Intergovernmental Oceanographic Commission

Workshop Report No. 79

IOC/WESTPAC Workshop on River Input of Nutrients to the Marine Environment in the Western Pacific

Penang, Malaysia, 26-29 November 1991

SC-92/WS-34

UNESCO

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1. INTRODUCTION

This Workshop is one of the continuing efforts of the River Input Programme of the WESTPAC region. It was an outgrowth of a consultation of WESTPAC experts held in Dalian, China, 11-22 April 1990. This Expert Consultation reviewed the progress of the WESTPAC River Input Programme and recommended that more emphasis should be placed on developing a regional understanding of nutrient fluxes to the marine environment by rivers. As an initial step in accomplishing this, it was recommended that a workshop involving participants from WESTPAC countries be held to assess the state of knowledge on river inputs of nutrients to the region, to identify gaps in that knowledge and agree on approaches to be used in studies to fill those gaps. The programme of the Workshop is attached as Annex I.

The Workshop was held in Penang, Malaysia on 26-29 November 1991 and was hosted by the Fisheries Research Institute, Department of Fisheries of the Ministry of Agriculture for Malaysia. Mr. Ong Kah Sin, Director of Research, welcomed the participants in a brief opening ceremony.

The Workshop was divided into two general parts. The first consisted of presentations by participants describing the state of knowledge on river transport of nutrients in their regions. Each participant was also requested to review information on the characteristics of river systems in their regions that they consider as being suitable for the study of nutrient transport to the marine environment. The second part of the Workshop consisted of group discussions on strategies and technical aspects of conducting studies on river transport of nutrients to the marine environment in relation to watershed characteristics. Based on these discussions, a number of recommendations were made and are presented below.

2. SUMMARY OF EXISTING INFORMATION

The following brief summary of existing information is based on the presentations by participants (see list of participants in Annex II and texts of presentation in Annex III), and group discussions during the Workshop.

The summary includes a review of existing data on nutrients, as well as information on other means pertaining to developing an understanding of the relation between land-use and nutrient fluxes in rivers.

2.1 DATA ON NUTRIENT CONCENTRATIONS AND TRANSPORT IN RIVER

Considerable data exist on nutrient concentrations in coastal and estuarine waters, with perhaps less data on rivers in the WESTPAC region. In almost all cases, however, these data were collected as part of the monitoring exercise of a general environmental survey programme. Insufficient data collected in rivers in a systematic way, together with a lack of pertinent hydrologic data, interfere with an adequate assessment of nutrient fluxes to the marine environment vis-a-vis activities on land.

In the case of existing data, there is an inconsistency in the nutrients and nutrient species analyzed. Rarely are total nutrient concentrations (e.g. total nitrogen) indicated; dissolved and particulate concentrations are not frequently analyzed and are reported separately; and data on dissolved silicates are often not reported.

2.2 RELATION BETWEEN REGIONAL CLIMATOLOGY AND RIVER TRANSPORT

The magnitude of riverine nutrient and sediment delivery to the ocean is in large part related to the volume of water passing through watersheds and river systems. Within geographic regions, the dynamics of river flow are directly and indirectly related to catchment area, rainfall within individual catchments, short-term rates of water input, land cover or land use within catchments and evaporative recycling to the atmosphere.

Fluxes of water through river systems are highly variable. This variability may be partitioned into event-related (e.g. storms), seasonal (e.g.monsoonal), inter-annual (e.g. "El Niño") and inter-decadal components. These sources of variability are generally hierarchical in nature, with event-scale and seasonal components nested within or being modulated by longer-term, large-scale processes. The magnitude and timing of different sources of this variability are to varying degree stochastic.

The large-scale climatology of Southeast Asia and Northern Australia is dominated by seasonal monsoon weather systems. Monsoonal weather patterns may give rise to significant seasonal changes of state in local or regional weather.

Within the regional climatology, the timing of monsoonal onset, its duration and intensity vary on an inter-annual and decadal basis. This variability is coupled to both ENSO and decadal forcing. At the few sites when medium-term climate (50- 100 years) records are available, there is clear evidence of decadal changes in rainfall and runoff. The extent to which records from a few well-documented sites can be regionally extrapolated remains to be established. Of particular interest in the extrapolation of climatic indicators is the estimation of the frequency and intensity of monsoonal rainfall, and the frequency and paths of cyclonic(typhoonal) activity.

Long-term records of river flow and flow variability in tropical rivers and catchments are virtually lacking. Instrumental records are of medium duration (50-100 years) in most cases. Many significant rivers are ungauged or have been adequately gauged for much shorter periods. The emphasis in such records is upon event-scale(flood) and seasonal(monsoon) variability. At present there are very few long term (>100 years) climate records based upon reliable proxies for climate variables (Coral bonding, tree rings, lake sediments). These records are now being extracted and analyzed. Suitable sites or samples for such records are not distributed through the region to allow for compensating for local effects. Coral and cores, which may provide records of up to 500 years in duration may be the most widely distributed and appropriated source of proxie record.

At present, there is little information suitable for predicting secular changes in regional climatology and river runoff as a result of anthropogenic climate change. Beyond the obvious impacts arising from changes in mean sea level, impacts may include all stroms of large scale monsoon dynanmics, changes in the frequency of ENSO events and changes in the frequency or paths of cyclones/typhoons. The present historical record, whether instrumental or from climatic proxies, is insufficient or inadequately analyzed to offer guidance.

2.3 REGIONAL PHYSIOGRAPHY AND LAND-USE PATTERN

The following is a brief summary of the physiography and land-use for specific rivers from the reports presented by the participants:

(i) Russian Federation (Amur River system)

Land uses in the watershed at present are as follows: mining and agricultural development near Blagoveschensk and Khabarovsk, and industrial uses in cities. Before the middle of the 14th century the area was pristine; this was followed by agricultural development in the plains and further industrial development in some places on the river. Further expansion of agriculture in the plains and further industrial development around cities are expected. Hydroelectric power stations have been built or are in construction on some tributaries of upper Amur.

(ii) Korea (Five Major River Systems)

There is some diversity in the characteristics of the systems, but they are generally as follows: Forest covers about 70% of watersheds mostly located in the mountainous terrain, and farmland amounts to 23 % at present. The Kum and Yongsan River systems were relatively pristine until 1960s. Rapid industrialization and urbanization are taking place along these river systems. Land use for agriculture will be decreased because of this urbanization and an increase in the population density.

(iii) Japan (Tama River System)

Forest covers 60% of the watershed mostly in the mountainous western region, and farmland occupies 10% at present. Housing and industrial facilities have been increasing at the expense of forest and farmland. The population density has increased markedly in the lower-lying areas which are part of the Tokyo metropolitan zone. Now the population density is also increasing in hill areas and the farmland will be further decreased in the near future.

Taking the country as a whole, forest (natural and artificial) covers most mountainous areas and this situation will not change drasticallly. Most lower-lying land is used as farmland and paddy fields. Population is concentrated in large cities and urbanization will continue to extend toward hills and piemonts in these areas. Land areas developed for leisure activities will increase in the near future.

(iv) China (Qiantang and Jiulongjiang River system)

Qiantang: The area of cultivated land has increased to more than 15% and this is used mostly as paddy fields. There are several large cities in the watershed. Land use will not change greatly in the future.

Jiulongjiang: Mostly (44%) forest. Cultivated land has increased by deforestation and is used for rice cultivation. As reforestation is now proceeding, the area of forest will not decrease. Some cultivated land will be removed from agriculture because of increased housing and other human facilities.

(v) Philippines (Pampanga and Pasig River Systems)

Pampanga: Mainly agricultural land (60% rice, mixed cropping, grassland). At present forest covers less than 30% of the watershed. It had decreased in the past and will continue to decrease because of industrialization. Mangrove areas will be converted to fishponds.

Pasig: The watershed is mainly composed of the major cities of Manila and Quezon and several municipalities. The population of Metro Manila was 7.8 millions in 1990 and 5.2% of these are living along the river banks and within 150 meters adjacent to the river. Nutrient fluxes have been enhanced by various human activities and soil erosion from the denudation of the forest at Montalban.

