitive to variation in the water quality, and wastewater from urban and industrial sources can be highly damaging. However, plans are now in place to install wastewater treatment plants for the urban centres, while industrial wastewater is under close monitoring. The plan for the industrial estate is also closely scrutinized for its potential impact on the water resources, and such impact is likely to be minimal.

Table A2.1: Population Distribution in Suratthani Province, by district, 1997

District	Area (Sq.km.)	Municipal Area	Population	Urban Population	Number of Households
Muang Suratthani	231.31	68.97	40,169	107,888	54,050
Kanchanadit	873.53		91,011		22,663
Koh Samui	227.25		34,792		12,397
Kiriratnikom	1,347.37		37,578		8,186
Chaiya	1,004.63		42,905		10,314
Don Sak	458		33,473		9,081
Tha Chang	1,160.42		28,819		6,577
Tha Chana	683.08		43,125		10,825
Ban Nasan	835.06	67.13	47,827	19,390	15,337
Panom	703.22		28,515		6,576
Phra Saeng	1,328.06		52,148		11,815
Phunphin	1,201.16	14.1	67,724	22,520	22,444
Wiangsa	420.39		56,678		13,235
Koh Pangan	193		9,029		3,218
Kiansa	580		35,503		8,191
Ban Ta Khun	1,300		13,211		3,572
Ban Nadoem	206		20,974		5,013
Chaiburi	112		18,552		4,381
Vipavadee	529.25		9,402		2,403
Total	13,393.73		711,435	149,798	230,278

Source: National Statistical Office

Table A2.2: Land Use

A2.2.1 Land Use : Forest and farm land

Year	Total area	Forest	Mangrove
	12891.47	5830	
1975			37.00
1979			58.08
1982		4138	
1985		3787	
1986			42.84
1988		3397	
1989		3388	37.67
1991		3283	22.04
1993		3166	31.64

A2.2.2 Farm Holdings by Type 1993

Land Use	Area (Sq.km.)
Total farm holding	
Housing area	137.59
Paddy land	501.19
Field Crops	33.16
Tree Crops	2772.62
Vegetable and flowers	16.18
Livestock	3.93
Idle land	79.17
other land	79.15
Unclassified*	6102.58

*includes encroached and degrade reserved forests

Table A2.3: Land use zonation in the mangrove area in Suratthani Province between the year 1993 and 1996 (Charuppat and Ongsomwong, 1995; Charuppat and Charuppat, 1997).

Land use	Area in ha	
	1993	1996
Mangrove (conservation area)	3,164.00	3,133.80
Shrimp farms	6,115.20	6,337.60
Urban development	3.44	35.44
Other coastal development	2,520.36	2,296.16

Table 2.4: Gross Provincial Products in 1994

Sector	Current Prices (1,000 Baht)	% Share	Constant Prices (1,000 Baht)		% Growth
	1994		1989	1994	
Agriculture	13,389,171	37.64%	8,665,187	12,010,134	6.53%
Crops	9,138,789	25.69%	6,501,716	8,753,855	5.95%
Livestock	584,431	1.64%	420,307	589,878	6.78%
Fishery	2,285,042	6.42%	778,488	1,541,236	13.66%
Forestry	0	0.00%	57,418	0	-100.00%
Agri.Services	44,097	0.12%	44,784	34,302	-5.33%
Agri.processing	1,336,812	3.76%	862,474	1,090,863	4.70%
Mining and Quarrying	666,666	1.87%	392,801	384,885	-0.41%
manufacturing	2,728,564	7.67%	1,901,190	2,228,548	3.18%
Construction	2,270,185	6.38%	715,854	1,476,789	14.48%
Electricity and Water Supply	830,443	2.33%	364,530	643,102	11.35%
Transportation and Communication	1,829,373	5.14%	794,954	1,539,903	13.22%
Wholesale and retail trade	4,472,944	12.57%	2,495,807	3,318,153	5.70%
Banking and Insurance	2,268,615	6.38%	551,373	1,701,362	22.54%
Ownership of dwelling	1,224,930	3.44%	656,647	828,333	4.65%
Public administration	1,747,087	4.91%	718,024	955,115	5.71%
Other services	4,143,827	11.65%	1,778,276	2,409,640	6.08%
Total	**35,571,805**	**100.00%**	**19,034,643**	**27,495,964**	**7.36%**

3. Estimation of emission

3.1 The methodological approach

The approach that is used to estimate the anthropogenic emission of CNP fluxes is based on the input-output table and the production -emission relationship. Input-output table is a representation of interrelationship between various sectors of an economy. The economy is classified into sectors of productions. Each sector is assumed to require input from other sectors, and at the same time it produces outputs, some of which are used as inputs by other sectors, and some output is consumed. The output consumed by other sectors is referred to as intermediate demand, while the output that is consumed is referred as final demand. Total output is the sum of intermediate and final demand. Assuming a linear relationship between input and output, the flows between sectors can be represented by a matrix equation as follows:

$$X = AX + F$$

Where X = vector of gross output
A = matrix of input coefficients
F = vector of final demand

Using matrix algebra, the equation can be solved for gross output vector, X, as follows:

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

To estimate the emission from production activities, the relationship between output and emission is assumed to be linear, and can be written in matrix form as follows:

$$E = eX$$

Where E = vector of emission of type 1 to k,
e = matrix of unit emission from activities
X = gross output vector

E as estimated from the above model will be the amount of emission generated by production activity X. In addition, emission will be generated from household consumption activities, which has to be estimated separately. This is done by estimating the amount of emission from households directly.

3.2 Construction of the Input-output table for Suratthani

In order to apply the above approach to the study area, it is necessary to construct an input-output table, which is appropriate for the area. In principle, this can be done by conducting a field survey of activities presented in the area. However, due to budget and time constraints, this approach is not possible to be done. Instead, an input-output table for Suratthani was constructed from the national input-output table for the year 1990. The methodology for this is described below.

- Step 1: The activities considered to be present in Suratthani is selected from the total classification of 180 sectors in the national IO table.
- Step 2: Selected sectors are aggregated into 10 sectors to be used in the analysis. This step requires the reclassification of sectors into a more aggregated classification.
- Step 3: The aggregated sectors are transformed into a matrix of input coefficients, arranged by columns.
- Step 4: For each column, the ratio of value-added to total output is computed.
- Step 5: The gross output for each is obtained by applying the computed ratio of gross output to value added for the sector.
- Step 6: The flows in the transaction table are computed using the input coefficients for each sector (column).
- Step 7: The gross output by row is assumed to equal the computed gross output by column, so that the IO table is balanced. The ratio between intermediate and final demand is checked for consistency and found to be plausible.
- Step 8: The table is used to project the gross output for the year 1997-1998.

The constructed 10x10 sector A matrix is presented in Table A3.1.

Table A3.1 Inter-industry Coefficient matrix for the Suratthani economy.

Description	Agriculture	Fishery	Manuf1	Manuf2	Utilities	Construction	Trade	Rest. & hotel	transcom	Othserv
Agriculture	0.0591	0.0010	0.1230	0.2639	0.0000	0.0036	0.0000	0.0480	0.0001	0.0024
Fishery	0.0059	0.0182	0.0726	0.0000	0.0000	0.0000	0.0000	0.0239	0.0000	0.0011
Manufacturing I	0.0017	0.0020	0.1255	0.0072	0.0000	0.0031	0.0009	0.0571	0.0018	0.0009
Manufacturing II	0.0138	0.0532	0.0070	0.0330	0.0015	0.1308	0.0034	0.0342	0.1144	0.0062
Utilities	0.0019	0.0020	0.0094	0.0099	0.0869	0.0028	0.0106	0.0261	0.0046	0.0143
Construction	0.0012	0.0003	0.0011	0.0030	0.0006	0.0017	0.0016	0.0032	0.0009	0.0057
Trade	0.0328	0.0310	0.0735	0.0306	0.0063	0.0625	0.0051	0.0787	0.0232	0.0212
Rest&Hotel	0.0005	0.0000	0.0021	0.0025	0.0031	0.0040	0.0227	0.0046	0.0060	0.0042
TransCom	0.0081	0.0088	0.0203	0.0236	0.0133	0.0546	0.0129	0.0165	0.0412	0.0063
Other services	0.0152	0.0155	0.0138	0.0133	0.0159	0.0143	0.0839	0.0147	0.0223	0.0287
Total Inter-Surat	0.1402	0.1321	0.4483	0.3870	0.1275	0.2773	0.1412	0.3071	0.2145	0.0910
Total Imported	0.1539	0.2348	0.1996	0.2934	0.3322	0.3412	0.0751	0.2551	0.3518	0.0903
Total value added	0.7059	0.6331	0.3521	0.3196	0.5402	0.3815	0.7837	0.4378	0.4337	0.8187
Total Output	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

3.3 Estimation of emission coefficients

To obtain estimates for the emission coefficients, a number of data sources were consulted. Where specific data relating to Suratthani are not available, Thailand country data is used. Where the national data are not available, the WHO values for the comparable activities are used as default values. However, due to data limitations, only BOD is used as the measure of emission from anthropogenic activities. This limitation is justified with reference to the study area on the reasoning that most of the activities are generating only wastewater from production processes.

The resulting coefficient matrix and total BOD emission from economic activities are presented in Table A3.2. The major sources of human-based BOD generation are agriculture and manufacturing, which together account for around 50% of the total BOD generation. The household sector also generated a high proportion of around 15% of total BOD.

3.4 Results

Using the calculated values of gross output and the estimated emission coefficients, the total amount of BOD emission is calculated as shown in Table A3.3. The CNP fluxes are estimated from the BOD flux using standard ratios.

Table A3.2 BOD emission coefficient vector and estimates of total emission from economic activities in Suratthani.

Sector	Output (VA based)	Coefficient	Total BOD discharge	
	mB	ton/mB	ton/year	%share (total human=100)
Agriculture	12,182	0.1075	1,309.70	20.92%
Fishery	2,246	0.0537	120.75	1.93%
Manufacturing I	8,101	0.2150	1,741.88	27.82%
Manufacturing II	2,231	0.1075	239.88	3.83%
Utilities	1,035	0.2150	222.59	3.56%
Construction	3,774	0.1075	405.76	6.48%
Trade	4,620	0.0709	327.51	5.23%
RestHotel	3,582	0.0709	253.92	4.06%
TransCom	2,672	0.1075	287.24	4.59%
otherservices	5,746	0.0709	407.31	6.51%
Total from production			5,316.56	84.92%
Domestic household	679,672	0.0014	943.89	15.08%
Total from Human activity			6,260.44	100.00%

Table A3.3 Estimated Emission of CNP from BOD from Economic Activities in Suratthani

Estimated from IO table for 1997	ton/year	C ton/year (C:BOD=1.7)	N ton/year (N:BOD=0.5:1)	P ton/year (P:BOD=0.042:1)
Total BOD	6,260.45	10,642.76	3,131.7	262.8
Assimilation rate 80%	0.2	2,128.55	626.34	52.56

4. Economic uses of Bandon Bay ecosystems

The economic activities that are closely related to the ecosystems of Bandon Bay are:

- shrimp farming, which takes place on the shore area, initially using mangrove, which was cleared to make way for the shrimp farms. Later, with improved farming techniques for water and feed management, the mangrove area was used less. Nevertheless, the damage to the mangrove ecosystem has been done. Mangroves do not grow back on disused shrimp farms naturally.

- Oyster farming in the bay area is done by placing poles into the bay to provide anchor for the oysters to attach to. The oysters are left to feed naturally in the bay until it is big enough for harvest, usually taking about 18 months to 2 years. In addition, fishery in the Bandon Bay provides employment and income for a significant number of small-scale fishermen. The main catch consists of shrimps, which have a good price in the market. Finally, the mangrove forest provides a range of use values for the local population. Villagers collect wood and marine animals such as shrimps and crabs for both own consumption and for sale.

For the analysis of the economic returns from each activity, see section 4.1 in the main report, and Tables 4.1 to 4.3 (main report).

5. Valuation of carbon in the ecosystem of Bandon Bay

5.1 A conceptual model to estimate the economic value of carbon in Bandon Bay

The economic value of carbon in the Bandon Bay can be estimated in terms of the highest value use of carbon in the area. Based on existing activities, it is oyster farming that is generating the highest income among all activities.

5.1.1 Approach to modelling economy and ecology interaction

The approach for modelling the linkage between economy and ecology of Bandon Bay is based on de Kok (1998). This approach views the link in the form of flows of materials between the two systems. The economy takes nutrients from the ecosystem for producing goods, and in exchange the economy discharges wastes into the ecosystem.

The main links in Bandon Bay area are:

- **Uptake of nutrients:**
  - Oyster and clam production takes up the nutrients from the bay
  - Fishery also removes nutrients from the bay.
  - Conversion of mangrove to shrimp farms removes nutrient supply from the bay.

- **Input of nutrients**
  - Mangrove forest provides nutrients to the bay.
  - Economic activities, including shrimp farms, discharge waste into the bay.

The value of nutrients in the bay can be estimated from the value of goods produced. In this analysis, we use the value of oyster as a proxy for the value of a ton of carbon.

The analysis proceeds in step as follows:

- First, the amount of carbon input into the Bandon Bay is estimated. Carbon input to the bay is derived from 3 sources: anthropogenic emission (1.1), mangrove under natural conditions (1.2) and shrimp farm waste (1.3).

- The uptake of carbon is then estimated. Under the natural conditions, the process would be through the food chain from primary production to fishery. However, due to the favourable conditions of the bay for oyster and clam growth, part of the primary production goes to support oyster and culture. The use of carbon in the food chain for oyster production can be considered to provide a measure of the opportunity cost of carbon in the bay area. This is calculated in (2).

- The total flows of carbon from different uses in and around the Bandon Bay are estimated in (3).

- When the carbon balance for the bay is calculated, it can be seen that carbon in the form of primary production is converted into fishery biomass. The lower the carbon input, the lower will be the fishery biomass that can be produced in the Bandon Bay ecosystem. Thus, a trade-off can be identified between activities that reduces the carbon input and the use of the carbon in the bay. This can be considered as the resource cost of the carbon in the bay. Among the alternative uses of carbon in the bay, the highest value use is oyster culture. Thus, it may be reasonable to assume that the loss of oyster value is an appropriate measure of the value of carbon in the bay area.

  The rationale for this assumption is that because oyster is the highest valued product that can be obtained from the bay, a trade-off exists between it and other uses of carbon. This trade-off would apply to all other users of carbon in the bay, so that more oyster would mean fewer shrimps in the sea to be caught, for instance. But the most obvious use of the carbon input, and one that is irreversible, is the conversion of the mangrove into shrimp farms on land. Thus, the potential loss of oyster due to the loss of mangrove carbon input provides a direct measure of the external cost of the shrimp farm conversion of mangrove.

- When this reasoning is applied to the case of mangrove removal for shrimp farming, the cost of mangrove removal can be estimated (4).

  The calculation indicates that shrimp farms in mangrove areas cause a loss of carbon by the amount of 87 thousand tons carbon per annum. This is equivalent to the same amount of carbon in primary production, which in turn can be converted into oyster. Using the unit value of carbon estimated from oyster production, the total value of the loss of carbon input to the bay can be estimated. Finally, the cost of carbon loss per unit area can be estimated from the total area of shrimp farm established in mangrove. The result is that 1 rai of shrimp farm causes a loss of value of approximately 11,000 Baht.

See Table 4.6 (main report) for the value flows of carbon in Bandon Bay.

5.2 A model for calculating the economic value of carbon in Bandon Bay

The above process of reasoning points to an approach to estimate the economic value of the carbon flows in the Ban Don Bay. In order to formalize the analysis, a model is proposed to generalize the analysis.

Let Q = production of oyster

$Q = f(CPP)$

Where CPP = carbon in primary production

Let P = net price of oyster, in Baht kg^{-1}
Then value of oyster production is

$V = PQ = P\ f(CPP)$

The marginal product of CPP can be expressed as
$dV/dCPP = P\ f'(CPP)$

where $f' = df/dCPP$

Let $f(CPP) = a_1 a_2 CPP$, assuming a simple linear production function for oyster and primary production,

Where a_1 = ratio of kg_{oyster} to $kg_{carbon\ in\ oyster}$ = 1:0.05
a_2 = ratio of $kg_{carbon\ in\ oyster}$ to $kg_{carbon\ in\ primary\ production}$ = .0084:1

Then dV/dCPP = P* (1/0.05)*(0.0084/1)

From the analysis of oyster profit margin, value added of oyster is 38.xx Baht/kg. Thus, the marginal product of CPP = 6.53 Baht/kgCPP, or 6,530 Baht/tCPP

If the process of primary production can be described in terms of nutrients and other factors, we then have a way of relating the feedback of CNP fluxes to one of the economic activities. In this case, the value is applied to the loss of carbon from mangrove clearing for shrimp farming, which leads to the same result as described in 5.1. However, the relationship between production of economic value, such as oyster, and primary production needs to be further elaborated. It is likely that natural processes will not be linear as presented here, and therefore there is a need to specify the relationships more fully.

An extended model, which is specified for the Bandon Bay case is proposed below:

For primary production:

PP = f(C,N,P, other environmental conditions)

For oyster, production will also depend on investment, including growing materials, as well as operations. In addition, there is competition for primary production from other living organisms. Thus, the production function for oysters may be written as:

Qoyster = f(PP, INVESToyster, other fishery production)

Other fishery production may be dependent also on effort, such as the number of fishing boats with pushnets, or the number of artisanal fishermen. Thus, we can write the production function for other fishery as

Qotherfishery= f(PP, fishing effort)
Investment in oyster production and in fishing effort can in tern be thought of as responsive to price changes.. Thus, for each type investment,

INVESToyster = f(price oyster, price of fish)
INVESTfisheryeffort = f(price of fish)

The above equations can be estimated and then solved simultaneously, so that they jointly determine the optimal levels of production of oysters, fishery and other variables.

By substituting the variables in the equation system, it is possible to reduce the number of equations to two, which are:

Qoyster = f(CNP, price oyster, price other fishery)
and
Qother fishery. = f(CNP, price other fishery product)

This model may be refined and empirically estimated at a later stage.

6. Summary of Results

In this study, we have attempted to integrate the biogeophysical and the socioeconomic modelling by setting three objectives as follows:

(1) To estimate the amount of anthropogenic inputs of CNP fluxes into the environment
(2) To valuate the human use of the nutrients in the natural ecosystem and
(3) To estimate the economic value of these elements in the ecosystem.

The approaches for estimation and valuation are based on well-known models being widely used in economic analysis, namely the input-output model and analysis of farm budgets.

For the estimation of anthropogenic emissions, the input-output table for the study area was constructed, based on the national input-output table but modified to fit the conditions of the study area in terms of activities and scale of output. This was then used to estimate the value of production of output generated by the economy. The amount of emission of BOD was then estimated using emission coefficients estimated from a variety of data sources, which were then applied to the estimated output figures. It was found that anthropogenic emission of BOD was a significant share of total CNP fluxes in the Bandon Bay ecosystem.

Human activities impact on Bandon Bay in terms of emissions and uptake of nutrients

The study calculates the estimated input of BOD is 6,240 ton/year, or 10,642 ton carbon/year. Shrimp culture adds approximately 3,000 ton carbon/year from shrimp farm waste discharge. However, the main impact is due to the removal of mangrove forest fringing the bay area, which results in the loss of approximately 87,000 ton carbon/year.

The analysis of the utilization of ecosystem elements was focused on the use of carbon flows into and uptake from the bay area ecosystem. A range of economic activities was identified to be associated with varying magnitudes of carbon flows. For each economic activity identified, an economic value of the activity was estimated, which was then related to the value of carbon flows associated with the activity. In the specific case of Bandon Bay, the value of carbon was estimated with reference to the value of oysters being cultured in the bay area. Bandon Bay provides a rich breeding ground for marine aquatic life, and is being used for culture of oysters and clams which have a high market value, estimated at around 1,200 million Baht per year in terms of value added.

