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Laguna Lake (Philippines)
Water Quality Trend Analysis Study

By:
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LAGUNA LAKE (PHILIPPINES)

WATER QUALITY TREND ANALYSIS STUDY

BY:

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1. INTRODUCTION

The assignment was undertaken within the framework of the program and functions of the WHO Western Pacific Regional Centre for the Promotion of Environmental Planning and Applied Studies (PEPAS) in providing technical cooperation services to member states. It was carried out in response to a request from the Government of the Philippines for the services of a consultant for a period of two months in the field of water quality trend assessment beginning 30 December, 1989. The work was done at the Environmental Protection Division, Laguna Lake Development Authority, Manila. The report describes the activities and findings during the assignment.

The terms of reference for the assignment were:

1. Review all the available water quality data of the Laguna de Bay and its tributaries, including sampling locations and frequencies and their associated costs, and to conduct field inspection, if necessary;

2. Review relevant existing and future laws pertaining to water quality;

3. Conduct the necessary statistical analyses on these data for correlation and trends with a view to identifying indicators of changes in the lakes' and rivers' quality, and state in relation to the present and future uses;

4. Recommend the optimum (maximum information at least cost) sampling programme for monitoring compliance with the present and future ambient water quality standards for the lake and its tributaries;

5. Prepare a report at the end of the assignment and submit to the collaborating agency all relevant mathematical models and computer programmes developed during the assignment. The consultant will train the staff of the agency on the use of these models and programmes; and

6. Prepare the terms of reference to future consultant assignments in this subject area, if deemed necessary.

2. BACKGROUND INFORMATION

Laguna Lake, approximately 15 km south-east of Manila is the largest lake in South-East Asia. The surface area (Fig. 1) is 90,000 ha with a shoreline of 220km and an average depth of 2.8M. There are 21 tributaries flowing to the lake and the drainage basin is used for industry, agriculture, and housing. The lake itself is used for fish farming, cooling water, open water fishing, irrigation, and oil barging as well as industrial water supply. There are imminent plans to withdraw about $2.5 \times 10^6 M^3$ of water daily for domestic supply to Metropolitan Manila (population approximately 11 million).

A fundamental and outstanding feature of the lake is its size. The three bays of the lake are on the order of 30-40 km long and 7-20 km wide. These fetches coupled with the shallow depth mean that the lake will almost always have a high content of resuspended sediment in the water; most of the Secchi transparencies are much less than 1 M. Another outstanding feature is the high background nutrient levels in the rivers. Four rivers have been tested for far upstream quality. Mean nitrogen was 114 ug/L and mean P was 187 ug/l in PO_4. These concentrations are expected due to the volcanic sources of most of the soils in the watershed. This means that eutrophication aspects of lake water quality will be fairly unresponsive to nutrient load changes.

The annual surface runoff and groundwater flow provide flushing at the rate of once per year. This is consistent with lower concentrations for most parameters in the lake compared to the rivers. The majority of the flushing occurs during the rainy season from May to October when the lake level rises from the preceding low levels attained during the dry season.

There are many local issues which the LLDA, with its mandate for resources development and management, has been dealing with. Historically, the seasonal water level decrease in the dry season has allowed sporadic backflow from Manila Bay via the Pasig River. The installation of a hydraulic control structure (HCS) to control lake salinity by preventing backflow has been blamed for declining fish production by the fish farmers. The lake will be used for drinking water but, due to the turbid appearance, there is some local skepticism. There are increasing numbers of industrial developments in the lake basin and control over these must continue in order to protect the variety of uses. Open water fishing including benthic trawling for snails is difficult to control given the size of the lake and the number of fishermen. Conflicts include the desire of fish pen operators to use artificial feeding and the potential damage to fish habitat by disruption of rooted aquatic plants by the snail dredgers. There are thousands of people and livestock living on the lakeshore and

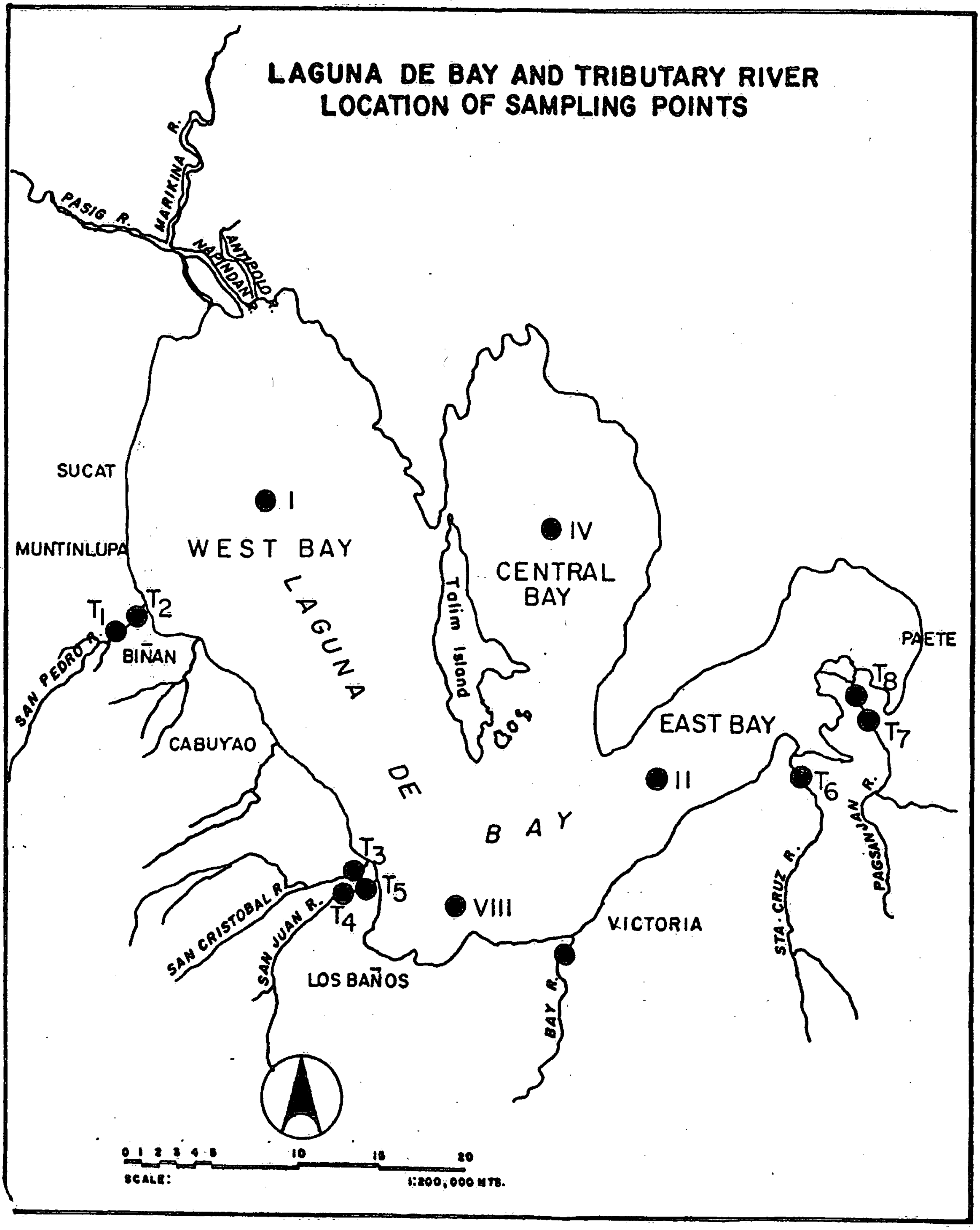

Fig. 1. Laguna Lake and tributary sampling locations.

tributary banks without benefit of satisfactory sanitary facilities. More extensive background information is contained in WHO reportt# ICP/RUD/001 (P. Guo, WHO/PEPAS, 1988). The author agrees with the findings and recommendations of the 1988 report particularly in regard to the importance of deforestation and non-point sources.

3. MAJOR FINDINGS AND DISCUSSION

3.1 Data storage and analysis

There are now enough data at LLDA to present a daunting task to a consultant in a 2 month term. The apparent lack of a comprehensive bibliography is a minor problem. Orientation can take a week or two in order to begin to appreciate the environmental problems and the state of the organization and their data. Two months is just barely a practical period in which to produce a useful report. The author reviewed as much of the data as possible and attended 2 field trips to observe sampling practices. Two seminars were presented and a briefing was given to LLDA management.

The only practical way to examine the data at LLDA is by computer. LLDA is now storing data with IBM style clone microcomputers using Lotus 123 software. Storing the data in spreadsheets however is only the first step towards analysis and presentation. For some analyses, the computer files had to be completely reorganized. At the same time normal work at LLDA had to proceed. The author was able to do some statistical analyses on reorganized LLDA files and found previously unused or other small data sets to use as examples. All available data are not yet computerized and this hampers comprehensive trend analysis. In the future, LLDA should have available a modem program on both sizes of diskettes to facilitate file transfers (the only hardware needed is a serial cable). Providing full access to files with compatible hardware and software is crucial to efficient use of the consultant's time. Had not the consultant, in this case, arrived with his own unexpected machine a meaningful report could not have been produced without seriously disrupting EPD/LLDA's ongoing work. The author strove to provide model spreadsheet procedures which he hopes will decrease the need for consultants.

LLDA has since 1974 produced an extensive data set which is now invaluable. Whereas the tendency has been to compare data between recent years the accumulated data provide a means to decide whether there has been any real change in the lake as opposed to simple differences between years. Until now, presentation of the latest data in a long-term context has been very tedious and difficult. One of the main uses for new data is to detect gradual change and to do this the ease of data presentation in the context of the old data is important. With enhanced use of spreadsheet programs LLDA can analyze and present their data in a convincing fashion.

The author agrees with LLDA's strategy of using microcomputers and spreadsheets to store and manipulate data. Elements still lacking in the strategy are sufficient hard disk storage and a laser printer for good quality graphic and text output. To date, the effort has been mainly in data storage and spreadsheet printing with only some effort on analysis and presentation. The author has provided staff with training on techniques of data consolidation and techniques to summarize data into effective presentations. The present technology is capable of all demands of LLDA with the addition of updated versions (registered) of "123" and perhaps "Harvard Graphics". LLDA should subscribe to and purchase back issues of "LOTUS" magazine for the many tips, techniques and clear instructions presented. A key finding is that spreadsheets should be constructed with the end use of analyzing and presenting long-term data in mind. To that end, the author has constructed spreadsheets to use as examples of long-term data analysis. Powerful database functions in 123 make possible selections and summaries from the data quickly. The author recommends purchase and use of a small number of "add-in" programs such as "SSR[2] for special statistical procedures run within 123. Information about these programs is available in the computer press and Lotus magazine.

Presently, LLDA data reports are just that; reports of monthly means accumulated over one year. Except for comments on standards exceedances, the author finds these reports useful only for delivering the data to others for analysis. For the purpose of deciding whether the lake is changing these reports would have to be accumulated and analyzed by any outside group. LLDA should consider reducing the extent of numerical reporting and concentrate instead on graphic presentations in the long-term context and brief numerical summaries of standards violations and wet/dry season means. In summary, the monitoring program can be improved by increased emphasis on data analysis and presentation. The author has endevoured to provide examples of the means to effectively use the information now and in the future.

3.2 Sampling and field techniques

Sampling is conducted on major tributaries monthly and at lake stations every two weeks. Water samples are collected with a bucket tied to a rope or with a VanDorn sampling bottle. Benthic organism samples are collected with an Eckmann dredge. Zooplankton are collected by pouring water into a 1M long plankton net and then pouring the strainer cup contents into a bottle. At the same time phytoplankton samples are collected and primary production experiments conducted. Biological work is not routinely done on the tributaries. Dissolved oxygen (DO) samples are fixed in the field; Secchi transparency is measured at lake stations. Chemical analyses are conducted at the LLDA laboratory as are benthic and phytoplankton enumeration.

Currently, the following are reported annually: NH_3, NO_3, DO. pH, Temperature, Turbidity, TDS, Coliforms, Net Primary Production, and "Water Quality Index". The following are not regularly reported: benthos, zooplankton, phytoplankton, and Secchi transparency. Occasionally, heavy metals and pesticides are reported. The author maintains that all the biological enumeration and Secchi information is important and should be reported as regularly as the other data.

The parameter list represents a selection of well chosen basic descriptors of water quality which can hardly be improved upon. Total suspended solids measurements with Loss On Ignition (organic matter) would be useful to corroborate phytoplankton biomass as would Chlorophyll.

Field methods for benthos should be improved, suggestion are provided in annex 8.

Full day incubations for primary production experiments are probably not yielding a relevant increase in accuracy consistent with the field effort exerted. A rationale and suggestions for different field methods as well as improved calculation methods are provided in annex 2. Suggestions are meant to be consistent with equipment on hand at LLDA and do not represent state of the art techniques. Nevertheless, they are more consistent with International practice. The author doubts that these measurements are useful per se for any management purposes since they depend mostly on the water turbidity not the algal biomass in Laguna Lake. The author conducted a 1/2 day seminar for biologists on field methods and primary production methods.

During a field trip to the lake the water sampler (VanDorn bottle) could not be opened or closed at both ends simultaneously. This means only grab samples were obtained. During Blue-Green algae blooms there will often be a high concentrations of algae near the surface. (This is actually found in some early data when samples from 2 depths were enumerated.) Simply grabbing a surface sample will distort the results by overemphasizing the small volume with high concentrations. A vertically integrated series of samples is required and this should be standard practice at all times. The sampler should be repaired. Four or more samples vertically should be mixed at each station to obtain a representative sample for plankton analysis. Alternatively, a simple tube sampler could be used to obtain a "core" of the water column.

A sampling of correlation matrices has not yielded any obvious relationships between parameters which would justify elimination of measurements. Secchi transparency is strongly related to turbidity and thus could supplant turbidity measurements but this would not be a significant saving. Much more extensive work on correlations could be done but most of the parameters measured now are valuable in their own right as water quality indicators and are well chosen.

3.3 Monitoring philosophy

Monitoring programs such as at LLDA are partially effective for compliance purposes since the sampling interval (2 weeks) is too long and the lake is too large to cover with stations and the rivers can change rapidly. Nevertheless, the data will indicate gross problems if they occur and by inference are probably a fair representation of compliance to standards.

Chemical contamination is best measured and prevented at the sources. By the time toxic chemicals are detected in the environment a large quantity has been released. Environmental monitoring for toxics is still needed, however, and this is best done by sampling fish (especially carnivores) and other organisms which bioaccumulate toxics. Fish used for human consumption should be regularly tested for health purposes and these data should become part of LLDA's on-going program. The list of specific chemicals to analyse would have to be based on analysis of the URS report (Laguna Lake Toxic and Hazardous Waste Management Feasibility Study by: URS International INC, 1989) and knowledge of risk factors related to the chemical processes used in the drainage basin. These fish data would hopefully warn of increasing contamination before levels were high enough to prevent consumption.

The use of the lake as a drinking water source is addressed by monitoring coliforms. Coliforms do not register any particular health problem except for perhaps stomach upsets. Coliforms do indicate the presence of faecal matter which could contain more difficult to detect problems such as viruses. At the 4 lake stations 7 of the 48 monthly means were above the limit of 5000/100ml in 1988. These are examples of data which should not be averaged since disease control depends on microbiological safety at all times. At any rate, some assessment should be made of the meaning of sporadic high coliforms in terms of public health risk from non-coliform faecal microbes.

The biological integrity of the lake ecosystem and hence its usefulness as a food resource is probably most threatened by fishing activities. This is the reason the biological component of LLDA monitoring is so important. Disruption of the fish community can have far reaching effects on the plankton and algal populations. There have been several fisheries disasters world-wide which have resulted from overfishing. It is entirely advisable to achieve some information level on the annual catch and the number of fishermen as a minimum. At best, fisheries management seems to be largely empirical, again depending on information gathered from the industry. <u>The author strongly supports LLDA's efforts to exert control on the fishery.</u> The practice of snail dredging in Laguna Lake must be very disruptive to the benthos and rooted plants; this could, in turn, limit the food and habitat available to fish. <u>The author strongly supports LLDA's efforts to stop snail dredging.</u>

3.4 <u>Turbidity, Total Dissolved Solids and the effect of the Hydraulic Control Structure (HCS)</u>

A full range of turbidity can be found at low TDS therefore salt water backflows are not necessary for low turbidity to occur. There will be a seasonal turbidity cycle due to seasonal wind speeds. Co-incidence of the turbidity minimum with the backflows has led to the conclusion that there is a causal relationship. In fact, the backflow does not occur every year. The HCS has been open and there are still fishery problems. Nutrient levels are often very high in the lake; there is no threat to fishing due to use of the lake for drinking water provided attempts are made to maintain levels in compensation for the additional withdrawal. There is no long-term trend in the Secchi transparency in Laguna Lake.

3.5 <u>Algae</u>

The algae are dominated by diatoms except when there are blooms of Blue-Greens. Diatoms which dominate in the dry season, were lower than usual in 1986-88 but these numbers also occurred in 1979 and 1982. Blue-Greens tend to dominate in the wet season but the diatoms are still present. The intensity of Blue-Green blooms has decreased since 1981. Wet season biomass and species composition in 1988 were similar to 1976 and 1977. It is too soon to determine whether there is a real change occurring or whether the lake is representing some sort of cycle in response to meteorological factors. Since the algae are the biological foundation of the fish production the enumeration at LLDA should continue. Neither algal biomass nor primary production seem to be related to the presence or absence of salt water intrusions.

Since diatoms are a main algal component the possibility of silica limitation should be investigated by analysis of particulate and filtered Si. This could be correlated with biomass, species composition and photosynthesis.

3.6 Research needs

Even though the LLDA data can still be exploited in many exciting ways the monitoring can itself become routine and even boring. Research studies are one way to maintain interest, solve problems, add to understanding, and stimulate new ideas. The following ideas would seem useful:

1) Feasibility study on fish abundance Purchase a convenient length of common gill net and contract a fisherman to regularly set the net under strictly controlled conditions. This could be done 4 times per year, the catch would be enumerated and weighed for each species. If this proves practicable these data could become part of the regular work output. The main purpose is to compare relative fish abundance from year to year in relation to other biological variables.

2) Effect of fish culture on benthos Compare benthos populations inside and outside of fish pens to determine whether the fish utilize the natural benthos. If there is a large difference then understanding would be gained on the cause of the fish productivity decline.

3) Zone of influence of major rivers Survey the concentration gradients at river mouths in the dry season and the wet season to show the portions of the lake which are highly polluted by the rivers and likely to respond most to pollution abatement.

4) Water quality gradients in Laguna Lake Survey water quality on transverse transects to find whether there are any significant inshore-offshore gradients.

5) Cause of the sharp variations in NO_3 and PO_4. This may be found by documenting conversion of particulate organic N and P to soluble forms (algal decomposition) or by correlations with seasonal nutrient loading. Understanding these variations is important to nutrient dynamics modelling. Models will have to account for the strong seasonal component in nutrient and hydraulic loads.

6) <u>Effect of inorganic (ash) turbidity from sediment resuspension on algae.</u> Compare non-algal turbidity inside and outide enclosures with intense algal populations

3.7 Review of laws

Item 2 of the terms of reference (review of laws) proved to be largely superfluous due to a recent review in 1989 (URS report). A copy of the Water Quality Agreement between Canada and the U.S.A. was left at LLDA as another example of objectives and goals for pollution abatement. A copy of the 1989 International Joint Commission Report on Great Lakes Water Quality (Canada-U.S.A.) was left as an example of output from long-term monitoring programs enacted under legislation in Canada and the U.S.A.. The author judged that a comprehensive review of the laws would consume an inordinate proportion of time available considering the need for methods demonstration and training at LLDA.

A brief review of the list of environmental legislation showed the extensive good intentions of the Philippines government towards environmental quality. Enforcement is another matter and this is obviously very difficult given the numbers of people and industries in the Laguna Lake drainage basin. Based on observations while at LLDA it seems that, in general, there is the feeling that humane alternatives have to be provided the people in conjunction with enforcement. Due to infrastructure problems, enforcement is delayed and problems worsen. Even documenting reported infractions is difficult because agencies such as LLDA lack the logistic support and manpower to visit all the trouble areas.