(vi) Thailand (Bang Pakong, Mae Klong and Chao Phraya River Systems)

Bang Pakong: At present about 40% of the watershed is covered by forest. The rest is used mainly for agricultural purposes with light industrial activities. The forest area has been decreasing, though not as fast as it used to. Land clearing by illegal logging is slowing down in the upper part of the watershed. Land use has not changed much but new types of land use such as resorts and golf courses are emerging. Changes should not be very drastic in the next five years. However, once industrial complexes come into operation and more resorts and golf courses go into business, changes in population density and human activities will become significant.

Mae Klong: The present situation is similar to that in the Bang Pakong, though land clearing is more widespread and intense than in the Bang Pakong. Around the river mouth, mangrove forest has completely vanished by conversion into evaporating ponds for producing sea-salt, and into shrimp farms which were closed down in 1990. Again no drastic change is expected, except more intensive agriculture and some mining activities.

Chao Phraya: At present 80% of cultivated land in the watershed from Nakorn Sawan to Pathum Thani Provinces is used as rice paddies. Human settlements and industrial areas are distributed from Phatum Thani to Bangkok. The situation has not changed much for many years. No drastic change is expected in the future except slight expansion of human settlements.

(vii) Malaysia (Rewa River System)

Vast areas of forest have been cleared for plantation crops. At present about half of the watershed is covered by forest. Paddy fields and plantations of rubber, oil palm, etc., where trees are replanted periodically, occupy around 40% of the watershed. Large areas of the plantations were burnt down 10-20 years ago by dry season fires. Another land use characteristic of this region is the mining of tin and limestone, which covers 13% of the area. Swampy areas, covering about 140km, will be converted by reclamation to plantations in the near future. Completion of new highways will lead to increased deforestation.

(viii) Fiji (Rewa River System)

The Rewa catchment is at present covered with forest (approximately 65%) although it is difficult to differentiate disturbed and undisturbed areas. This represents a decline in forest cover from the mid-1950s of something of the order of 10-15%. The valley bottoms and the river delta area have intensive permanent agriculture with root crops, vegetables, cocoa and pastures for cattle production. In some areas sloping land has been deforested for ginger production but this is not a sustainable use of the land. The area under permanent agriculture represents about 15-20% of the catchment. Urban sprawland, mangrove reclamation are land use changes affecting relatively small areas. The remainder of the catchment is in unimproved grassland which is unlikely to be utilized for other purposes in the near future. Extension of commercial farming and shortening of fallow periods in shifting cultivation systems are likely in the future.

Over the whole country, the area of undisturbed rainforest is declining. In the drier climate zones, grasslands have developed; some of these are being converted into pine forests and, in areas of gentler slope, sugarcane cultivation is extensive. There is continuing pressure for increased agricultural production, both to feed the expanding local population and for export to earn foreign currencies.

(ix) Australia (South Johnstone River System)

The river system contains areas of rainforest and grazing land in the upper catchment with extensive sugarcane production in the lower areas. Recent trends have seen extension and expansion of grazing and other farming activities which are likely to continue. The lower catchment is likely to be affected by significant tourism and other urban developements in the next 20 years.

Based on the reports of the participants and general group discussion the regional physiography and land-use patterns for the WESTPAC region can be summarized as follows:

a) Most watershed areas, especially in mountainous regions, are covered by forests, both natural and plantation types.

b) In Korea and Japan, the lower lands have been developed for agricultural purposes with significant areas of housing and industrial use. With increases in population and industrial activity from the 1960's, much agricultural and lower-lying forest land have been converted to urban and industrial uses. This trend is continuing.

c) In central and southern China, lower lying areas are utilized extensively for agricultural purposes, mostly for rice. Mountains in the southern provinces are covered by forests and as a reforestation programme is now proceeding, decreases of forest cover will be minimal. Non-agricultural land uses, such as housing and industrial development, will increase in the future.

d) Over the Southeast Asia and West Pacific Island region as a whole, forest areas will continue to decline either because of commercial logging or the change in shifting agriculture. These deforested areas may be replanted with commercial plantation forests but the extent of this will not be sufficient to replace the original forest. The impact of land-use changes on run-off will depend on the new uses to which the cleared land is put. The planting of rice or other crops with high-water requirement, together with enhanced irrigation, may lead to decreased run-off. It is likely, however, that a major portion of the cleared land will not be developed in this way, so the run-off is likely to increase. The expansion of urban areas will also probably lead to increased run-off although greater water use by people and industry may alter the nature of run-off.

3. STRATEGIC CONSIDERATIONS AND RECOMMENDATIONS

Strategic considerations regarding the conduct of studies on river transport of nutrients in relation to land-use, include where and when to collect samples and what ancillary information on watershed of river systems must be available to allow for the proper interpretation of results. Decisions on where and when to collect samples are based primarily on the hydrologic characteristics of river systems. Strategic considerations related to this are described in detail in GESAMP Reports and Studies No.32 (Land-Sea Boundary Flux of Contaminants: Contributions from Rivers). Aspects of this report pertaining to the influence of hydrology on river transport of nutrients were discussed by Workshop participants. It was agreed that recommendations made in that report regarding the conduct of river transport studies should be applied in future studies within the WESTPAC region.

With regard to the requirements for ancillary information on watershed characteristics, the participants of the Workshop recommmended that the following types of information of physiographic characteristics and land-use patterns should be available for the watershed proposed for study. Many of these characteristics are amenable to GIS formatting.

(i) Physiographic Characteristics of Watershed

a) Relief - typically expressed in terms of standard deviation of mean elevations taken from a special grid.

b) Percentage vegetation ground-cover.

c) Geology - this includes the surface distribution of rock types and other information such as seismic activity.

d) Soils - The US soil type classification system is recommended.

e) Area of natural vegetation - This should include the breakdown of types(e.g. wetlands, forest, savannas, etc.) and description (e.g. mangrove, teak, etc.)

f) Hydrology - Appropriate discharge gauging is a major requirement.

g) Climate - Precipitation distribution and temporal patterns, temperature, winds, etc.

h) Others - Other unique characteristics of watershed.

(ii) **Land-use Characteristics:** This includes distributions and temporal changes in land use, both historical and future projections (if available)

a) Population density and distribution

b) Agriculture

- Rice (wetland and upland)
- Field crops
- Plantation tree crops
- Pasture/livestock production
- Shifting agriculture
- Aquaculture
- Fertilizer use

c) Logging/land clearing

d) Mining/ Quarrying

e) Reclamation

f) Urbanization

g) Dam/irrigation system

h) Channel modification - including dredging, diking, channelization, etc.

i) Industries

j) Waste treatment - Percentage of population for which waste treatment is available, location, etc.

4. TECHNICAL CONSIDERATIONS AND RECOMMMENDATIONS

The most important technical considerations regarding the conduct of studies on river transport of nutrients include methodology of sampling and analysis. Summaries of discussions and recommendations on methodologies are presented below.

4.1 SAMPLING METHODOLOGY

A manual on river sampling for the purpose of assessing nutrient flux is available through UNEP Regional Seas Programme. Procedures described in this manual were discussed by the group. In general the sampling procedures involve the collection of depth-integrated samples, using a pumping system, at several locations of a river cross-section. The Workshop participants agreed that integrated samples are more appropriated for assessing flux through a river cross-section, but recommmended that the choice of locations for sampling be coupled with the best possible understanding of the cross-sectional flow field.

It was also recognized by the participants that for logistical reasons, it is often only possible to collect discrete samples. This is especially true when high-resolution time-series sampling is desired. While integrated samples are already more desirable, data based on discrete samples still provide useful information for assessing nutrient transport in relation to land use.

4.2 ANALYTICAL METHODOLOGY

An accurate assessment of river nutrient fluxes should include all nutrient materials or species which are biologically or geochemically active in the coastal marine environment. These would include:

Carbon:	DOC - Dissolved organic carbon POC-Particulate organic carbon, including colloidal carbon.
Nitrogen:	DIN-Dissolved inorganic nitrogen(ammonia, nitrite, nitrate) PN - Particulate nitrogen
Phosphorus:	DIP-Dissolved (Reactive) inorganic phosphorus (PO4) poy-P-Dissolved (unreactive) inorganic phosphorus DOP - Dissolved organic phosphorus PP - Particulate phosphorus
Silicon:	Si - Dissolved (reactive) silicate SiO2- Biogenic particulate silicon (opal)

Unless local circumstances dictate that carbon be considered for nutritive or biogeochemical purposes, the Workshop recommmended that carbon flux studies be downgraded within the river nutrient studies programme. This was due in part to the need to acquire specialized instrumentation for carbon analyses and because, once mineralized or degraded, river-borne carbon would be difficult to trace in the presence of substantial marine pools of organic and inorganic carbon.