The value of the carbon was then applied to the loss of carbon flux as a result of mangrove clearing for shrimp farming. An estimate of the external cost of the shrimp farming activity was made with the values obtained from the analysis.

The resources of Bandon Bay have competing uses. The study focused on the trade-off between land-based shrimp farming in mangrove areas and the aquaculture in the bay area. The removal of mangrove for shrimp farms results in the loss of supply of nutrients to the bay and thus affects the growth of aquatic life in the bay ecology. This loss is calculated in terms of the market value of oysters to be around 12,000 Baht per rai of shrimp farm. It is proposed that this external cost of shrimp farming be internalised by imposition of a tax of the same amount on shrimp farmers.

Limitations of the study

However, the analysis depended on an assumption about the conversion of carbon flows into primary production and oyster biomass which need to be further refined and calibrated for the specific condition of the study area.

Nevertheless, the approach is considered to combine the findings from the biogeophysical and the socioeconomic analysis in an integrated framework for the analysis of the options in managing an ecosystem.

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SARCS/ WOTRO/LOICZ Vietnam Core Research Site
1996 – 1999 final report

Economic - Environmental Modelling of Coastal Zones in the Red River Delta, Vietnam

Economic Evaluation Studies of Mangrove Conservation and Rehabilitation in Nam Ha Province (Red River Delta)

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Research Team: Dr Nguyen Hoang Tri,
Dr Nguyen Huu Ninh,
Dr Tran Viet Lien,
Mr. Tran Dinh Trong,
Mr Bui Trinh,
Dr Nguyen The Chinh,
Mr Francisco T. Secretario

Vietnam National University

Hanoi 1999 (updated February 2001**)**

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PROJECT OVERVIEW

Covering a catchment of over 117,000 km² populated by 20 million people, the Red River system is facing global change via competing interests - economic, agricultural, environmental and urbanization, especially in the context of the 'Open Policy' of transition economy. Today, the coastal zone of the system is in serious trouble.

- It has suffered from flooding, storm surges and extreme events, along with changing water quality and declining fish production.
- Habitats are declining; some native species are listed as endangered, especially migratory birds, e.g. Black-faced Spoonbill.
- Mangroves are effective as buffers for sea dyke protection, but continuous conversion of the mangrove to aquaculture continues, while there are many sea dykes structurally week and in a high risk of failure.

Reasons to care

- The Red River delta is the second largest river system in Vietnam, and is home to many aquatic and terrestrial plants and animals.
- The system is vulnerable to failure, especially due to flooding during the typhoon or monsoon season, which causes serious damage to people and properties.
- Thousand of shore birds migrate through and live in the coastal areas, and hundreds of fish species and valuable marine products are found there.
- The system contributes over 30 % of national' Gross Domestic Product (GDP)' in terms of agriculture, forestry and fishery.
- The Hoa Binh Dam which covers over 200 km², is the nations biggest hydroelectric power generator, but its impact has not been estimated for the Delta environment.

Relevance to LOICZ and SARCS

- Contributing directly to the goals of LOICZ focus 4 - 'to develop integrated models, scenarios and/or forecasts for a specific area or system, encompassing both natural and social driving forces of change'
- Contributing to the SARCS Immediate Objective 2 ' to integrate natural-social science assessment of changes in the coastal zones of the SACRS region'

Results of this study form the basis for future integrated management of the coastal areas and development of capacity building and regional/international contribution of local expertise.

A new approach

The SARCS/WOTRO/LOICZ program represents a new approach to model human-induced environmental change in the coastal zone. A basis for the linkage of the biogeochemical or budget models with the ecological process models and with the economic models has been provided by guidelines resulting from discussions of program's workshops. Two conceptualized interacting subsystems have been accessed into the framework. The environmental subsystem comprises the biogeochemical processes, whereas the economic subsystem comprises all the economic activities taken into consideration, as shown in the figure below.

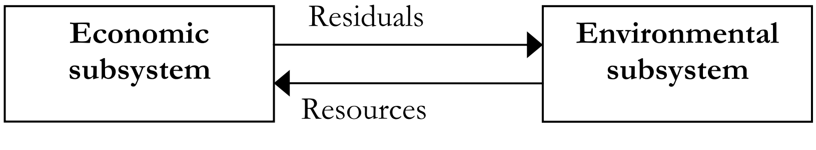


Figure 1. Conceptual integrated model for the coastal zone

Vietnam

We attempt to construct a regional Input-Output (I-O) table with the view of providing an appropriate and effective analytical device for I-O modelling approach, which can be usefully applied up to the scale of a regional I-O model. Residual generation could then be predicted (C, N and P) for a geographical set of economic activities and population settlements under a number of different economic growth scenarios (Turner 1997).

The economic subsystem is described on the basis of an economic input-output model, which relates final demand to production in the sectors under consideration. The final demand depends on, among other factors, household consumption, policy intervention, economic growth and demographic change. The impact of each economic sector is expressed in terms of its residual output. This forms the basis for the linkage between the economic and environmental models.

Main results

- A set of information on natural and socio-economic pressures to the coastal zone has been collected and collated in order to serve the multidisciplinary research and analysis of Pressures-Impacts-State-Responses.
- Water, salt, C, N and P generated from natural and economic activities have been estimated in terms of budgets and fluxes, and one-box models for seasonal and annual balance of the residuals have been developed using LOICZ methodology.
- The biogeochemically dynamic processes were modelled using the Stella 2 and computation methods.
- The regional Input-Output (I-O) table was constructed and economic-environmental coefficients were developed by using WHO rapid assessment method and national monitoring network for estimating economic residuals from eleven economic sectors and household consumption.
- The feedback of the residuals has been initially tested, and the increased rates of residuals along with three scenarios of economic growth by sectors have been simulated.

SYNTHESIS REPORT

1. DESCRIPTION OF THE SITE

1.1. Geological history and coastal morphology

1.1.1. Sediment features: The coastal zone of Red River Delta (RRD) stretches from Do Son to Lach Tuong with he length of 145 km, the width 500 m in Van Ly to 15,000 m in Ba Lat. The total mudflat area is 452,000 ha of which the upper mudflat (188,000 ha) is covered partly by mangroves. The system carries to the sea 144 m^3 of water and 114 million tons of alluvium which are divided between branches of the distributaries such as: Luoc River: 10-15 %; Tra Ly: 10-15 %; Cua Day (Nam Ha):30-40 %; Cua Ba Lat: 40-45 %. Sediments flowing through the Ba Lat mouth create the largest mudflat, with an upper area of 9,412 ha and a lower area of 5,513 ha (see Map 1).

Table 1.1. Elevation (m) and deposition rate in the coastal area (cm per year)

Elevation (m)	Deposition rate (cm per year)
≤ 0 m (Oceanographic map)	1.5 - 4
0 - 1.85	1 - 3
1.86 - 2.5	5 - 20
2.6 - 3.5	1 - 3
> 3.5	< 1

The horizontal extension of the coastal area is estimated to be 345 ha per year for the upper mudflat and 200 ha per year for the lower one. However erosion occurs, at the rate of 2.65 m per year for the upper mudflat and 3.09 m per year for the lower one in Van Ly for instance. Suspended particles have been seen 20 -25 km off the coast of the Day river, Ba Lat and Do Son. Salt intrusion into the river is estimated at 10-15 km, even to 15-20 km in the Van Uc mouth in winter. Salinity may be as low as 0.1 % - 0.4 % in the rainy season in the Day River, Ba Lat and Van Uc.

Sediment is mobilized by the mixing forces of tidal and river flows and waves. Clay sediment is predominantly deposited from suspension of muds which are rich in ions such as Fe^{3+} Al^{3+} , Mn^{2+} and argyles. The soil comprises 1-5 % of diameter >0.1 mm; 5-10 % of 0.1 - 0.01 mm; 15-30 % of 0.01 - 0.001 and 15-30 % of argyles. The Red River mouth has rapid deposition of sediment, without a green-gray layer on the surface of sediment. In the lower mudflat, it is mainly sands with a lot of shell. Soil structure is characteristic of sediments with 10-15 % of diameter <0.1 mm; 20-24 % of 0.1 - 0.01 mm; 1- 5 % of 0.01 - 0.001 mm; and 0-10 % of < 0.001 mm.

1.1.2. Coastal morphology: The coastal zones of the Red River Delta are gradually rising due to the deposition of sediments and alluvium. The mangrove also contributes to the process by trapping sediments through its root systems. Topographic features depend on tidal range of each river mouth and can be divided into the following landscapes:

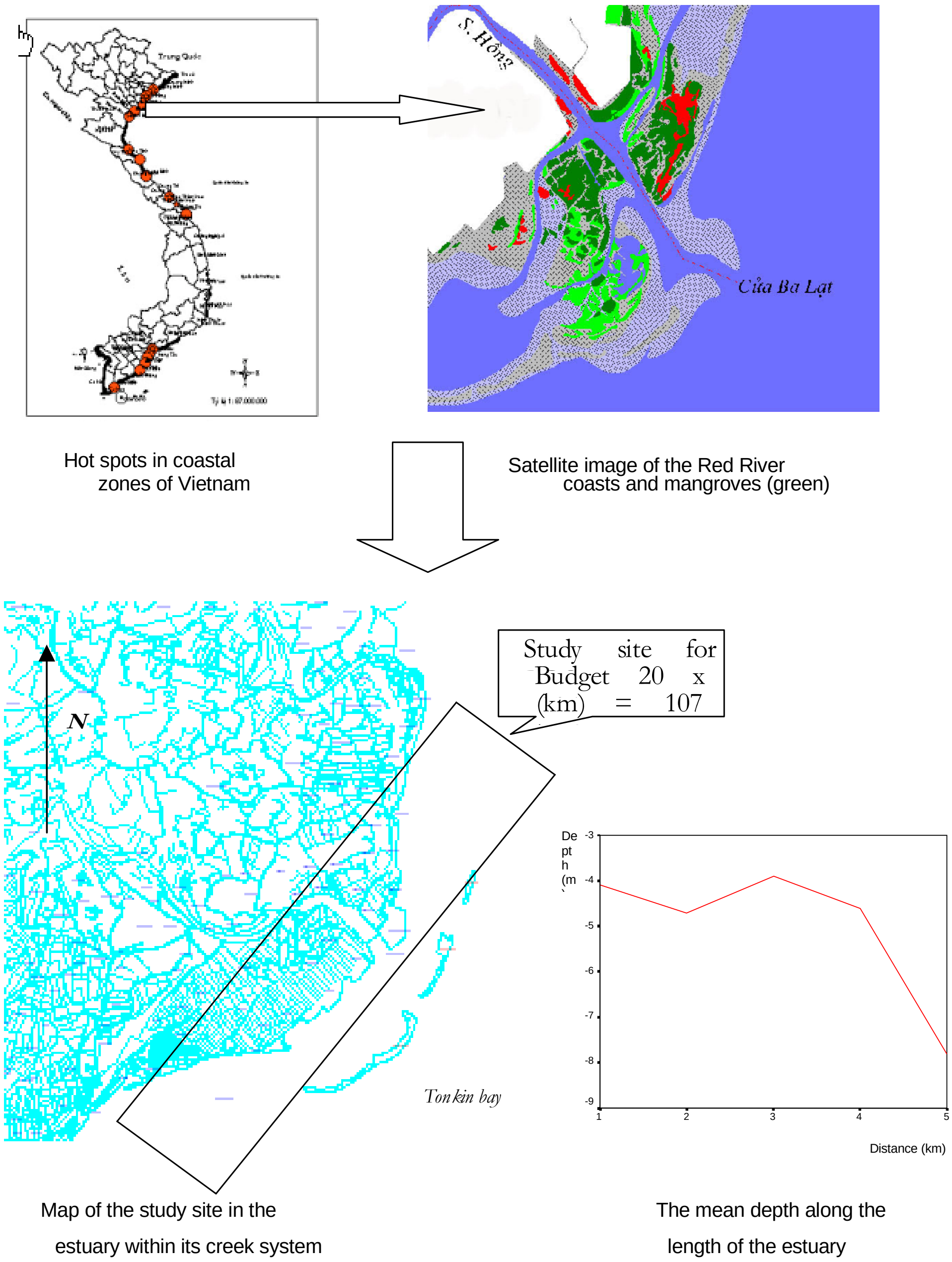
a. *Upper mudflat covered partly by mangroves*: This is located from the mean tide level up to the upper limit of tidal water. The elevation is from 0-2.5 m compared to 0 m on the terrestrial map. Mudflats of which the lower edges are mainly covered by mangroves dominate the area. Besides mangroves, *Cyperus* can be found, reeds and other grasses in upper areas. The area is most productive in biological processes by being exposed to the sun during the low tide. About 50 % total area of mudflat or 250,000 ha are inundated during spring tide for 2 -3 hours. This area has a large potential for mangrove reforestation.

b. *Lower mudflat*: The elevation ranges from 0 m (oceanographic map) to the mean tide level. The area is frequently inundated during the neap tide. It is exposed from 2 to 6 hours and inundated 16 - 18 hours per day during the spring tide. Mangroves cannot developed. Based on the ground formation, this area can be divided into the following two categories:

- *Lower mudflat with fine sand*: The area is located within the river mouths and affected by strong flow and wave action directly from the sea. It has high potential for supplying feeding grounds and shelters for shellfish culture including gastropod and bivalve mollusks such as cockles, clams and snails.
- *Lower mudflat with muddy clay*: The area is located in lower flat with low dynamic forces closing to mangrove swamps. It is usually developed along the coast or situated around small islands. There are a lot of benthic species providing a favorable habitat for shrimp, fish and crab culture.

c. *Small sand-islands in river mouth*: These are formed from sand carried in from rivers, then coastal flow and wave action creates small barriers located on both sides of the river mouths. The small sand islands emerge gradually depending on whether it is the dry or rainy season. The islands are usually elongated parallel with coast line and covered by mangrove pioneer species. The newly-formed islands are very favorable to fisheries and mangrove forestation.

d. *Tidal canal systems*: They are usually water canals which also carry sediments. There are two types of tidal canals. The first one is called "erosion canals" elevated over 0 m on OM (Oceanographic Map) and the other is called "successive erosion canals" deeper than 8-9 m for transportation.



Hot spots in coastal zones of Vietnam

Satellite image of the Red River coasts and mangroves (green)

Map of the study site in the estuary within its creek system

The mean depth along the length of the estuary

Map 1. The Red River delta coastal system.

1.2. Climate features

The climate in the Red River Delta (RRD) is typical tropical monsoon climate, in which the cold winter is rather wet and humid at the end of the season and the summer is hot with plenty of rain (Figure 1.1). The most constant problems in RRD are natural catastrophes occurring each year associated with heavy rain and strong winds which cause damage in the coastal area in June, July and August.

The mean annual temperature is about 23-24 ^oC. The difference between winter and summer is about 12 ^oC. The extreme minimum is occasionally recorded at about 4-5 ^oC. Hoarfrost or rime is rare, but it causes a lot of damage to vegetable crops, especially in their young stages.

The coastal area is usually affected by typhoons and storms during July-October in which most of the danger is associated with strong winds with a velocity of 40-50 m/s accompanied heavy rain of 200-300 mm per hour. The rainfall can total 400-500 mm per hour during storms. On average, the storms constitute 25-30 % of total rainfall in summer.

Table 1.2. Climate data recorded in RRD hydro-meteorological station in Nam Dinh province.

Temperature (T ^oC)	**Records**	**Rainfall (mm)**	**Records**
Annual average T ^oC	23.5	Annual rainfall	1,671
Highest T ^oC in month	29 (Jul.)	Number of rainy days	134
Mean extreme high T ^oC in month	32.5 (Jun., Jul.)	Rainfall in highest month	309 (August)
Mean extreme low T ^oC in month	14.3 (Jan.)	Rainfall in lowest month	25 (Feb.)
Extreme highest T ^oC	40.1	No. of rainy days in highest month	15 (Feb.)
Extreme lowest T ^oC	5.8	No. of rainy days in lowest month	7 (Dec.)
Annual amplitude T ^oC	12 - 13	Diurnal maximal rainfall	350
Diurnal amplitude T ^oC	6.0	Annual minimal rainfall	978

The average rainfall is 1,600-1,800 mm per year with rainy days of 130-140 per year. The rainy season occurs during 6 months from May to October with 85 % of total annual rainfall.

The maximal rainfall occurs in August with 16-18 rainy days or 300-350 mm. It may vary over 500 mm during 10-20 % of the observed years. The annual average humidity is 82-85 %. The total solar radiation through a year is about 1,600 - 1,700 with 150 sunny hours in the summer months.

The period of frequent typhoons is from July to October of which the most occur in August. The average number of typhoons in the Red River Delta during 55 years (1911 - 1965) are 1 in May, 2 in June, 9 in July, 13 in August, 10 in September and 5 in October. The typhoons create a very strong wind along with heavy rain. The maximum wind velocity and rainfall are also recorded during the typhoons. In the coastal area, the wind velocity may reach 40-50 m/s, which is gradually reduced to 30-35 m/s for landward areas.

There are a lot of tropical storms in the Red River Delta. Around 90 - 100 storm days are recorded each year. They occur mainly in summer (from May to October) with 20 -25 storms each month on average. However at the beginning and the end of winter, there are also 4 -5 storm days each month.

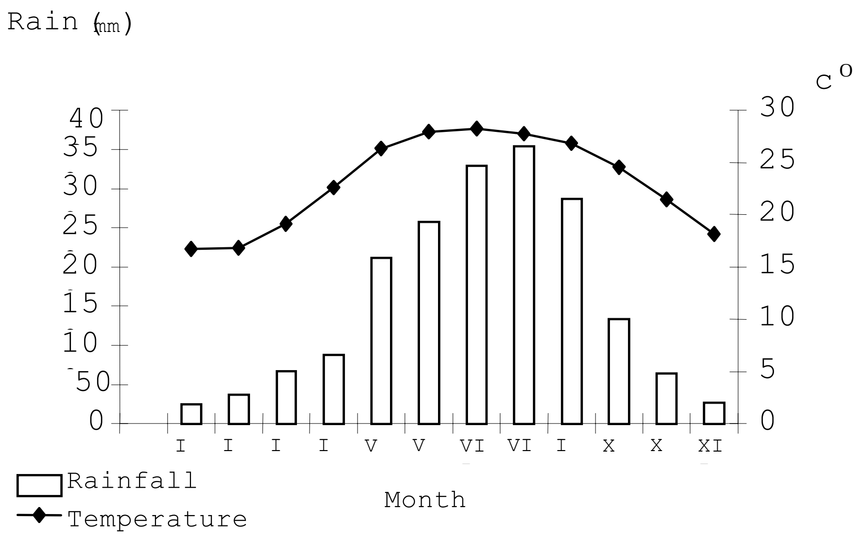


Figure 1.1: Climatic chart for the Red River Delta. Note: This chart is based on records of temperature in periods of 1904-1944; 1967-1970, rainfall in periods of 1904-1944; 1957-1970. The average values of rainfall and temperature were calculated within the long periods.

1.3. Catchments

The Red River is a second longest river in Vietnam after the Mekong. It originates in the Van Quy Highlands of South China and has many branches when coming into the country. The catchment area is about 117,700 km^2 with total annual water volume of 119.72 km^3. There are three main sub-river systems namely Da, Thao and Lo-Gam. The Thao is longest river in the system with length of about 1,126 km. In the northern plain, the Red River and Thai Binh River systems link together by many canals or sub-rivers. Water discharges from Red River into the sea through many river mouths. Hydrological features of the Red River system, including the downstream part in Vietnam, are presented in tables 1.3 and 1.4.

Table 1.3. Red River system and its hydrological features.