The LLDA is clearly pursuing industrial pollution under mandating legislation. The author witnessed many visitations by affected industrialists who needed to discuss their legal/environmental problems. The LLDA has a computerized database containing information on all industries in their jurisdictional area. LLDA,s activities result, in many cases, in plant closure as owners refuse to, or cannot, effect pollution control. Prioities for investigations and subsequent actions are based on inhouse chemical engineering expertise at LLDA. To the best of their ability, the staff of LLDA are striving to control industrial pollution. The author could not determine what proportion of the problems are dealt with.

In the future the objectives of a legal review should be stated in terms of assessing clarity, comprehensiveness, reference to standards, enforcibility, consistency with local attitudes and economic realities etc. The author submits that a serious review could well be done by a Philippine lawyer, judge, or law professor with experience in Philippine environmental law.

3.8 Conditions of facilities

A large part of the work of the Environmental Protection Division (EPD) at LLDA involves field work visiting the lake and industries. The author was priveleged to have transportation to and from the offices provided by EPD. Two of the three vehicles the author rode in were removed from service for safety reasons. One of these was a steering failure! Another of the vehicles has been in service since 1974. This is typical of the deteriorating equipment. Much of the facility was set up in the mid-70s and has not been replaced. Most of the laboratory equipment is at the end of its reasonable lifetime. The LLDA finds it impossible to replace equipment under present arrangements. The monitoring program is adequate but minimal now. The new drinking water agenda will bring new demands. Thus, any lapse in the activities caused by old equipment would be unfortunate. A way should be found for LLDA to enact a capital replacement/upgrade plan in order to avoid undesireable interruptions of service.

4. CONCLUSIONS AND RECOMMENDATIONS

1. LLDA possesses a wealth of important data which should all be computerized including the earliest records. Effective summaries and graphic presentations using all the historic data should be done similar to examples in the annexes and these can answer many questions about the lake. The main microcomputer should have an additional 40M hard drive as well as a laser printer. Named ranges and macros in spreadsheets should be used to facilitate data consolidation for presentation of long-term trends. There should be more emphasis on data analysis and presentation. Annual data reports should be replaced by less frequent documents containing analyses of the data and their implications.
2. The parameters of the monitoring programme are well chosen indicators of water quality. Sampling locations are adequate and practical. Sampling frequency could be reduced to monthly in the unproductive season. It is recommended that the programme continue with the addition of Chlorophyll and seston (weight and loss on ignition) measurements.

3. Many conclusions regarding the supposed effect of preventing Pasig River backflows are evident from the presentations of long-term data. The notion of serious deleterious effects is not supported by the pertinent data. For example, no trend is apparent in the lake turbidity measured by Secchi disk.

4. Fish used for human consumption should be regularly tested for contaminants. Analyses should be chosen based on information in the URS report (1989 and industrial chemistry knowledge. These data may provide an early warning should increasing contamination occur and should be included in LLDA's reports.

5. Sampling for benthos should be improved; suggestions are provided in annex 8.

6. Primary production measurements are almost irrelevant to quantitative fisheries management. Nevertheless, the data are good indicators of lake metabolism. Attempts should be made to correlate respiration with algal populations. Methods should be improved as per annex 2. Improved calculations will allow comparison with other lakes and their fish production.

7. Relative fish abundance should be monitored regularly by carefully controlled gill netting. Only by controlling fishing effort by standard mesh size, net length, setting time and duration as well as location can the relative abundance be checked. This may provide some warning of the possible situation in which fisheries landed tonnage rises even while fish abundance decreases.

8. Techniques to test for correlations between many variables have been left at LLDA. To discover correlations a correlation matrix is more efficient than graph plotting and individual regressions. Correlations in tributary data did not justify terminating any measurements. Total Suspended Solids (TSS) is highly correlated with turbidity but TSS allows sediment loading estimates. All the lake parameters are useful except pH which will vary with oxygen. All data should be reported.

9. It is recommended that research studies be conducted to provide useful information. Six studies are suggested:

   1) Feasibility study on fish abundance;
   2) Effect of fish culture on benthos;
   3) Zone of influence of major rivers;
   4) Water quality gradients in Laguna Lake;
   5) Cause of the sharp variations in NO_3 and PO_4;
   6) Effect of inorganic (ash) turbidity from sediment resuspension on algae.

10. Arrangements should be made for a capital plan enabling LLDA to replace and upgrade equipment in order to prevent interruptions in service caused by deteriorated equipment.

11. This report contains 34 figures which result from spreadsheets the author constructed. The spreadsheets have been left at LLDA and their usage has been demonstrated. It is recommended that many of these figures can be easily constructed for other parameters and these can be incorporated in future LLDA reports.

5. ACKNOWLEDGEMENTS

The author wishes to express his appreciation to his National counterpart Engr. Nyrh P. Cabance, Manager, Environmental Protection Division, LLDA for facilitating all stages of the work. The author wishes to thank EPD and other LLDA staff for for making him feel welcome. Dr. P. Guo (PEPAS) is thanked for his advice and support in arranging the consultancy. Dr. Basaran (WHO/WPRO) is thanked for his advice and support as well as for reviewing this manuscript. Dr. L. Xirong (WHO/WR Philippines) is thanked for his support and advice. Finally, staff at WHO/WPRO are thanked for their efficient support with financial and travel arrangements while the author was in Manila.

ANNEX 1 - TURBIDITY AND TDS

Laguna Lake is affected by a number of limnological and meteorological phenomena which affect water quality. The annual dry season causes a loss of 1-1.5 M in the period October to May. While the water level is low, saline water from the Pasig River can flow into the lake causing an increase in lake salinity. The increase in salinity, when it occurs, renders the lake useless for drinking water and irrigation. Co-incident with the salinity changes there have been observations that maximum primary production and minimum turbidity occur in the summer season. High primary production is desired for fisheries production. In the mid 80s a hydraulic control structure (HCS) was installed to prevent the salt water intrusions and this has stimulated local controversies amongst the fish farmers. It is evident from reports, LLDA data, and conversations with LLDA staff that salt intrusions do not occur every year and the HCS has been open most of the time. The fishermen claim the lake has become more turbid because of less salinity and this has resulted in less productivity and lower fish yields. Experiments with suspended sediments from Laguna Lake have indicated that settling is enhanced by additions of salinity. There are no data, on the other hand, showing that salinity prevents resuspension of sediments.

The HCS must prevent salt intrusions to ensure lake water potability. Nevertheless, it would be useful to know if there is any substance to the arguments of the fishermen that an additional use of the lake will be responsible for less productivity.

Figure 1 shows the recent total dissolved solids data (TDS) gathered by LLDA in 1986, 87, and 88. A strong salt intrusion occurred in 1986 and a lesser intrusion occurred in 1988. No intrusion seemed to occur in 1987 although there were minor variations perhaps due to evaporation. Fig. 2 shows that there was a seasonal turbidity cycle in 1987 despite the lack of a salt intrusion. Moreover, summer turbidity in 1987 was as low as it was in 1986 and 1988. Thus, the salt water intrusions are not always necessary for minimum turbidity to occur. On the other hand a summer turbidity minimum can be expected due to lower wind speeds and less resuspension. Fig. 3 shows that there was not a true relationship between turbidity and TDS; the full range of turbidity occurred at low TDS levels. At high TDS levels turbidity was low. Since turbidity will tend to be lower in the summer than in winter and salt intrusions only occur in summer it is doubtful that these data can prove the notion that salt controls turbidity. Fig. 4 shows the data from 1981 to 1988 as annual means. Again, there does not seem to be a consistent relationship between turbidity and salt content. Although it is tempting to draw straight lines to show a relation in Fig. 4 consideration of 1986 and 1981 compared with 1984 shows that this is the same form as Fig. 3.

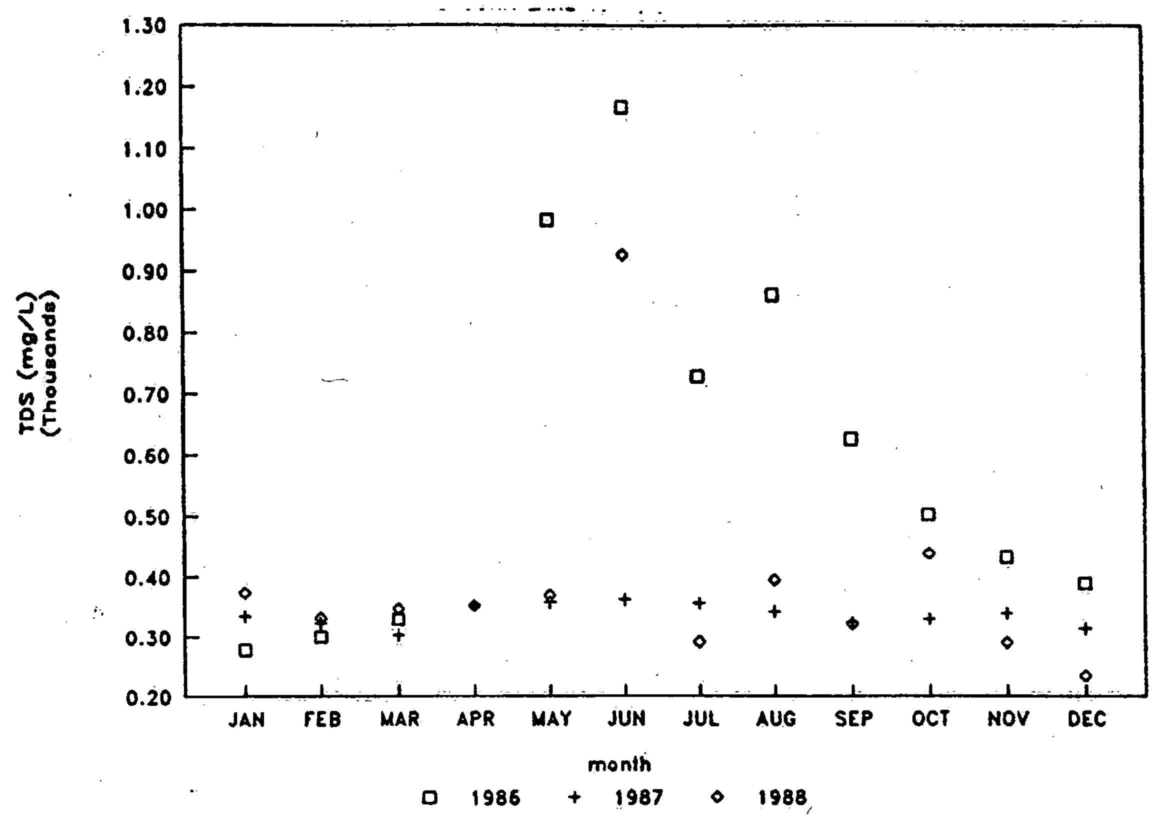

Fig. 1. Total dissolved solids in West Bay 1986, 87, 88.

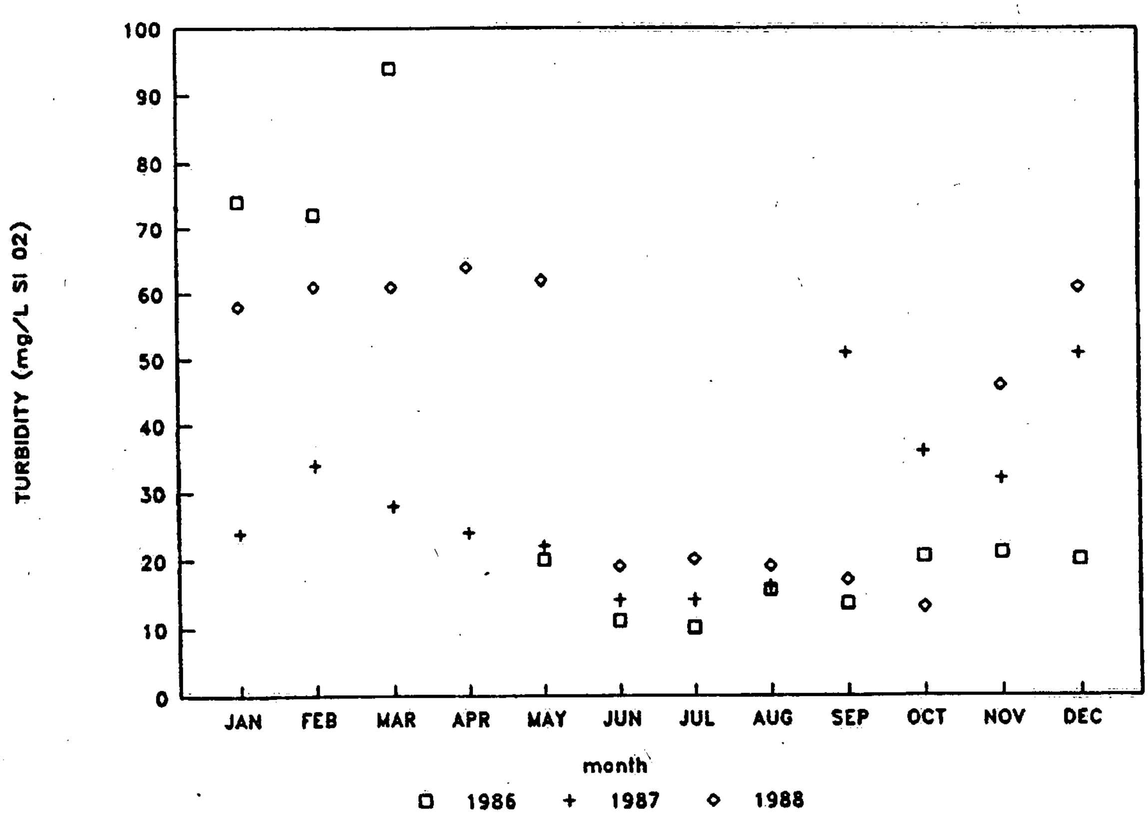

Fig. 2. Turbidity in West Bay 1986, 87, 88.

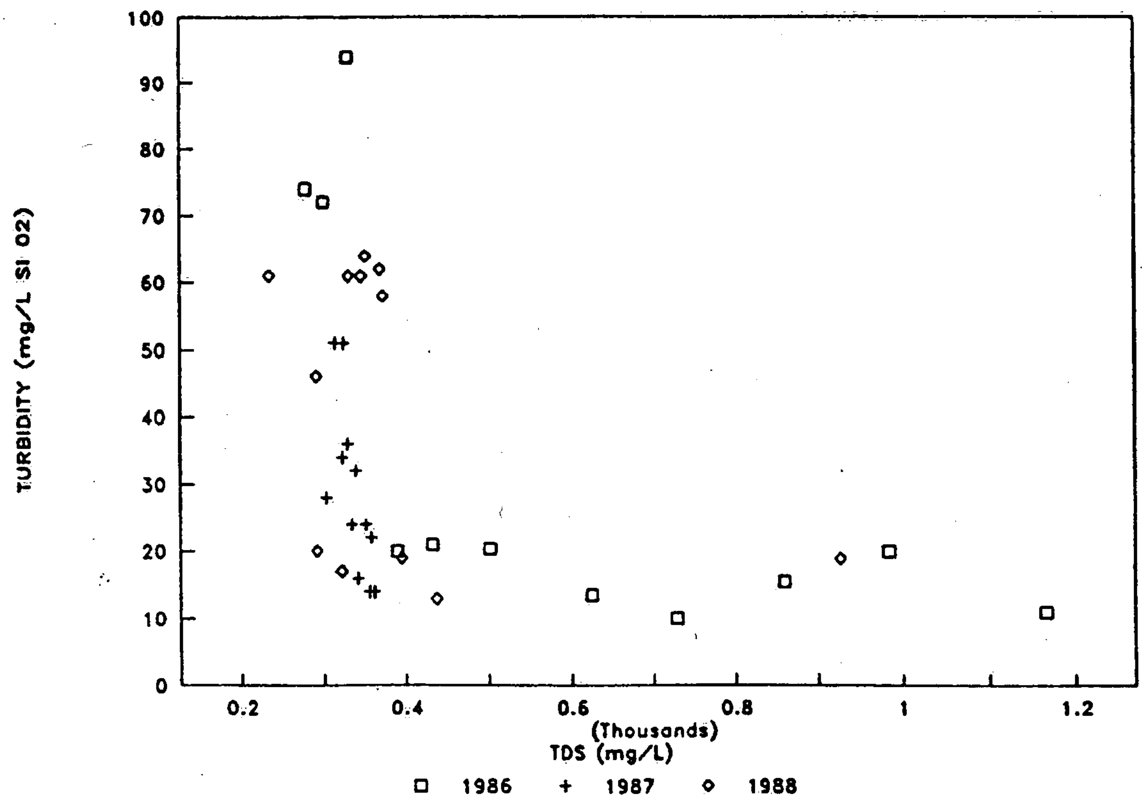

Fig. 3. Turbidity vs. TDS in West Bay 1986, 87, 88.

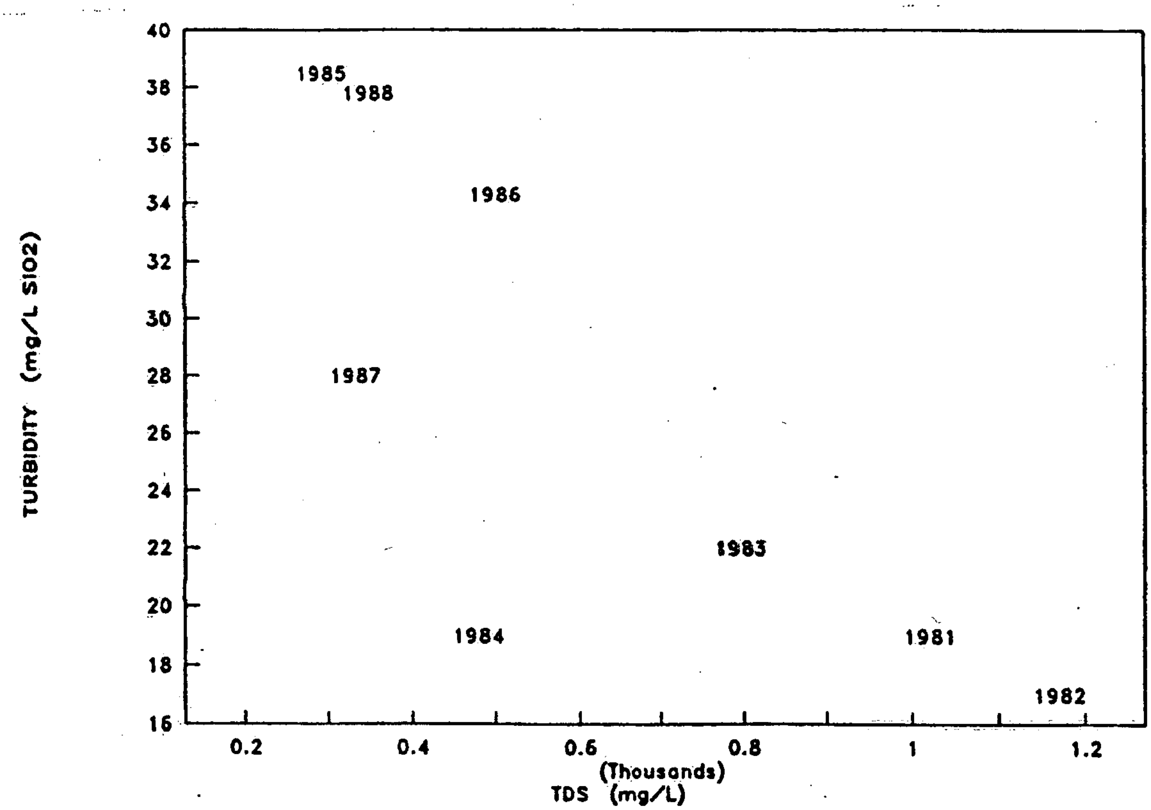

Fig. 4. Turbidity vs. TDS 1981 to 1988 (data from URS report).

ANNEX 2 - PRIMARY PRODUCTION

"Net primary production" has been measured with the in-situ oxygen bottle method for many years. The data represent daytime net production for the fraction of the water column where the net was positive each day and thus are not truly representative of photosynthesis or net daily production. Data for 1986-88 were examined to find causes of variability.

Data for West Bay, East Bay, and Central Bay are plotted in Fig. 1. The rates can be quite different in each bay although the differences are on the order of a factor of 2 or 3. Monthly primary production data are shown in Fig. 2 to elicit the seasonal cycle in West Bay. The cycle of rising productivity in May coincided with the usual increase in rainfall at the end of the dry season. In addition, decreasing wind speeds and the low lake levels at this time of year which lessen the prevalence of deep mixing would be more conducive to algal growth. There was a production peak in July followed by a low in Sept and another rising trend to November. Whether the annual productivity cycle is controlled mainly by physical factors such as turbidity or a combination of other factors such as silica depletion and rainfall is an interesting research question.