Particulate nutrient species are defined operationally as that nutrient material which can be collectd on a filter. The type of filter used, its porosity and the method of filtration will affect the amount of particulate of colloidal materials collected.

A significant proportion of the total "particulate" phosphorus in river or estuarine samples may be present in chemical or mineral phases which are biogeochemically unreactive (e.g. apatites, Fe phosphates). Inclusion of these unreactive P flux into marine P nutrient pools. Extraction and analytical techniques for particulate P should emphasize biogeochemically reactive P rather than total P in the strictest sense.

A variable proportion of the total N and P in the particulate fraction of river water samples will be ionic N and P (chiefly ammonium and phosphate) adsorbed to minerals or clay particles. Some, though not all, of these N and P is subjected to desorption by ionic replacement as particles move into high ionic strength estuarine environment.

The Workshop participants recommmended that total N (dissolved and particulate), inorganic silicate (molybdate reactive) and total biogeochemically reactive P (dissolved and hot acid soluble) be measured for all river studies. For constancy, the following methods are recommmended. All are well-tested, have been compared and are robust with regard to small modifications to fit local conditions or for field use. It is recognized that improvements in sensitivities and precision, and in some cases recovery, can be achieved with recently developed instrumentation; nonetheless, the following methods provide a solid base from which to begin.

Nitrogen:	Ammonia -	Phenol-hypochlorite colorimetric method (e.g. Solarzano,1969)
	Nitrite -	Azo dye formation (Strickland and Parsons, 1972)
	Nitrate -	Cd reduction-azo dye formation (Strickland and Parsons, 1972)
	DON -	Persulfate or UV oxidation, inorganic analysis
	-	High tempeature combustion (recommended, but degree of improvement unresolved)
	PON -	High temperature instrumental combustion of filtered material (recommended)
	-	Kjedahl or persulfate oxidation of filtered material
	Total N -	High temperature instrumental combustion of unfiltered samples (recommmended)
	-	persulfate or Kjedahl oxidation/reduction of unfiltered samples
Phosphorus:	PO4 -	molybdate blue colorimetric determination (Strickland and Parsons, 1972)
	DOP -	acid persulfate digestion followed by molybdate blue colorimetric determination
	PP -	hot dilute acid (0.1N HCl) hydrolysis, followed by acid persulfate oxidation and molybdate blue quantification
Silicate:	Si -	molybdate blue clorimetric method (Strickland and Parsons, 1972)
	Opal -	warm (85 C) basic hydrolysis followed by molybdate blue quantification

Suspended solid: gravimetric quantification after capture on filter (0.45 micron recommmended)

All of the colorimetric methods for inorganic nutrients have been adopted to segmented flow (SFA) and flow injection (FIA) automated analysis. When done manually, the inorganic analyses are readily scalable in volume, depending on the facilities available.

Where analyses for nutrient species cannot be carried out within a short period after collection, both filtered materials and particulate nutrient samples should be frozen, chilled or otherwise preserved or stabilized to prevent losses or changes. This may be less critical for total nutrient determination in pristine or semi pristine waters, but highly critical in polluted samples with high organic and high ammonium content.

Where suitable instrumentation is available, analysis of dissolved organic nitrogen (plus DOC) and particulate nitrogen (plus POC) should be carried out with instrumentation employing high-temperature combustion. PN and DON can be significant proportions of total N transported in rivers. If such instrumentstion is not available, analysis of DON and PN should still be carried out by chemical digestion techniques. It is preferable to have an underestimated flux of DON and PN than no estimate at all. Chemical oxidation methods tend to underestimate DON (DOC) and PN (PC) relative to combustion methods.

5. INTERCALIBRATION OF METHODOLOGIES

The Workshop resolved that appropriate analytical intercalibration exercises be carried out regularly by the various WESTPAC groups involved in river nutrient studies to enable a valid regional compilation of river flux estimates to be developed. Such exercises should be initiated early in the project to identify any systematic differences between laboratories or deficiencies and guide regional training programmes to achieve the necessary consistency and accuracy.

Because of the stated focus upon quantifying total N, soluble Si and biogeochemically active P fluxes, standards distributed for analysis should be primarily focussed upon quantifying nutrients as these broad classes, with scope for separatly quantifying individual species. The standards should have a composition reflecting riverine materials, be sufficiently robust so as to permit distribution without elaborate shipping and storage procedures, and give sufficient material for replicate analyses by a diversity of methods. The overall aim is to assess consistency between laboratories. Laboratories with more extensive instrumentation will endevour to analyze samples comprehensively.

At present, appropriate standard materials and procedures for river nutrient samples do not exist in the WESTPAC region. A working party of M. Furnas (Australia), J. Morrison (Fiji) and G. Jacinto (Philippines) was formed to develop an appropriate means of providing and distributing materials for intercalibration purposes. This would include materials for both dissolved and particulate analyses.

6. SUMMARY OF RECOMMENDATIONS

(i) Intercalibration exercises preferably in 1992, among the participating laboratories, by correspondence; using solid nutrient samples to be provided by the IOC/WESTPAC. Parameters to be analyzed are total P, total N, silicon and carbon.

Based on the result obtained, there may be a need for a Workshop/Training Exercise to evaluate the results and correct the irregularities found among the laboratories in late 1992 or first half of 1993.

(ii) A joint symposium with the euthrophication group, to review the results of the study of nutrient transport of the rivers, as proposed at this meeting, in late 1993 or early 1994.

ANNEX I

PROGRAMME OF THE WORKSHOP

TUESDAY, 26 NOVEMBER

0800 - 0900	Registration
0900 - 1000	Opening Session
	Welcome Remark: Dr. Herb Windom, Workshop Coordinator Mr. Yihang Jiang, IOC Secretariat
	Official Opening: Mr. Ong Kah Sin Director of Research Fisheries Research Institute Malaysia
1000 - 1030	Morning Coffee
1030 - 1230	General Discussion (Chairman - Dr. Herb Windom)
1230 - 1400	Lunch Break
1400 - 1730	Presentation I (Chairman: Dr. Ong Jin Eong)

WEDNESDAY, 27 NOVEMBER

0830 - 1245	Presentation II (Chairmen: Dr. Miles Furnas Dr. Tianbao Fu)
1245 - 1400	Lunch Break
1400 - 1715	Presentation III (Chairman: Dr. M. Maeda)

THURSDAY, 28 NOVEMBER

0900 - 1245	Technical Session I (Chairwoman: Dr. Hungspreugs)
1245 - 1400	Lunch Break
1400 - 1715	Technical Session II (Chairwoman: Dr. Hungspreugs)

FRIDAY, 29 NOVEMBER

0900 - 1100	Discussion on Recommendation and Report
1100 - 1130	Coffee Break
1130 - 1230	Adoption of Report and Closure

ANNEX II

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ANNEX III

SCIENTIFIC PAPERS

CONTENTS

CHARACTERISTICS OF THE TAMA RIVER SYSTEM

Masaru Maeda
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The Tama River system is proposed for the study of River Inputs of Nutrients to the Marine Environment in the WESTPAC Region. The system is located in the central region in Japan and empties into the pacific Ocean through Tokyo Bay. The river originates in the Kanto Mountains and flows through the Kanto Plain toward southeast. The river length is 135 km and its watershed covers 1,240 km². The western region of the watershed is mountainous and affected by human activities very little. The eastern area is extensively urbanized and heavily populated. The river has two faces; rather natural upstream and severely polluted mid- and down stream regions.