Sub-river systems	Rivers	Length (km)	Area of catchment (km^2)	Annual water volume (km^3)	Flow velocity (m^3/s)
Da	Da, Nam Na, Nam Muc, Nam Mu and Nam Bu	570	26,800	59.42	1,880.0
Thao	Thao, Bua and Thia	1,126	51,900	28.40	900.0
Lo - Gam	Lo, Gam, Chay, Pho Day, Mien, Nho Que and Nang	470	39,000	31.90	1,010.0
Total		**2,166**	**117,700**	**119.72**	**3,790**

The hydrological regime of the Red River has also two seasons. They are called "exhausted" or dry and "flooding" seasons. The flooding season lasts about 6 months from June to November in the upstream area; 5 months from June to October in the downstream area. In this season, the water-flow discharges about 80 to 85% of annual total. The run-off is very high with maximum value possibly up to 17,200 m^3/s in the Da River, 21,800 m^3/s in the Thao River and 14,000 m^3/s in the Lo River.

Table 1.4. Data of hydrological features collected from main stations by provinces in the catchment area.

Stations	River	Water level (cm)			Runoff (m^3/s)		
		January	July	year	January	July	year
Laichau	Da	7027	7695	7232	383	2750	1110
Hoabinh	Da	1421	1903	1588	544	4070	1690
Laokai	Hong	7494	7668	7564	231	956	526
Yenbai	Hong	2461	2690	2568	328	1310	768
Ghenhga	Lo	1704	2066	1843	242	1670	760
Thacba	Chay	2042	2222	2111	74.9	388	194
Sontay	Hong	592	1083	781	1270	7630	3560
Hanoi	Hong	320	793	504	1040	5590	2710

Suspended sediment concentration in river water is very high. In the flooding season, this value is up to 4.86 kg/m^3. Annual variation of water and sediment flows in some main rivers of the Red River system is presented in the figures 1.2 and 1.3.

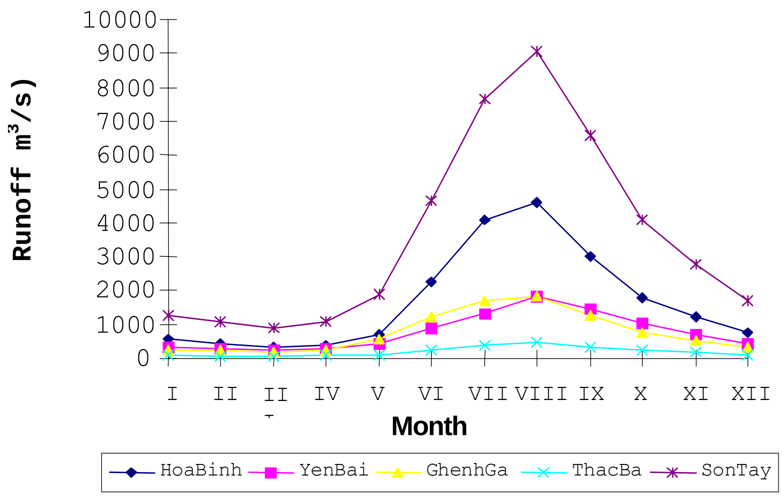


Figure 1.2. Annual variation of run-off in the Red River system.

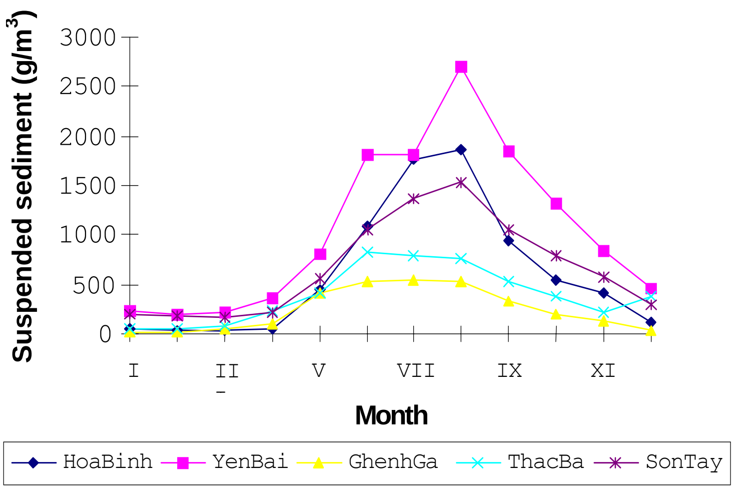


Figure 1.3. Annual variation of suspended sediment in the Red River system.

In the context of the SWOL core project, the research site chosen in Vietnam is an area of mangrove reserves in the coastal zone of Xuan thuy district, Nam dinh province. This is the mouth of the Balat, the biggest estuary in the North Vietnam.

1.4. Mangroves and sea grasses

The mangrove: There are 26 species of mangrove found in the coastal zones, covering over 30,000 hectares. In the past a luxurious cover of mangroves existed in the area. Due to under-valuation of this resource, a major part of the mangrove forest has been reclaimed and converted to agriculture, especially aquaculture ponds in recent years. Almost all the mangrove was cut down due to these activities. The rehabilitation of the mangrove was started in 1991 as a result of great efforts from national and international projects. One third of the area has been replanted, dominated by *Kandelia candel* and *Sonneratia caseolaris*. However, the mono-plantation of *Kandelia candel* is facing problems with respect to changing climate, gradual elevation of mudflats, diseases and other factors.

Some bio-ecological parameters of *Kandelia candel* presented in Table 1.5 show that the forest is still young and very important to the ecological processes of the system in terms of primary production and nutrient cycle.

Table 1.5. Growth rate, biomass and litter production of the mangrove forest

Growth rate	Age							
	1	2	3	4	5	6	7	8
Height (cm per year)	30.84	31.68	14.64	21.6	20.16	30.36	43.32	56.76
Diameter (cm per year)	0.12	0.12	0.84	1.08	1.2	0.36	1.32	0.6
Biomass (d.w kg per ha)	15	56	1,530	6,549	5,934	18,975	20,199	34,271
Litter production (d.w kg/ha/year)	650	664	879	1,534	1,950	1,993	2,636	4,601

Source: Tuan *et al.* (1999); Giang (1999)

The mangroves are mainly dwarf, fringed with small trees, but they have an economic importance as buffer defense protection of the sea dyke. The data presented in the Table 1.6 shows that the length of sea and river dyke system is equal to the coastline, so mangroves are considered to be of great importance in this context. It is estimated that function values of the mangrove are 20-30 % of avoided cost for annual maintenance and protection of the dyke system.

Table 1.6. Mangroves and dyke systems by provinces in coastal areas.

Province	Coastline (km)	Sea and river dyke system (km)			Mangroves (ha)		
		River dykes (km)	Sea dyke (km)	Total (km)	Planted mangroves (ha)	Natural mangroves (ha)	Total (ha)
Quang Ninh	377	66	64	130	600	12,694	13,294
Hai Phong	110	48	67	115	500	2,882	3,382
Thai Binh	50	135	135	270	3,700	2,500	6,200
Nam Dinh	65	15	76	91	5,236	1,764	7,000
Ninh Binh	17	6	24	30	400	100	500
Total	**619**	**270**	**366**	**636**	**10,436**	**19,840**	**30,376**

Seagrasses: Six species are reported in Quang Ninh, Hai Phong and Nam Dinh provinces. They are *Halophyla ovalis, Halophyla beccarii, Halophyla minor, Ruppia maritima*, *Zostera japonica* and *Zostera marina*. They play an important role in regulating disturbances and supplying nursery grounds for fish, shrimp and other marine products. In recent years, seagrass beds have been degraded due to increased turbidity from habitat disturbances through human activities.

1.5. Human activities

1.5.1. Population, income sources and consumption features

As presented in the Table 1.7, there are about 20 million people in over 80,000 km² in the region. The population density varies from 50 in the mountains to 2,000 people/km² in the cities. The average birth rate decreased from 2.8 % in 1990 to 1.8 % in 1998. The population distribution by age groups shows that the highest percentage of the population pyramid, 14-38% in the mountains and 11-12% in the delta area, belongs to ages of 0-4 and 5-9. The exploitation patterns of natural resources and the relationship between nature conservation and economic development in the future is dependant on this driving force.

Table 1.7. Areas and population distribution by provinces.

Provinces	Area (km²)	Population	Density (persons per km²)	No. of districts
RR Mountainous areas				
1. Ha Giang	7,831.1	505,643	65	9
2. Tuyen Quang	5,801.3	61,3595	106	5
3. L.ai Chau	17,139.7	481,496	28	10
4. Lao Cai	8,049.5	514,547	64	8
5. Yen Bai	6,801.5	616,702	91	7
6. Son La	14,210.0	753,512	51	9
7. Hoa Binh	4,611.8	698,496	151	9
Subtotal	**69,281.0**	**6,348,433**		
RR Delta areas				
9. Hai Hung (Hai Duong, Hung Yen)	2,551.6	2,611,788	1,024	10
10. Ha Tay (Ha Dong, Son Tay)	2,152.9	2,169,522	1,008	12
11. Hai Phong	1,503.5	1,542,343	1,026	8
12. Hanoi	920.5	2,106,051	2,288	5
Subtotal	**7,128.5**	**8,429,704**		
RR Coastal Areas				
13. Nam Ha (Nam Dinh, Ha Nam)	2,418.6	2,531,317	1,047	11
14. Thai Binh	1,523.5	1,738,157	1,141	7
15. Ninh Binh	1,386.8	818,462	590	5
Subtotal	**5,328.9**	**5,087,936**		
Total	**81,738.4**	**19,866,073**	**608.5**	**126**

Source: GSO, 1996.

Data in Table 1.8 indicates that the unemployment rate is 4.95-8.07 % in both regions. In fact, this rate depends on the availability of non-farm self-employment activities. Agricultural and forestry activities are the major sources of income.

Table 1.8. Employment status of active population (%) and sources of income (10^3 VND per year)

Employment status of active population (%)	Mountainous and mid-land	Red River Delta
Employed	95.05	91.93
Unemployed	4.95	8.07
Sources of income (Th.VND per year)		
Agricultural, and forestry activities	505.4	437.6
Non-farm self-employment	158.3	400.2
Wages	89.3	181.8
Pension, subsidies and scholarship	44.8	67.5
Other income	3.1	8.7
Total	**800.9**	**1095.8**

Source: State Planning Committee (SPC) and General Statistic Office (GSO), 1994;
Vietnam living standard survey 1992-1993.

Food expenditure for daily consumption is mainly for cereals from agricultural activities, as presented in Table 1.9. Lifestyle and consumption features of people are related to agricultural development. The traditional 'rice field' culture dominant in the region has considerable effect on the land-use and land-cover change in the area.

Table 1.9. *Per capita* food expenditure (10^3 VND per year) for consumption.

	Mountainous and mid-land	Red River Delta
Cereal	336.4	335.7
Meat, egg, fish...	156	186
Vegetable and fruits	90	95
Others	52	107

1.5.2. Land use

About 17 million people or 80 % of population is involved in agricultural activities, as presented in Table 1.10. This is driving land-use and land-cover change. Figure 1.4 shows the degradation of forests during five decades. The main cause is the reclamation of forest for agricultural activities, especially for rice fields.

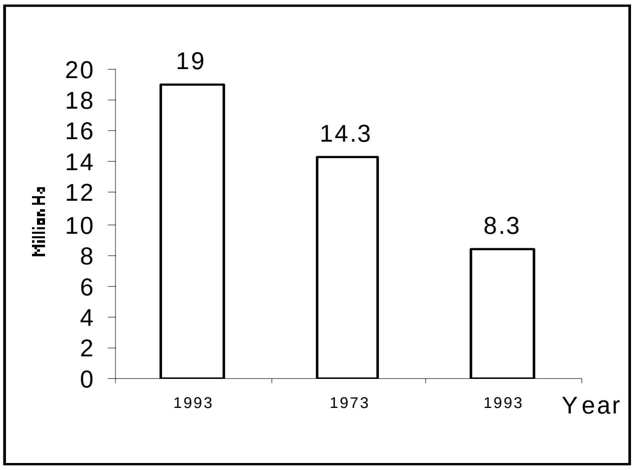


Figure 1.4. Forest degradation over five decades

Table 1.10. Land use of the Red River Region in 1995.

Data baseline of Red River area 1995	Total area (10^3 ha)	Agriculture land (10^3 ha)	Forest land (10^3 ha)	Agricultural population (10^3 person)
RR Mountainous (9 Provinces: Lai Chau, I.ao Cai, Yen Bai, Son La, Ha Glang, Tuyen Quang, Vinh Phu, Phu Tho and Hoa Binh)	6,928.2	1,438.7	1,421.8	6,632.6
RR Delta (7 provinces: Ha Noi, Hai Phong, Ha Tay (Ha Dong, Son Tay, Hal Hung (Hai Duong, Hung Yen)	716.9	387.3	35.5	6,206.5
RR Coastal provinces: Thai Binh, Nam Ha (Nam Dinh, Ha Nam), Ninh Binh	541.5	324.4	20	4,607.8
Total	**8,186.6**	**2,150.4**	**1,477.3**	**17,446.9**

In the land-use pattern, the annual crop accounts for 65.62 - 86.70 %. The forest is only 13.26 % in the mountainous area and 1.34 % in the Delta. As presented in Table 1.11, the annual harvest of perennial crops is equal to that of annual ones, but this activity has only developed in recent years.

Different categories of crop cultivation expenses presented in Table 1.12 show that the expenditure for chemical fertilisers is half that of all agricultural expenses. The trend is increasing annually, as shown in Figure 1.5. The use of chemical fertilisers is increasing both intensification and extension of agriculture. It is also contributing to the nutrient budgets in the coastal zone.

Table 1.11: Type of agricultural and forestry land (%) and annual value of harvest (10^3 VND /ha)

	Mountainous and mid-land	Red River Delta
Type of agricultural and forestry land (%)		
Annual	65.62	86.70
Parennial	7.63	5.50
Water surface	2.02	5.11
Forest	13.26	1.34
Other lands	11.47	1.34
Annual value of harvest (Th. VND /ha)		
Annual	9,176	10,649
Parennial	9,706	16,310
Water surface	2,582	3,683
Forest	11,358	10,700

Source: State Planning Committee (SPC) and General Statistics Office (GSO) 1994, Vietnam Living Standard surveys 1992-1993

Table 1.12: Crop cultivation expenses (%) in the region

Items	Mountainous and mid-land	Red River Delta
Seed	39.16	20.12
Chemical fertilizers	43.09	52.52
Bio. fertilizer	0.68	0.48
Insecticide	6.35	10.86
Transportation	0.22	0.36
Services	6.25	7.06
Equipment rental	2.57	7.04
Hiring labor	1.68	1.57

Source: State Planning Committee (SPC) and General Statistics Office (GSO) 1994, Vietnam Living Standard surveys 1992-1993

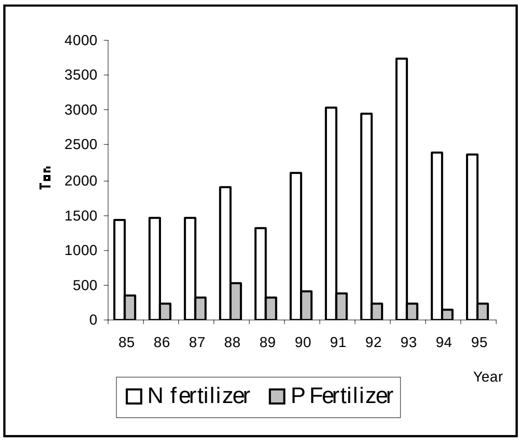


Figure 1.5. N and P fertilizers used during 1985 – 1995.

The Gross Domestic Product (GDP) has annually increased from 76 billion VND in 1991 to 110 billion in 1992, 136 billion in 1993, 174 billion in 1994 and 222 billion in 1995. It contributes up to 20-30 % of GDP value in the country. Figure 1.6 shows this trend. The economic triangle Ha Noi-Quang Ninh-Hai Phong, and industrial center of Viet Tri is the main economic contributor in the region. It is also driving residuals from the economic activities.

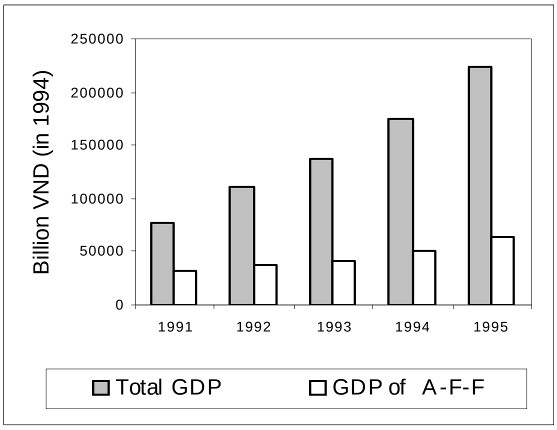


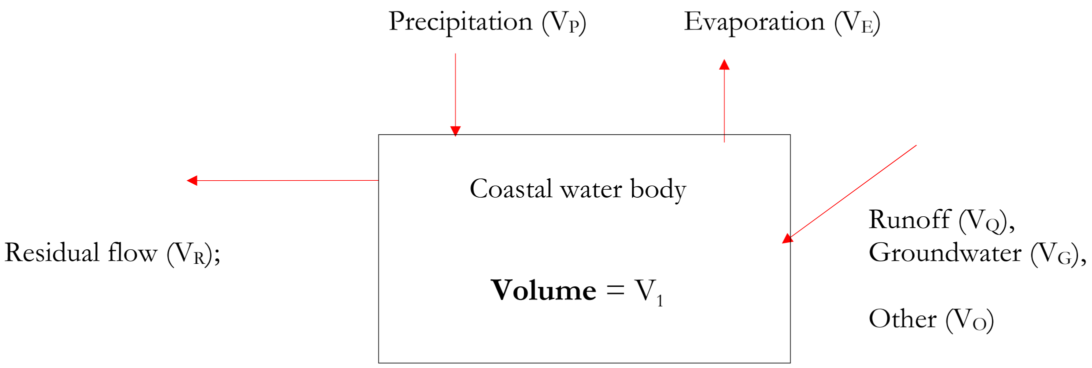
Figure 1.6. GDP growth during five years of Open-Policy. (Note: A-F-F=Agriculture, Forestry and Fishery).