Although there are only 3 year's data shown in Fig.1 it is clear that the lack of a salt water intrusion in 1987 did not cause lower primary production.

The relationship between primary production and turbidity is shown in Fig. 3. While there was a tendency for lower productivities in the winter at higher turbidity, there were also low productivities at low turbidity in the summer. occasionally, there were high productivities at low turbidity in the winter.

Primary production and turbidity do not seem to be clearly related to the salt intrusion phenomenon. Instead, there may be several factors acting at once to give the impression that the salt intrusions are responsible for the productivity cycle of the lake.

Laguna Lake with a mean depth of 2.8M and a fetch of up to 40km is prone to wind driven resuspension of bottom sediments. Wind speeds follow a seasonal cycle with a minimum in August rising to a maximum in April. Declining water levels between October and May coincide with the higher wind speeds and this would accentuate the resuspension potential of the winds. Thus, a seasonal turbidity cycle (as in 1987) could be expected regardless of the salt intrusions from the Pasig River.

The available primary production values for 1986-88 have been examined for correlations with some other variables such as

Secchi depth, turbidity and biomass to determine the causes of variability. As has been intimated in earlier reports, primary production is not correlated with algal biomass in Laguna Lake (Fig.4). When production is high, the production per unit biomass is also high. The main controlling factor seems to be turbidity. A multiple regression of NPP on turbidity yielded the relation: lnNPP = 0.336 - 0.023TURB - 0.001BIOMASS (R=0.73). Biomass was included in the regression more for completeness than accuracy; the correlation is slightly better including only turbidity. Comparing predicted with observed values in Fig.5 much scatter around the 1:1 line is still evident since at R=0.73 only 52% of the variance is accounted for. Nevertheless, there are strong theoretical reasons to predict that turbidity will negatively affect photosynthesis which are consistent with the regression equation. This is distinct from other correlations which occur due to variations which happen to occur at the same times of the year.

The measurement of Primary Production fits into a research scheme best when there are other fluxes being measured simultaneously. At Laguna Lake the only other flux measured is fish production. Since the fish production depends ultimately on primary production the logic at LLDA has been to measure the latter. The primary production measurements have been used to roughly scale the amount of fish production possible.

Calculation of the primary production from oxygen measurements in bottles seems straight forward but there are numerous pitfalls. Currently, "net primary production" is calculated as the difference in oxygen between an initial bottle and a clear bottle suspended at depth for about 12 hours. Although seemingly a mater of semantics, there is no way to measure net primary production in lake water. The measurement is closer to "net community production". This is because algal respiration alone cannot be measured in the lake; the respiration of all plankton is included in the "net". This can be appreciated in the following table:

During a Primary Production Incubation

	Case A	Case B
Oxygen change due to photosynthesis	+2	+2
Oxygen change due to algal respiration	-1	-1
Oxygen change due to bacteria etc	-0.5	-0.75
Net community production	0.5	0.25.

Comparing case A and B it can be seen that the "net" production can vary according to the respiration of all the plankton even when the actual photosynthesis remains constant.

An unfortunately unique approach used at LLDA is to sum only those net productions which are positive (in a vertical series) to achieve an areal estimate. The result has some unknown relationship to maximum volumetric photosynthesis but is completely incomparable to data from other lakes. Only by calculating maximum volumetric photosynthesis, areal photosynthesis, respiration (areal and volumetric) and net community production can comparisons be made with data from investigators who use more standard methods.

A much more useful calculation model produces figures for photosynthesis, respiration, and net community production for 24 hr periods. Over a 24 hr period the net carbon available for fish production is much smaller than currently estimated because the community respiration continues unabated overnight.

Considering a typical incubation in bottles for T hr.:

Initial O_2 (mg/L)	I
Clear bottle O_2 after incubation	L
Dark bottle O_2 after incubation	D

Photosynthesis Rate	(L-D)/T
Respiration Rate	(I-D)/T
Net Community Production Rate (daytime)	(L-I)/T

Net Daily __Areal__ Community Production (NDACP) = Daily photosynthesis - Community respiration integrated from surface to bottom for 24 hr:

$$(\int_b^s((L-D)/T)\times\sim 12) - (\int_b^s((I-D)/T)\times 24) = NDACP$$

It can be appreciated that in turbid water in which the photosynthesis profile does not reach the bottom a small respiration rate integrated to the bottom for 24 hr is able to eliminate much if not most of the carbon fixed by photosynthesis in the water column. This is consistent with the slow rates of change seen in algal biomass except under bloom conditions. In a 3M water column a typical biomass of 15g/m^3 would amount to about 2gC/m^2 compared to a "Net Production" of 1-2 gC/M^2/day. The expected and unsustainable growth of %50-%100 per day never occurs. Instead there are moderately positive growth rates in blue-green blooms and a relatively stable biomass at other times. Thus, the NDACP is a more relevant calculation to compare to fish production than is "net primary production".

Conversion of algae to fish

The assimilation efficiency of herbivorous fish will likely be less than %50 of carbon ingested. The growth efficiency will likely be less than %50 of carbon assimilated. Thus, the conversion efficiency of ingested algal carbon to fish carbon will be about 25% or less. If we assume that typical net production levels of 1gC/M^2/day are actually available to fish then the maximum fish production could be:

1x10000x365x0.2 = 0.73 tonnes C/ha/yr.
$\sim$ 1.46 tonnes dry wt./ha/yr
$\sim$ 14.5 tonnes wet wt./ha/yr.

Realistically, however, due to night time respiration as shown above, the daily net production is much less than daytime net production currently calculated. The diurnal oxygen curve found in the 70s (Final report; Comprehensive Water Quality Management Program Laguna De Bay 1978) shows an oxygen rise in daytime followed by an equivalent fall at night. The night time respiration therefore eliminates most of the photosynthetic carbon fixed during daytime. Thus, the amount of carbon available for fish growth is a small fraction of the carbon fixed during photosynthesis. Indeed the historical respiration data summarized by Oosterberg (1987 Algal Productivity in Laguna De Bay, Philippines: A Statistical Analysis of LLDA Data) show that these rates are around 1gC/M^2/day which, in nighttime, will account for the so-called net primary production in the daytime. Additionally, we cannot expect the fish to crop the algae to the extent which would lead to unstable algal populations. The prediction of fish productivity from algal metabolism (NDACP) will likely be less accurate than +/- 300% making the primary production measurements useful only for gross scaling arguments not detailed fishery management. Unfortunately, the author is not aware of any studies on the relationship between stocking density and fish production. Recent unpublished data from LLDA experiments show fish production rates of 0.2-0.4 tonnes/ha/yr which are equivalent to 3% or less of the rates predicted from the net algal production figures.

Recommendations:

LLDA should reconsider whether primary production measurements are in fact being used or are usable - are they needed in relation to fish production? Results of calculations revised as suggested are valid for monitoring purposes and to allow comparisons with other lakes (eg: is the lake eutrophic?).

The need for 12 hour incubations is questionable both on technical grounds and doubt that the supposed better accuracy is needed. The results from short incubations can be extrapolated to a whole day with the ratio: radiation during incubation/radiation received during whole day. The ratio can be obtained by mathematical integration from a strip chart or by direct area measurement by planimetry. A pyranometer is needed for this calculation. Alternatively, standard irradiation curves for each day can be generated from meteorologist's data. Another method is to use an onboard incubator which uses neutral density filters (layers of window screen) to simulate the exponential decrease in light with depth. With extinction coefficient data from an underwater light meter, the depth being simulated can be calculated and the thickness of the water column interval represented by each bottle can be calculated.

Primary production results should be broken down into calculations of Photosynthesis (max volumetric and total areal), Respiration, and NDACP. These calculations are valid for monitoring and to compare with data from other lakes.

Duplicate samples should be used for initial, clear and dark bottles. Titrations which are not close should be repeated.

LLDA should measure the lowest oxygen each day at daybreak as well as the ambient oxygen at the end of the day when NPP work is done. The difference gives the true open water NDaytimeACP. A subsequent measurement the next morning gives the nighttime respiration (R_{12}).NDaytimeACP +R_{12} = daily photosynthesis. NDaytimeACP - R_{12} = NDACP.

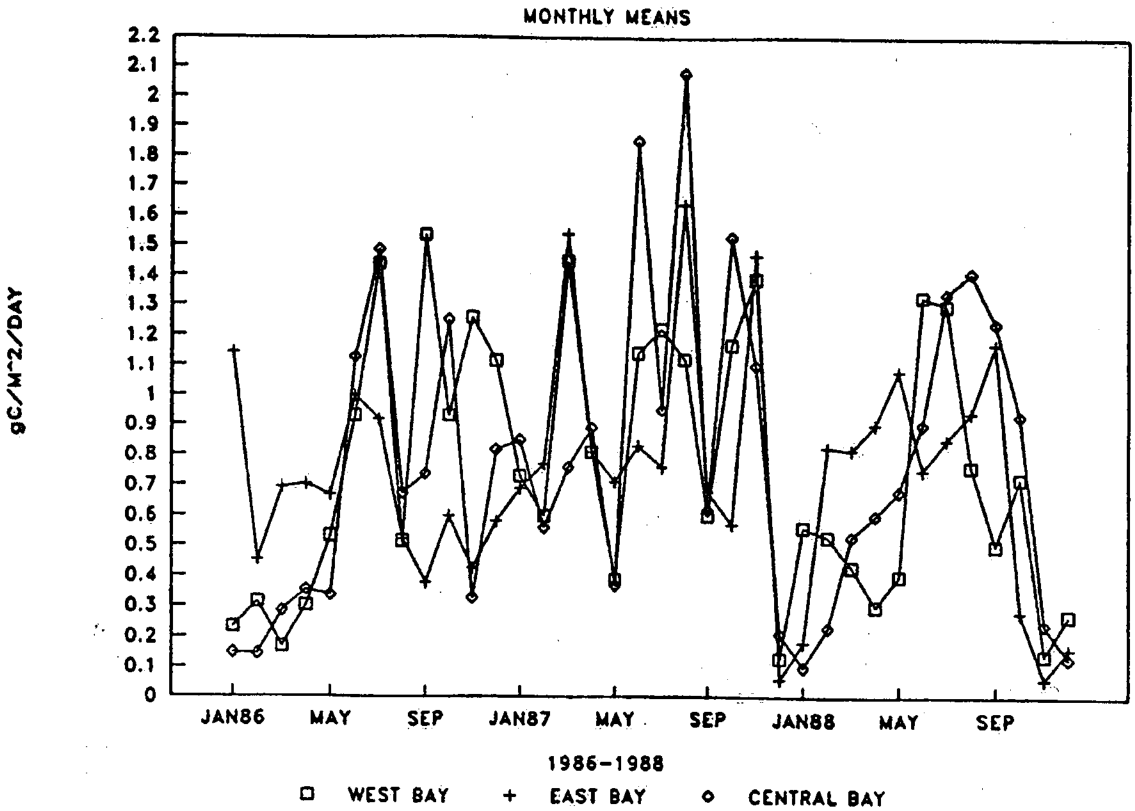

Fig. 1. Comparison of primary production in West Bay, East Bay, and Central Bay 1986-1988.

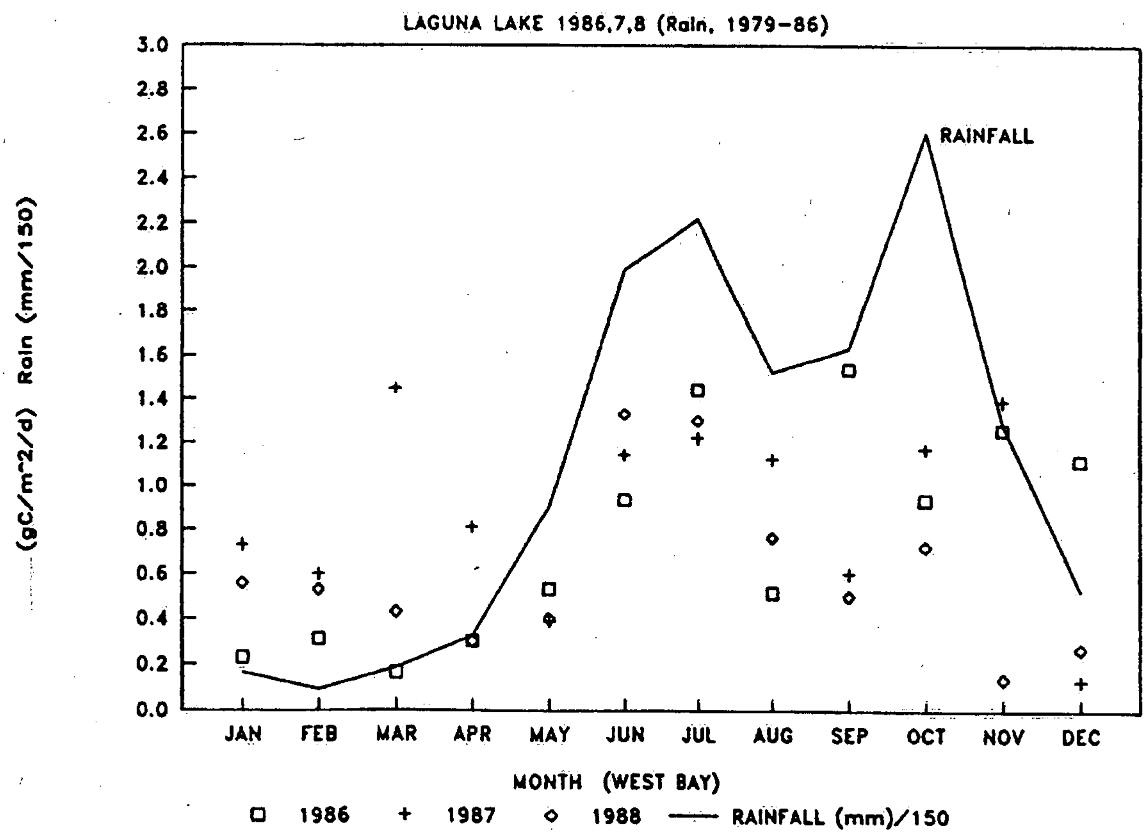

Fig. 2. Annual primary production cycle compared to annual rainfall cycle.

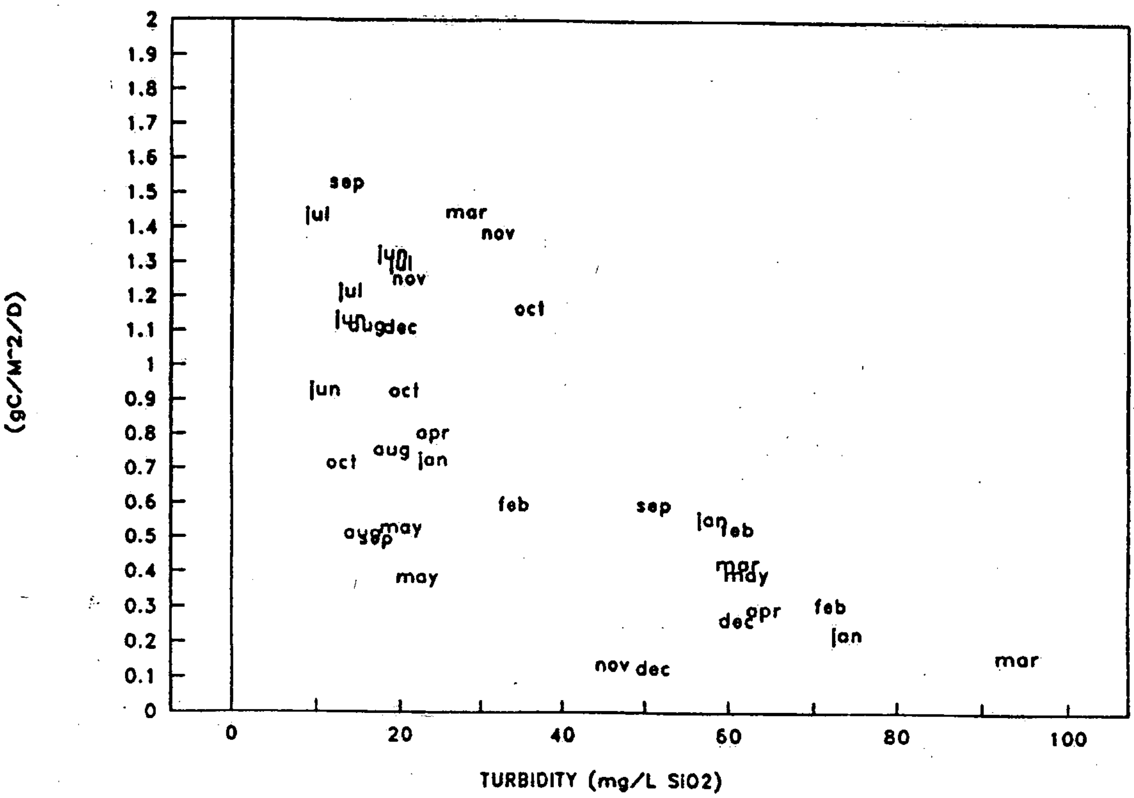

Fig. 3. Relationship between primary production and turbidity in West Bay 1986-88.

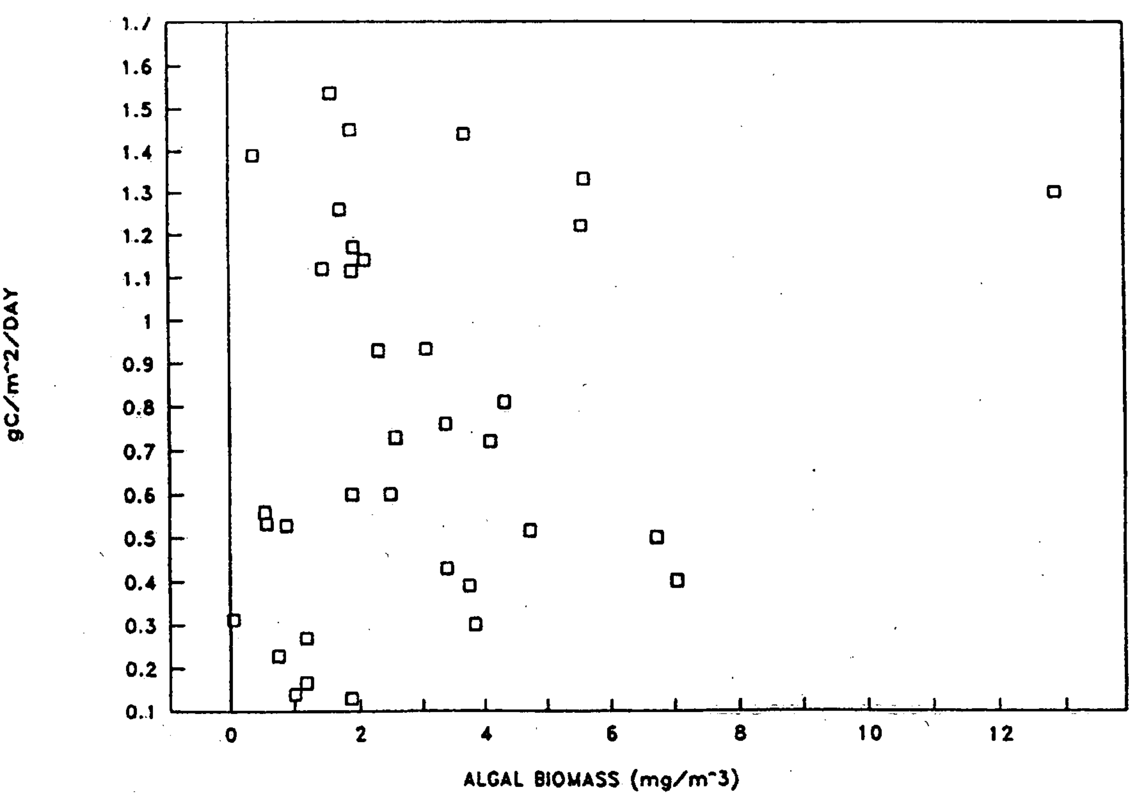

Fig. 4. Lack of a relationship between primary production and algal biomass in West Bay 1986-88.