1. GENERAL DESCRIPTION

The river system is located in the central region of Japan, almost southern end of the Kanto Mountains and the Kanto Plain, and empties to Tokyo Bay which is connected to the Pacific Ocean (Fig. 1). The length of the main channel is 135 km and the watershed covers about 1,240 km² in a feathery shape (Fig. 2). The mean width of watershed is about 10 km and characteristically marrow. The ranks of the river system in Japan are 23rd in the length and 63rd in the size of watershed area, respectively (Fig. 3).

The main stream originates at a mountainous area with elevation of around 2,000 m and flows through mountain valleys with steep slopes. At about a half of its length the river comes to a lower lying region covered with hills, terraces and alluvium plain. In the mountainous headwaters and upstream areas the watershed is covered with forests mostly planted artificially. The terraces and plains in the downstream are heavily urbanized. Recently human activities such as housing and construction of public facilities are extending rapidly to the hill area. The effects of human activities are minimal in the upper mountainous area, but downstream of the middle point the river is affected and polluted severely by various human wastes.

2. THE RIVER SYSTEM

The river system is shown in Fig. 2 in detail. Several streams such as Ichinose, Taba and Kosuge Rivers, which have their sources in steep slopes of the mountains, empty into a man made reservoir, Okutama Lake, dammed by the Ogouchi Dam. The dam is 145 m in height and its maximum storage volume is around $2x10^8$ m^3. Immediately downstream of the dam, another small dam, the Shiromaru Dam, is located. Between the dams the river water is used for generation of electric power three times. The water travels in tubes through this distance and appears again on the riverbed upstream of Hikawa. One of main tributaries, the Nipparagawa, which also originates in the northern high mountains and flows through limestone outcrops, joins to the main channel around this place. Then the river comes to a fan developed from Ohme to east of the mountainous regions The river length from headwaters to Ohme is about 65 km, roughly a half of the total river length, and the elevation of riverbed at Ohme is around 170 m (Fig. 6).

Downstream of Ohme the river flows through hills, terraces and then alluvium plain. A weir for tap water is located at Hamura, downstream of Ohme, and almost all of the river water is taken up at this weir. In the mid-steam of the river from the Hamura Weir to the Chofu Weir, located 13 km upstream of the river mouth, several main tributaries contribute to the main channel. The Akikawa, which also has its source at high mountains, flow through a less polluted watershed and joins to the main channel near Hamura. Other tributaries such as the Hiraigawa, the Asakawa and the Nogawa are severely affected by human activities. The river water in this region is composed of waters from tributaries and waste water. The water is also taken up for agricultural irrigation and industrial uses. There are seven weirs downstream from the Chofu Weir to the river mouth is tidal. The river empties into Tokyo Bay at Haneda which is located on a reclaimed land. This section of the river is called locally as the Rokugogawa. Once the river water in this region was severely polluted but in these days water qualities have been improved significantly.

3. MORPHOLOGY

The distribution of land elevation is shown schematically in Fig. 4. Occupations in the watershed classified with altitude are tabulated in Table 1. Mountainous area with more than 200 m of altitude covers 50% of the watershed and is located mostly in the western side.

The morphology of the Tama River watershed is shown in Fig. 5. The watershed is roughly divided into two districts from the view point of morphology; mountainous western and rather flat eastern districts. The former is further subdivided into three regions; summits and ranges, steep mountainous slopes, and piedmonts. Sizes in area classified morphologically are shown in Table 2 with mean elevations. The mountainous and piedmont areas cover around 70% of the watershed. Figure 6 shows steepness of the riverbed as a reflection of the elevation and relief of the mountainous region.

The summits and ranges are located in a range from 1,800 to 2,100m of altitude. They are round, however, in shape and relief is rather moderate. The valleys are V-shaped. The third is a piedmont region with gentle slopes developing along eastern end of the mountainous district. Figure 7 shows a morphological block diagram of watersheds of some tributaries. The watershed of the Kosugegawa and the Kita-Akikawa are located in the second region and their relieves are extremely large. On the other hand the watershed of Kita-Asakawa sits in the piedmont region and its relief is moderate. The watershed of the Ohkurigawa is located in the hills district and its relief is very small. In Table 3 relief of each watershed is compiled as a standard deviation (S.D.) to mean altitude. Table 4 shows surface stability classified by a degree of the standard deviation. The second and third regions belong to an unstable class and an extremely unstable one, respectively.

4. GEOLOGY

Geological distribution of the watershed surface is shown in Fig. 8.

The rocks which crop out in the mountainous district are mostly consolidated geosyncline sediments; some of them are Paleozoic and rests are Mesozoic in age. They also form the basement rocks of the Kanto Plain. The rocks are composed of sandstone, grace, slate, chert, limestone, etc. The thickness of the formation is more than 20,000 m. Intrusive granodiorites are seen on spines of some mountains.

The hills are underlain by rocks of Cenozoic age, mostly Quaternary but some Tertiary. The stratum is called the Kazusa Group and its surface has continuous gentle (2-5 °) eastward slope. The rocks are composed of sandstone, mudstone and gravels. The Tama Hills are marine origin, but other northern hills are Terrestrial one. The rocks underlying the terraces are rather unconsolidated sediments which are mid-diluvial and younger in age. The basement floor on which the terraces and alluvium lowland sediments rest is the Kazusa Group

The surface of hills and terraces are covered with Kuroboku soils which are weathered volcanic ash containing much amount (5-10 %) of humus. They are black in color. They have porous characteristics and their retentiveness and permeability of water are high. They cover about 80% of agricultural field in the watershed. Gray alluvium soils are seen on the alluvium lowlands. Brown soils are seen on gentle slopes in the piedmont region. They are not volcanic ash origin and retentiveness of water are poor.

5. LAND USE

Distribution of land-use in the watershed is shown in Fig. 9 for 1955 and 1972. The woodland covers almost all of the mountainous region. The terraces and lowlands are highly used for human activities such as dwellings, agriculture, and industry. The distribution of population density in the watershed corresponds to that of land-use (Table 6 and Fig. 13). The area of woodland changed little through 1995 to 1972. Changes in the land-use in the lower lying district are remarkable. The changes are also suggested clearly in Fig. 10 which shows changes in the land-use areas classified by altitude. The land area for agriculture, farming and orchard decreased extensively. These lands were converted to urban areas for dwelling, industry and business activities before 1970s. Table 5 shows the changes as numerical figures. The increase in the area for dwelling and industry corresponded clearly to the decrease in that of farmland. The changes were also seemed to be a reflection of increase in the population of the metropolitan area after the World War II (Table 7). In recent years the population changed little, but developments for dwellings and public facilities are extending to the hill area. For example, in the district of Tamashi (22 in Fig. 13) a construction of collective housings, called as "The Tama New Town" started in 1965. In this plan, an area of 30 km² will be developed and a population of 410,000 persons is supported.. In 1991 the population of this city has increased 8 times of that in 1965. The town is located in the watershed of Ohkurigawa and much effect of human activities already appeared in water qualities of the tributary.

6. POPULATION

As most part of the watershed is included in the area of the administrative district of Tokyo, the changes in population of Tokyo can be a good indicator of that in the watershed and human activities in the area.

Changes in the population of Tokyo is tabulated in Table 6. The population increased rapidly after the World War II until 1985 and then changed little or decreased somewhat in recent years. Statistics of the population density in each administrative district in the watershed (Fig. 13) are compiled in Table 7 with their yearly changes. The population densities ranged from around (10) to 13,300 persons/km² in 1990 among the districts. The population densities are classified into five groups matching with the morphological regions; in the unit of person/km², less than 100 in the higher lying mountainous region, 500 to 1,000 in the peidmont area, 1,00 to 3,000 in the western hills south of the river, 3,000 to 8,000 in the eastern hills south of the river and also in the hills north of the river, and more that 8,000 in terraces and alluvium plain regions. In the mountainous region the population density has been decreasing. On the contrary recent increases are remarkable in the southern hills. In the northern hills and terraces the population density increased rapidly after the war but settled in recent years. The numbers are very large in the lower lying region, but decreasing a little now. It looks that many persons are shifting from the central region of the metropolis to the outer hills because of difficulty in getting housings.

7. CLIMATE

Changes in yearly mean air temperature with distance from the rive mouth is shown if Fig. 11 with changes in lowest (January) and highest (July) mean temperature. The yearly mean temperature is 15 °C in the lowland and around 10 °C in the mountain area. The difference in temperature between both regions is observed through a year.