2. THE BIOGEOCHEMICAL MODEL

2.1. Methodology: Methods for constructing the biogeochemical model are mainly from the LOICZ Biogeochemical Modelling Guidelines (Gordon et al. 1996)

2.1.1. Water and salt balances

The following is a simple model of the water exchange process in the estuary



The equation presented this process [5,6]:

$$\frac{dV(t)}{dt} = V_Q + Vp + Vo + V_G + V_{in} - V_E - V_{out} \qquad (1)$$

$$V_{in} - V_{out} = \frac{dV(t)}{dt} - (V_Q + V_P + V_O + V_G - V_E) \qquad (2)$$

In which

V_Q: Runoff (m^3/day) ; V_P: Rainfall (m^3/day)

V_O: Sewage (m^3/day) ; V_G : Ground water discharge (m^3/day)

V_E: Evaporation (m^3/day)

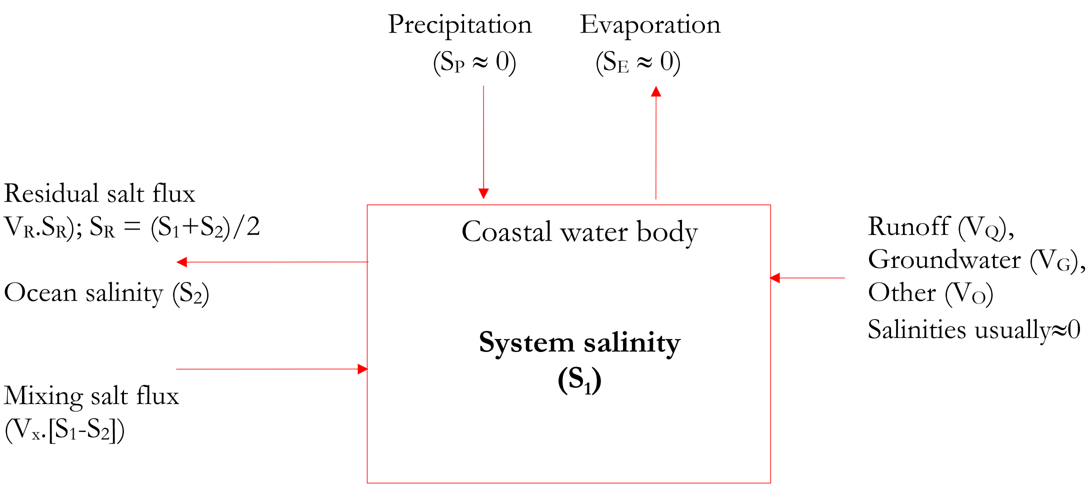
V_{in} and V_{out}: Input and output water to the system (m^3/day) and

$$V_R = V_{in} - V_{out} = \frac{dV(t)}{dt} - (V_Q + V_P + V_O + V_G - V_E) \qquad (3)$$

if $\frac{dV(t)}{dt} = 0$ we have :

$$\boxed{V_R = -(V_Q + V_P + V_O + V_G - V_E) = -V_{Q*} \qquad (4)}$$

In the condition of steady state, this exchange process has to be balanced by the salinity in the system. The figure below presents a simple model of this process



The basic equation of salt balance is as follows

$$\frac{d(V_1S_1)}{dt} = V_{Q^*}S_{Q^*} + V_{in}S_2 - V_{out}\,S_1 \qquad (5)$$

S_1 and S_2 are inside and outside salinities of the system. For most applications, all other salinities except S_1 and S_2 is very small and can be considered to be 0.

$$\frac{d(V_1S_1)}{dt} = V_{in}S_2 - V_{out}\,S_1 \qquad (6)$$

In this equation, the mixing change terms (V_{in} V_{out}) is unknown. By combining the above equations and expanding the term $d(V_1S_1)$, V_{in} and V_{out} it can be evaluated as follow:

$$V_{in} = \frac{1}{(S_2-S_1)}[Vq^*.S_1 - V_1\frac{dS_1}{dt}] \qquad (7)$$

and

$$V_{out} = \frac{1}{(S_2-S_1)}[Vq^*.S_1 - V_1\frac{dS_1}{dt}] - \frac{dV_1}{dt} + Vq^* \qquad (8)$$

If V_1 is constant, $\frac{d(V_1)}{dt} \approx 0$, $V_{in} = V_{out} - V_{Q^*}$

It is convenient to redefine V_{in} as the water exchange flow: V_x, and the salinity at the boundary is defined as S_R, we have

$$V_x = \frac{1}{(S_2-S_1)}[-V_1\frac{dS_1}{dt} - VrSr] \qquad (9)$$

or

$$V_x = \frac{1}{(S_1-S_2)}[V_1\frac{dS_1}{dt} + VrSr] \qquad (10)$$

S_r is the estimated average residual salinity of inside and outside of system

$$Sr = \frac{S_1+S_2}{2}$$

If S_1 is also constant:

$$\frac{d(S_1)}{dt} = 0$$

$$V_x = \frac{1}{S_1 - S_2}\left[\frac{Vr(S_1+S_2)}{2}\right] \quad (11)$$

2.1.2. Conservative and non-conservative material balance

With conservative material Y (salinity: Y=S) the balance or budget equation is as follow

$$\frac{d(VY)}{dt} = \sum V_{in}.Y_{in} - \sum V_{out}.Y_{out}$$

or (12)

$$V\frac{dY}{dt} + Y\frac{dV}{dt} = \sum V_{in}.Y_{in} - \sum V_{out}.Y_{out}$$

With non-conservative materials Y (such as DIN, DIP..) the balance or budget equation as follow :

$$V\frac{dY}{dt} + Y\frac{dV}{dt} = \sum V_{in}.Y_{in} - \sum V_{out}.Y_{out} + \Delta Y$$

or (13)

$$\Delta Y = V\frac{dY}{dt} + Y\frac{dV}{dt} - \Sigma V_{in}Y_{in} + \sum V_{out}Y_{out}$$

ΔY can be considered as the material balance in the system. Its units are mass of material per time, generally presented as moles per day or mmol per m^2 per day. *ΔY* may be contributed to by physical and biotic chemical processes.

2.1.3. Stoichiometrically linking the non-conservative C, N and P budgets

Phosphorus - Carbon stoichiometry:
The ratio of C:P in the particulate material $(C:P)_{part}$, multiplied by the non-conservative flux of DIP becomes an estimate of organic matter (*p-r*) [6]

$$(p\text{-}r) = -\Delta DIC_o = \Delta DIP\,(C/P)_{part} \quad (14)$$

- System with ΔDIP > 0 is interpreted to be production DIC via net respiration (*p-r*<0)
- System with ΔDIP <0 is interpreted to be consuming DIC via net organic production (*p-r*>0).
-

If the system is a calcifying system, then:

$$\Delta DIC_t = \Delta DIP\,(C/P)_{part} + \Delta DIC_g + \Delta TA/2 \quad (15)$$
$$\Delta DIC_g = \Delta DIC_t - \Delta DIP\,(C/P)_{part} - \Delta TA/2 \quad (16)$$

Nitrogen - phosphorus stoichiometry
Conversion from N_2 gas to organic nitrogen is termed "nitrogen fixation" while conversion from NO_3- to N_2 is termed "denitrification". (*nfix - denit*) is the net effect of this transfer and often qualitatively significant to the nitrogen budget.

$$(nfix - denit) = \Delta DIN - \Delta DIP\,(N/P)_{part} \quad (17)$$
$$\Delta DIN_{obs} = \Delta N_{(NO3)} + \Delta N_{(NH4)} + \Delta N_{(NO2)} \quad (18)$$

$\Delta N_{(NH4)}$, $\Delta N_{(NO2)}$ tend to be small relative to $\Delta N_{(NO3)}$. The ratios N/P, C/P depend on the ecosystem:

- Redfield C: N: P molar ratio of 106:16:1 can be used for plankton.
- With various land plants the C:N:P ratio is 1000:30:1

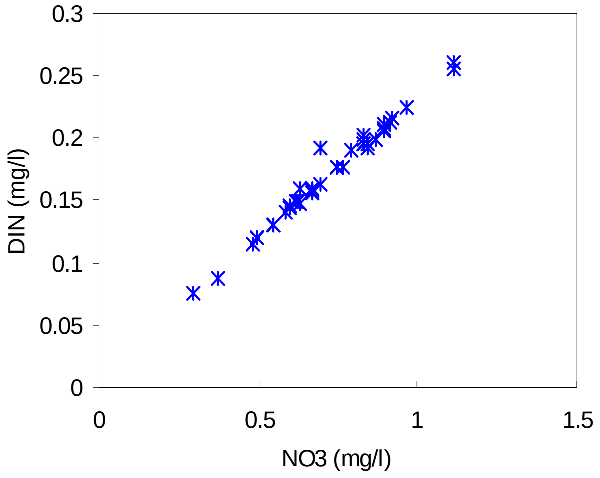


Figure 2.1. Relationship between DIN and NO3 in the flooding season

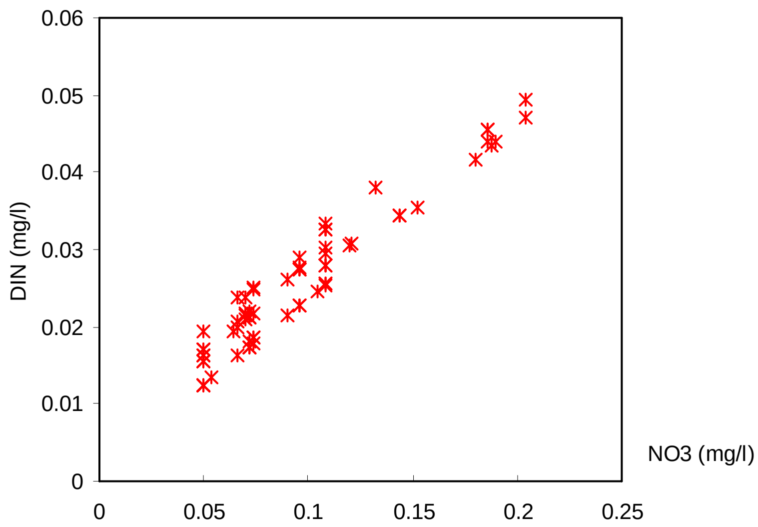


Figure 2.2. Relationship between DIN and NO3 in the dry season.

For the biogeochemical modelling, water data including salinity, alkalinity, pH, PO_4, NH_4, NO_3, CO_3, HCO_3, total P and total N have been collected and analyzed from a set of secondary data available from the National Hydro-meteorological Monitoring Station Network and recent surveys during 1996 - 1998 within the context of the SWOL project.

A close relationship among the chemical data have been found, such as: the correlation coefficient between NO_3 and DIN is 0.857; Total N and DIN : 0.864; , Total P and DIP : 0.890; NH_4 and DIN :0.895, as presented in the two figures above.

2.2. Results

2.2.1. Water and salt budget

The differentiation of data collected in two seasons from the Red River system with respect to the salt budget have been analyzed for March (dry season) and August (wet season).

The input data and components of water balance of the research site is presented in tables 2.1 and 2.2.

Table 2.1. Input data for water balance in the research site.

	Evaporation (mm)	Rainfall (mm)	Run-off (m^3/s)	S1 ($^o/_{oo}$)	S2 ($^o/_{oo}$)
March	35.8	34.5	318.5	11.36	26.7
August	99.7	335.2	3,164.0	6.34	19.0
Annual total	**973.8**	**1838.2**	**1246.0**	**9.20**	**24.4**

Based on equations from 1 to 11, it can be calculated daily values of freshwater volume of inflow to system from rainfall (P), Runoff (Q), Groundwater (G); going out system from Evaporation (E), outflow (Vr) and exchange flow (Vx). These calculated results were in round figures to (10^3 m^3 /day) and presented in the table below.

Table 2.2. Components of water balance in the research site ($10^3 m^3$/day).

	Rainfall	Evaporation	Runoff	Ground water	Vr	Vx
March	119	-124	27,518	74	-27,588	34,224
August	1,157	-344	273,370	74	-274,256	274,473
Annual total	**539**	**-285**	**107,654**	**74**	**-107,980**	**119,346**

From these results it is noted that:

- The hydrological regime of the two seasons yields a difference of evaporation in the estuary, especially at the beginning and end of the dry and wet seasons.

- The runoff of the system is high. For example, in the dry season the total is much smaller than that in flood season but the value of freshwater flows into the system by runoff is still ten times than rainfall. It affects the value of freshwater outflow (Vr). The exchange flow of system (Vx), therefore, is positive. The saline-water daily input from the sea by tidal flow is large. This has a considerable significance in salinity balance of the system.

2.2.2. DIP budgets

The dissolved inorganic phosphorus (DIP) is mainly taken from PO_4. Concentration of P in PO_4 of water is considered as DIP. Up to now, data has been scarce with respect to PO_4 in rain and ground water; therefore we have to assume that PO_4 in rainwater is 0 and PO_4 in ground water equals PO_4 in river water. The DIP concentration in water sources within the system are presented in Table 2.3.

Table 2.3. PO_4 concentration in water sources (g/m^3).

	River branches	Whole system	Sea
March	0.12	0.07	0.03
August	0.50	0.27	0.09
Annual total	**0.29**	**0.14**	**0.05**

Based on equations 13 and 14, the DIP budgets were calculated and Table 2.4 shows some of these calculated results. The model of DIP budget and flow is presented in Figures 2.3, 2.4 and 2.5.

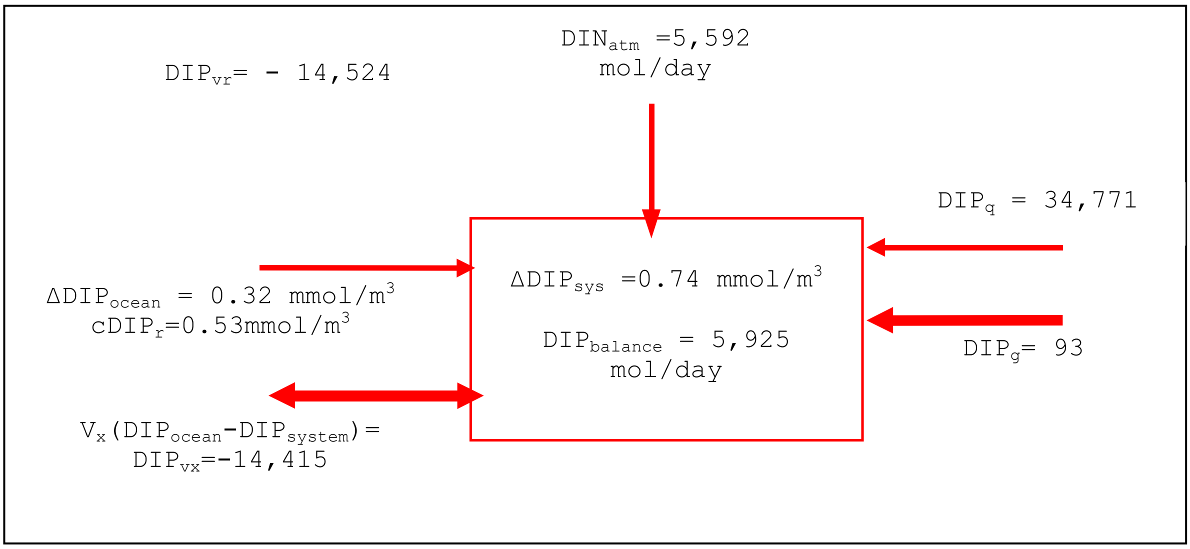


Figure 2.3. Daily DIP budgets in March (mol/day).

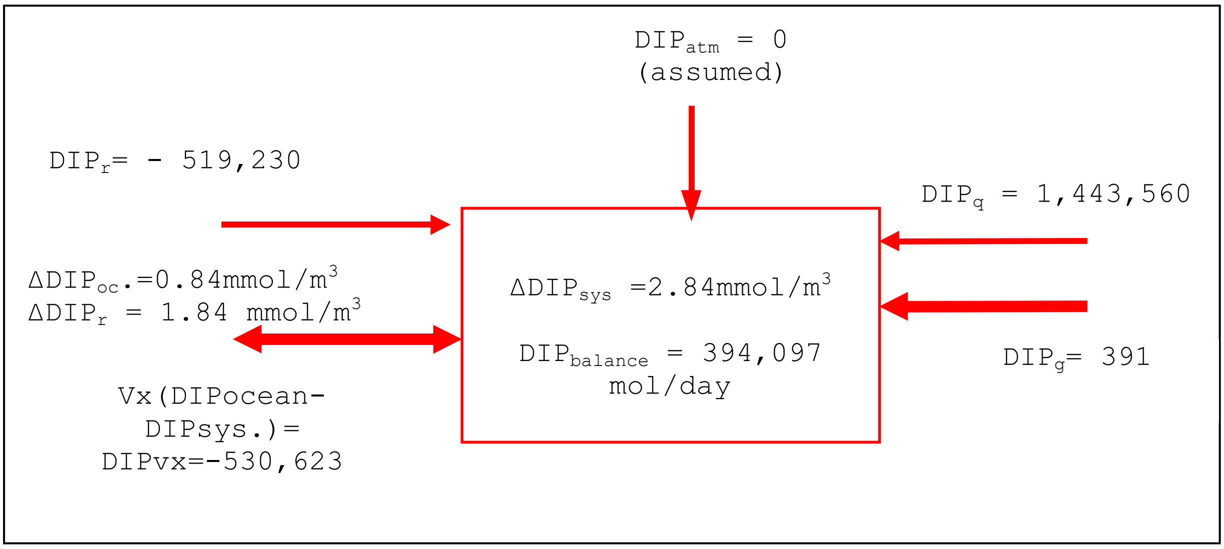


Figure 2.4. Daily DIP budgets in August (mol/day).

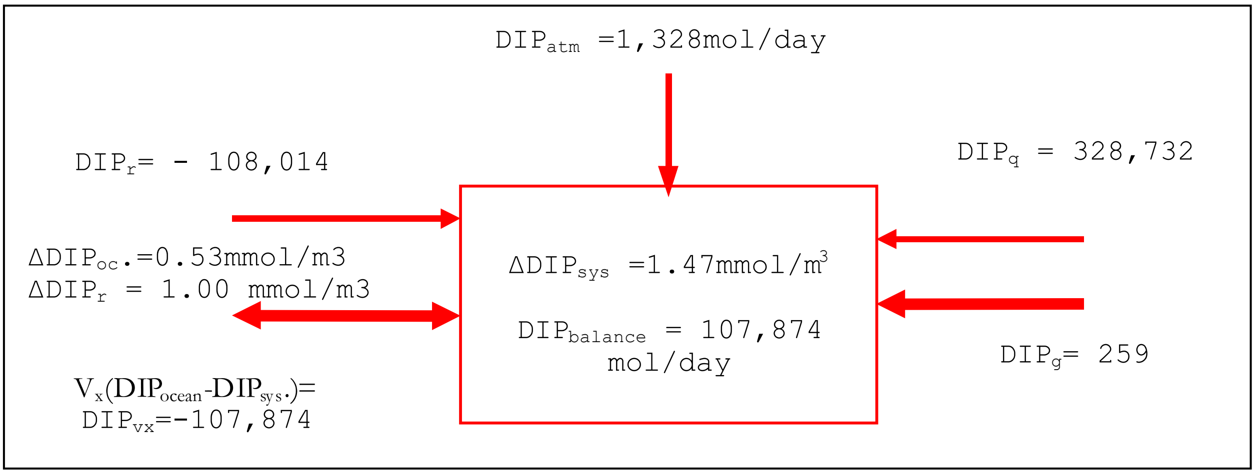


Figure 2.5. Annual DIP budgets (mol/day).

Table 2.4. Inorganic P flows and balances in mmol m^{-2} d^{-1} for the study system.

Month	DIP_g	DIP_r	DIP_{vr}	DIP_{vx}	Daily DIP input	Daily DIP balance
January	0.000	0.128	-0.081	-0.096	0.129	-0.049
February	0.000	0.203	-0.103	-0.104	0.203	-0.004
March	0.001	0.325	-0.136	-0.135	0.326	0.055
April	0.002	0.751	-0.243	-0.221	0.752	0.288
May	0.003	2.069	-0.598	-0.534	2.071	0.939
June	0.003	6.213	-2.096	-1.861	6.216	2.259
July	0.004	11.387	-3.903	-3.488	11.391	4.000
August	0.004	13.491	-4.853	-4.959	13.495	3.683
September	0.003	8.772	-2.958	-3.195	8.776	2.623
October	0.003	4.427	-1.317	-1.165	4.429	1.947
November	0.002	2.129	-0.626	-0.594	2.131	0.911
December	0.001	0.604	-0.251	-0.262	0.604	0.092
Average	**0.002**	**4.208**	**-1.430**	**-1.385**	**4.210**	**1.395**

From the results presented, it can be noted that:

- Nutrients in general and PO_4 in particular has a quick reduction during transport from the river to the sea. Its concentration in the flood season is greater than that in the dry season.

- Annual discharge of freshwater from the Red River system to the sea is rather large, driving DIP input to the system from river up to hundreds of thousand mol per day. DIP balance in the estuary is always positive with annual value being more than a hundred thousand mol/day, up to more than three hundred thousand mol/day in flood season.

2.2.3. DIN budget

The dissolved inorganic nitrogen (DIN) is largely nitrogen as NO_3 and NH_4. It is also an important nutrient in the water. Table 2.5 presents the concentration of NO_3 in water sources participating to the exchange process of DIN in the system. The NO_3 and NH_4 data has been collected and analyzed from three stations: PhuLien, HaiDuong and NinhBinh during two years 1996-1997 of the observation.

Table 2.5: NO_3 concentration in water sources (g/m^3)

	From rainfall	River branches	Whole system	Sea
March	0.48	0.41	0.14	0.09
August	0.34	0.79	0.12	0.08
Annual total	**0.44**	**0.55**	**0.13**	**0.09**

As with PO_4, the concentration of NO_3 is also reduced quickly from the river system to the sea. The concentration of NO_3 and DIN in the flood season is only higher than that in dry season in the case of river branches. The DIN exchange in the river estuary has been calculated by using equations 13 and 14. The result is presented in Table 2.6.