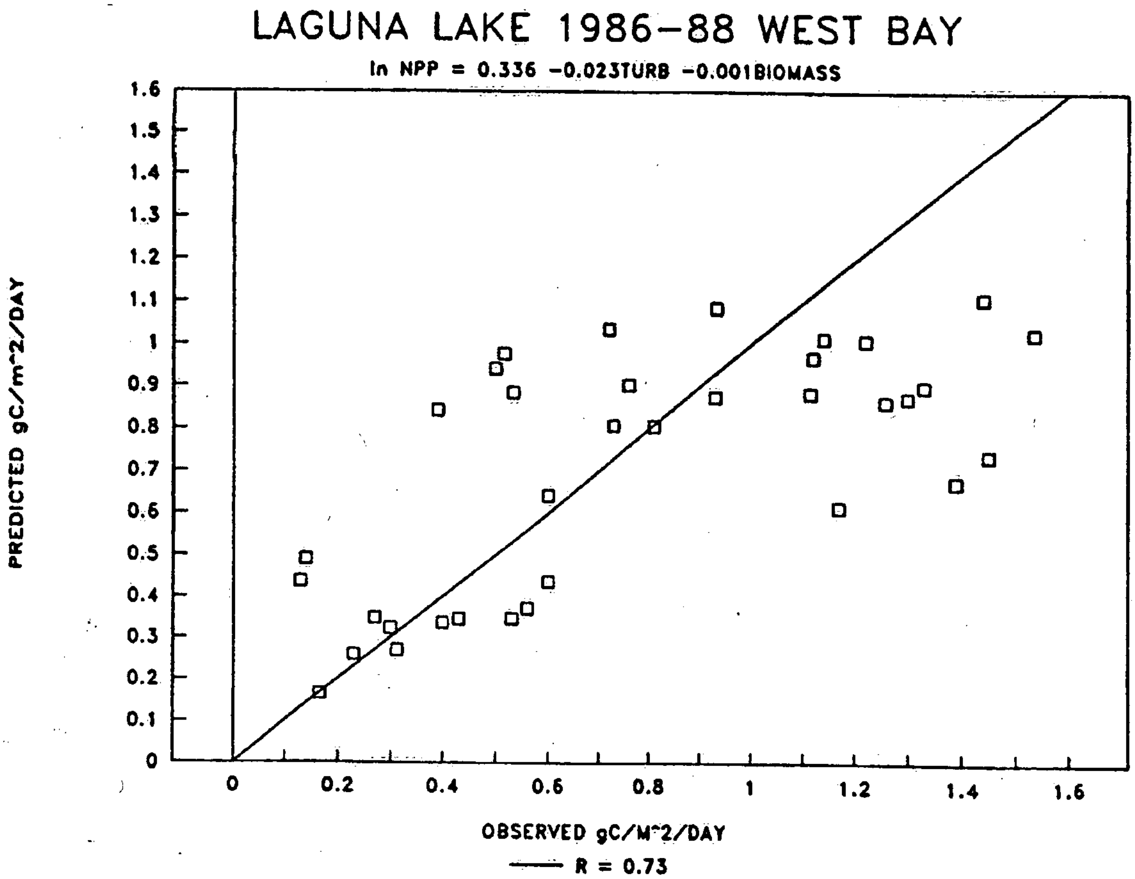

Fig. 5. Multiple regression equation of lnNPP on turbidity and biomass with comparison of predicted and observed values (line represents 1:1).

ANNEX 3 - CORRELATIONS BETWEEN PARAMETERS

A brief review of the lake data seemed to indicate that although some parameters such as phosphorus and nitrogen vary during the productivity cycle each was valuable and could not be eliminated from the sampling. Therefore, tributary data were examined in more detail. Only subsets of the data were examined to diagnose whether this activity would be profitable.

LLDA has been monitoring six rivers tributary to Laguna lake FIG.1. Each river has nutrient concentrations approaching or even exceeding that of sewage treated to North American standards.

The monitoring effort at the 9 tributary stations is substantial. Now that there are several years data accumulated, they can be examined to determine whether measurements of any parameters are unnecessary due to solid relationships with other parameters. Data from 1988,87 and 85 ware combined in one spreadsheet and the program "SSR^2 (Background Development Co., P.O. Box 13598, Tallahassie,Florida,32317, USA) was run on the spreadsheet to produce descriptive statistics and correlation matrices.

The main effort was in amalgamating spreadsheets to accumulate enough data. Rather than tediously plotting individual graphs of XY pairs or calculating individual regression equations the SSR^2 program calculates a correlation matrix. This yields a table of correlation coefficients for each possible comparison of 2 columns in the spreadsheet. The values in the matrix can be quickly compared to the critical correlation coefficient (depending on the number of samples) to find which relationships are worth investigating further. This method is fast and easy. Care must be taken that the "relationships" revealed are actually reasonable. Typically, water quality data result in many spurious and confusing correlations. LLDA should use software such as SSR^2 for screening purposes when looking for correlations amongst many variables. For 2 column regressions the function built into "123" is adequate. The SSR^2 program also performs multiple regression analyses and can select data in named ranges from spreadsheets on diskettes. The author has provided training in the use of SSR^2.

The first run was done using 28 observations of TP, IP, and NO_3 to determine whether data from different stations on the same river are correlated.. Table 1 shows the correlation coefficients between stations on the same river; T1-T2, T4-T5, and T7-T8:

Table 1: Correlation coefficients between data at upstream and downstream stations

STN	Tot-P	IP	NO_3
T1-T2	0.17	0.73	0.92
T4-T5	0.24	0.70	0.39
T7-T8	0.81	1.00	0.76

Most of the coefficients were high as expected but 3 were low. Mean TP at stn T1 was 1252 ug/L compared to 1118 ug/L at stn T2 (R=0.17). Mean TP at stn T4 was 704 ug/L compared to 797 at stn T5 (R=0.24). Mean NO_3 at stn T4 was 960 ug/L compared to 549 ug/L at stn T5 (R=0.39). The low correlation coefficients mean that the variations in concentration were not closely matched at the 2 stations. Indeed this could be expected for T4-T5 due to the substantial differences between means for NO_3 and TP. These findings suggest that monitoring at the upstream and downstream stations sometimes yields different results. On the other hand, many of the differences between stations are relatively small and LLDA may wish to review continuation of upstream-downstream work depending on knowledge of industrial locations and non-point sources.

With regard to relationships between parameters a statistically significant correlation coefficient at P=0.05 would be 0.37 for this data set. Disregarding spurious correlations between rivers, there are only rarely significant correlations between Tp and IP or NO_3 as shown in Table 2:

Table 2. Correlation coefficients at P=0.05 between TP, IP, and NO_3 (1988,87,85)

STN/PARAMETER	R	STN/PARAMETER	R
T2TP vs. T1IP	0.67	T7TP vs. T7IP	0.69
T7TP vs. T8TP	0.69	T2TP vs. T2IP	0.89
T8TP vs. T7IP	0.39	T4TP vs. T5IP	0.43
T8TP vS. T8IP	0.39		

The most prevalent correlation was between TP and IP as would be expected since IP is a large portion of TP. NO_3 and IP were not related at the P=0.05 level. Thus, there is, for these data, no justification to eliminate parameters.

The ratios NO_3/IP and IP/TP are examples of indicators which can reveal whether the quality of loading is consistent between each river. Table 3 shows that there are large variations in these ratios. This means that predictions of one variable from another would have to be based on a separate relationship derived for each river.

Table 3. Ratios (means) of NO_3 to IP and IP to TP (1988, 87, 85)

Station	T1	T2	T3	T4	T5	T6	T7	T8	T9
NO_3/IP	0.26	0.25	0.91	2.50	1.67	0.57	0.66	0.75	0.88
IP/TP	0.62	0.81	0.51	0.52	0.41	0.55	0.37	0.24	0.39

The final search for correlations was performed between parameters at each station. A spreadsheet called "CONS.wk1" was assembled to hold the monthly means of parameters measured at each station; dissolved oxygen (DO), biological oxygen demand (BOD), chloride (CL), chemical oxygen demand (COD), coliform bacteria (COLI), nitrate (NO3), oil (OIL), pH (PH), inorganic dissolved phosphorus (IPO4), temperature (TEMP), total phosphorus (TP), total solids (TS), total suspended solids (TSS), and turbidity (TURB). A correlation matrix was then obtained for each station using the program "SSR^2. The individual printouts are available at LLDA. The correlation matrices were examined for all Rs above the critical value of 0.58 at P<=0.05. The statistically significant correlations are reported in Table 4.

Table 4. Correlations between tributary variables at each station in 1988

	DO	BOD	CL	COD	COLI	NO3	OIL	PH	IPO4	TEMP	TS	TSS
STN 1	COD NO3 -PH TSS TURB	CL OIL TS	OIL IPO4 TS			-PH -TEMP TSS	TS	-TSS -TURB	TS -TSS			TURB
STN 3	NO3 -IPO4 -TEMP TSS TURB	COD -PH TS	TS TSS	-PH TS		-IPO4 -TEMP TSS TURB	IPO4		TURB	-TSS -TURB		TURB
STN 4	-TEMP	COLI IPO4				OIL					TURB	TURB
STN 5	-CL TSS	TEMP	TEMP -TSS	-TS	OIL			IPO4	TS			TURB
STN 6	-TEMP	CL -TURB	-NO3		OIL TSS	-TP			-TSS			TURB
STN 7	-TEMP			-TS				IPO4 TURB	-TURB			TURB
STN 8	-TEMP		TS	TS				IPO4 -TSS -TURB				TURB
STN 9	-TS	TSS						-TURB				

* Correlations are reported for those R values above the critical 0.58 (n=12) for P<=0.05. Station 2 was omitted.

Except for the expected relation between TSS and Turbidity there are no relations which suggest that a parameter is redundant at each site. Of course, this is only from data of one year and many more of these correlation matrices can eventually be produced. The results are, however, consistent with the author's contention that the parameters are a good set of basic water quality indicators. Savings involved in eliminating unneeded or redundant measures such as turbidity or pH would be insignificant.

Perhaps the best use of correlation matrices is to aid understanding and to provide clues on placement of river loadings. For example Table 4 shows that the most correlations were in the two rivers known to have the worst coliform counts (San Pedro and San Cristobal). In these rivers, DO can be low enough to inhibit decomposition of wastes so there can be some surprising changes between NH_3 and NO_3. The prevalence of correlations may mean that the pollution tends to be of one type or from one source.

ANNEX 4 - EFFECT OF DRINKING WATER WITHDRAWAL

Laguna Lake loses about 1.5M of depth during the dry season. This is equivalent to the loss of $1.4x10^9M^3$ from November to the end of April. Drinking water demand will be about $0.49x10^9M^3$ during the same period. Thus, when the lake is losing water depth naturally there will be an additional draw down of roughly 0.5M which is significant compared to the remaining depth.

MEAN DEPTH		2.8	M
AREA		90000	ha
DEPTH LOST	NOV-APR	1.5	M
VOLUME LOST	NOV-APR	1.4E+09	M^3
DAILY DEMAND	DRINKING	2700000	M^3
DEMAND	NOV-APR	4.9E+08	M^3

This additional drawdown will be a negative factor limnologically since the worst algae blooms and fish kills occurred at times of low water. Although the full extent of the effects are dependent on more knowledge of the hypsometric curve, the projected water use may have a substantial effect on levels and lake conditions. The strategy of operations at the Napindan River Control Structure should take into account the need to minimize the change in water levels potentially caused by drinking water withdrawal.

ANNEX 5 - PHYTOPLANKTON BIOMASS

Since 1974 algal samples have been collected and counted using the Utermohl method. The data have been tabulated in major groups as Greens, Blue-greens, Diatoms, and Phytoflagellates. Sampling has been at the frequency of twice per month in recent years but there have been several months with no samples.

Until now, there have been few presentations of the data. This is unfortunate because algae are the basis of the fish production in the lake. To rectify the situation the author has obtained the data and constructed an example spreadsheet to record the data and to facilitate easy and effective presentation of the data. The spreadsheet ("BIOSPP74.WK1") contains all the data of the West Bay station as well as formulae and procedures to calculate seasonal means and present pertinent graphs. The format of the spreadsheet is convenient for print presentation as well as for statistical analysis. Simple spreadsheet functions coupled with a macro have been used to summarize the data into wet and dry season means. A more advanced method is to use the 123 database functions (eg: "@Davg") by varying the month and year selectors in a "criterion range". The 123 database functions are very powerful in that they provide a convenient way of selecting and summarizing specific data from a long-term data base. For example, if the formula +D1>=5#AND#+D1<=10 is in the month column 79 is in the year column the @DAVG function will produce the mean for a parameter in the wet season months of 1979 even though the spreadsheet contains many years of data. By using the /RV command the results can be converted to non-active numbers and the basic formula used with different criteria to produce the mean for another year until all the data are summarized. An example of this technique is provided in the spreadsheet. The importance of summarizing the data will become apparent in the following discussion.

Figs. 1 and 2 show monthly average total algal biomass data from 1974 to 1988 for West Bay and Central Bay. These figures serve the purpose of providing a preliminary inspection of the data. The recent tendency for lower biomass can readily be seen but these graphs are cluttered and confusing due to the differences between months and years. Typically, graphs of this type are presented with lines joining the points which makes the clutter even worse.

Figs. 3 and 4 show an elementary summary of the data into annual means with the standard deviation amongst the months. By summarizing the data into annual means it is now apparent that the West Bay has more biomass and more variability than the Central Bay. Also, low biomass occurred in the mid 1970s and biomass in the late 80s was about 50% of the previous low values. The highest points in Fig.3 are due to only a few samples. It is particularly interesting that low biomass occurred in 1977 which was the year of reportedly intensive blooms and fish kills due to algal die off. Clues should be sought to explain this in weather patterns, water levels, lake circulation, algae counting methods etc.

Searching for trends in specific months is also possible as is shown by Figs.5 and 6. Here it is obvious how inconvenient missing data can be when one wishes to determine whether there has been a real change in two of the most productive months. Nevertheless, the data from the late 1980s are not very different from 1976.

The data become more interesting and useful when they are broken down into wet and dry months (May-Oct and Nov-April). Fig. 7 is a comparison of total biomass each year in the two seasons. Now it is apparent that there has been hardly any change in the dry season which constitutes 1/2 of each year. Most of the variability is in the wet season with the extremes noted before in the early 1980s. Wet season biomass in 1988 was not much different than biomass in 1976-77. Biomass was very low in 1986 despite the strong salt water incursion which occurred that year.

A further breakdown into the major algae types of Blue-Greens and Diatoms is shown in Figs. 8 and 9. The majority of the variability in the wet season is due to Blue-Green algae blooms. Diatoms tend to dominate in the dry season showing as yet no real trend over the years (Fig. 9). By appreciating the difference in scale between Figs. 8 and 9 the tremendous modification to the ecosystem caused by Blue-Greens becomes apparent. Blue-Green blooms increase the biomass 5-10 times over normal background levels which consist of mostly diatoms. Clearly, for six months of the year, consumers in the lake depend heavily on Diatoms since the Blue-Greens are largely absent. Comparing wet and dry season Diatom biomass over the years (Fig. 10) the two seasons are fairly similar. A regression through the 1974 to 1987 wet season data would surely produce a statistically significant downward slope. With the addition of the 1988 data, however, that conclusion might seem premature. The next five years would seem critical for determining whether the lake is actually changing or is progressing through a series of cycles.

The importance of enumerating the algae in the various main groups is that ecological changes in species abundance can be detected. Fig. 11 shows, not surprisingly, that the species composition as % of total biomass has not changed in the dry season. Fig. 12 is completely different. There have been dramatic changes in relative biomass abundance but the long-term data show that these changes in the late 1980s have occurred before in the mid-1970s. Again, this is consistent with the notion of cycling or random differences as opposed to the notion that there is a permanent long-term change.

The value of seasonal summaries is thought to be in the realization that lake biota must endure whether or not dramatic Blue-Green blooms occur, Thus a fairly long integrating interval such as a season seems appropriate. Indeed comparing the long-term data on relative abundance in July and August (Figs. 13 and 14) it is apparent that either Blue-Green dominance or Diatom dominance is normal depending on the month. The seasonal data, on the other hand show the fundamental difference which is not sensitive to the presence or absence of Blue-Greens in any one month.

Plotting the monthly averages of %Diatoms of total biomass (Fig.15) and %Blue-Greens (Fig. 16) gives an impression of the number of times each is dominant. Assuming sampling is not biased, it is perhaps surprising to see how rarely the Blue-Greens do dominate. The seasonal mean can be skewed by a few very high Blue-Green numbers. Another way to examine the data may be to calculate the number of occurrences or days with Blue-Green biomass greater than 50%.

In summary, the algae data have suffered from lack of analysis and presentation; a beginning has been made here. The spreadsheet techniques have been transferred to LLDA staff. The data are important as basic background biology at the bottom of the food chain. It is important to regularly sample the phytoplankton as these results show the real food base which supports fish production. The importance of Blue-Green algae blooms has perhaps been misunderstood. It is important to achieve a better understanding of monthly foodchain energy flow to appreciate the meaning of the cycling species abundance shifts. Diatoms seem to be fairly stable and their importance should be better understood.

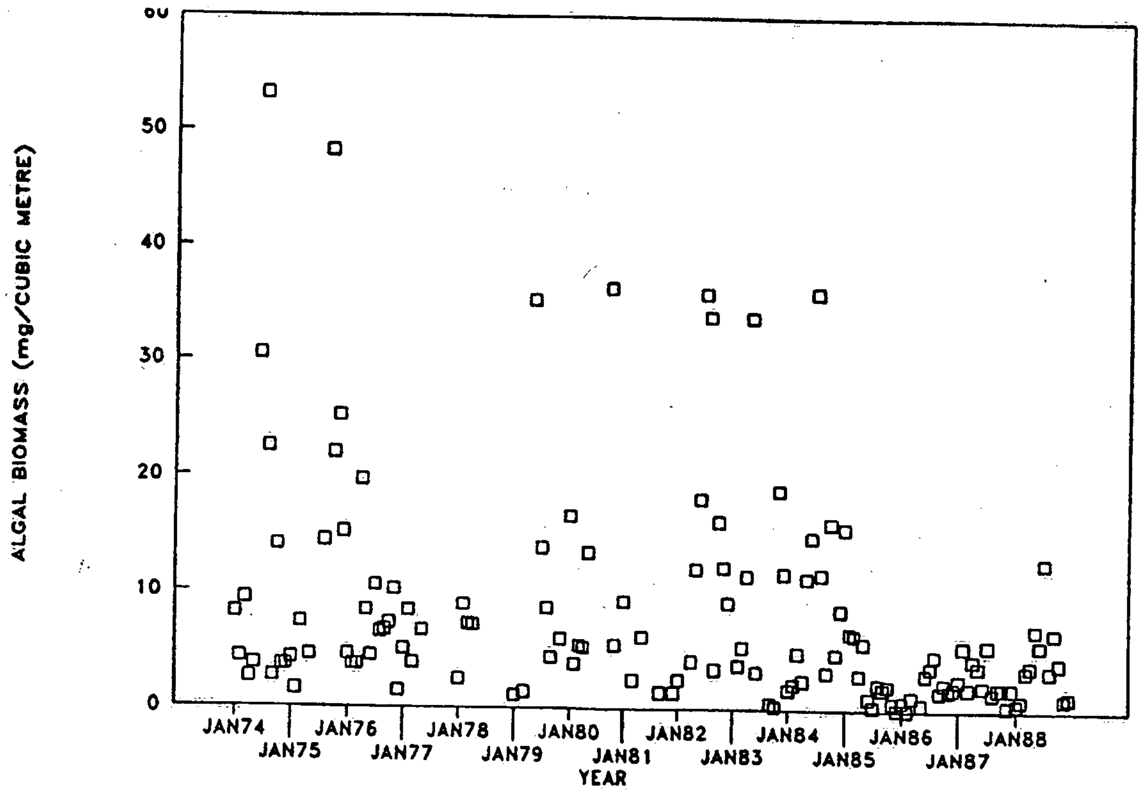

Fig. 1. Long-term distribution of total algal biomass monthly means in West Bay 1974-1988.