The watershed belongs to a zone with much precipitation in Japan. Figure 12 shows monthly changes in precipitation at three stations along the river. There is much precipitation in summer season (June to September) because of "tsuyu (wet season) and typhoons. In winter season from November to February, the catchment area receives small amount of precipitation there is some dispersion in the precipitation according to locations in the watershed (Table 8). Mean annual precipitations range 1,104 to 2,143 mm among the stations with a mean of 1,534 mm.

8. DISCHARGE

Mean discharges at four stations along the river are tabulated in Table 9. As mentioned in Paragraph 2, almost all the river water is taken up for tap water at the Hamura Weir. The discharge rates shown in the table as Hamura are data obtained upstream of the weir. At the Chofu Weir, which locates 13 km upstream of the river mouth, the mean discharge is around 13 m^3/s. Figure 14 shows changes in daily discharge at the weir in 1985 and 1986. The discharge changes unevenly with occasional peaks and there is much difference in the pattern year by year. Discharge ratios estimated from the precipitation and evaporespilation rates (579 to 800 mm) range from 0.46 to 0.64, not much different from those calculated using the precipitation and discharge rates.

9. WATER QUALITY

Changes in concentrations of BOD and Pb along the river are shown in Figs. 15 and 16, respectively. The effect of human activities clearly appear near Hamura, almost halfway from the headwaters. The river can be sectioned into four regions from the view point of water quality; the headwaters area and Okutama Lake, Okutama Lake to Hamura Weir, the Hamura Weir to the Chofu Weir and the Chofu Weir to the river mouth.

(1) The headwaters area and Okutama Lake

In this region the effect of human activities is minimal. Ranges of concentration of some chemicals are as follows: ($NO_{2+NO}3$) 230-540 $\mu g/l$, PO^4-P 1-12 $\mu g/l$, TOC 0.3-0.8 mg/l in 1978.

(2) Odutama Lake to the Hamura Weir

Though waste water with a flux of around 0.2 m^3/s joins to the main channel, the amount of water form the lake and tributaries exceeds that of waste water. The water quality in this region is not affected severely by human activities. The concentration of chemicals ranges 180-1,180 $\mu g/l$, 2-20 $\mu g/l$, 0.3-1.0 mg/l for (NO_2 + NO_3)-N, PO_4-P and TOC, respectively[14].

(3) The Jamura Weir to the Chofu Weir

This mid-stream region covers 41 km of the river length and severely affected by human activities. In the upper stream in this region two relatively unpolluted tributaries flow into the main channel and contribute to the discharge of main channel significantly. Waters from another ten tributaries, which are highly affected by domestic wastes, flow into the main channel and pollute the river water heavily. Many chemicals such as NO_2, NO_3, NH_4 and PO_4 exhibit their highest concentrations in this region. The concentration of NH_4 -N varies tremendously through a year[15]. The concentration ranges from 0.7 mg/l in August to more than 10 mg/l in March at the Chofu Weir.

(4) The Chofu Weir to the river mouth

The water quality in this region has been improved significantly because of improvement in sewage treatment facilities. Nutrient concentrations decrease finally to levels in sea water, but change non conservatively during the mixing of the river water and sea water.

Monitoring stations for hydrology and water quality of the river are located rather densely along the river channels (Fig. 17). Many data obtained at the stations have been accumulated and issued. Newly obtained data will be published within two years. Many research works also have ben conducted in this river system and results are compiled in reports [16,17]. and books [18,19].

10. BUDGETS OF NUTRIENTS IN TOKYO BAY

The Tama River empties to Tokyo Bay, which is one of the most eutrophicated semi-enclosed Bays in Japan. The dimensions of the bay are 1.0×10^9 m^2 in area and 17 m in mean depth. There are several rivers which flow into the bay and their total annual discharge amounts 8.0×10^9 m^3 on the average. The residence time of bay water and the sedimentation rate in the bay were estimated to be 0.13 year [20] and 1.8×10^3 $g/m^2/yr$ or 1.8×10^{12} g/yr as a total [21], respectively.

Ogura [22] compiled budget data of chemical elements in Tokyo Bay. Estimations on fluvial fluxes of nitrogen and phosphorus in 1972 and 1980 are tabulated in Table 10. The values include waste water fluxes added directly to tidal estuaries and coastal areas. The flux of dissolved organic carbon decreased in recent years, while the phosphorus flux increased a little. There are no estimations on carbon and silicon budgets yet.

Output fluxes of nitrogen and phosphorus in around 1980 were estivated by Matsumoto [23] using amount of the elements in the bay water, the residence time of bay water and sedimentation rates of both elements (Table 11). The degrees of flux to outer sea (net flux) to total output flux were 93% for nitrogen and 86% for phosphorus, respectively.

Kamatani and Maeda [24] compared the budget of phosphorus at present with that in the past. For that purpose they analyzed the element in a sediment core sample from the central part of Tokyo Bay. The phosphorus concentration at the surface was 750 $\mu g/g$ and decreased gradually with depth in the core. Below 60 cm the concentration around 500 $\mu g/g$ varied with minimal fluctuation. Most of the increase in recent years was ascribed to a result of human activities. Rates of input and sedimentation were estimated to be 4.0 and 0.9×10^9 g/yr before 1930s (below 60 cm), and 14 and 1.3×10^9 g/yr at present, respectively. This suggests that the ratio of phosphorus flux to outer sea (net flux) to input (gross flux) might depend on the size of input flux of the element. Most phosphorus input at present is eventually flushed out into outer sea without sedimenting in the bay, although the increase in input keeps primary productivity high in the bay.

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Table 1 . Altitude classification of the Tama River watershed. Sakaguchi andOhmori, (4))

Class	Altitude m	Ratio %	Area km^2
A	0-200	39	300
B	200-400	12	123
C	400-600	9	92
D	600-800	10	102
E	800-1000	8	81
F	1000-1200	7	72
G	1200-1400	7	72
H	1400-1600	6	61
I	1600-1800	2	20
J	1800-2000	0	0

Table 2. Morphological classification of the Tama River watershed. (Kubo,(3))

Morphlogy	Mean Elevation m	Area km^2	Ratio %
Mountain	913	632	51.5
Piedmont	242	243	19.8
Hills	128	115	9.4
Terraces	60	188	15.3
Lowland	17	49	4.0

Table 3. Relief of tributary watersheds in the Tama River System.
(Sdakaguchi and Ohmori, (4))

Tributary	Area km^2	Mesh m	Points	Mean Alt. m	S.D. m	SDR* $m^3/km^2/yr$
Ohkurigawa	41	125x125	2654	116	12.6	1.72
Kita-asakawa	45	125x125	2861	381	51.6	144.5
Kita-akikawa	46	125x125	2966	721	94.1	954.7
Kosugegawa	49	125x125	3127	1019	80.4	581.1

*SDR is Sediment Delivery Rate, estimated by following equation,

$$SDR = 0.5993 \times 10^{-3} \times D^{3.1426}$$

where D is standard deviation.