Table 2.6: Inorganic N flows and balance in mmol m^{-2} d^{-1} for the study system.

	DINg	DINp	DINr	DINvr	DINvx	Daily DIN input	Daily DIN Balance
January	0.004	0.009	2.027	-1.513	-0.490	2.040	-0.037
February	0.005	0.011	2.361	-1.249	-0.373	2.377	-0.755
March	0.007	0.012	2.531	-1.040	-0.293	2.551	-1.218
April	0.008	0.035	3.614	-1.192	-0.286	3.657	-2.179
May	0.010	0.065	7.503	-2.071	-0.384	7.577	-5.122
June	0.011	0.074	21.013	-5.033	-0.735	21.098	-15.329
July	0.012	0.080	36.836	-8.153	-1.130	36.928	-27.645
August	0.012	0.091	43.643	-9.728	-1.619	43.746	-32.400
September	0.011	0.084	29.670	-7.199	-1.438	29.765	-21.128
October	0.010	0.055	16.437	-4.545	-1.005	16.502	-10.952
November	0.008	0.023	9.090	-3.156	-0.943	9.120	-5.021
December	0.005	0.007	3.728	-1.967	-0.650	3.741	-1.125
Average	**0.009**	**0.045**	**14.871**	**-3.904**	**-0.779**	**14.925**	**-10.243**

The DIN mass from runoff water occupies a major part of DIN balance in the system. DIN from direct rainfall is also rather high. Annual value of DIN balance is up to 8 hundred thousand mol per day.

The mixing flow has a negative value in removing more than 32 thousand mol per day. In order to support this net export, there must be a positive value for DIN balance. Thus, calculated value presented in Table 2.6 for annual as well as monthly DIN balance is positive with values from hundred thousand to million mol/day. The model of DIN budget and flow is presented in Figures 2.6, 2.7 and 2.8.

2.2.4. Modelling

By using Stella 2, a linkage at the same time of three sub-models of water and salt budgets as well as DIP and DIN budgets of the complex system has been done and presented in Figure 2.9. These models are linked together in one combined model as a united form of all systems. All elements are incorporated into the system are linked. Any change of one quantity will influence the others and the final result. First is the basic model, the second and the third depend only on the first and are independent of each other but in the next step they are linked together to study the stoichiometric modelling.

Table 2.7. Monthly water budget input data for the Red River estuary (10^3 m^{-3} d^{-1}).

	Evaporation V_e	Ground water V_g	Precipitation V_p	River flow V_q	S system S_1 (0/00)	S ocean S_2 (0/00)	Residual flow V_r	Exchange flow V_x
January	204	74	66	38,405	11.69	28.3	-38,340	46,154
February	149	74	96	32,357	11.13	27.5	-32,378	38,186
March	124	74	119	27,518	11.36	26.7	-27,588	34,224
April	168	74	372	32,054	10.8	27.2	-32,332	37,457
May	321	74	766	56,851	9.65	27.4	-57,370	59,860
June	396	74	937	140,918	7.37	25.4	-141,533	128,654
July	433	74	1,090	230,731	6.34	22.1	-231,462	208,844
August	344	74	1,157	273,370	6.34	19	-274,256	274,473
September	331	74	970	198,979	7.17	19	-199,692	220,877
October	352	74	587	123,077	7.67	21.5	-123,386	130,122
November	328	74	214	83,462	9.83	22.8	-83,422	104,937
December	265	74	61	51,106	11.55	25.9	-50,976	66,518

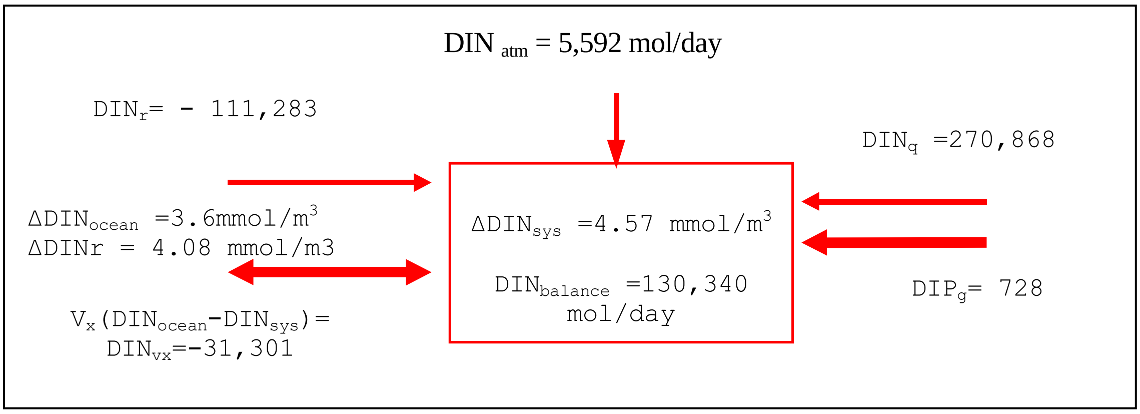


Figure 2.6. Daily DIN budgets in March (mol/day).

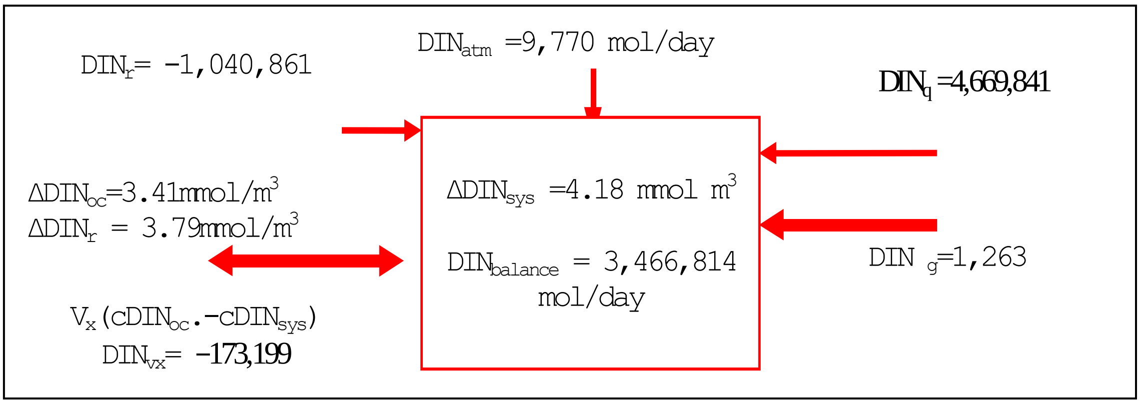


Figure 2.7. Daily DIN budgets in August (mol/day).

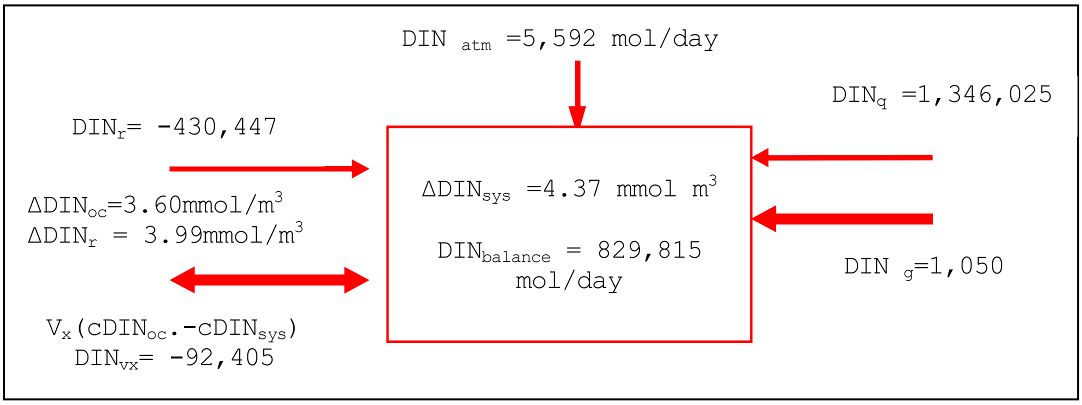


Figure 2.8. Annual DIN budgets (mol/day).

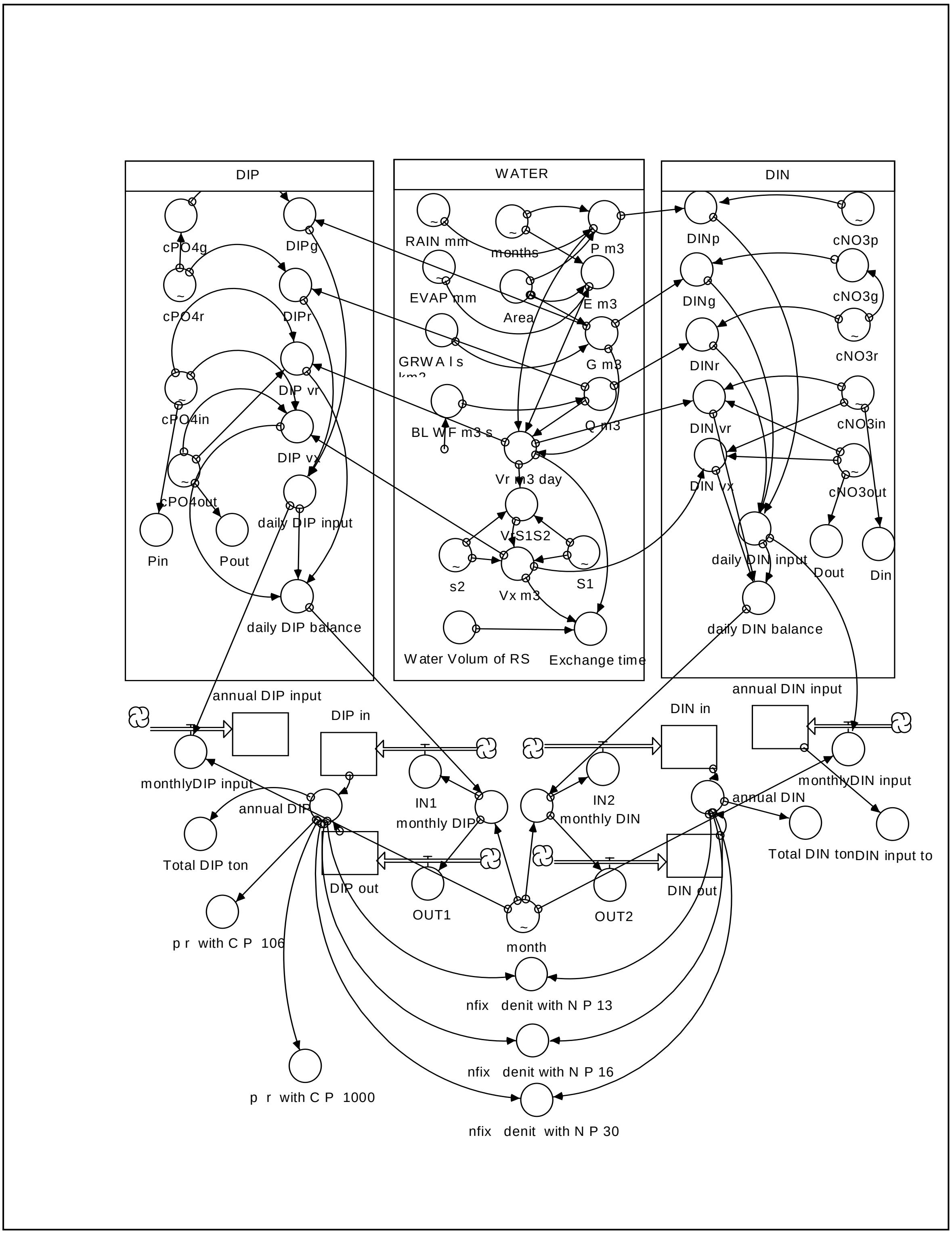


Figure 2.9. Modelling water and C, N and P budgets and flows in the system.

Assuming steady state and all above conditions are satisfied, Stella 2 gives us water and salt budget for all 12 months presented in Table 2.7. The annual total value of DIP and DIN input and balance in the system of the system is presented in Table 2.8.

Table 2.8. Annual DIP and DIN input and balance of the system.

	Annual balance(10^3mol)	Annual input (10^3mol)	Total (ton)
DIN	402,496	586,225	5,635
DIP	54,894	165,610	1,700

Stoichiometric calculations of aspects of net system metabolism

By using stoichiometric modelling, the value of $\Delta(DIC)_{est}$ and $\Delta(DIN)_{est}$ can be indirectly calculated from the ratio of C/P , N/P and ΔDIP of the system. Then, the values of (*p-r*) and (*nfix-denit*) of the system are also calculated following equations 14 and 18

In this report ratios of C:N:P and N/P were chosen as follow
- Redfield C:N:P ratio of plankton: 106 : 16 : 1
- In the state of more typical of various land plants C : N : P = 1000: 30 : 1
- With mangrove in the north of Vietnam N : P = 13 : 1

From the models developed by Stella 2, values of (*p-r*) and (*nfix-denit*) of the annual state of the system have been calculated. These results are presented in the Table 2.9.

Table 2.9: Annual state of system (10^3mol/day)

Months	*nfix - denit* with N/P=13	*nfix - denit* with N/P=16	*nfix - denit* with N/P=30	*p-r* with C/P =106	*p-r* with C/P =1000
Annual total	-852	-1,304	-3,409	-15,942	-150,395

From these results, the following remarks have been highlighted:

- In the three states, the calculated values of (*nfix-denit*) are negative. Denitrification exceeds nitrogen fixation throughout the year and the coastal system is therefore, an important sink of nitrogen.

- Regarding both states, the net ecosystem metabolism (NEM or [*p-r*]) is negative. That means that the system is net heterotrophic throughout the year.

2.3. Conclusion

This is the first time C, N and P budgets and fluxes of the coastal zone of the Red River system have been done by biogeochemical modelling. Data input, especially parameters of hydrological and chemical concentrations are still limited not only in quality but also quantity. Therefore, the results presented in this report are only preliminary ones. In order to have better results estimating water balance as well as the DIP and DIN budgets in the Red River estuary, it is necessary to continue doing surveys as well as research in this area. The Stella 2 is a sound application for biogeochemical modelling in this case study.

Table 2.10. Summary of data collected and analyzed in the biogeochemical modelling for the Red River system.

Water and salt budget			
Evaporation	Ve	10^3 $m^{-3}d^{-1}$	284.58
Ground water	Vg	10^3 $m^{-3}d^{-1}$	74
Precipitation	Vp	10^3 $m^{-3}d^{-1}$	536
River flow	Vq	10^3 $m^{-3}d^{-1}$	107,402
S system	S1	0/00	9
S ocean	S2	0/00	24
Residual flow	Vr	10^3 $m^{-3}d^{-1}$	-107,728
Exchange flow	Vx	10^3 $m^{-3}d^{-1}$	112,526
Inorganic N flows and balance			
DINg		mmol m-2 d-1	0.009
DINp		mmol m-2 d-1	0.045
DINr		mmol m-2 d-1	14.871
DINvr		mmol m-2 d-1	-3.904
DINvx		mmol m-2 d-1	-0.779
Daily DIN input		mmol m-2 d-1	14.925
Daily DIN balance		mmol m-2 d-1	-10.243
Inorganic P flows and balance			
DIPg		mmol m-2 d-1	0.002
DIPr		mmol m-2 d-1	4.208
DIPvr		mmol m-2 d-1	-1.43
DIPvx		mmol m-2 d-1	-1.385
Daily DIP input		mmol m-2 d-1	4.21
Daily DIP balance		mmol m-2 d-1	1.395

Stoichiometric calculation for the annual state of the system. Annual total (10^3 mol per day)

nfix - denit with N/P = 13	- 852
nfix - denit with N/P = 16	- 1,304
nfix - denit with N/P = 30	- 3,409
p-r with C/P = 106	- 15,942
p-r with C/P = 1000	- 150,395

3. THE REGIONAL INPUT - OUTPUT MODEL

3.1. The Region and Surveys

The Red River region covers 19 provinces, namely: Lai Chau, Lao Cai, Yen Bai, Son La, Ha Giang, Tuyen Quang, Vinh Phuc, Phu Tho, Hoa Binh, Son Tay, Ha Dong, Ha Noi, Hai Phong, Hai Duong, Hung Yen, Thai Binh, Nam Dinh, Nam Ha and Ninh Binh. The region has mountainous, mid-land, delta plain and coastal areas. This region was chosen because economic sectors in all provinces have impact on environmental changes in the coastal zone.

The eleven sectors recommended by the World Health Organization (WHO) plus household consumption are defined for Vietnam as: (1) agriculture, (2) fishery/aquaculture, (3) forestry and hunting, (4) mining and quarrying, (5) manufacturing 1 (heavy), (6) manufacturing 2 (light), (7) electricity and gas, (8) water supply, (9) transportation, (11) other services and (12) household consumption sector. All survey for regional I - O table is designed by following procedures:

- Preparation of questionnaires
- Identifying establishments: main products, by-products and others
- listing production units for sectors
- Sampling survey design/ conduct of pre-survey.
- Survey training: surveyors (economic, account...)
- Conduct of Field Survey Operations

3.2. Constructing the regional I-O table

3.2.1. Methodology and Data sources

The conventional I-O table of 11x11 sectors for the Red River region was initially constructed based on the GSO's national I-O tables for 1995 and 1996. Proper adjustments were then effected on this initial table based on data that were generated from the regional survey.

Available data obtained form the National Accounts Department of the General Statistical Office (GSO) and other government statistical sources provided the basic data. These were augmented by a ground-up field evaluation in the provinces covered to better meet the data requirements of the I-O model. Regional data on the household consumption sector were derived from a national project on "Vietnam Living Standards Survey, 1992 - 1993" by the State Planning Committee and the GSO.

The problem of how to maintain homogeneity of product grouping, one of the main attributes of I-O economics, also exists in constructing regional I-O tables. This problem occurs when a production unit engages in the production of not only its principal or characteristic product, but also secondary products. A secondary product if defined to be a good or service whose output is relatively smaller than the principal product of the unit's total gross output. Depending on the availability of information, the rule in I-O compilation is that the production structure of secondary products should be separated from its main or principal product. In other words, output of secondary production together with its corresponding cost or inputs should be transferred to the I-O sector where it is classified as the main product.

This problem of output and input transfers between sectors is best solved by conducting a highly-specialized supplemental survey to obtain more detailed information. When resources are insufficient to conduct this *ad hoc* survey, the alternative is to make use of mechanical methods of "purifying" the I-O table, following some restrictive technology assumptions. This mathematical method of adjusting the coefficients was adopted in this exercise.

As in national I-O tables, the first task in constructing regional I-O tables is to compile the basic tables, given the basic information generated from the regional I-O survey. These basic tables are the output or MAKE matrix of the industry x product format and the input or USE table of the product x industry format.

The second phase of the work is to "purify" the basic USE table. "Purifying" the USE table refers to the intersectoral transfer of inputs and outputs in order to produce a product x product I-O that is deemed best useful and meaningful for I-O analysis.

3.2.2. Constructing the MAKE Matrix
The MAKE matrix shows the distribution of the values of products produced by industries during the accounting period, based on the classification scheme of sectors identified in this study. Entries in this matrix are valued at producers' prices.

The MAKE matrix is an industry x product table where in the rows represents the industries while the columns represent the products. It is formulated by the following function:

$$V = (V_{kj})_{\text{industries x products}}$$

where V_{kj} represents industry sector k producing product j.

It can be observed that cell elements along the diagonal of the V matrix are the main products of each column sector and elements off diagonal account for the secondary products (if any).

3.2.3. Constructing the USE Matrix
The USE matrix is calculated from input or production structures of each sector surveyed. It is a product x industry table where in the rows represent the products and the columns denoting the industries. The following function is introduced:

$$X^1 = (X^1_{jk})$$

where X^1_{jk} is sector k using product j in the production process.