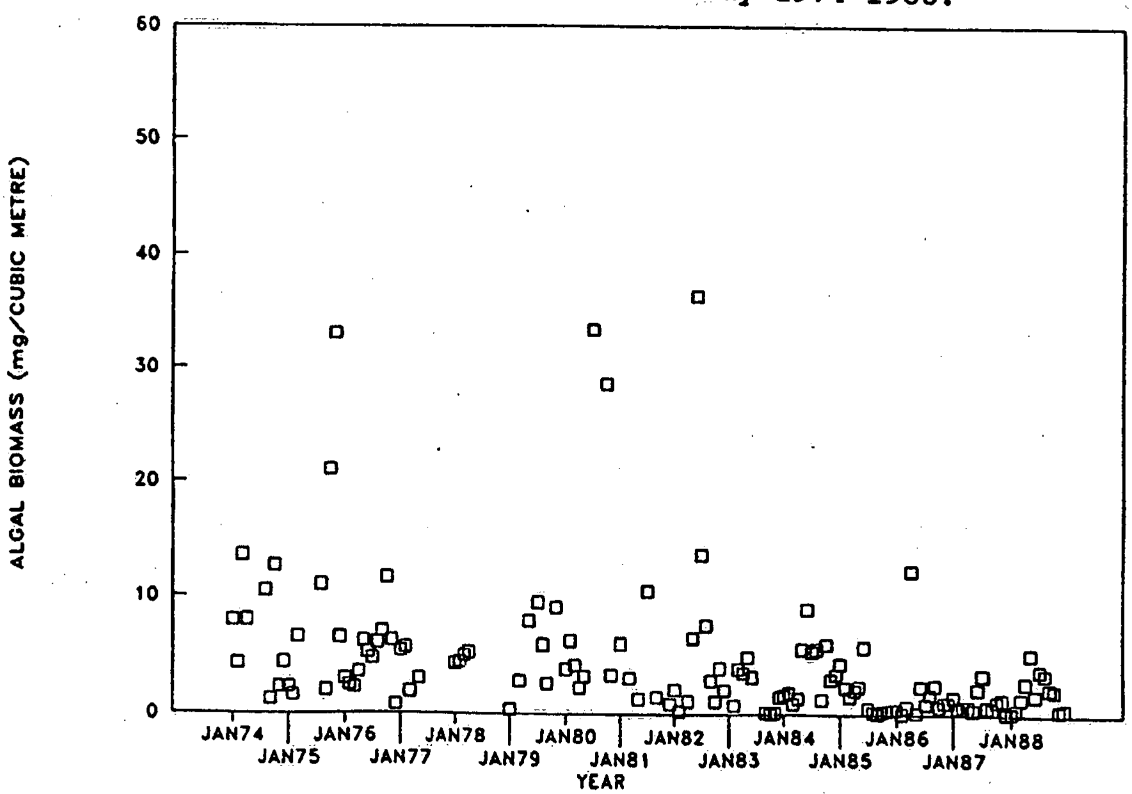

Fig. 2. Long-term distribution of total algal biomass monthly means in Central Bay 1974-1988.

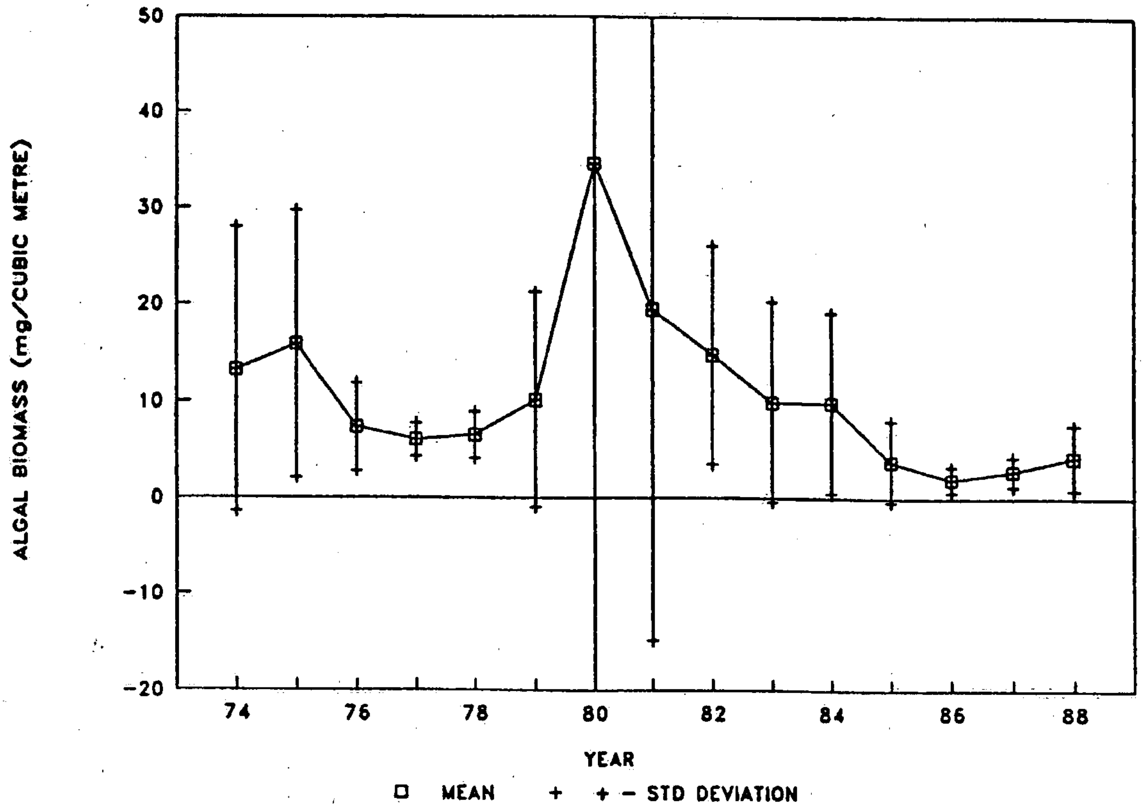

Fig. 3. Long-term mean (+/- std deviation) annual total algal biomass summary in West Bay 1974-1988.

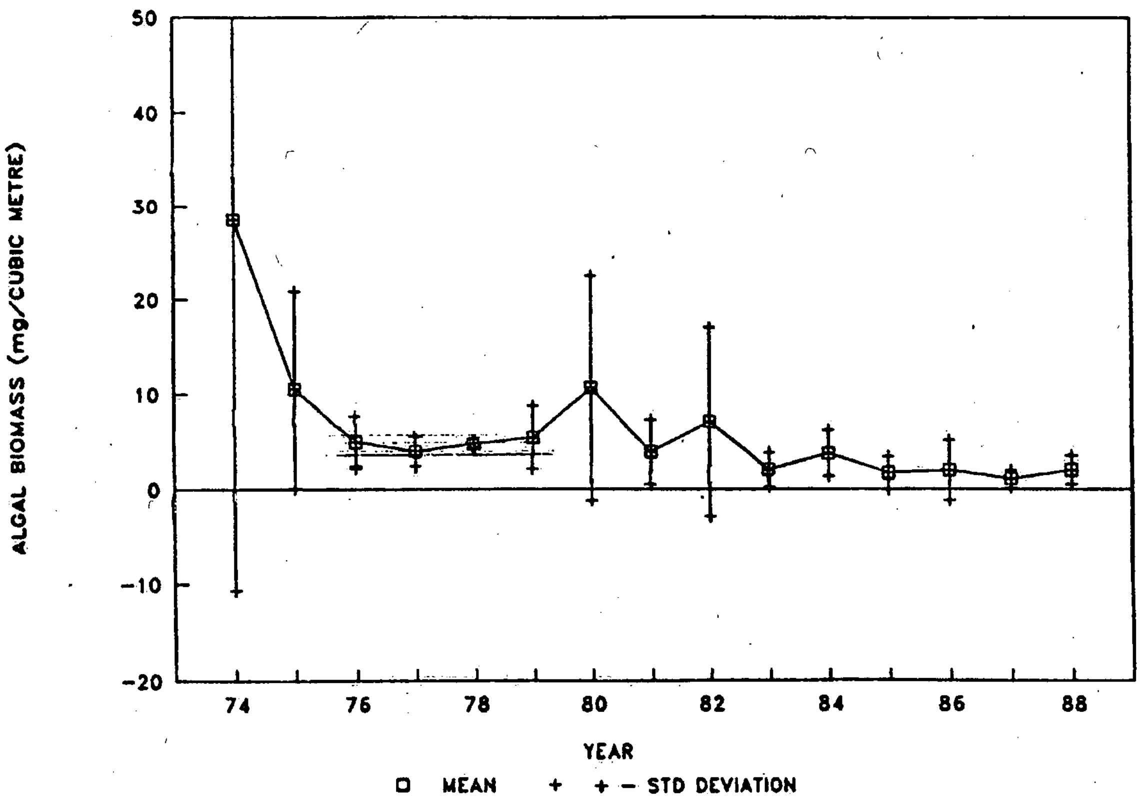

Fig. 4 Long-term mean (+/- std deviation) annual total algal biomass summary in Central Bay 1974-1988.

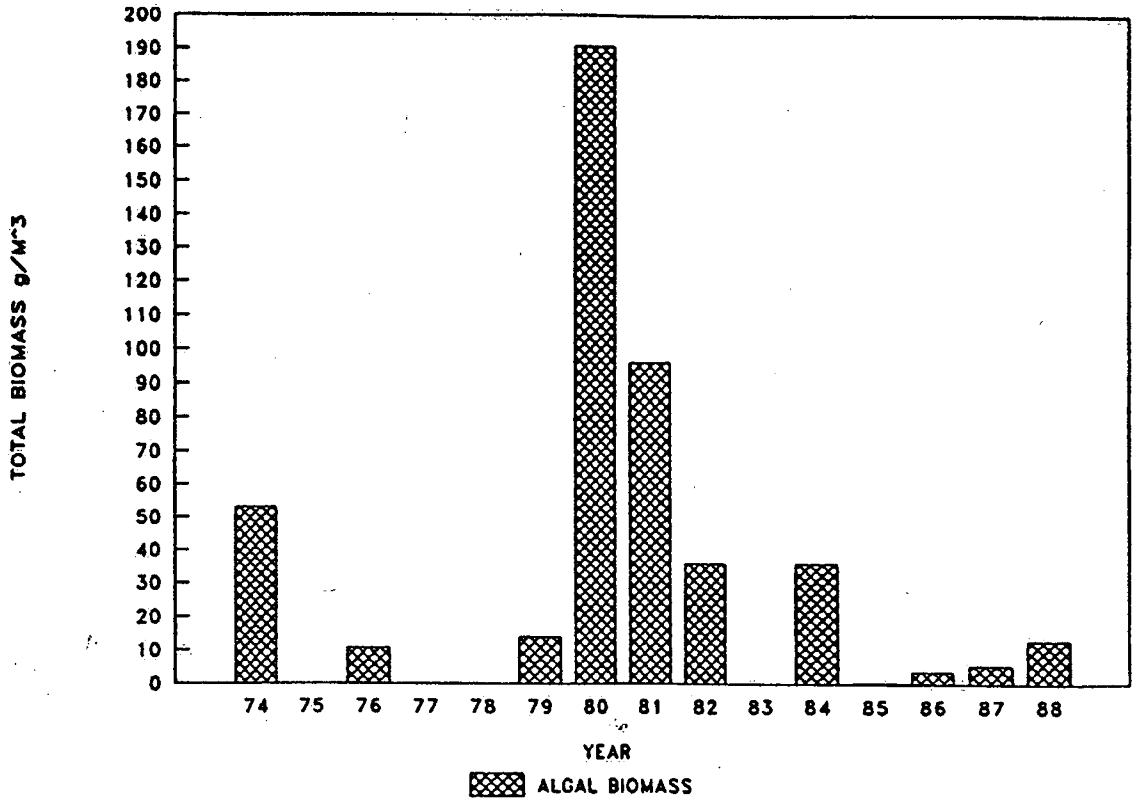

Fig. 5. Long-term summary of total algal biomass in West Bay during July 1974-1988.

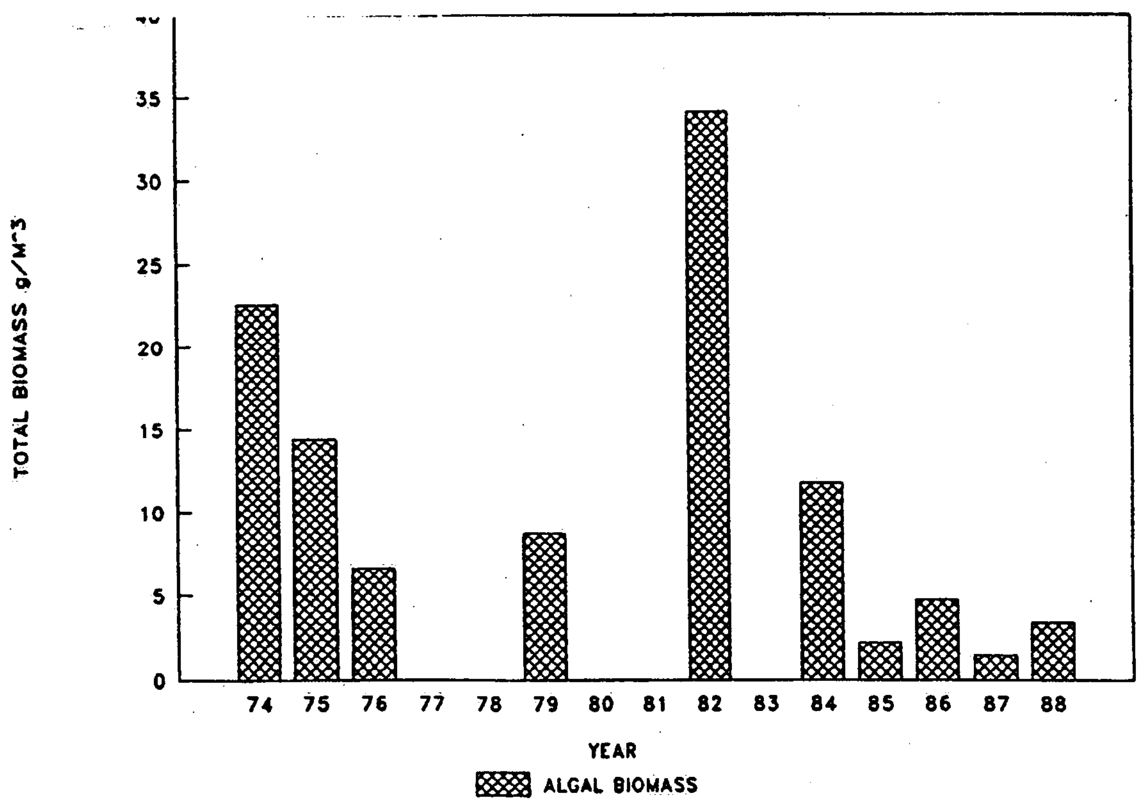

Fig. 6. Long-term summary of total algal biomass in West Bay during August 1974-1988.

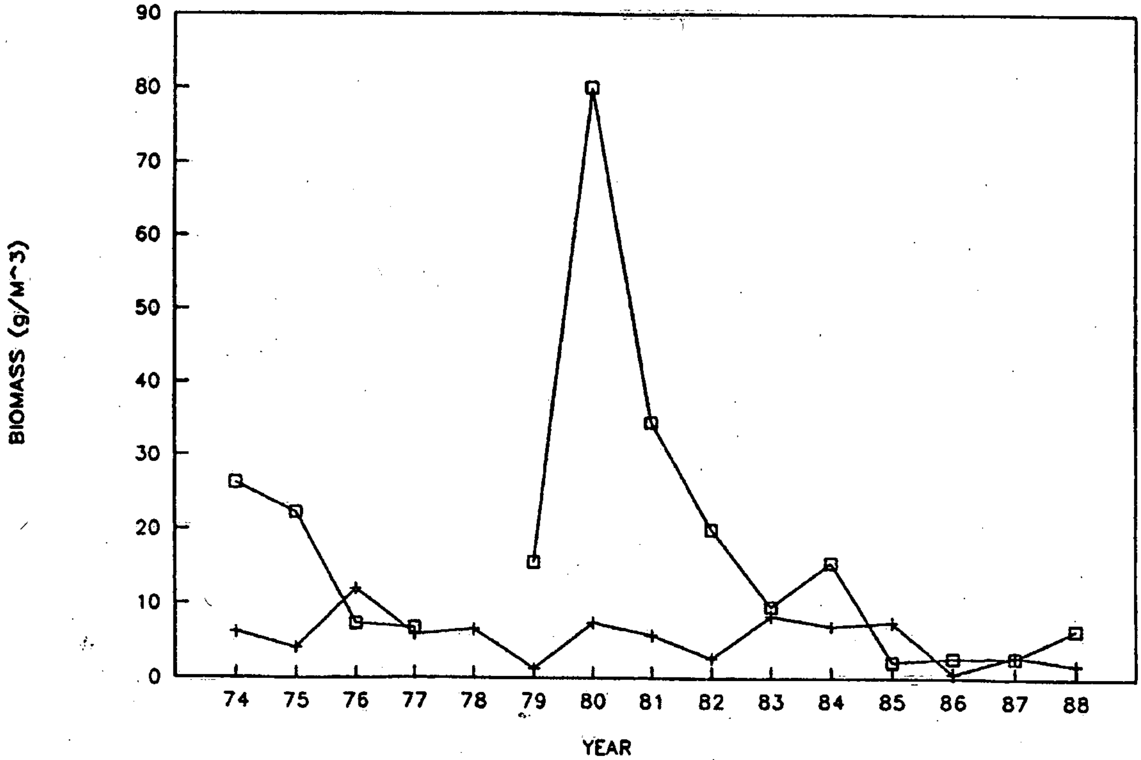

Fig. 7. Comparison of total algal biomass in the wet season with biomass in the dry season 1974-1988.

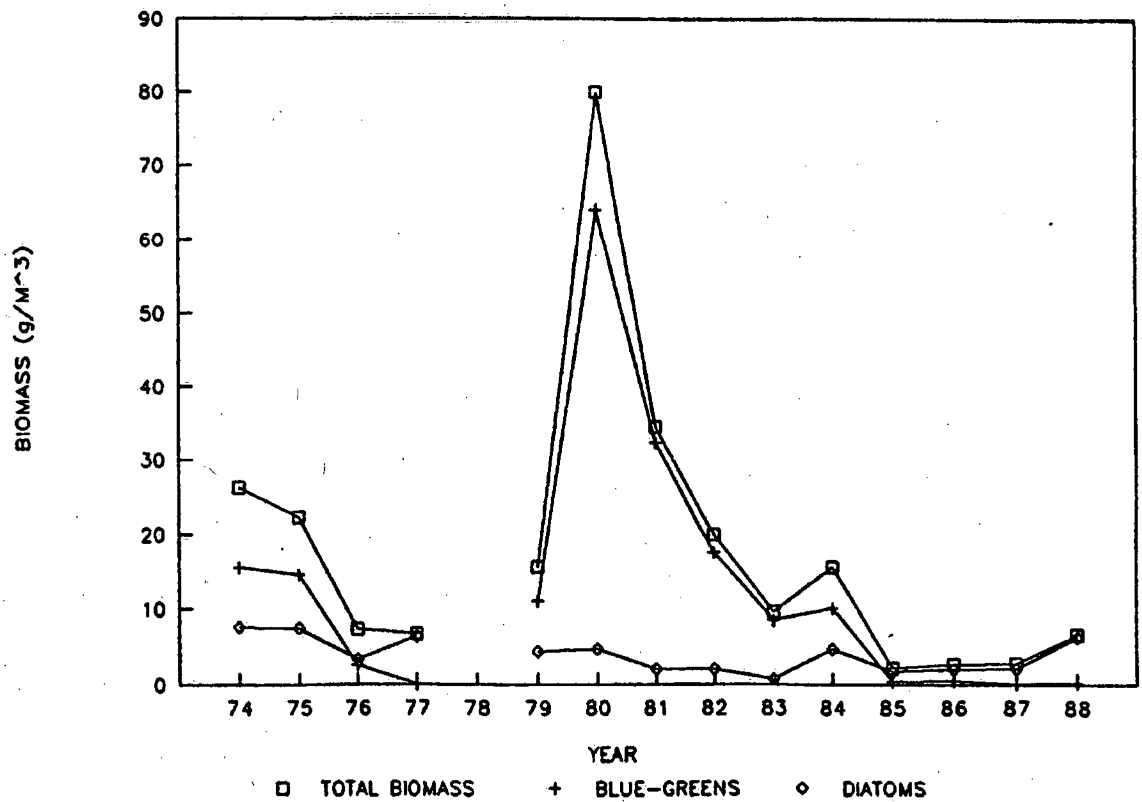

Fig. 8. Long-term summary of wet season total algal biomass, Blue-Green biomass, and Diatom biomass in West Bay 1974-1988.