Table 4. Relation between standard deviation to mean altitude and land surface stability.[4]

Class	S.D. m	Stability	Remarks
A, B	<20	stable	
C, D	20-40	rather stable	
E, F	40-60	rather unstable	
G, H	60-80	unstable	many landslides
>I	>80	extremely unstable	bare rocks, falling rocks

Table 5. Changes in landuses in the Tama River watershed. (Kubo, (3))

Landuses	ca.1910		ca.1930		ca.1950		ca.1970	
	Area km^2	Ratio %	Area km^2	Ratio %	Area km^2	Ratio %	Area km^2	Ratio %
Woodland	830	67.7	807	65.9	775	63.2	742	60.6
Badland Marsh	49	4.2	51	4.2	69	5.6	78	6.4
Farmland	285	23.2	287	23.4	213	17.4	131	10.7
Dwellings Industry	60	4.9	79	6.5	162	13.2	270	22.1
Others	2	0.2	1	0.1	6	0.5	3	0.3

Table 6. Change in population of Tokyo. (5)

Year	Population	Year	Population
1935	6,369,919	1983	11,613,000
1947	5,000,777	1984	11,671,000
1950	6,277,500	1985	11,780,500
1955	8,037,084	1986	11,768,000
1960	9,683,802	1987	11,764,000
1965	10,869,244	1988	11,728,000
1970	11,324,994	1989	11,692,000
1975	11,568,852	1990	11,698,060
1980	11,506,944	1991	11,684,920

Table 7. Changes in population densities of the administrative districts in the Tama River watersheds (person/km^2). (6)

No.	District	1950	1955	1960	1965	1970	1975	1980	1985	1990
1	Enzanshi	80	164	160	149	144	145	144		
2	Tabayamamura	21	22	22	19	15	13	11		
3	Kosugemura	41	43	38	31	28	25	24		
4	Okutamamachi	71	68	60	57	51	46	43	41	39
5	Hinoharamura	60	56	53	51	48	44	40	38	37
6	Itsukaichimachi	142	296	294	302	327	367	392	408	429
7	Hinodemachi	30	294	285	286	313	406	491	560	578
8	Ohmeshi	147	532	547	585	682	828	951	1066	1203
9	Hamuramachi	869	1049	1142	1637	2327	3384	4291	4822	5198
10	Mizuhomachi								1607	1844
11	Musashi-murayamashi								4001	4267
12	Fussashi	1417	1845	2125	2989	3683	4462	4677	4945	5668
13	Akikawashi	616	636	663	794	1304	1728	1933	2066	2266
14	Hachiojishi	497	955	954	1104	1347	1717	2061	2272	2451
15	Hinoshi	667	1410	1600	2507	3635	4679	5365	5756	5885
16	Akijimashi	1756	2135	2483	3468	4399	4875	5194	5671	6027
17	Tachikawashi	5876	7240	7730	4121	4813	5705	5893	6052	6287
18	Kokubunjishi								8374	8645
19	Kunitachishi		2862	4035	5380	7389	7982	7938	8030	8004
20	Koganeishi								9220	9079
21	Fuchushi	1011	1963	2740	4222	5464	6111	6436	6764	6983
22	Tamashi	416	406	520	982	1623	3165	4605	5906	6729
23	Inageshi	557	572	625	1098	1750	2494	2734	2883	3244
24	Chofushi	456	2064	3147	5413	7227	8073	8285	8769	8927
25	Mitakashi								9878	9792
26	Komaeshi	1646	2385	5250	6500	9804	11389	11518	11997	11363
27	Setagayaku	6941	8903	13214	12631	13387	13701	13557	13795	13329
28	Ohtaku	9602	13633	16936	18118	13387	14957	13716	13412	11518
29	Kawasakishi	2552	3562	5061	6575	7487	7513	7653	7977	

Table 8. Mean annual precipitation and days with precipitation in the Tama River watershed. (9)

Station	Elevation m	Duration years	Precipitation mm	Days with prep.
Ichinose	1123	5	1655	144
Ochiai	1123	52	1701	148
Taba	635	52	1581	128
Hikawa	364	63	1739	133
Hinohara	360	40	1123	68
Itsukaichi	207	34	2148	189
Asakawa	183		1812	137
Ohme	170	17	1483	135
Hamura	145		1434	118
Hachioji		23	1500	110
Tachikawa	75	24	1531	125
Tama	38	33	1332	110
Fuchu		34	1477	116
Denenchofu		12	1104	82
Setagaya	41	32	1387	114
mean			1534 256	124 27

Table 9. Mean discharge and relative discharge of the Tama River (mean of 1955–1972). (10)
High water; 95th largest, Ordinary water; 185th largest, Low water; 275th largest, Droughty water; 355th largest.

Location	Discharge (m^3/s)					Relative Discharge ($m^3/s/100km^2$)				
	High	Ordi.	Low	Drough.	Mean	High	Ordi.	Low	Drought.	Mean
Ogouchi	9.55	6.62	4.73	3.23	9.16	3.56	2.47	1.76	1.21	3.18
Hamura	16.53	12.21	8.96	6.11	15.56	3.39	2.50	1.84	1.25	3.41
Kawara Br.	17.43	11.15	6.74	3.44	20.40	1.68	1.07	0.65	0.33	1.96
Chofu Weir	18.36	9.51	5.67	3.09	19.24	1.49	0.77	0.46	0.25	1.56

Table 10. Fluvial fluxes (10^9 g/yr) of nutrients to Tokyo Bay (compiled by Ogura[22])

Year	DOC*	N	P
1973	650	110	8.0
1980	260	110	10

*Dissolved organic carbon.

Table 11. Output fluxes (10^9 g/yr) of nutrients from Tokyo Bay[23]

Output	N	P
Flushing	99	7.3
Sedimentation	4.9	1.2
Others	2.2*	

* Denitrification.

Table 12. Budget of phosphorus in Tokyo Bay ($\times 10^9$ gP/yr).[24]

Item	Pre-1930s (>60cm)	Present (0-10cm)
Input	4.0	14.0
Dissolved	3.3	13.1
Riverine(natural)	0.06	0.06
Riverine(human origin)	0	9.8
Intrusion of seawater	1.2	1.2
Release from minerals	2.0	2.0
Particulate	0.7	0.9
Riverine(natural)	0.74	0.74
Riverine(human origin)	0	0.19
Output	4.0	14.0
Sedimentation	0.9	1.3
Minerals	0.74	0.74
Human origin	0	0.19
Biological activity	0.14	0.37
Flushing	3.1	12.7

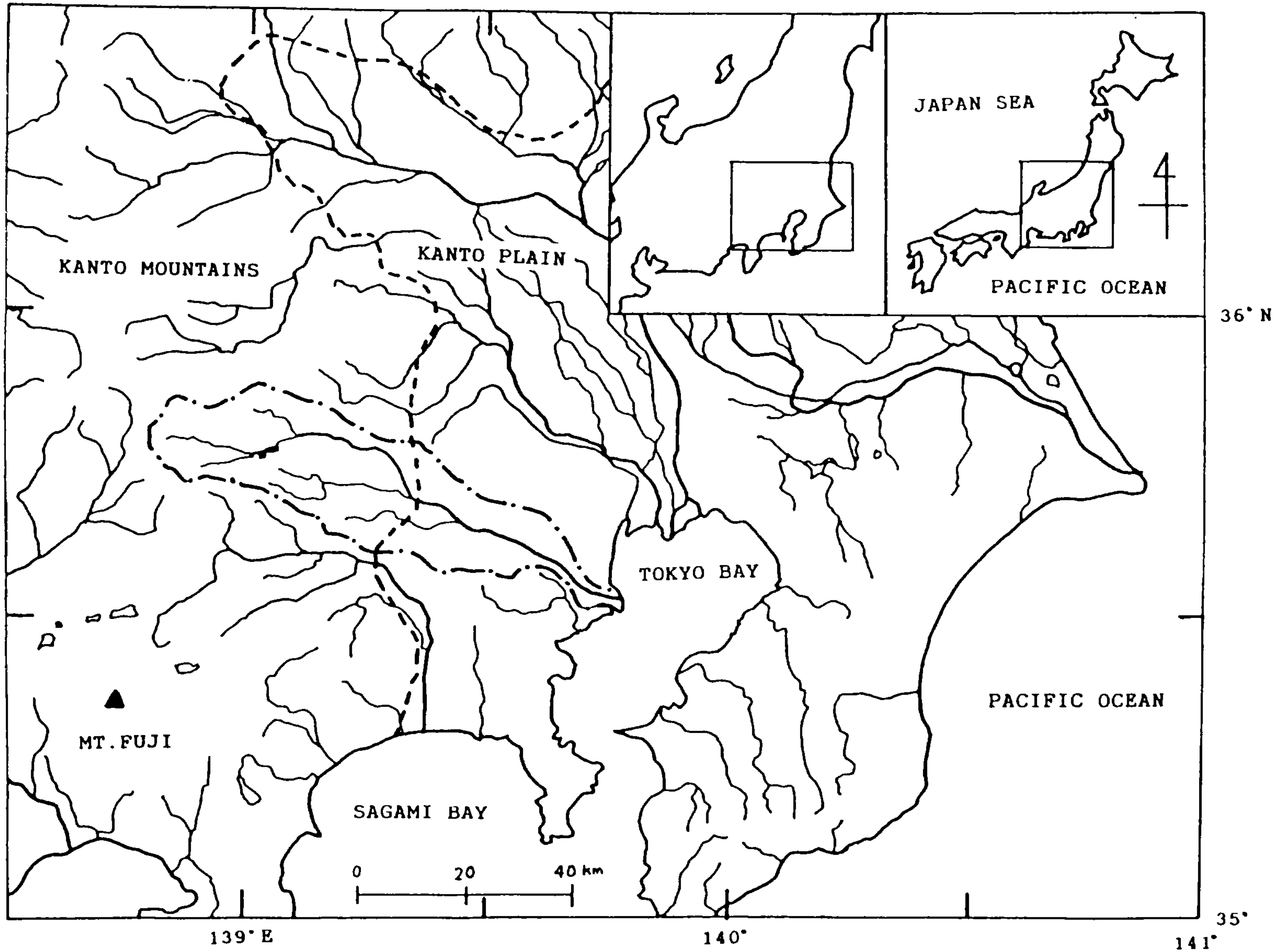

Fig.1 Map showing location of the Tama River system.