We then have the following model:

	k	
j	X^1 (Plot I)	Y^1 (Plot II)
	L^1 (Plot III)	

The model can be constructed from survey results. It includes the matrix of intermediate input or USE structures of industries, X^1, the matrix of value added, L^1 and the consumption matrix, Y^1.

The compilation of these matrices is articulated in sufficient detail in the Technical Appendix of this Paper.

3.2.4. Constructing the matrix of intermediate input coefficients
In its economic sense, the main objective of constructing I-O tables is to measure and analyze the relationship between sectors in the process of production and consumption. This relationship can be determined using the following equation:

$$q = (E - A)^{-1}.\ Y$$

where q: vector of gross output
Y: vector of final demand
E: unit matrix
A: matrix of intermediate input coefficients

As stated earlier, I-O analysis based on a product x product table gives more meaningful results. It is therefore essential to convert he basic product x industry USE matrix (X^1) into a "pure" product x product matrix of intermediate input transactions. In other words, matrix A in the formula should be computed from a USE table of product x product format.

The method used in "purifying" the basic USE matrix is the mathematical approach for the simple reason that resources for the conduct of an in-depth survey to gather required inputs data at the product level are quite limited.

The procedure for calculating the matrix of intermediate input coefficients, A, is shown as follows:

1. Given the MAKE matrix (V), the vector of industry outputs, g, can be derived from the following function:

$$g = Vi \qquad (1)$$

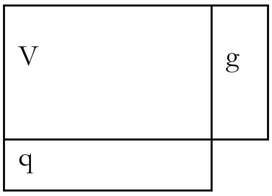
where: i: unit vector

By transposition, we have:

$$q = V'i \qquad (2)$$

where: q: gross outputs of products
v': transposed matrix of V
i: unit vector

It is described by the following model:



2. The coefficients of intermediate demand matrix (A^1) can be calculated from the equation:

$$X^1 = A^1.\hat{}g \qquad (3)$$

where: X^1: coefficient of intermediate demand matrix
^g: diagonal matrix in which element of vector g are shown in the diagonal and elements in the off-diagonal are all equal to zero.

3. The coefficients of the MAKE matrix (V) can be calculated from equation:

$$V' = C\hat{}g \qquad (4)$$

where: V': transpose of matrix V
C: coefficient matrix of V

$$C_{jk} = \frac{V_{kj}}{g_k}$$

where C_{jk}: elements of C matrix
V_{kj}: value of product j produced by industry k
g_k: gross output of industry k

4. Given the USE matrix and vector of final demand, Y, we have: $q = X^1 i + Y$.
Substituting X^1 in equation (3), we have:

$$q = A^1 g + Y \qquad (*)$$

where $g = \hat{}gi$.

5. We have $Cg = C\hat{}gi$. From equation (4), we have: $Cg = V'i$ and $Cg = q$ or $g = C^{-1}.q$. Equation (*) therefore becomes $q = A^1.C^1.q + Y$, and

$$q = (E - A^1.C^{-1})^{-1}.C^1.Y \qquad (5)$$

6. The coefficient matrix of intermediate demand (A) is therefore equal to:

$$A = A^1.C^{-1} \qquad (6)$$

where:
A^1 is coefficient matrix of product (row) x industry (column) dimension level;
C^{-1} is inverse of coefficient matrix of industry (row) x product (column) dimension level.

The level of matrix A is "purified" into a product x product matrix of coefficients through the *commodity technology* assumption which assumes that products have the same input structures wherever they are produced. This approach is deemed to be more economically plausible than the *industry technology* assumption which states that a secondary product produced by an industry possess the same input structure as its main product.

Using equation (6), however, produces some negative numbers that are economically insensible. To eliminate these negative coefficients in matrix A, the following procedures are adopted:

i. If negative numbers are observed to be very minimal, these coefficients are then considered to be zero, and rebalance the A matrix using the RAS method

ii. If negative coefficients in A are relatively large, make adjustments by reviewing basic data used in constructing the MAKE and USE matrices, and recalculate the A matrix using equation (6). Apply the RAS method when negative numbers are found to be small.

A comprehensive discussion of the RAS method of adjusting the coefficient table is shown in the Technical Notes of this paper.

3.2.5. "Purifying" the matrix of value added, L^1 (plot III in I-O model)
Plot III (value added matrix) is "purified" following the same method used in "purifying" Plot I (matrix of intermediate input coefficients), as follows:

$$L = L^1.C^{-1}$$

where:
L: matrix of value added of product x product dimension level;
L^1: matrix of value added with its columns representing industries or sectors and its rows denoting the primary factors of production consisting of compensation of employees, production tax, consumption of fixed capital and operating surplus; and
C^{-1}: inverse of the MAKE matrix of coefficients.

3.2.6. Product x Product I-O Tables for the Red River Region
Table 3.1 shows the matrix of direct input coefficients computed from the final transactions table for the Red River Region for 1996. Table 3.2 is the matrix of inverse coefficients, i.e. $(E-A)^{-1}$ in the Leontief equation, $X = (E-A)^{-1}Y$.

Each cell element in Table 3.2 accounts for the total (direct plus indirect) output requirement of a certain product (sector) per unit of its final demand. It can be observed that coefficients along the diagonal are more than unity. This means that production by a particular product (sector) has to be increased by more than one unit to meet the input requirements of other production sectors so as to satisfy one unit of ultimate demand by the final consumption sectors.

Table 3.1: Conventional 11x11 sectors input - output table for 19 provinces in the Red River region in 1996 *(at producer's price in million VND)*

Sectors	1	2	3	4	5	6	7	8
1. Agriculture	3,277,066	37,367	90,329	651	1,045,215	53,662	-	-
2. Fishery	-	72,858	-	-	748,557	12,780	-	-
3. Forestry and hunting	1,885	1,175	55,223	2,978	44,364	348,913	1,947	-
4. Mining and quarrying	1,795	7,304	27,933	18,773	32,213	58,409	113,993	-
5. Manufacturing I (Heavy)	2,550,576	85,768	36,933	11,096	3,502,665	653,602	554	-
6. Manufacturing II (Light)	465,418	180,262	11,823	251,056	451,756	2,967,563	433,569	47,166
7. Electricity, gas	257,330	3,141	74,597	36,854	100,356	185,798	162,218	7,536
8. Waterworks and supply	5,270	1,649	802	1,001	13,014	6,163	3,561	4,001
9. Construction	3,687	4,666	43,748	12,026	24,557	248,510	18,200	4,650
10. Transportation	1,139,354	27,817	27,530	34,802	450,951	322,096	40,938	11,335
11. Other services	2,096,987	68,253	119,947	100,125	614,197	814,099	94,436	19,184
Intermediate consumption	9,799,368	490,261	488,866	469,361	7,027,845	5,671,594	869,415	93,872
Value added	17,690,506	720,401	1,274,972	459,082	9,315,980	6,657,958	1,614,675	214,468
GI (gross input)	27,489,874	1,210,662	1,763,838	928,443	16,343,825	12,329,552	2,484,090	308,340

Sectors	9	10	11	First Demand	Consumption Expenditure	in which Consumption of household	Accumulation	Export - Import	GO	Y
1. Agriculture	48,292	6,811	1,031,591	5,590,984	12,244,273	12,244,273	(34,003)	9,688,619	27,489,874	21,898,890
2. Fishery	-	-	78,620	912,815	799,315	799,315	-	(501,469)	1,210,662	297,847
3. Forestry and hunting	31,455	269	73,410	561,619	464,664	464,664	7,077	730,478	1,763,838	1,202,219
4. Mining and quarrying	22,322	-	27,822	310,563	-	-	53,489	564,391	928,443	617,880
5. Manufacturing I (Heavy)	19,147	425,237	936,952	8,222,530	6,935,162	6,935,162	283,261	902,872	16,343,825	8,121,295
6. Manufacturing II (Light)	8,325,388	985,945	1,819,533	15,939,481	4,762,013	4,762,013	3,672,355	(12,044,297)	12,329,552	(3,609,929)
7. Electricity, gas	43,638	16,818	570,509	1,458,796	417,483	417,483	-	607,812	2,484,090	1,025,295
8. Waterworks and supply	2,783	1,886	38,560	78,690	162,927	162,927	-	66,722	308,340	229,650
9. Construction	-	786	439,656	800,485	-	-	12,414,711	-	13,215,196	12,414,711
10. Transportation	215,657	11,986	283,122	2,565,587	1,055,934	1,055,934	124,080	(822,241)	2,923,359	357,772
11. Other services	408,467	187,342	2,116,784	6,639,821	26,272,122	12,292,178	261,296	(12,176,453)	20,996,785	14,356,964
Intermediate consumption	9,117,148	1,637,081	7,416,559	43,081,370	53,113,892	39,133,948	16,782,266	(12,983,564)	99,993,964	
Value added	4,098,048	1,286,278	13,580,226	56,912,594			16,782,297			
GI (gross input)	13,215,196	2,923,359	20,996,785	99,993,964						

Table 3.2: Leontief inverse matrix (at producer's price)

Sectors	1	2	3	4	5	6	7	8	9	10	11
1. Agriculture	1.154508592	0.055033522	0.070322916	0.018996763	0.103017506	0.024784458	0.009329293	0.010137223	0.02295647	0.030873933	0.072413382
2. Fishery	0.008341901	1.071283715	0.00305047	0.004557034	0.064331464	0.007571633	0.002299605	0.002364836	0.00540805	0.012591541	0.00924674
3. Forestry and hunting	0.003353709	0.009565576	1.035387017	0.017484557	0.007095184	0.041624876	0.010427265	0.008375	0.029341795	0.015946514	0.009892914
4. Mining and quarrying	0.001900345	0.009052831	0.019937585	1.026245452	0.004461253	0.009297702	0.052474942	0.003323679	0.008042862	0.004416151	0.004694769
5. Manufacturing I (Heavy)	0.159817673	0.13444428	0.052570839	0.069432729	1.311156863	0.114040904	0.033674006	0.034377486	0.08140055	0.236678591	0.092190369
6. Manufacturing II (Light)	0.080685998	0.262465481	0.080908477	0.450303344	0.103110126	1.39408466	0.306271902	0.267584995	0.894591513	0.501398159	0.184102124
7. Electricity, gas	0.017942423	0.012777218	0.053262615	0.057726802	0.014682339	0.0296672	1.080466241	0.034930872	0.024108961	0.020986943	0.038510102
8. Waterworks and supply	0.000690338	0.001982331	0.000887543	0.001866611	0.001429708	0.001144261	0.001992152	1.01359241	0.001048432	0.001421517	0.002409494
9. Construction	0.004759333	0.012263295	0.030178802	0.026949702	0.00637045	0.032206202	0.016812507	0.023333993	1.021602652	0.014069501	0.028444725
10. Transportation	0.056886698	0.039979587	0.026318457	0.057297006	0.046570739	0.044616999	0.030865094	0.04841874	0.046286523	1.028162618	0.02760015
11. Other services	0.116575379	0.102485166	0.100217238	0.169847844	0.080471119	0.119596179	0.080510927	0.098988151	0.114070672	0.126600203	1.142263395

3.3. Estimating residuals generated from production and consumption

From *LOICZ Meeting Reports* No. 28 and 32, the economic-environmental coefficient is calculated by the following formula:

$D^* = D\ (I - A)^{-1}\ Y$

Where: D^* = economic-environmental coefficients for generated residuals when increasing an unit of final demand from each sector:

$D = (d_{ij})_{mxn}$

where: D = Residual matrix

d_{ij} = quantity of residual type of i generated from sector j

m = type of residuals

n = number of sectors

The economic-environmental coefficient tables is presented in Table 3.3.

Table 3.3: Economic-environmental coefficients of residuals per unit of final demand for each sector (ton per million VND)

	1	2	3	4	5	6	7	8	9	10	11
BOD5	0.005427799	0.000663945	0.001845498	0.000719778	0.001139388	0.001198656	0.000416328	0.000876835	0.000912678	0.001178779	0.00170388
TSS	6.830030347	0.538894503	1.772544679	2.667895666	0.88279324	0.747439526	0.437900473	0.293664937	0.603329137	0.539517701	1.55272651
Nitrogen	0.001430745	0.00013562	0.000222435	0.000145343	0.00017368	0.000242689	9.08591E-05	0.000111522	0.000183108	0.000169156	0.00043372
Phosphorous	0.00086879	7.89479E-05	9.03975E-05	0.000321952	0.00012926	0.000130762	5.23455E-05	5.32742E-05	9.45641E-05	8.35325E-05	0.0002072

3.4. Forecasting the relationship between economic growth and residual generation

Prediction of natural processes and socio-economic aspects is a vital task in developing integrated modelling in the context of IGBP in general and SWOL in particular. The three scenarios of economic development for the Red River region have been designed from secondary documents (MOSTE 1994; GSO 1997). They illustrate economic growth in the last decade and predict for the next one. Economic development is obviously dependent on the institution and the social forces driving the development. The growth rate for each sector in Table 3.4 has been computed from the three scenarios.

Table 3.4: Forecasting the growth rate (in percentage) of each sector to the scenarios of socio-economic development

	Scenario 1	Scenario 2	Scenario 3
Growth rate of GDP (%)	*5.03*	*6.08*	*7.4*
1. Agriculture	3.50	4.23	3.80
2. Fishery	1.50	1.81	1.20
3. Forestry and hunting	0.00	0.00	0.00
4. Mining and quarrying	1.80	2.18	1.00
5. Manufacturing I (Heavy)	8.70	10.52	8.00
6. Manufacturing II (Light)	7.50	9.07	9.00
7. Electricity, gas	3.50	4.23	4.00
8. Waterworks and supply	3.50	4.23	3.50
9. Construction	4.00	4.83	8.00
10. Transportation	8.00	9.67	8.00
11. Other services	7.50	9.07	8.50

Economic development usually drives residual generation. It is also not exceptional for the region. However it is dependent on technical innovations of clean industry or reforestation efforts of national plans. The data presented in Table 3.5 shows percentages of increased residuals along with economic growth of the three scenarios, assuming that the status would be as at present.

Table 3.5: Forecasting the increased residuals (in percentage) to the scenarios of socio-economic development

	Scenario 1	Scenario 2	Scenario 3
Growth rate of GDP (%)	*5.03*	*6.08*	*7.4*
BOD5	4.39	4.85	6.83
TSS	3.78	4.04	6.45
Nitrogen	4.45	4.96	6.81
Phosphorous	4.18	4.51	6.73

3.5. Testing the extension of the I-O model in analysis of feedback

As presented, a basic I-O model of Leontief matrix showing the vector of production X in relation with the vector of final demand Y is following:

$$X = (I - A)^{-1}.\ Y \qquad (1)$$

where: A: input-output matrix; I: identity matrix

The extension of the I-O matrix to environmental variables is as following:

$$\begin{bmatrix} I - A & \phi \\ -V^* & I \end{bmatrix} \begin{bmatrix} X \\ V \end{bmatrix} = \begin{bmatrix} Y \\ \phi \end{bmatrix} \qquad (2)$$

where: V^*: matrix of residuals generated directly from production
V: vector of overall impacts of residuals
ϕ: the null matrix

The equation (2) is only related to residuals generated directly from production. A question is posing that whether the residual effects to production as a feedback, and V is a vector of two-ways impacts of residuals. We suggest the following equation to resolute the problem:

$$\begin{array}{c|c|c} & n & m \\ \hline n & I - A & \phi_1 \\ m & -V^* & I \end{array} \quad \begin{array}{c} X \\ \hline V \end{array} \quad \begin{array}{c} Y \\ \hline \phi_2 \end{array} \qquad (3)$$

Where: ϕ_1 is the feedback matrix in which residuals effect to production.
The matrix ϕ_1 is following:

$$\phi_1 = \left[\phi_{1ij} = \frac{U_{ij}}{V_j} \right]_{n \times m}$$

where: n: number of sectors in the I-O table
m: number types of residuals
U_{ij}: expenditure of sector i (i = 1, n) for abating the residual j
V_j: total residual j
ϕ_2: vector of the residual coming from other sources: rainfall, atmosphere and outside the border in the case of RRD.

from (3) we have:

$$(I - A).\ X - \phi_1.\ V = Y \qquad (4)$$

$$- V^*.\ X + V = \phi_2 \qquad (5)$$

$$\boxed{V = \phi_2 + V^*.\ X}$$

from (5) we have: (6)

ϕ_2: residual generation from other sources
$V^*.X$: residual generation from production
V: total residuals

from (4) we have: $X = AX + Y + \phi_1.\ V$
and $Y = X - AX - \phi_1.\ V$

then we have: $\boxed{V = X - AX - U}$ (7)

where U is vector of total cost of production sectors for abating the residuals

then we have $\boxed{\Sigma\ Y = GDP - \Sigma\ U = \text{Real GDP}}$ (8)

from (3) we have

$$\begin{array}{c} X \\ V \end{array} \quad \begin{array}{cc} I - A & -\phi_1 \\ -V^* & I \end{array}^{-1} \quad \begin{array}{c} Y \\ \phi_2 \end{array} \qquad (9)$$

This is a basic relation in the extension of I-O table.

Supposing B =

$$\begin{matrix} I - A & -\phi_1 \\ - V^* & I \end{matrix}$$

B is a matrix of total economically cost efficient production and residuals for a unit of final demand and residual from nature.

The total cost is not only an amount by columns of the Leontief matrix, but also a residual coefficient of these sectors. Otherwise the total cost also must include expenditure for combating the residuals from nature, an increase of one unit.

Supposing that increment of final demand of any sectors affecting Δij: Production value of sector i effected by residual j. We have a change: ΣY = GDP - ΣΔ, so Real GDP = GDP ± net ΣΔ.

Table 3.6 and 3.7 present the computed results and the cost of pollution abatement would be 5,084 MVND and real GDP of 56,907,509 MVND in comparison with GDP of 56,912,594 MVND.

Table 3.6: Input - Output table with consideration of environmental impacts of the residuals

Sectors													**FEED BACK**			
		1	2	3	4	5	6	7	8	9	10	11	**BOD5**	**TSS**	Nitrogen	Phosphorus
1. Agriculture	**(I-A)**	0.88079	-0.03086	-0.05121	-0.00070	-0.06395	-0.00435	0.00000	0.00000	-0.00365	-0.00233	-0.04913	0.00000	0.00000	0.00000	0.00000
2. Fishery		0.00000	0.93982	0.00000	0.00000	-0.04580	-0.00104	0.00000	0.00000	0.00000	0.00000	-0.00374	-0.00424	-0.00181	-0.01360	-0.25797
3. Forestry and hunting		-0.00007	-0.00097	0.96869	-0.00321	-0.00271	-0.02830	-0.00078	0.00000	-0.00238	-0.00009	-0.00350	0.00000	0.00000	0.00000	0.00000
4. Mining and quarrying		-0.00007	-0.00603	-0.01584	0.97978	-0.00197	-0.00474	-0.04589	0.00000	-0.00169	0.00000	-0.00133	0.00000	0.00000	0.00000	0.00000
5. Manufacturing I (Heavy)		-0.09278	-0.07084	-0.02094	-0.01195	0.78569	-0.05301	-0.00022	0.00000	-0.00145	-0.14546	-0.04462	0.00000	0.00000	0.00000	0.00000
6. Manufacturing II (Light)		-0.01693	-0.14890	-0.00670	-0.27041	-0.02764	0.75931	-0.17454	-0.15297	-0.62999	-0.33726	-0.08666	0.00000	0.00000	0.00000	0.00000
7. Electricity, gas		-0.00936	-0.00259	-0.04229	-0.03969	-0.00614	-0.01507	0.93470	-0.02444	-0.00330	-0.00575	-0.02717	0.00000	0.00000	0.00000	0.00000
8. Waterworks and supply		-0.00019	-0.00136	-0.00045	-0.00108	-0.00080	-0.00050	-0.00143	0.98703	-0.00021	-0.00065	-0.00184	0.00000	0.00000	0.00000	0.00000
9. Construction		-0.00013	-0.00385	-0.02480	-0.01295	-0.00150	-0.02016	-0.00733	-0.01508	1.00000	-0.00027	-0.02094	0.00000	0.00000	0.00000	0.00000
10. Transportation		-0.04145	-0.02298	-0.01561	-0.03748	-0.02759	-0.02612	-0.01648	-0.03676	-0.01632	0.99590	-0.01348	0.00000	0.00000	0.00000	0.00000
11. Other services		-0.07628	-0.05638	-0.06800	-0.10784	-0.03758	-0.06603	-0.03802	-0.06222	-0.03091	-0.06408	0.89919	0.00000	0.00000	0.00000	0.00000
BOD5	**V***	-0.00447	-0.00006	-0.00129	-0.00010	-0.00038	-0.00060	-0.00005	-0.00051	-0.00006	-0.00048	-0.00105	1.00000	0.00000	0.00000	0.00000
TSS		-5.77592	-0.00022	-1.15391	-2.17763	-0.12433	-0.29213	-0.08207	-0.03928	-0.03918	-0.03835	-0.91236	0.00000	1.00000	0.00000	0.00000
Nitrogen		-0.00120	0.00000	-0.00009	-0.00001	-0.00001	-0.00012	-0.00001	-0.00003	-0.00001	-0.00003	-0.00028	0.00000	0.00000	1.00000	0.00000
Phosphorus		-0.00073	0.00000	-0.00001	-0.00025	-0.00003	-0.00007	0.00000	-0.00001	0.00000	0.00000	-0.00012	0.00000	0.00000	0.00000	1.00000

Table 3.7: Overall coefficient of residual generation with consideration of its feedback.