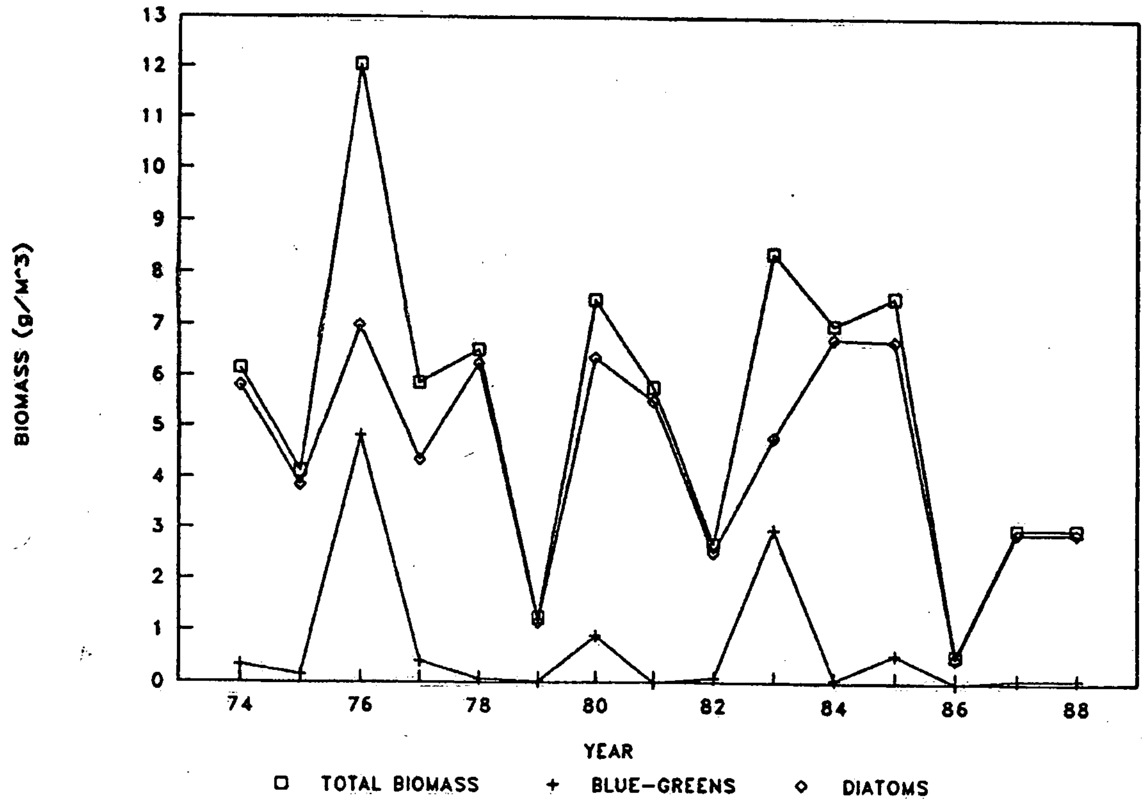

Fig. 9. Long-term summary of dry season total algal biomass, Blue-Green biomass, and Diatom biomass in West Bay 1974-1988.

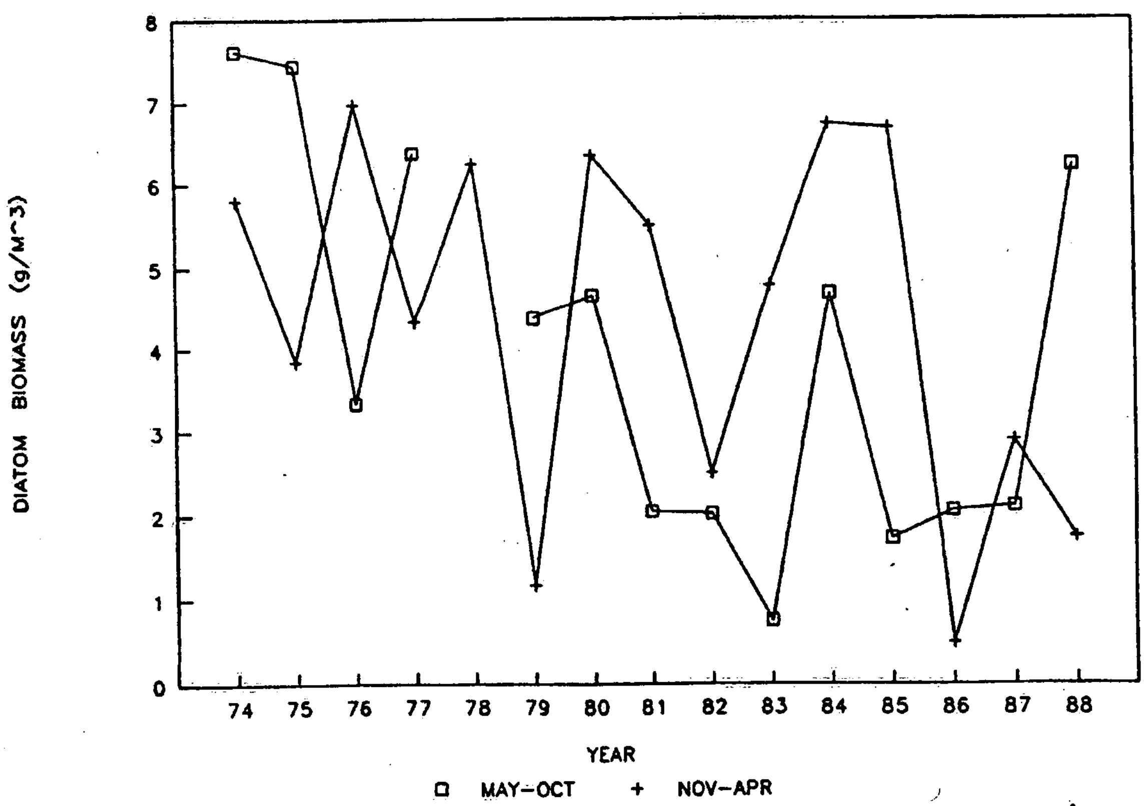

Fig. 10. Comparison of wet and dry season diatom biomass in West Bay 1974-1988.

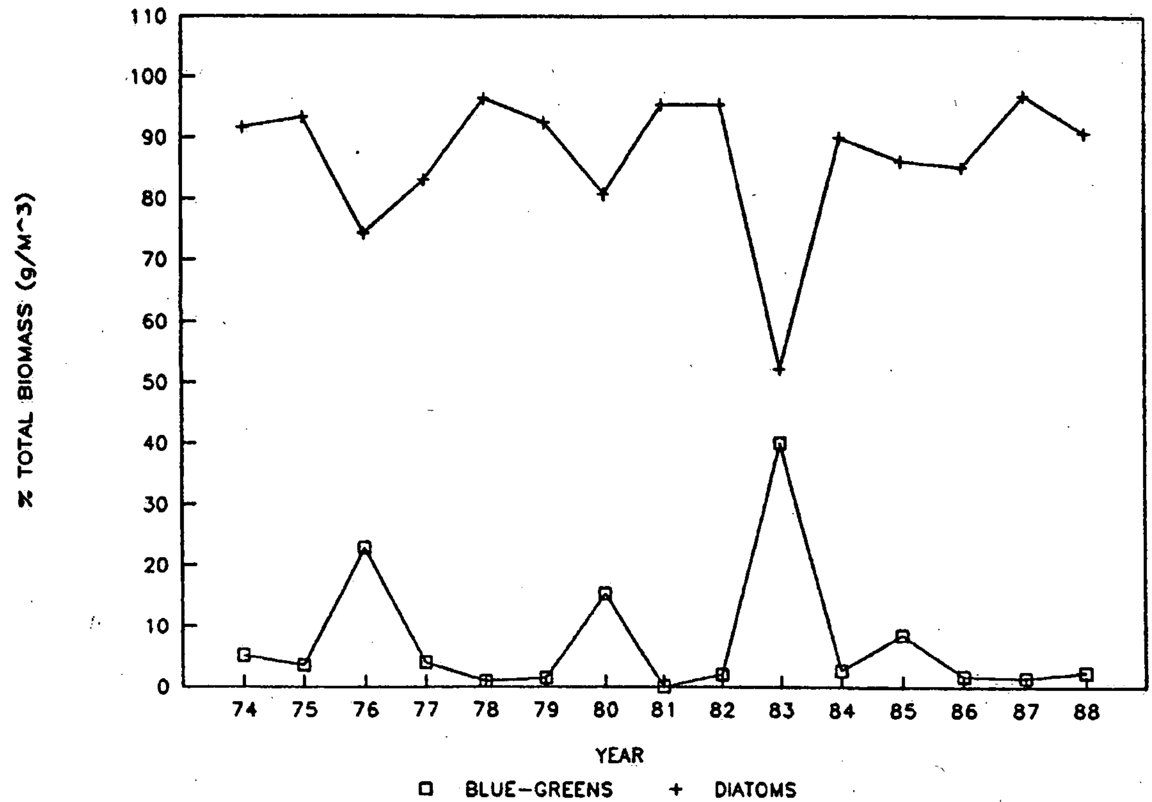

Fig. 11. Percent composition of major phytoplankton biomass groups in West Bay 1974-1988 during the dry season.

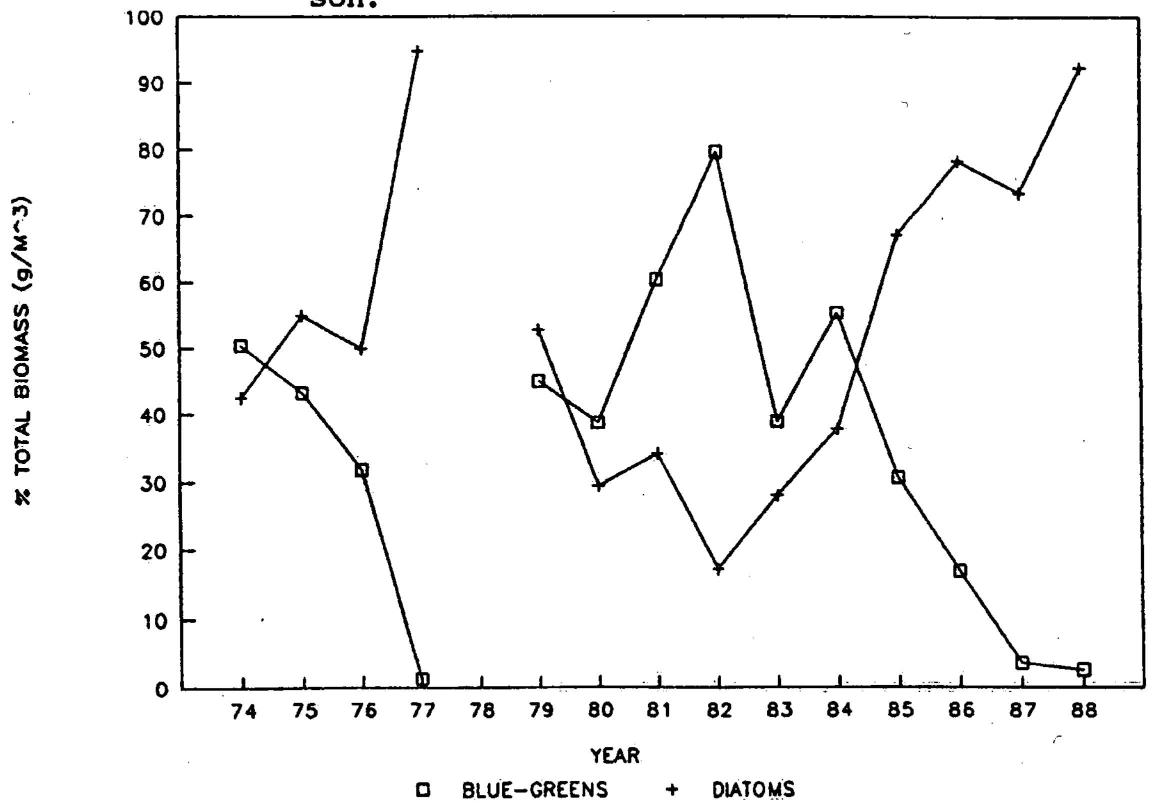

Fig. 12. Percent composition of major phytoplankton biomass groups in West Bay 1974-1988 during the wet season.

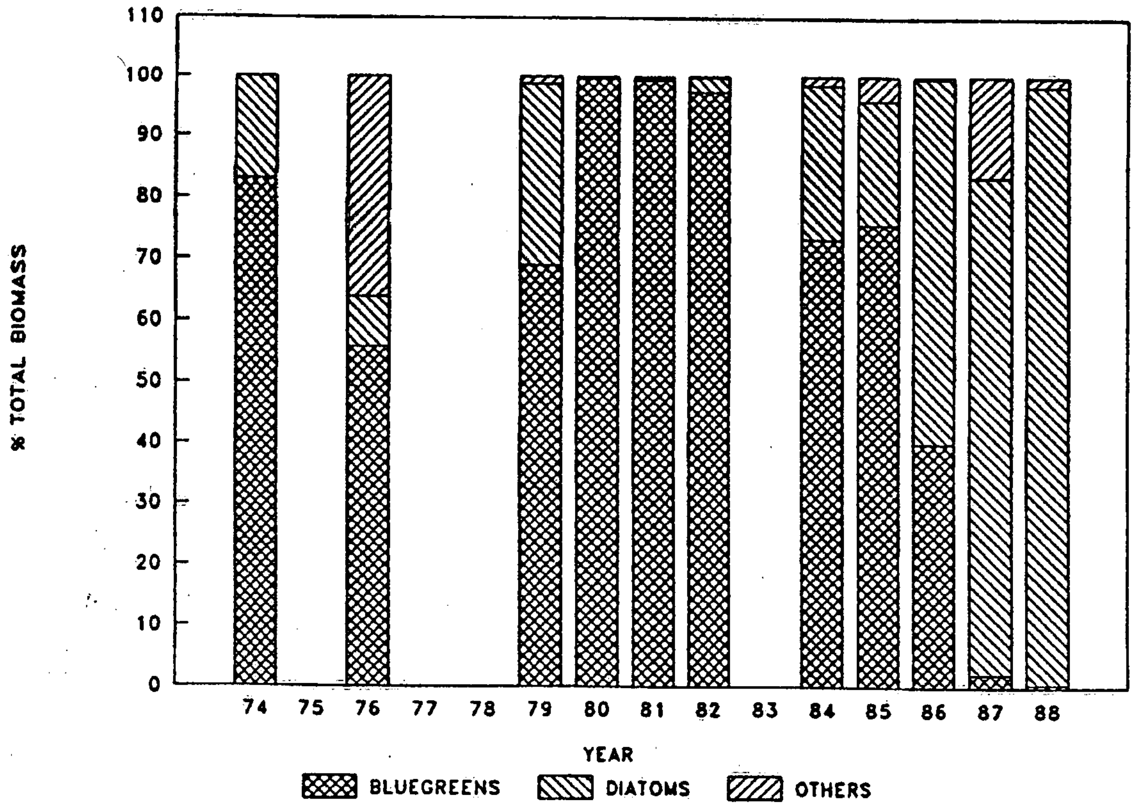

Fig. 13. Percent composition of major phytoplankton biomass groups in West Bay during July 1974-1988.

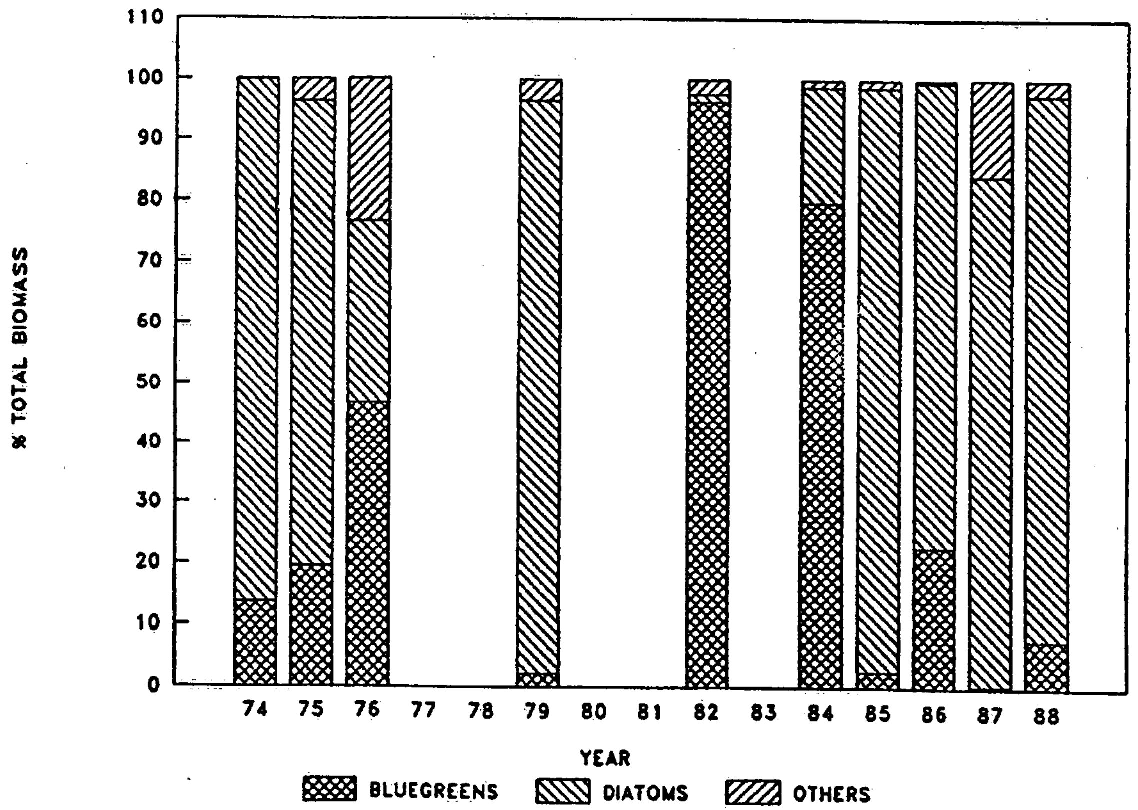

Fig. 14. Percent composition of major phytoplankton biomass groups in West Bay during August 1974-1988.

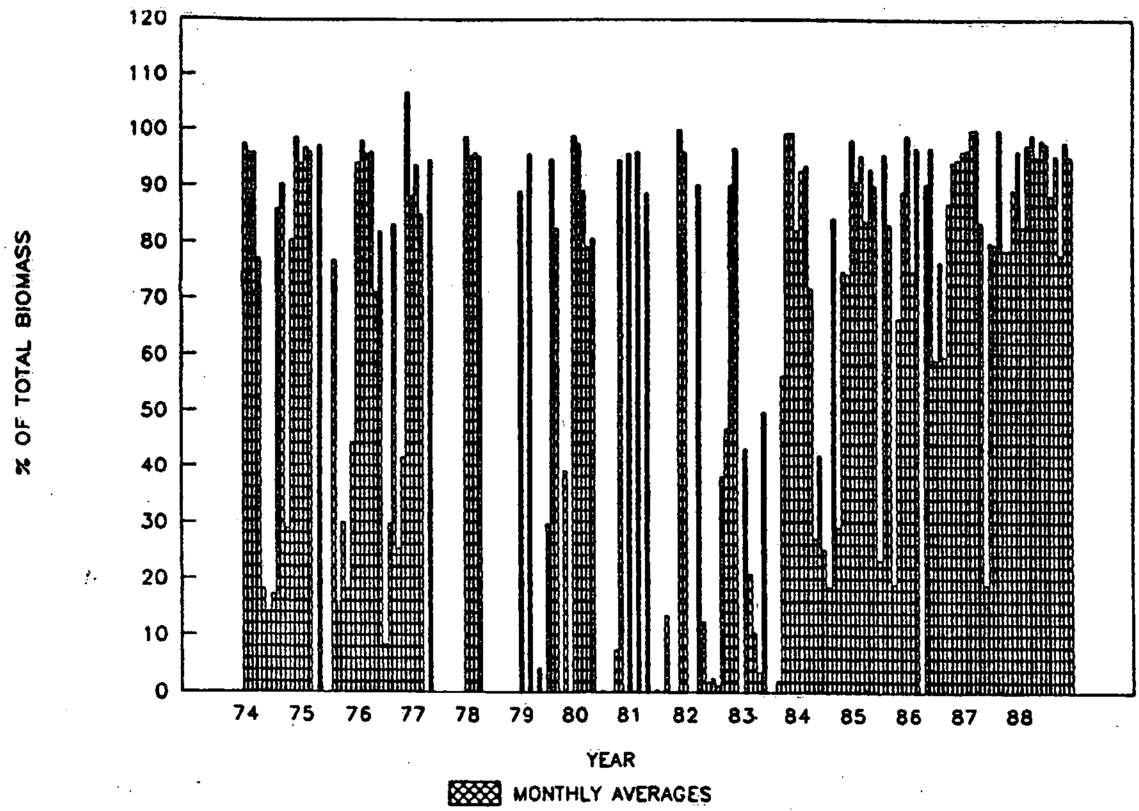

Fig. 15. Occurrence of Diatoms as % total biomass in West Bay 1974-1988.