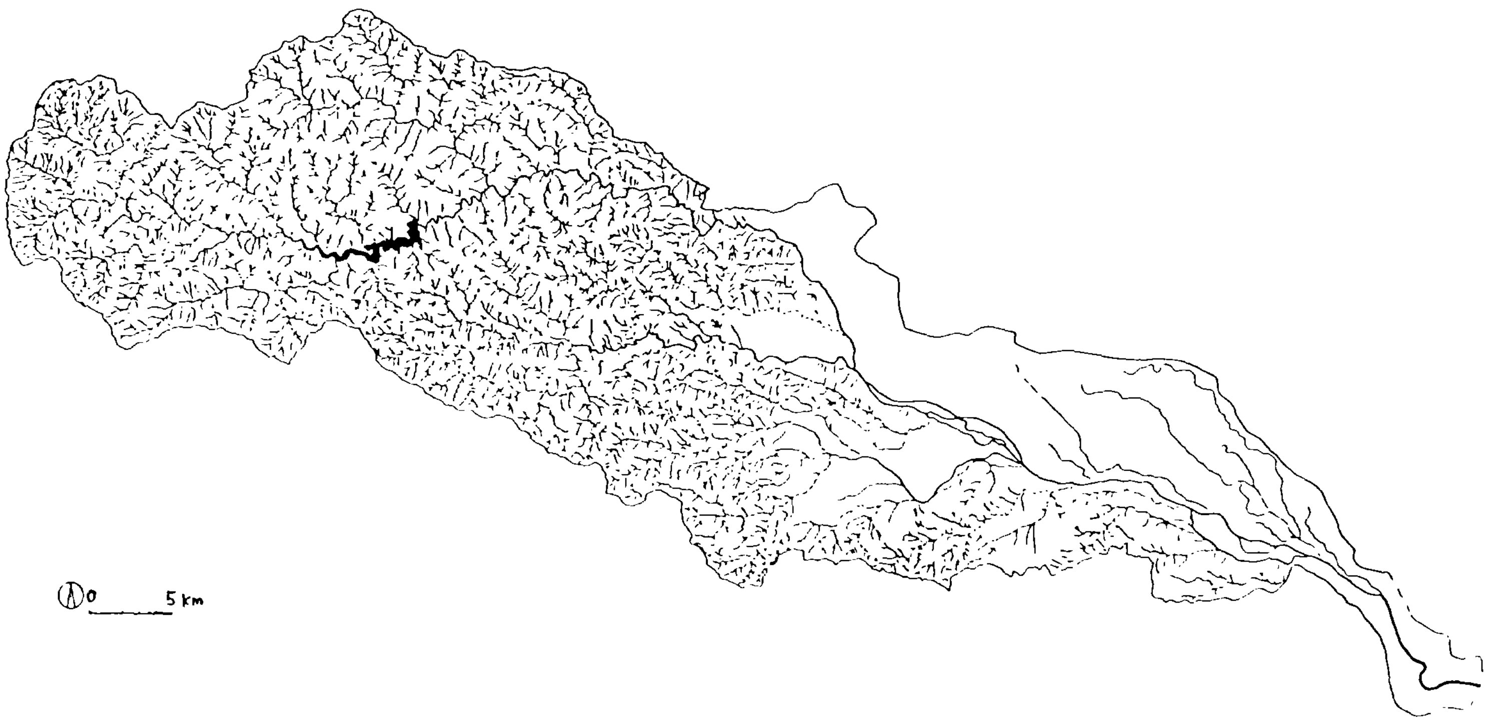

Fig.2 The Tama River System.(1)

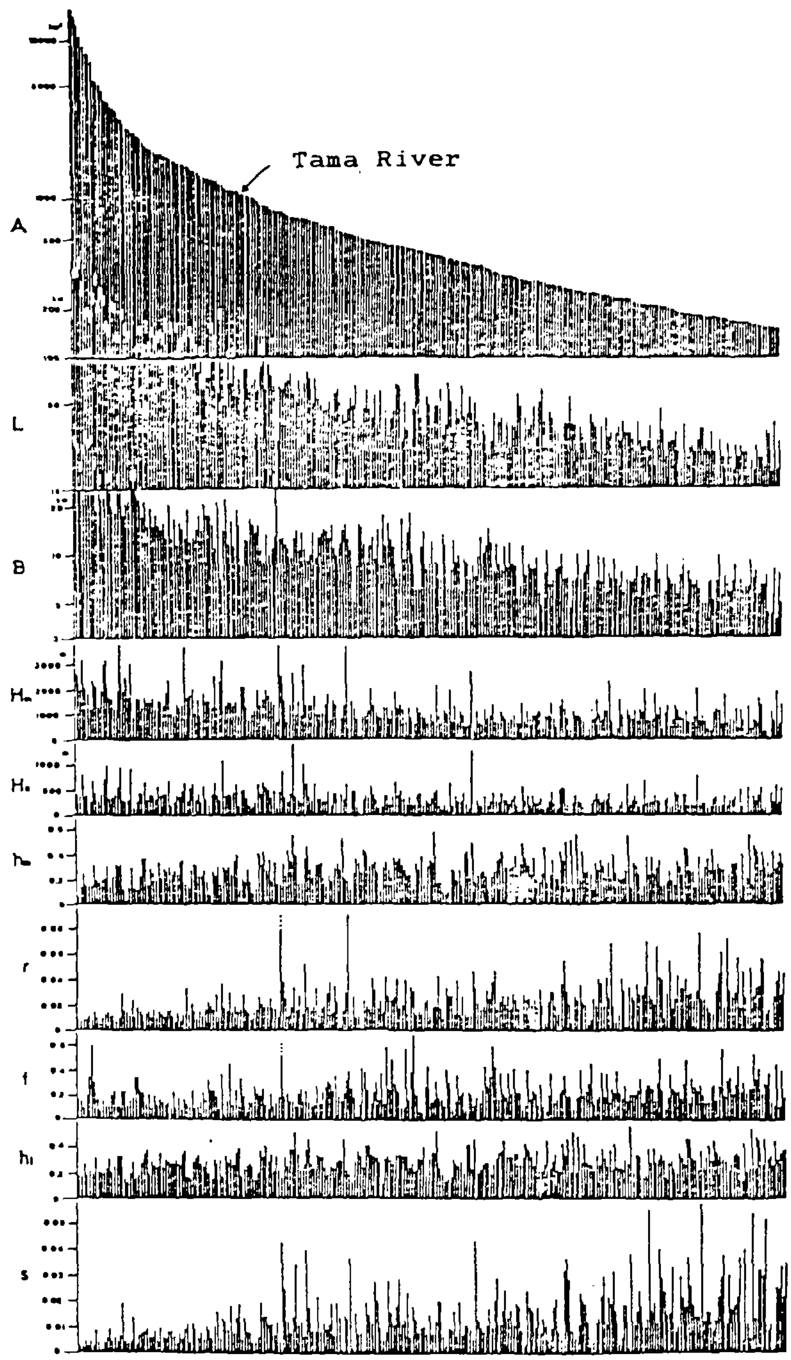

Fig.3 Characteristics of the Tama River watershed. (Sakaguchi, (2))
A:Area, L:Length, B:Mean width, Hm:Highest elevation, Ha: Mean elevation