Sectors												FEED BACK			
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**BOD5**	**TSS**	Nitrogen	Phosphorus
1. Agriculture	1.15520	0.05509	0.07050	0.01927	0.10311	0.02486	0.00937	0.01017	0.02302	0.03093	0.07257	0.00023	0.00010	0.00075	0.01421
2. Fishery	0.02188	1.07236	0.00653	0.00983	0.06609	0.00907	0.00317	0.00295	0.00661	0.01367	0.01233	0.00455	0.00194	0.01458	0.27663
3. Forestry and hunting	0.00347	0.00958	1.03542	0.01753	0.00711	0.04164	0.01044	0.00838	0.02935	0.01596	0.00992	0.00004	0.00002	0.00013	0.00247
4. Mining and quarrying	0.00201	0.00906	0.01997	1.02629	0.00448	0.00931	0.05248	0.00333	0.00805	0.00443	0.00472	0.00004	0.00002	0.00012	0.00234
5. Manufacturing I (Heavy)	0.16152	0.13458	0.05301	0.07009	1.31138	0.11423	0.03378	0.03445	0.08155	0.23681	0.09258	0.00057	0.00024	0.00183	0.03472
6. Manufacturing II (Light)	0.08400	0.26273	0.08176	0.45159	0.10354	1.39445	0.30648	0.26773	0.89489	0.50166	0.18486	0.00111	0.00048	0.00357	0.06778
7. Electricity, gas	0.01810	0.01279	0.05330	0.05779	0.01470	0.02969	1.08048	0.03494	0.02412	0.02100	0.03855	0.00005	0.00002	0.00017	0.00330
8. Waterworks and supply	0.00072	0.00198	0.00089	0.00188	0.00143	0.00115	0.00199	1.01359	0.00105	0.00142	0.00242	0.00001	0.00000	0.00003	0.00051
9. Construction	0.00491	0.01228	0.03022	0.02701	0.00639	0.03222	0.01682	0.02334	1.02162	0.01408	0.02848	0.00005	0.00002	0.00017	0.00317
10. Transportation	0.05739	0.04002	0.02645	0.05749	0.04664	0.04467	0.03090	0.04844	0.04633	1.02820	0.02772	0.00017	0.00007	0.00054	0.01032
11. Other services	0.11787	0.10259	0.10055	0.17035	0.08064	0.11974	0.08059	0.09904	0.11419	0.12670	1.14256	0.00044	0.00019	0.00139	0.02646
BOD5	0.00544	0.00066	0.00185	0.00072	0.00114	0.00120	0.00042	0.00088	0.00091	0.00118	0.00171	1.00000	0.00000	0.00001	0.00017
TSS	6.83684	0.53945	1.77430	2.67055	0.88368	0.74819	0.43834	0.29396	0.60393	0.54006	1.55428	0.00229	1.00098	0.00734	0.13916
Nitrogen	0.00143	0.00014	0.00022	0.00015	0.00017	0.00024	0.00009	0.00011	0.00018	0.00017	0.00043	0.00000	0.00000	1.00000	0.00004
Phosphorus	0.00087	0.00008	0.00009	0.00032	0.00013	0.00013	0.00005	0.00005	0.00009	0.00008	0.00021	0.00000	0.00000	0.00000	1.00002

Appendix: Technical Notes

1. Relationship Between Regional and National I-O Tables

There are two types of regional I-O tables, namely: (1) intra-regional or single-region and (2) inter-regional I-O tables. An intra-regional I-O table is similar to the format of national I-O tables except that exports and imports in the final demand matrix now refer to transactions not only with foreign countries but also with the other regions of the country. It may be constructed of the competitive-imports or non-competitive-imports type of I-O transactions, depending on the availability of data.

Intersectoral transactions is a competitive-imports type of I-O table, with no distinction between locally-produced and imported goods and services. An I-O table of the non-competitive-imports type requires the separation of locally-produced from imported products. An inter-regional I-O table describes the national economy's transactions of goods and services, both intra-regionally and inter-regionally. For a better appreciation of its main features, a highly-simplified inter-regional I-O model of a two-region economy is illustrated below.

Two-region Inter-regional I-O Table

To / From	Intermediate Demand		Final Demand		To Foreign Countries	Gross Output
	Region Z	Region W	Region Z	Region W		
Region Z	A_1	A_2	F_1	F_4	F_7	X_i
Region W	A_3	A_4	F_2	F_5	F_8	X_j
Foreign Countries	A_5	A_6	F_3	F_6		
Value Added	V_i	V_j				
Gross Input	X_i	X_j				

The model is a national I-O table that is being disaggregated into two intra-regional sub-tables. Reading along the rows, it shows the disposition of outputs of economic activities to meet intermediate and final demands by economic activities and final consumers is the region itself as well as demands by other regions and foreign countries. This is, for Region Z,

$\sum (A_1 + A_2 + F_1 + F_4 + F_7) = X_i$

where,

A_1: Matrix of intermediate demand by sectors in Region Z for products produced by the region Z itself;

A_2: Matrix of intermediate demand by sectors in region W for products produced by region Z;

F_1: Matrix of final demand by region Z for products produced by region Z itself;

F_4: Matrix of final demand by region W for products produced by region Z itself (or exports to region W of products produced by region Z); and

F_7: Matrix of products produced by region Z exported to foreign countries.

By reading down the columns, it shows input structures of economic activities in each region as well as its final consumption patterns. Intersectorial transactions are further broken down into origin or source, whether locally-produced, from other regions or from foreign countries. So, for region Z,

$$\sum (A_1 + A_3 + A_5 + V_i) = X_i$$

where,

A_1: Matrix of intermediate demand by sectors in region Z for products produced by the region Z itself;

A_3: Matrix of intermediate demand by sectors in region Z for products produced by region W (or imports by region Z of products produced by region W)

A_5: Matrix of intermediate demand by sectors in region Z for products coming from foreign countries (or imports by region Z of products coming from foreign countries)

V_i: Value added of region Z ($\sum_i V_i$ = GDP of region Z).

The same interpretation could be made of the row and column elements of region W. It should be emphasized that the sum of the respective elements in the inter-regional table should equal to corresponding elements in the national table. For example, the sum of vectors $X_i + X_j$ is equal to vector of the nation's gross output (= gross input). The sum of vectors $V_i + V_j$ is equal to the nation's GDP.

Let,

B_1 is coefficient matrix of A_1
B_2 is coefficient matrix of A_2
B_3 is coefficient matrix of A_3
B_4 is coefficient matrix of A_4

Then,

$$B = \begin{matrix} B_1 & B_2 \\ B_3 & B_4 \end{matrix}$$

Given gross output, $X = (X_i, X_j)$ and final demand, $Y = (Y_i, Y_j)$, we have the following Leontief equations:

$X = (I - B)^{-1}Y$ for the nation
$X_i = (E - B_1)^{-1}Y_i$ for Region Z; and
$X_j = (E - B_4)^{-1}Y_j$ for Region W

where Y_i = vector of final demand for products produced in Region Z (F_1, F_4, F_7);
Y_j = vector of final demand for products produced in Region W (F_2, F_5, F_8); and
$(E - B_1)^{-1}$ and $(E - B_4)^{-1}$ are Leontief matrices of the regions.

2. Method for calculation of regional gross output, consumption and accumulation

As mentioned in section 2.4.3. of this paper, the I-O table consists of three plots representing the input and output structures of production activities of the country's economy. Plots I and III present the input structures. Plots I and II shows the output structures. Total of plot II (total final demand) must be equal to total of plot III (total value added).

2.1. Vector of gross output of the region

This vector can be calculated by using the following information:

i. Annual reports compiled by provincial statistical offices in the region;
ii. Data from industrial surveys conducted by industrial statistics section of provincial statistical offices in the region; and
iii. Data from business surveys.

2.2. Consumption Matrix

In this matrix, the rows represent the sectors identified in the I-O table and the columns denote the final demands of state or government and households.

For state consumption, its value is equal to the gross output of state management and is recorded in the intersection of the row for the state sector and the final demand column for state consumption.

The vector of household consumption is calculated using data obtained from multi-purpose household survey conducted by the GSO for some 100 kinds of goods and services consumption by households.

All gross outputs from activities by non-profit institutions, lotto operations, household income from employment and imputed rents from ownership of dwellings are treated as household consumption. Data are from statistics reports of provincial/city statistics offices. Excluded as household final consumption are usage of fertilizers, insecticides, agricultural medicines and products of construction. These products are considered either as intermediate inputs or as accumulation.

2.3. Accumulation Matrix

This matrix is of the form $T = (t_{ij})_{nx2}$

where i: 1,n (number of sectors survey in the model)
j: 1,2
t_{i1}: accumulation of fixed assets
t_{i2}: change in inventory stocks

Accumulation of fixed assets (t_{i1}) occurs within sectors that produce material products. These include machinery and other durable equipment and construction. Also included are the value of animal breeding stocks, orchards, vineyards and other perennial tree plantations.

Change in inventories (t_{i2}) refers to the difference between beginning and ending periods of non-completed products or stocks (for material products only). Data are obtained from provincial/city statistical reports of the GSO.

3. Calculation of regional exports and imports

In regional I-O table compilation, it is necessary to determine the value of outflows (exports) of products produced by a particular region to other regions and to foreign countries, further disaggregated into its intermediate and final use. Similarly, inflows (imports) to that particular region of products produced by other regions and foreign countries should be determined and further broken down into intermediate consumption and final demand sector consumption. These data requirements could be obtained only through in-depth ground-up surveys since existing statistical records on these types of information are very limited.

For the purpose of this study, exports and imports are calculated residually. Exports net of imports is estimated as the difference between gross output and the sum of intermediate demand, final consumption demand by households and state, and accumulation of fixed assets and inventory stocks.

4. Aggregation of Sectors

Aggregation of sectors depends on the objectives and purposes of constructing I-O tables. As stated earlier, this regional study involves eleven (11) sectors which were aggregated in conformity with the sector classification of the national I-O table.

5. The RAS Method of Updating I-O Tables

The compilation of I-O is a very taxing exercise. Its mathematics is relatively simple, but the assembly, balancing and reconciliation of the basic data that are usually gathered from various sources require enormous time, effort and money. It is for this reason that, in Vietnam, benchmark I-O tables are constructed only once every five years. However, the increasing demand for I-O tables as effective tools for micro-economic analysis and forecasting underscores the need for up-to-date I-O data.

To satisfy this practical issue, some non-survey methods such as the well-known RAS method are usually resorted to by most countries in updating I-O tables.

5.1. Objective of the RAS Method
The primary objective of the RAS method is to produce an I-O table for any current year t, given base-year (t_0) I-O data and available, though limited, information for current year t. For example, in Vietnam, the national I-O table was constructed in 1989 based on survey data. In order to meet the demands by economic planners and policy makers for up-to-date I-O data, the 1989 benchmark I-O table has to be updated annually.

Specifically, the 1989 matrix of intermediate input coefficients (A_0), which is a vital source of data in the micro-economic analysis of structural changes in the production process, has to be adjusted periodically.

At present, an I-O table for 1995 has been generated using the RAS method supplemented by a limited number of 1995 data obtained from surveys and other available sources.

5.2. Requirements and Assumptions of the RAS Method

Based on survey data, a benchmark I-O table is constructed initially with industries in the columns and products in the rows, i.e. it is of product-by-industry format. Then it is "purified" or converted into a product-by-product table for effective analytical purposes. This includes the matrix of intermediate input coefficients which is the main matrix that needs to be updated using the RAS method.

When using the simple RAS method, the following information for current year t has to be generated:

a. Vector of gross output, X, obtained from GSO estimates;
b. Matrix of final demand, Y, generated based on national accounts estimates;
c. Vector of value added, V, generated based on national accounts estimates.

The generation of levels for matrix Y is based on the assumption that there were no changes in the structural patterns of final demands between the base-year period, t_0, and the current (update) year, t. Similarly, it is also assumed that there existed no changes in the structure of sectoral value added ratios between t_0 and t in order to calculate vector V for current year t.

5.3. Main Steps in Using the RAS Method

As stated earlier, the objective of using the RAS method is to update base-year input coefficients, A(o), to chosen update year coefficients, $A_1(t)$, given predetermined levels of total intermediate demands and total intermediate inputs relating to current year t. The following general model describes the main steps to be followed in using the RAS method of adjustment:

A	R	F	X
S			
V			
X			

where: A(o): Coefficient matrix of intermediate inputs of base-year I-O table
A(t): Coefficient matrix of intermediate inputs of update year t
R(t): Vector of intermediate demand of update year t
F(t): Vector of total final demand of update year t
S(t): Vector of total intermediate inputs of year t
V(t): Vector of value added of year t
X(t): vector of gross output of year t.

From the above analytical model, the following relations can be established:

a. Total intermediate demand + total final demand = total gross output

$$R + F = X$$

b. Total intermediate input + total value added = total input

$$S + V = X$$

In practice, there are three main steps to be followed when using the simple RAS mehod, given matrix A(o):

Step 1. Construct the matrices of final demand, F(t), and value added, V(t), for update year t, based on available information.
Step 2. Compute for vectors of intermediate demand, R(t) and intermediate inputs S(t) , given gross output levels, X(t), and matrices F(t) and V(t); and
Step 3. Apply the interation method of adjusting A(o), given row and column contraints, R(t) and S(t), respectively

The iteration method is a proportional adjustment of elements of A(o) successively along the rows and columns until convergence is reached, i.e. the iterated row and column sums are equal to known row and column totals as determined in Step 2.

5.4. Implementing Procedures of the RAS Method
Step 1. Balancing along the rows

Let X'(t) be a matrix with vector of output, X(t), as elements on the diagonal:

$$A_1(t) = A(o) \times X'(t)$$

and $R_1(t)$ be a matrix with elements on the diagonal:

$$R_1 ij = \frac{R_i}{\sum_{j=1}^{n} a_1 ij}$$

where $a_{1\,ij}$ are elements of matrix $A_1(t)$.

Then we have:

$$A_2(t) = R_1(t) \times A_1(t) = R_1(t) \times A(o) \times X'(t)$$

Matrix $A_2(t)$ has a total along the rows equal to vector R(t) (vector of intermediate demand).

Step 2. Balancing down the columns

Let $S_1(t)$ is a matrix with elements on the diagonals:

$$S_1 ij = \frac{S_j}{\sum_{i=1}^{n} a_2 ij}$$

where $a_{2\,ij}$ are elements of matrix $A_2(t)$.

Then we have

$$A'_2(t) = A_2(t) \times S_1 = R(t) \times A(o) \times X(t) \times S_1(t)$$

The new matrix, $A'_2(t)$, has column totals equal to S (vector of intermediate input). However, adjusting along the columns results in new row totals (intermediate demand). The matrix is then iterated successively along the rows and columns until both row and column totals are equal. We then have the following equation:

$$A(t) = R_n(t) \times R_1(t) \times A(o) \times X_1(t) \times S_1(t) \times \ldots \times S_n(t)$$

The *n* number of iterations depends on ratio differentials between intermediate input and demand ratios relative to base-year, t(o). The RAS method cannot be applied if ratio differentials are relatively large.

5.5. Lessons learned from using the RAS method in Vietnam
Based on the I-O table constructed in 1989, the RAS method is used for adjusting and updating an I-O table of 25 sectors by sectors for 1994 and 1995. It has supplied the required analyses and predictions of the macro-economy of the country while reducing the time and budget costs.

The I-O table constructed in 1994 is relevant to the year issuing a fixed price table. So it is important initially for calculating GDP at the price of the original year (1994) from the I-O table.

In using the RAS method for adjusting and updating the I-O table for 1994-5, some issues have arisen:

- The economy of the country is under transition, so all factors can not be kept stable as supposed by the RAS method. Additional data from surveys in 1992 and 1994 for adjusting and updating plots of I and II are referenced in using the RAS method. So the result obtained is relevant to the economy in practices.
- Affected by changes of goods and commodities imported from foreign countries, the results of using the RAS method is still limited, as the economy is unstable.

For constructing the I-O table of 1996, more information should be gathered for adjusting and updating, in relation to practical issues, especially production investment from outside, technology innovation and equipment improvement, etc.

4. THE INTEGRATED ECONOMIC-ENVIRONMENTAL MODELLING

As required, all residuals of C, N and P should be modelled in the integration. However, due to shortage of relevant data available, we are testing only nitrogen in the integrated economic-environmental modelling.

4.1. Estimation of modelling components

For constructing an integrated model for natural processes and socio-economic activities in the Red River region, three main parts should beincluded:

- The residuals generated from production and household consumption inside Vietnam territory. These have been introduced by the I-O model.
- Residuals generated from the nature including direct rainfall and forest runoff in the watersheds.
- Residuals in runoff and flows coming from outside the country, contributing a significant source.

4.1.1. Nitrogen source from direct rainfall

This is calculated from data of rainfall and air quality collected in the meteorological and environmental network in the river basin. If the river basin is divided into n parts, each part with area S_i (km2), rainfall is considered as identical with annual value R_i (mm) and N concentration in rainwater c_i (mg/l). The N value in rainwater is usually calculated directly from NO_2, NO_3, and NH_4. The total N may be calculated indirectly from NO_3 recorded by following formula:

$$\mathbf{c(N) = 0.235361 * c(NO3) + 0.16576} \qquad (1)$$

The relation between total N and NO_3 in freshwater from surveys was presented in Figure 4.1. From this result, the simple formula for calculating annual total N (ton/year) driving to the river basin is as follow:

$$\mathbf{TN_{atm} = 1/1000.\sum S_i R_i c_i(N)} \qquad (2)$$

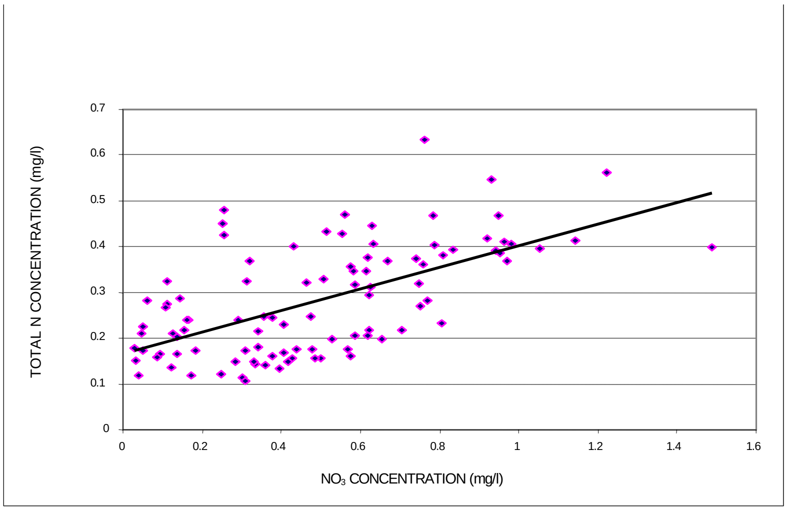


Figure 4.1. Correlation of total nitrogen and NO_3 concentration in fresh water.