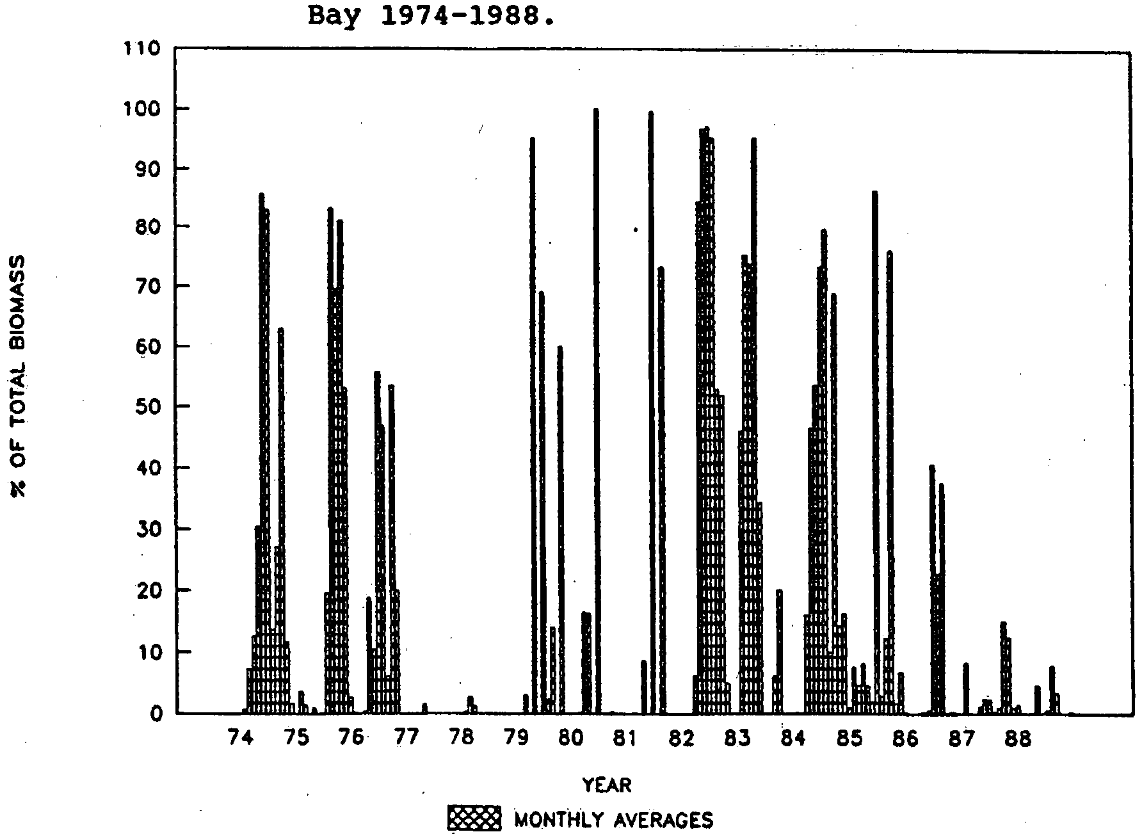

Fig. 16. Occurrence of Blue-Green algae as % total biomass in West Bay 1974-1988.

ANNEX 6 - HYPOTHESIS FOR DECLINING FISH PRODUCTION RATE

When fish pen culture was introduced to Laguna Lake in the 1970s the yield and profitability were so encouraging that eventually one third of the lake was covered with fish pens. In the 1980s, fish productivity decreased along with the profitability of the operations. Originally the cultured fish were to exist solely on the algal resources of the lake. Now there is pressure to allow the operators to artificially feed the fish. There has not been a definitive explanation for the decline in fish growth rates.

Superficially, one would expect the fish productivity to be directly dependent on algal populations. In the mid 1980s a study entitled "Primary Productivity Study of Laguna Lake in Relation to the Operation of the Hydraulic Control Structure" (LLDA staff) showed that algal biomass tended to be slightly higher inside fishpens than outside! While this may be due to feeding operations by the fishermen it may call into question the idea that the milkfish exist only on algae. This observation may be inconsistent with the notion that recent decreases in fish growth rate are due to slightly lower algal numbers. The fact that the fish are, in some pens, fed artificial food shows that their feeding behaviour is plastic. The pattern of high fish production on initiation of the pen technique followed by eventual low fish production appears similar to other resource overutilization phenomena. This leads the author to the following hypothesis:

The early fish production was based partly on consumption of benthos. When the population of benthos was eventually reduced, the fish had to survive on algae and productivity then decreased.

This hypothesis can be tested by comparing the abundance of benthos inside and outside the pens. If there is much less benthos inside the pens the fish production is dependent on benthos and the cause of the productivity decline is known. If there is no difference, the benthos in the pens may be usable by co-cultures of other species or other techniques such as periodic fallowing of areas in the pens may be applicable. This study would take a few years since the benthos are most abundant in summer. Very careful sampling must be carried out. The techniques could include insect emergence traps. This study would provide useful baseline data on the ecology of the fish pens. The author does not wish to convey any belief in or commitment to the hypothesis itself beyond the supposition that fish would grow best on animal protein. The author finds it difficult to believe that stocking fish would have no impact on benthos given the plastic feeding behavior demonstrated. Thus, the author proposes that it is important to test the hypothesis if only to reduce the number of possible explanations for declining fish productivity.

ANNEX 7 - SECCHI TRANSPARENCY

Water transparency has been measured with a Secchi disk since 1976 in Laguna Lake. Unfortunately, the data have not been reported before now. The Secchi disk is easy to use and there is a world wide body of data to the extent of inclusion of these measurements in water quality indices. Thus, the Secchi data allow comparisons with other lakes. In theory, the Secchi disk offers some advantages over laboratory methods such as turbidity. For example, the Secchi disk is used directly in the field. There is no overhead for maintenance and the disk can be constructed and replaced easily. Laboratory methods are thought to suffer from the possibility that particles may settle or coagulate during storage. With a few minutes training the Secchi disk can be used by almost anyone. Perhaps the best reason to use Secchi transparency is that the method can be easily demonstrated to the public and the measurement is meaningful to the public since it represents the visibility of underwater objects.

Data were extracted from LLDA reports for 1986,87,88 for the purpose of portraying the seasonal cycle. Fig. 1 shows the seasonal transparency increase beginning around May-June. The three bays are fairly similar. The transparency decrease from peak levels occurred in 1987 despite the lack of a salt water intrusion washout. Thus, it can be inferred that the typical transparency decrease from Aug to Jan does not depend on washout of salt during the rainy season.

All of the Secchi data from 1976 to 1988 were obtained from LLDA files and entered into a Lotus 123 spreadsheet. Perhaps the same general conclusions would have been forthcoming had the author analyzed turbidity but the effort involved in entering hitherto unrecorded Secchi data was less than that required to reorganize the 123 turbidity files and LLDA now has more data computerized.

The long-term data for the dry season are plotted as maxima, means, and minima in Figs. 2, 3, and 4 for the West, Central, and East Bays respectively. The years 1986 and 1988 tended to have less transparency than other recent years. Taking all the data back to 1976 into account, there is no support for the notion that the lake is becoming less transparent.

The long-term data for the wet season are plotted as maxima, means, and minima in Figs. 4, 6, 7 for the West, Central, and East Bays respectively. Transparency tends to be greater in the wet season than in the dry season. This is directly opposite to the experience in most eutrophic lakes which have low transparency in the productive season due to excessive algal populations. Again, these Secchi data do not support the notion that there has been a long-term degradation of the water transparency

Secchi data from 1986, 87, 88 were regressed against turbidity in Fig.8. The Secchi readings were transformed into 1/Secchi to make them comparable to concentration units. The regression produced the equation:

$$1/\text{Secchi} = 0.0058 + 0.000547\text{Turbidity} \qquad R = 0.9.$$

It should be gratifying to LLDA staff to find such a good relationship. Clearly, the lake water turbidity is represented well by Secchi readings. The effort which is now expended on turbidity measurements could well be spent on suspended solids and loss on ignition.

The Secchi data contribute directly to answering the controversy about whether the lake has become more turbid. This shows the importance of periodically reporting all data available in an accessible format.

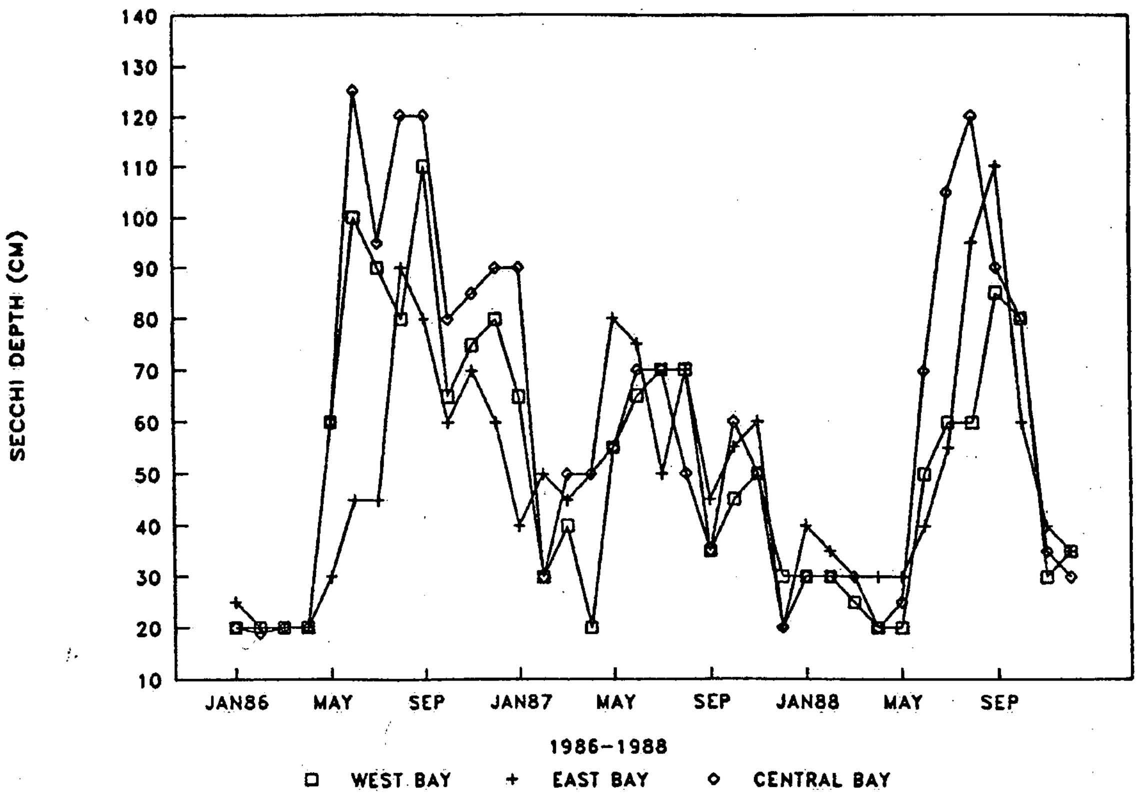

Fig. 1. Comparison of monthly mean Secchi depth in west Bay, East Bay, and Central Bay 1986-88.

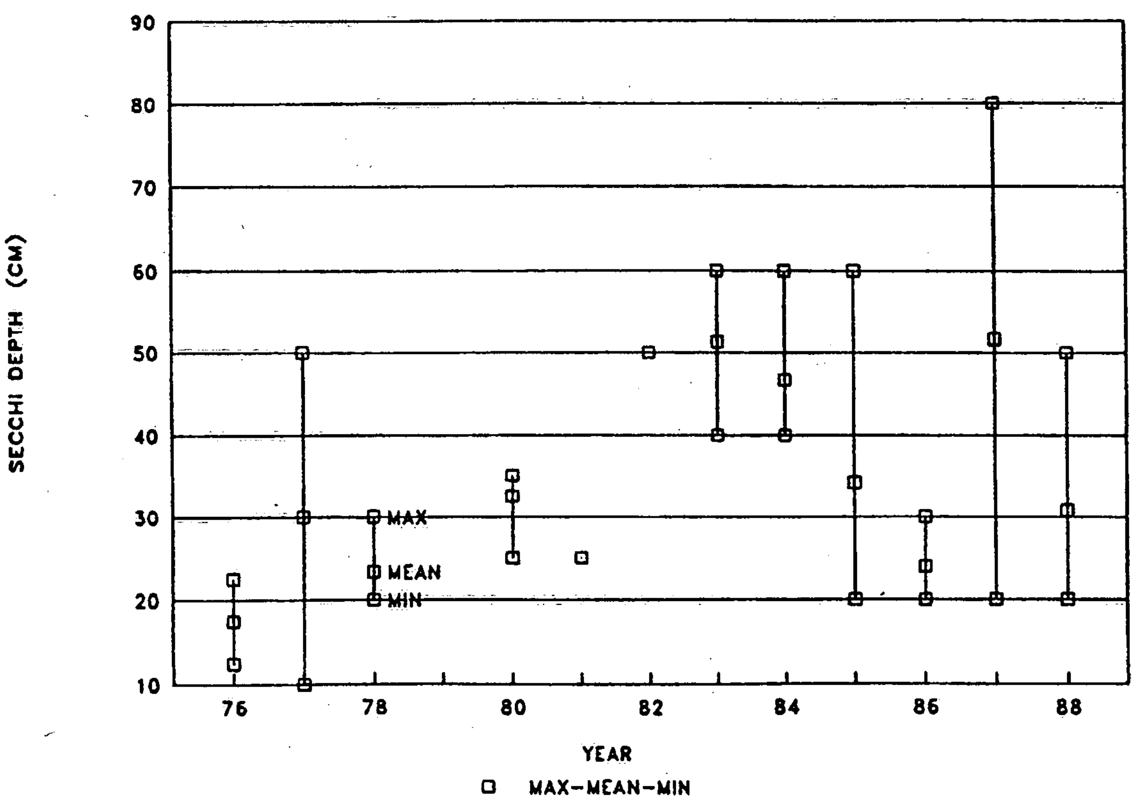

Fig. 2. Long-term summary of max-mean-min monthly Secchi depths during the dry season in West Bay 1976-1988.

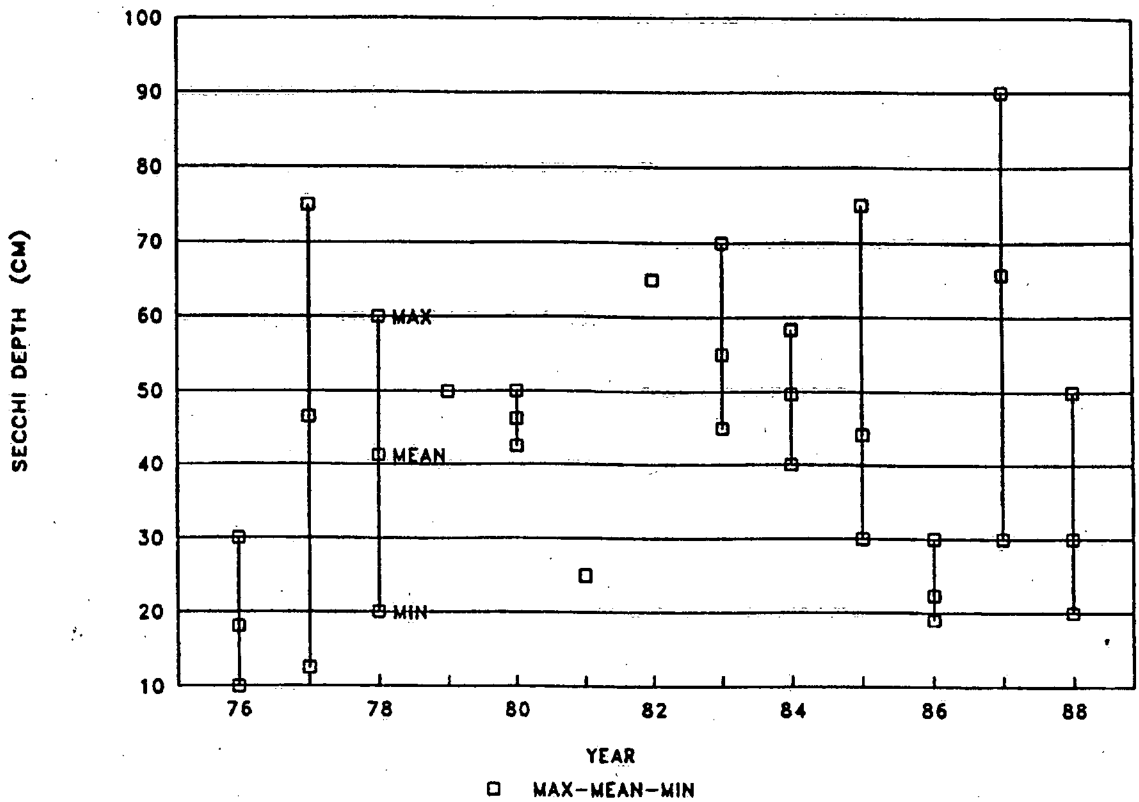

Fig. 3. Long-term summary of max-mean-min monthly Secchi depths during the dry season in Central Bay 1976-1988.

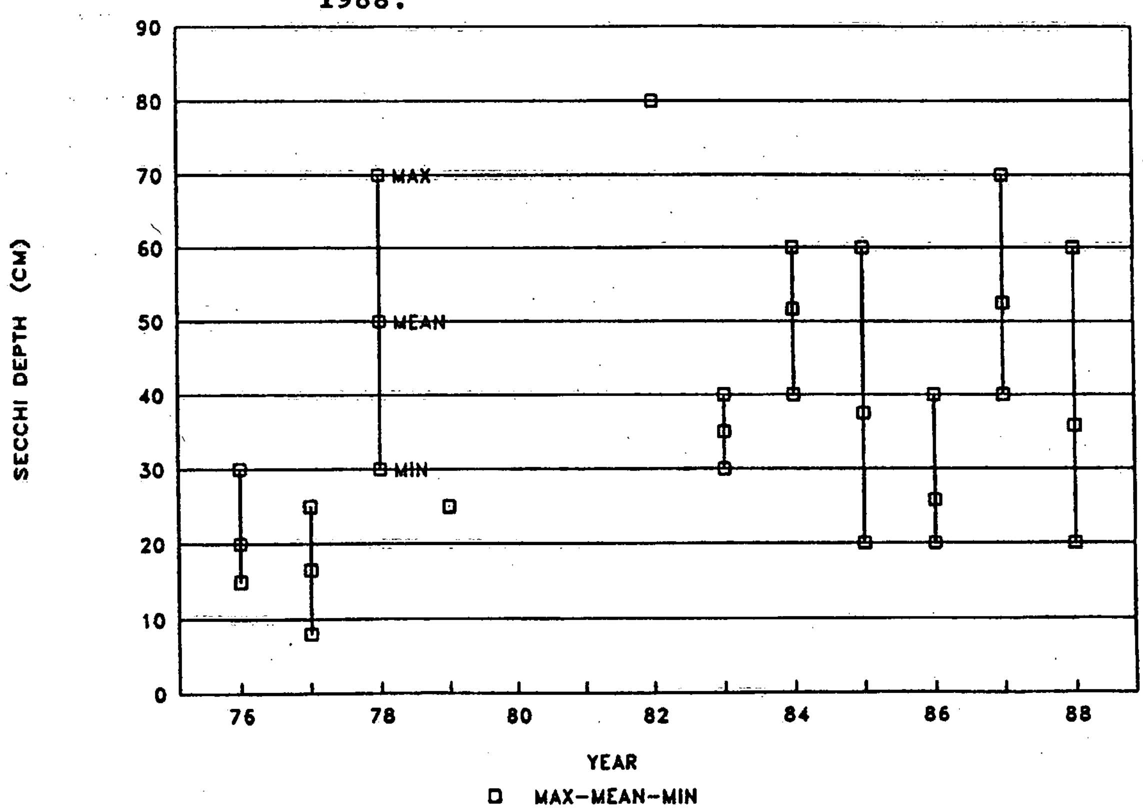

Fig. 4. Long-term summary of max-mean-min monthly Secchi depths during the dry season in East Bay 1976-1988.

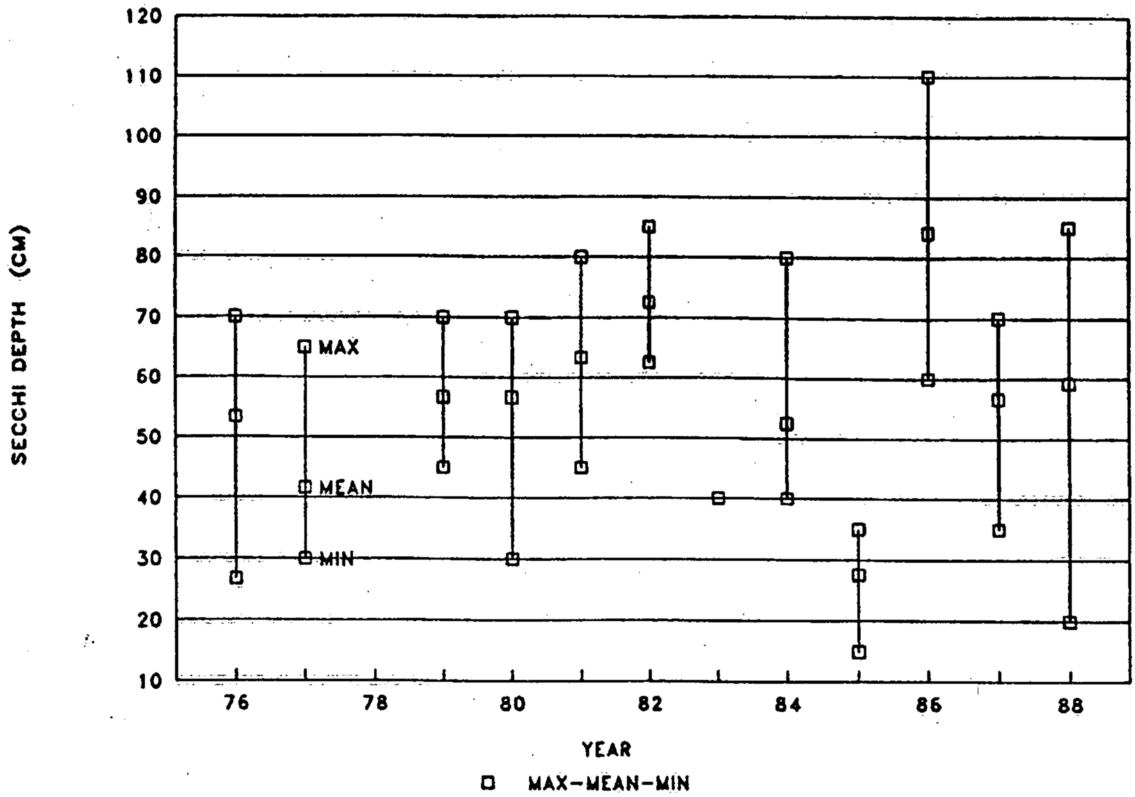

Fig. 5. Long-term summary of max-mean-min monthly Secchi depths during the wet season in West Bay 1976-1988.

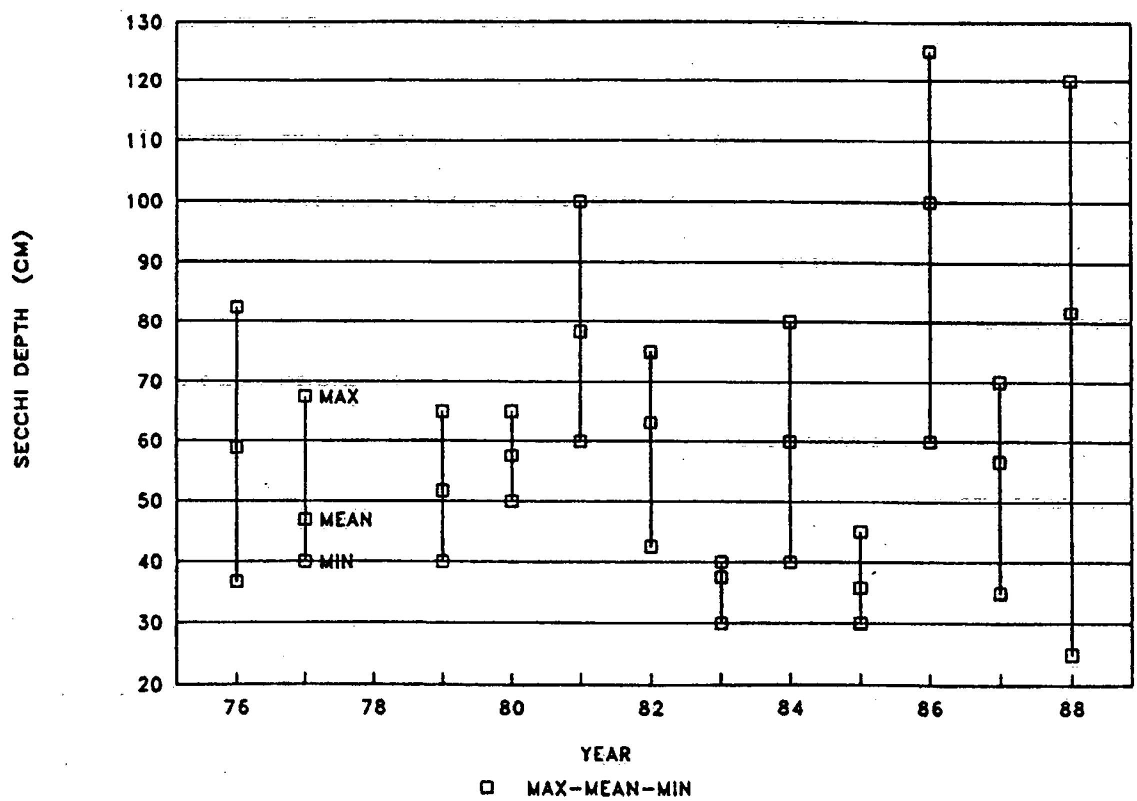

Fig. 6. Long-term summary of max-mean-min monthly Secchi depths during the wet season in Central Bay 1976-1988.

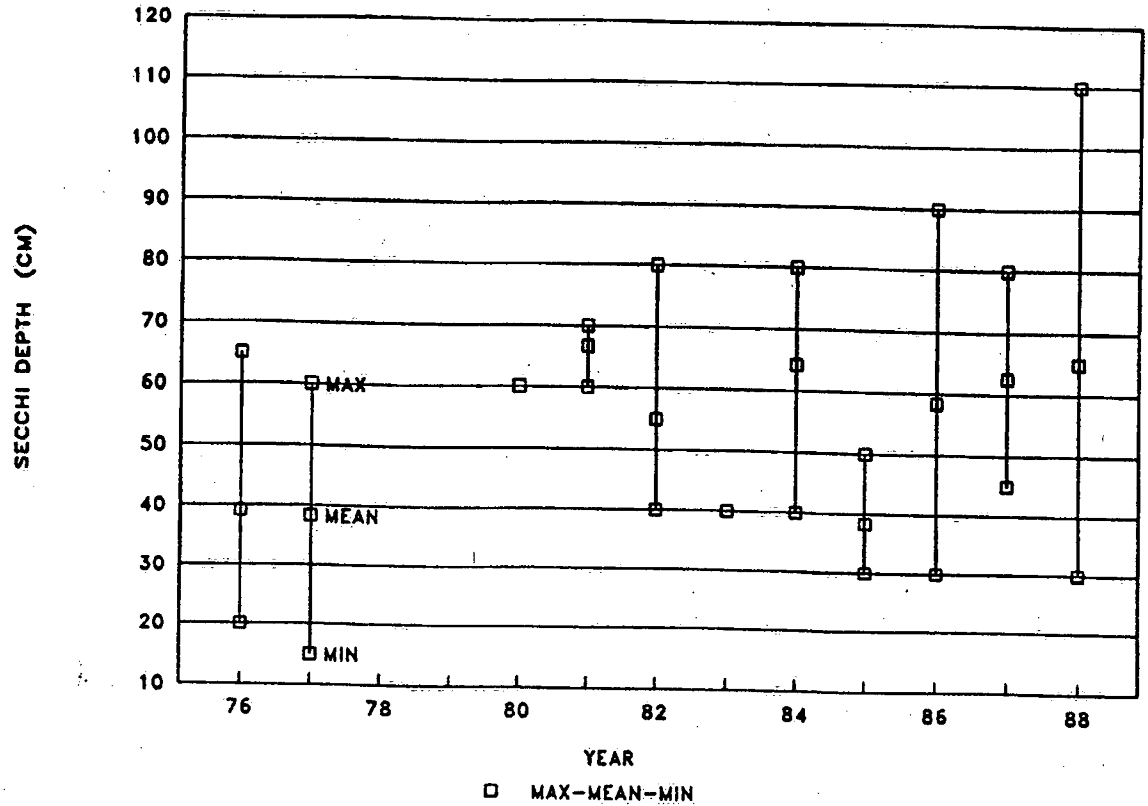

Fig. 7. Long-term summary of max-mean-min monthly Secchi depths during the wet season in East Bay 1976-1988.

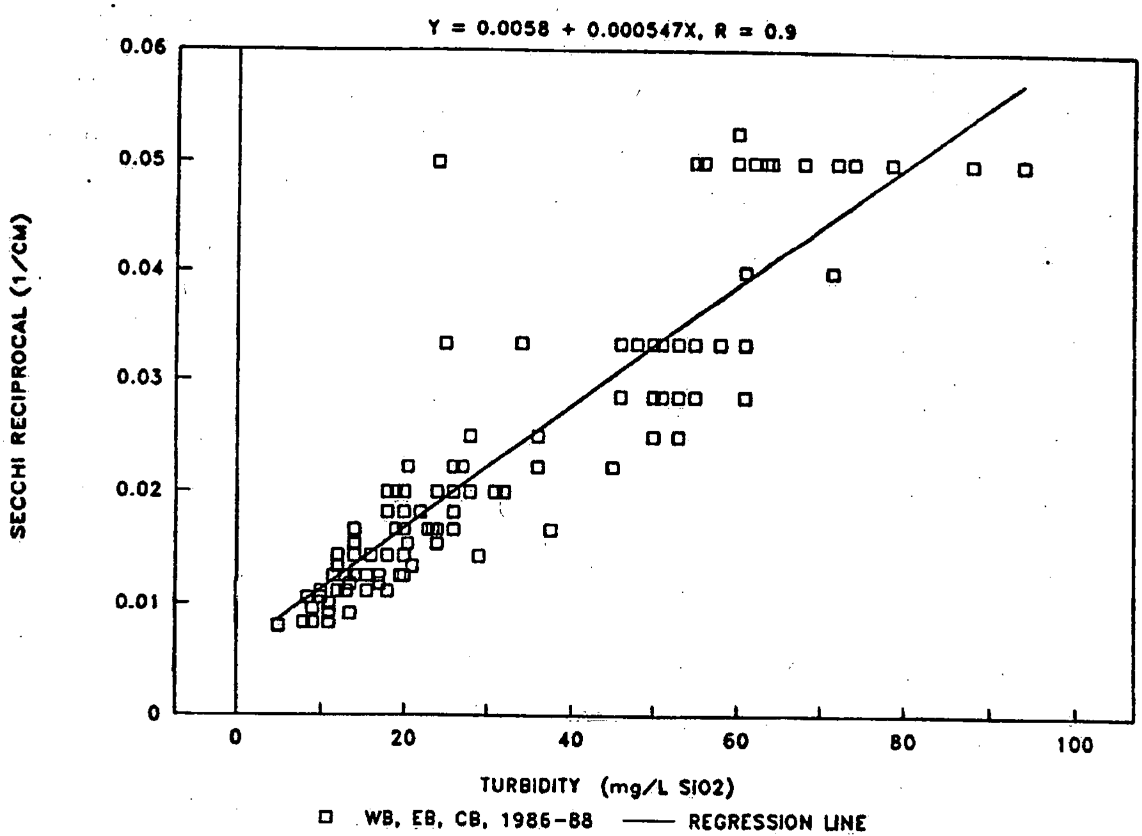

Fig. 8. Relationship between Secchi reciprocal and turbidity in West, Central, and East Bay 1986-88.

ANNEX 8 - BENTHOS SAMPLING

The following observations were made on Feb 6 while the author attended a routine sampling episode on Laguna Lake.

1) The Eckmann dredge is equipped with a small hinged door in the top to allow water to escape upon lowering. This is supposed to prevent a "bow wave" effect from displacing the organisms. The door is too small and too heavy to prevent the "bow wave" effect.

2) On arrival at the station the dredge was simply dropped by a boatman. Some tension was then kept on the line to ensure the messenger would slide down. It was impossible for the captain to maintain position in the strong wind. Consequently the dredge must land with maximum disturbance and then be dragged along on one edge before it is triggered to close.

3) The sediment samples were liquefied by stirring in a pail. The sample was then gradually poured through a set of stacked geological screens being shaken by a biologist. It was impossible to hold the screens together tightly enough by hand to prevent some of the sample from escaping between the screens

The procedures noted are likely to produce inconsistent, invalid and misleading results.

The boat should be in a stable position before sampling commences. This can be achieved by tying the bow to a stake as is done at the west station. The boat should approach the stake into the wind. At some distance from the stake the stern anchor should be deployed and the boat allowed to approach the stake and tie up. The stern anchor line should then be tightened thereby fixing the boat's position.

The dredge must be lowered slowly. The line should be vertical when the dredge is triggered.

The geological stacking screens are meant for dry material and are meant to be clamped together on a shaker machine. These screens should be mechanically clamped together for benthos use to prevent sample loss. A simple wood frame top and bottom held together by rubber bands (bungee cord or inner tube) should suffice. It is imperative to eliminate as many sources of error as possible since the data under the best conditions will be difficult enough to interpret.

The author has used a box screen with some success. This consists of a wood box about 6" high by about 18" square. Precision made stainless screen can be obtained from North American sources if unavailable in the Philippines. The screen is stapled to the bottom edge of the box and 1/2 round trim nailed over the screen with silicone glue to seal the screen to the wood. Some water is placed in a large square wash tub. The dredge is emptied on the screen. Since the screen is so much larger than the dredge the water in the dredge escapes through the screen. The screen is then agitated and slapped vigorously up and down on the water surface. This erodes the clay mud from below through the screen until all the mud has gone through the screen. The box should not be allowed to fill with water and no attempt should be made to liquefy the sample as this usually results in screen clogging. Decisions on how many dredges to screen before rinsing out the organisms would have to be made by local staff.

It is to be stressed that benthos sampling should only be conducted under favourable conditions. Since windy conditions occur often, procedures should be standardized to overcome drift and keep the sampling platform stationary. Field crews may have to try many times to obtain good samples. Doubtful or bad samples should be rejected. Careful work is required for the experiment described in Annex 6.

ANNEX 9 - GENERAL COMMENTS ON THE MONITORING PROGRAM

The author generally concludes that, given the situation at LLDA, the parameters chosen and the frequency of sampling are mostly ideal. Based on the author's experience, however, the following modifications may be considered.

Lake oxygen measurements are made in the daytime and are almost invariably indicating good conditions due to oxygen production by phytoplankton. There should be a pronounced diurnal oxygen variation caused by community respiration in the lake which results in much lower concentrations at night. Diurnal fluctuations are much more interesting and important than single daytime measurements. The oxygen sag at night may be an important stress to fish. The diurnal fluctuation can be measured by comparing early morning concentrations with those at dusk. These two measurements can be used to calculate a rudimentary photosynthesis-respiration balance in the open water. It would be interesting to compare present day diurnal curves with those found in the mid-1970s.

Oxygen measurements should continue in the tributaries since lethally low levels (to fish) are often found there. These baseline data should be useful to document the degree of change caused by pollution abatement.

Measurement of pH is probably not necessary since no out of limits values have been recorded. There may be some scientific interest in observations such as the systematic decrease in pH and O_2 between stations T4 and T5. These decreases coincide with an increase in NH_3. In the lake, pH tends to show some seasonal variations consistent with productivity but, again, use of these measurements is unlikely.

Measurement of salt content has been done by determining total dissolved solids. This measurement could be replaced with the easier electronic conductivity method.

Inclusion of fairly stable indicators such as oxygen and pH in the water quality index will tend to reduce variations caused by more changeable parameters such as turbidity, biomass,and NO_3.

Lake sampling frequency could possibly be reduced to monthly between November and April. Biweekly sampling is a good compromise for the more variable productive season.

Monitoring for toxics (organics and metals) can be done once per year in sediment at deposition zones near river mouths and selected factories if applicable. Concentrations in water are usually more difficult to detect.

ANNEX 10 - POTENTIAL FOR FUTURE CONSULTANT WORK

LLDA faces a new challenge to upgrade Laguna Lake to meet "Class A" specifications for drinking water. Although the need to reduce and eliminate contamination by human and feedlot waste is a common theme in most reports beginning over 10 years ago action is now imperative because Manila plans to use the lake for potable supplies within 2 years.

At least two potential avenues for potential aid are apparent.

1) LLDA needs to demonstrate successful rehabilitatiom of one watershed or river reach. The problems are complex comprising important socio-economic aspects of relocation and compensation and provision of infrastructure as well as technical details. A new monitoring program will be needed to document the success of controls. This new program will have to be technically correct and at the same time sustainable by EPD/LLDA. Consultant experience with this type of problem in Asia would seem a prerequisite.

2) LLDA needs to mobilize public acceptance of the need to eliminate sewage pollution, feedlot pollution and garbage dumping. There is a need for public relations materials including films, videos and other presentation devices showing the benefits of a clean environment. These may include the benefits of a secure and clean water supply even for those affected by the clean-up effort. Such an effort must be an integrated and coordinated plan with reasonable phasing of infrastructure, relocation, compensation? and public participation and public information. In the author's experience, public acceptance may be as important as the availability of funds. Presently, LLDA lacks expertise and facilities to produce a public relations campaign. Materials are extant in N. America (perhaps North American Lake Management Society) but these tend to relate to expensive high tech solutions and would have to be carefully screened for applicability in the Asian context. Asian sources would seem preferable. The author notes the impression of a strong film and video industry in the Philippines. In summary, the author feels that aid in producing public acceptence of the clean-up of Laguna Lake would be useful.

<u>footnote</u>

The author notes that it is very important that the water supply be safe and be seen to be safe. Apparently, there are no particular technical safety problems with treating Laguna Lake water. On the other hand, the existance of sporadic coliform exceedances in the lake is public knowledge. This information can be misused and disseminated to an International public only too willing to believe the inevitability of Philippines problems. The damage to the National psyche and to tourism could be important. It is for this reason the author stresses the dual role of a lake clean-up and a well founded public relations campaign. The author notes that in conversations with professionals in Manila and other expatriates there is scepticism regarding treatability of Laguna Lake water. Assuming the water is treatable this information should be conveyed to professionals in order to prevent unfortunate impacts their possibly unfounded opinions may have if repeated in the media.

FIGURES AND CAPTIONS

-ANNEX 7-

Fig. 2. Long-term summary of max-mean-min monthly Secchi depths during the dry season in West Bay 1976-1988.

Fig. 3. Long-term summary of max-mean-min monthly Secchi depths during the dry season in Central Bay 1976-1988.

Fig. 4. Long-term summary of max-mean-min monthly Secchi depths during the dry season in East Bay 1976-1988.

Fig. 5. Long-term summary of max-mean-min monthly Secchi depths during the wet season in West Bay 1976-1988.

Fig. 6. Long-term summary of max-mean-min monthly Secchi depths during the wet season in Central Bay 1976-1988.

Fig. 7. Long-term summary of max-mean-min monthly Secchi depths during the wet season in East Bay 1976-1988.

Fig. 8. Relationship between Secchi reciprocal and turbidity in West, Central, and East Bay 1986-88.

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