Table 4.1. Nitrogen deposits from rainfall by provinces in the catchment area.

Provinces	Area (km^2)	Average rainfall (mm)	Nitrogen (ton)
Ha Giang	7,831	2,692	4,322
Tuyen Quang	5,801	1,573	1,871
Lai Chau	17,140	2,259	7,937
Lao Cai	8,050	1,469	2,424
Yen Bai	6,802	2,048	3,437
Son La	14,210	1,667	4,856
Hoa Binh	4,612	1,374	1,564
Vinh Phu	4,836	1,416	1,478
Hai Hung	2,552	1,606	1,210
Ha Tay	2,153	1,829	978
Hai Phong	1,504	1,829	629
Ha Noi	921	1,240	285
Nam Ha	2,419	1,305	788
Thai Binh	1,524	1,237	431
Ninh Binh	1,387	1,467	567
Total	81,738		32,777

Source: Data of rainfall and chemicals in rain water collected in 1995-1996 from Meteorological and Environmental Monitoring Networks (Lien 1996)

4.1.2. Nitrogen source from forest runoff

Natural nitrogen source generated from forest runoff can be estimated by following formula, although it also depends on forest structure and function.

$$\mathbf{N}_{\text{forest}} = \sum \mathbf{SF}_j \, . \ \mathbf{c}_j(\mathbf{N}) \qquad (3)$$

in which $\mathbf{SF}_j$ is area of forest belonging to category j (km^2)
$\mathbf{c}_j$ is weight of N (kg) generated from 1 km^2 per year of that forest category.

Due to shortage of data measured directly for each category of forest, the total nitrogen generated from a forest of about 143-357 kg/km^2/year in US and 840 kg/km^2/year in Swiss pre-Alps has been tested (Dekker 1987; Arceivala 1986). A primary estimation of nitrogen regenerated from forest in the Red River basin has been calculated by assuming that the whole forest area is identical in nitrogen generation and an average value is about 250 kg total nitrogen per km^2 per year (cN).

The forest area is covering 14,973 km^2 in the Red River basin. Based on formulae (1) and (3), the nitrogen generated from forests totals about 3,743 tons per year.

4.1.3. Nitrogen sources from outside the national border

There are four main river-branches in Red River system. They are Gam, Lo, Thao and Da River. Four these river-branches originate in China. The area upstream belonging to China occupies more than half of the river basin. Therefore, the contribution of water and chemicals from outside the border is a significant volume. Based on the data from the National Hydrological Monitoring Network and other sources, preliminary estimation of water flow and NO_3 or total N concentration in water of Gam, Lo, Thao and Da river at national border areas have been done. Total N inputted from outside to the down stream of the Red River in 1996 is about 21,649 tons, in which :

Gam river :	365 ton	Lo river : 965 ton
Thao river:	6,525 ton	Da river: 13,794 ton

4.1.4. Nitrogen generation from economic activities

This source is taken from the I-O model. The formula for calculating of total N generated by economic sectors as follows:

$$X_{pro} = B \vartheta Y_{FD} \qquad (4)$$

Where:

$X_{FD} = \{xp_j\}$; xp_j is vector of annual total nitrogen generated by production sector i (ton).

$B = \{b_i\}$ (i=1... 11) is vector of "economic environmental co-efficient of nitrogen residual per unit of final demand for each sector" (ton/million VND), was presented in part 2.

ϑ is Scalar multiplication

$Y_{FD}= \{yp_j\}$, yp_j is vector of annual total final demand of sector i (million VND).

The total residual generation by economic and household consumption has been estimated (Table 4.2).

Table 4.2: Estimation of residual generation from economic activities based on the final demand and economic-environmental coefficient.

	Final demand (MVND)	Nitrogen (ton)	Total suspended solid (ton)	Phosphorus (ton)	Biological oxygen demand (ton)
Agriculture	21,898,890	31,332	149,570,083	19,026	118,863
Fishery	297,847	40	160,508	24	198
Forestry and hunting	1,202,219	267	2,130,987	109	2,219
Minning and quarying	617,880	90	1,648,439	199	445
Manufacturing I	8,121,295	1,411	7,169,424	1,050	9,253
Manufacturing II	-3,609,929	(876)	(2,698,204)	(472)	(4,327)
Electricity,gas	1,025,295	93	448,977	54	427
Waterworks and supply	229,650	26	67,440	12	201
Construction	12,414,711	2,273	7,490,157	1,174	11,331
Transportation	357,772	61	193,024	30	422
Other services	14,356,964	6,227	22,292,439	2,975	24,463
Total		**40,943**	**188,473,275**	**25,123**	**163,493**

The percentage of nitrogen generation from nature and economic activities is presented in the table 4.3. However, regarding the ambient concentration, many branches and canals in the downstream link the Red River system and Thai Binh river system with each other. It is estimated that there are about 24% of water volume of Red river system contributing to Thai Binh river system. The annual percentage of water volume flowing through seven river mouths as follow: Kinh thay 7%, Van Uc 11.5%, Thai Binh 16%, Tra Ly 9%, Balat 38%, Luc 10.5% and Ninh co 8%.

Table 4.3. Percentage of nitrogen generated from different sources.

Sources	**Nitrogen**	
	(ton)	(%)
Economic activities	40,943	43.97
Out-side border	21,649	23.25
Forest run-off	3,743	4.02
Direct rainfall	26,777	28.76
Total	**93,112**	**100**

The rate of nitrogen loss in transport process is evident, but it is not possible to identify for the whole river basin. The loss is a complicated process depending on many factors. The total DIN inputted to Balat estuary from fresh water runoff of Red River was 8,181 ton. It is estimated about 11,612 ton of nitrogen or 25.8 % of total nitrogen was generated in the basin flowed to the Balat river mouth. Supposing that the N flow is identical for all river system as well as at river mouths, the loss function is simple i and total nitrogen inputted at the river mouth j (NRMj) (j=1,7) is:

$$NRM_j = A_j \; . \; Res. \; Co \; . \; TN / 100 \qquad (5)$$

where:

A_j is the percentage of annual water volume of all Red River basin flowed into river mouth j;

Res.Co is residual co-efficient of nitrogen - the difference between total nitrogen generated and loss in the basin.

The maximum nitrogen generated from natural and economic sources of the year 1996 in the Red River basin is estimated about 99,111 tons. An ambient measurement of nitrogen during field trip surveys and data collected from monitoring stations in 1996 is presented in Table 4.4.

Table 4.4. Ambient distribution of nitrogen (ton) input to the Red and Thai Binh river mouths.

River mouth	Total Nitrogen flow (ton)	
	Maximum	1996
Kinh thay	6,938	1,567
Van uc	11,397	2,476
Thai binh	15,858	3,445
Tra ly	8,920	1,938
Ba lat	37,662	8,181
Luc	10,407	2,261
Ninh co	7,929	1,722
Total	**99,111**	**21,590**

* Maximum amount is calculated assuming no losses during transportation

** Amount in 1996 is an ambient measurement during field trip surveys and data collected from monitoring stations during this year.

4.2. Integrated modelling

4.2.1. Integrated model for nitrogen

By using the Stella 2, the nitrogen generated from economic activities in the catchment linking to biogeochemical processes in Ba Lat estuary has been modeled. However, there are some modifications in consideration of variables. In this case, the variable in "cumulated operator" such as sectors and areas have been used as time variables. Because of the difference in variables, the process must be separated into parts, which aren't connected together. But the result of the block will be linked in terms of input data. There are five blocks in the model, described in Figure 4.2..

- Block of nitrogen generated from direct rainfall
- Block of nitrogen generated from forest runoff
- Block of nitrogen inputted from outside the national border
- Block of nitrogen generated from production and household consumption
- Block of nitrogen accumulated from all generated sources and its delivery to river mouths.

Based on the modelling, the estimation on nitrogen and phosphorus as well as DIN or DIP exchange in the estuaries of the Red River can be done at the same time. However, because of some problems in lack of data, the estimates are still limited. It is necessary to extend the study in the next phase of the Project.

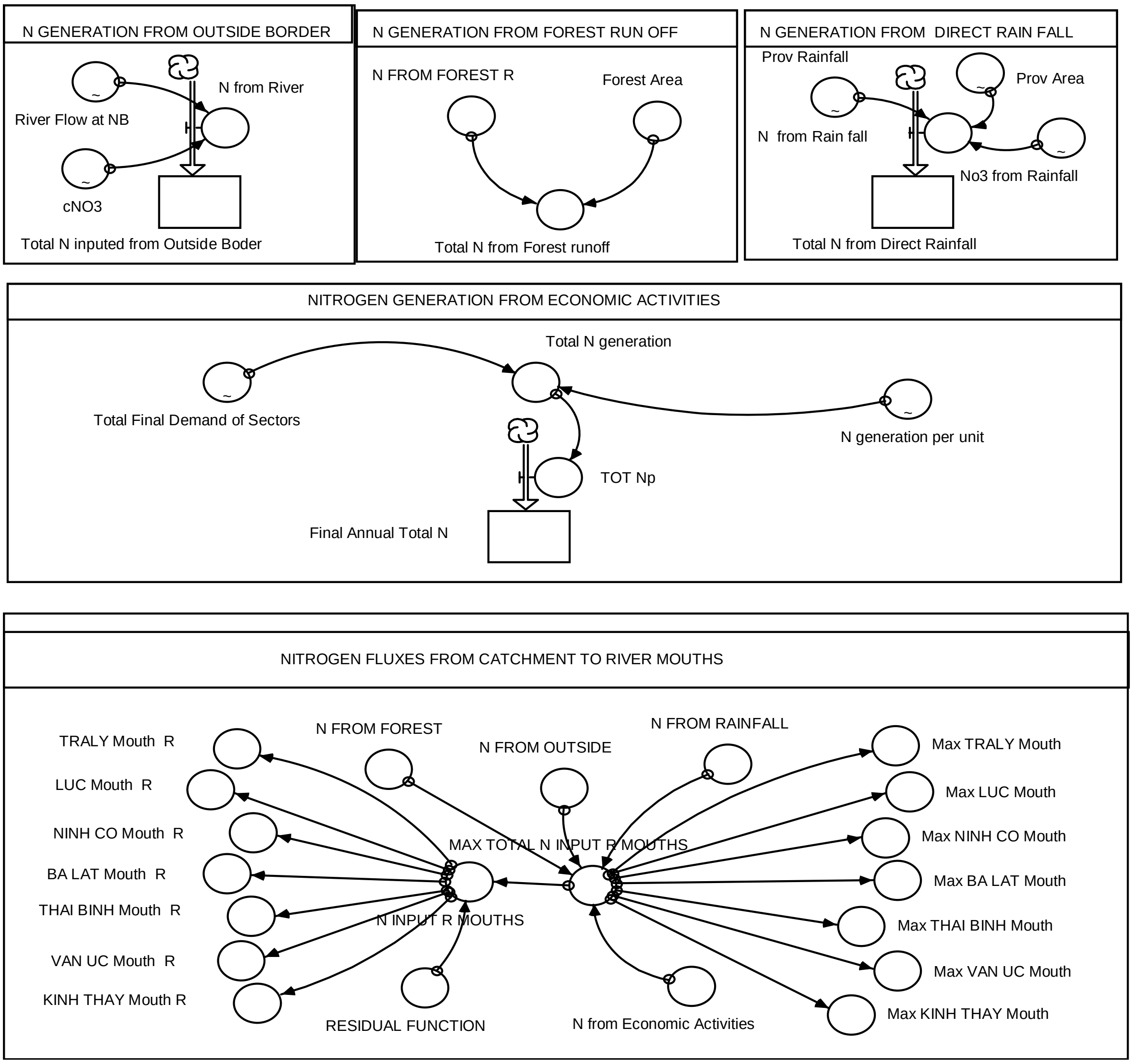


Figure 4.2. Integrated modelling for the nitrogen generation

4.2.2: Scenario development for the integrated modelling

Based the scenarios developed in previous parts, the increased nitrogen has been estimated. It is stated that in the period of 10-20 years, the economy in the region is still dependent to the agriculture development including foodstuff and industrial tree plantation. The agriculture sector is remaining over 75 percent of total generated nitrogen residual. However the attention should be paid to the consumption derived from population growth which is included in the final demand as described in the I-O model.

The forecasting will be extended for the rest of residuals, such as phosphorous, carbon, total suspended sediment and biological oxygen demand.

Table 4.5. Forecasting the increased nitrogen generation (ton) from the scenarios of socio-economic development in the region

Sectors	Scenario 1 (Increased GDP 5.03%)	Scenario 2 (Increased GDP 6.08%)	Scenario 3 (Increased GDP 7.4%)
Agriculture	32,725.99	32,885.78	33,465.42
Fishery	42.19	42.40	43.14
Forestry and hunting	279.32	280.68	285.63
Mining and quarrying	93.80	94.26	95.92
Manufacturing I	1,473.27	1,480.47	1,506.56
Manufacturing II	(915.08)	(919.54)	(935.75)
Electricity, gas	97.30	97.78	99.50
Waterworks and supply	26.75	26.88	27.36
Construction	2,374.39	2,385.99	2,428.04
Transportation	63.21	63.52	64.64
Other services	6,504.00	6,535.76	6,650.95
Total	**42,765.15**	**42,973.96**	**43,731.41**

4.3. Testing Dose-Response model

In order to estimate the impact of residuals resulting from economic activities through the biogeochemical processes, a model of dose-response for selected species has been tested by suitability index.

The dose-response index is calculated for selected species, based on the following assumption

SI = minimum $\{I_1, I_2, I_3... \ I_n\}$

Where SI is Suitability Index; I_n is index as derived from evaluation species requirements a long with ambient concentration of C, N and P.

A dose-response of nitrogen and phosphorus has been tested for *Kandelia candel,* a dominant species extensively planted in the area. The results show that adding nitrogen to the soil is getting a positive result in terms of growth rate and successful establishment rate of seedlings, but no response for phosphorus addition.

The uncertainty of the result requires intensive research in the area. An addition, the dose-response model should be tested for biological producers, in particularly mangroves and phytoplankton.

4.4. Proposed indicators for sustainable management

The research is meeting the SARCS and LOICZ objectives, and also contributing to the national priorities in rehabilitation and sustainable management of the coastal ecosystems.

Based on the national program on monitoring research, a set of indicators for coastal ecosystems health is developed, and proposed indicators for mangrove ecosystem health in the Red River Delta are designed by using the Stella 2 in clarifying the relationship and necessity of the work.

Five blocks in the model indicate different areas in networking of the indicators. These include energetic and nutrient dynamics, hydrology, geomorphology, natural habitats and biological communities. So, C, N and P budgets are only one indicator for ecosystem health. The understanding of changes of the residuals should be elucidated through its relationship with other factors, such as sediment, topography, habitat disturbance and sea level rise.

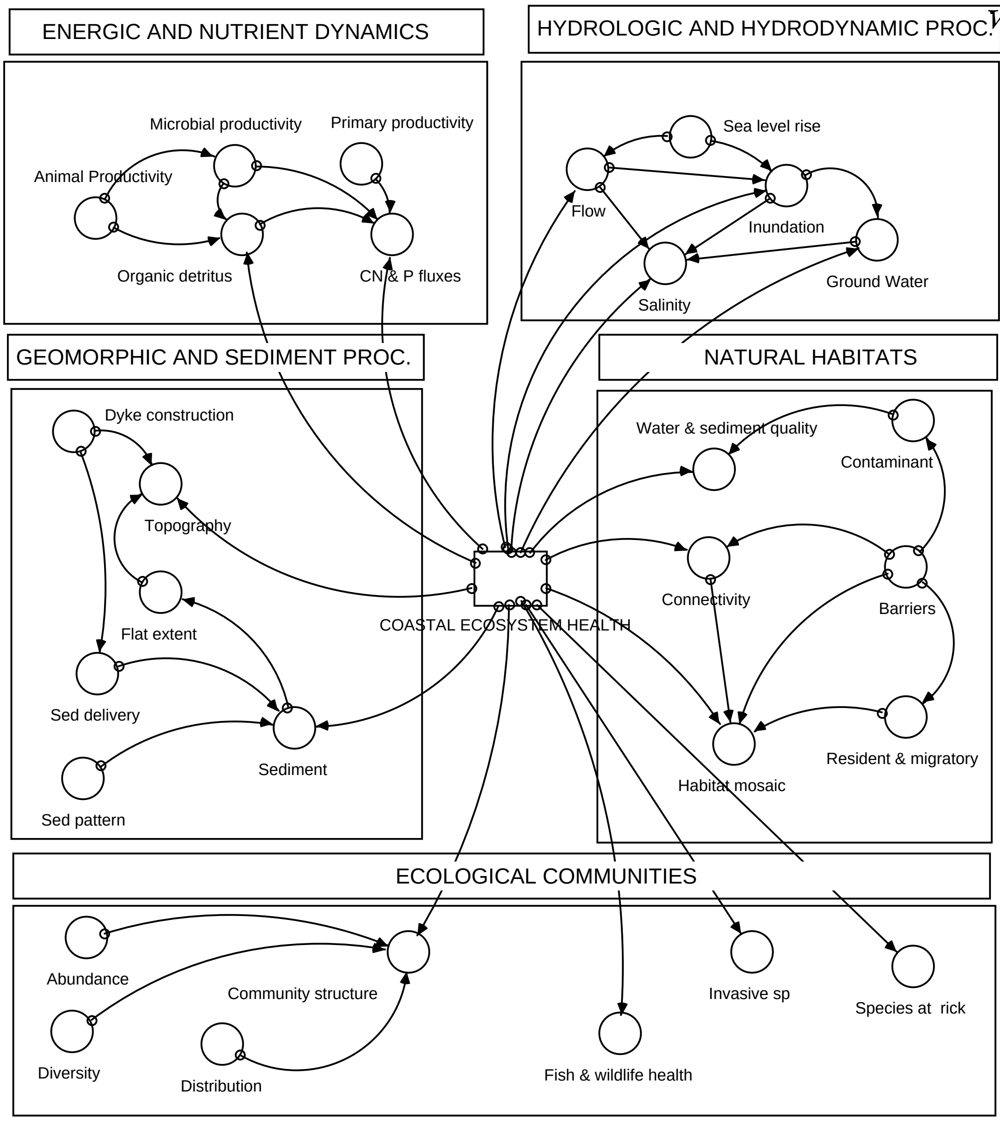


Figure 4.3. Proposed indicators for coastal ecosystem health in the Red River Delta

5. CONCLUSION AND SUGGESTIONS

The budgeting of C, N and P in the Red River system depends on size, hydrological and hydrographical regime and biogeochemical function. Within the context of system analysis at three states (N/P=13; N/P=16 and N/P=30), the calculated values of (*nfix-denit*) are negative. That means that denitrification exceeds N fixation throughout the year and it is, therefore, an important sink of nitrogen. Regarding both states, the net ecosystem metabolism (NEM or [*p-r*]) is negative, so it is a net heterotropic system thoughout the year.

Human impacts in terms of economic activities and household consumption contribute significant residuals into the coastal zone with 43.97% contribution to the total 93,112 tons of nitrogen in 1996. The relationship of the growth rate of Gross Domestic Product (GDP) and residual generation is evident. Land-use and land cover change and other activities are driving changes in C, N, P and sediment fluxes in terms of the time and space patterns. The elucidation of the change to ecosystem health in the coastal zone and feedbacks to the economic activities need more appropriate approaches.

Results from the research are providing a sound scientific basic for the sustainable management of the coastal zone in the Red River Delta and as a demonstration site to the strategy of conserving and enhancing the coastal environment.

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