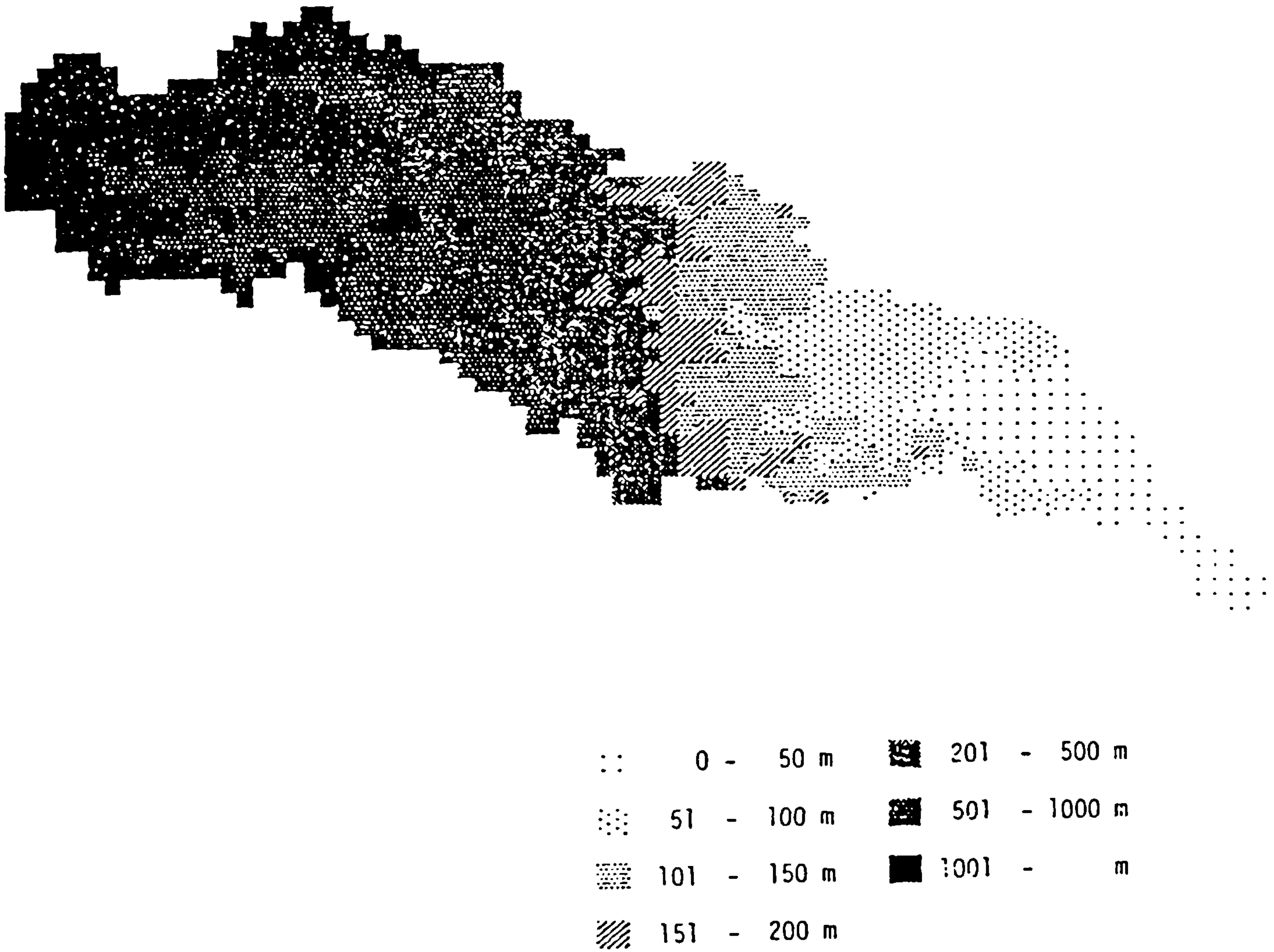

Fig.4 Elevation in Tama River watershed.(Kubo,(3))

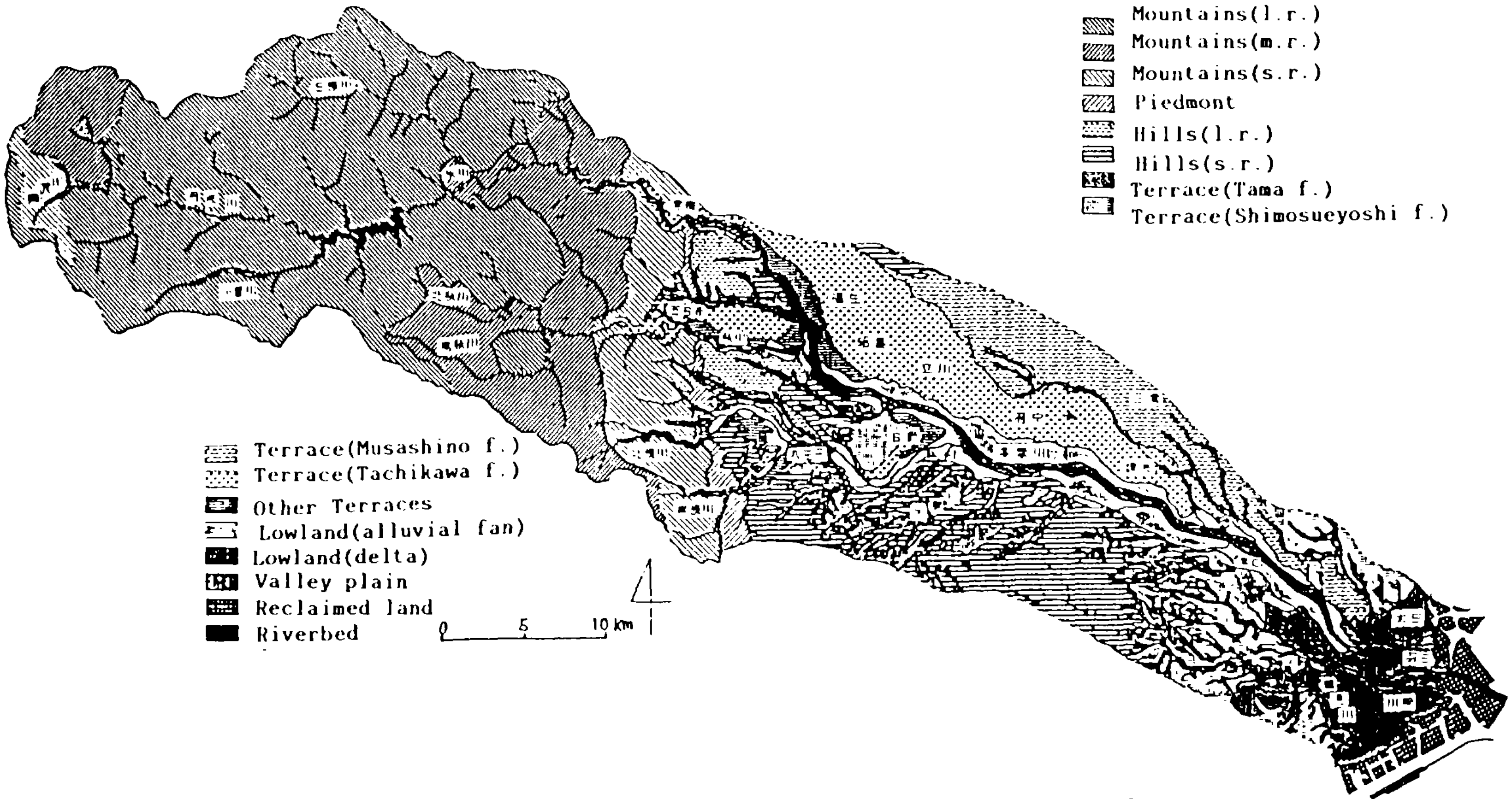

Fig.5 Geomorphology of the Tama River watershed.(Sakaguchi and Ohmori,(3))
l.r.:large relief, m.r.:moderate relief, s.r.:small relief, f:formation

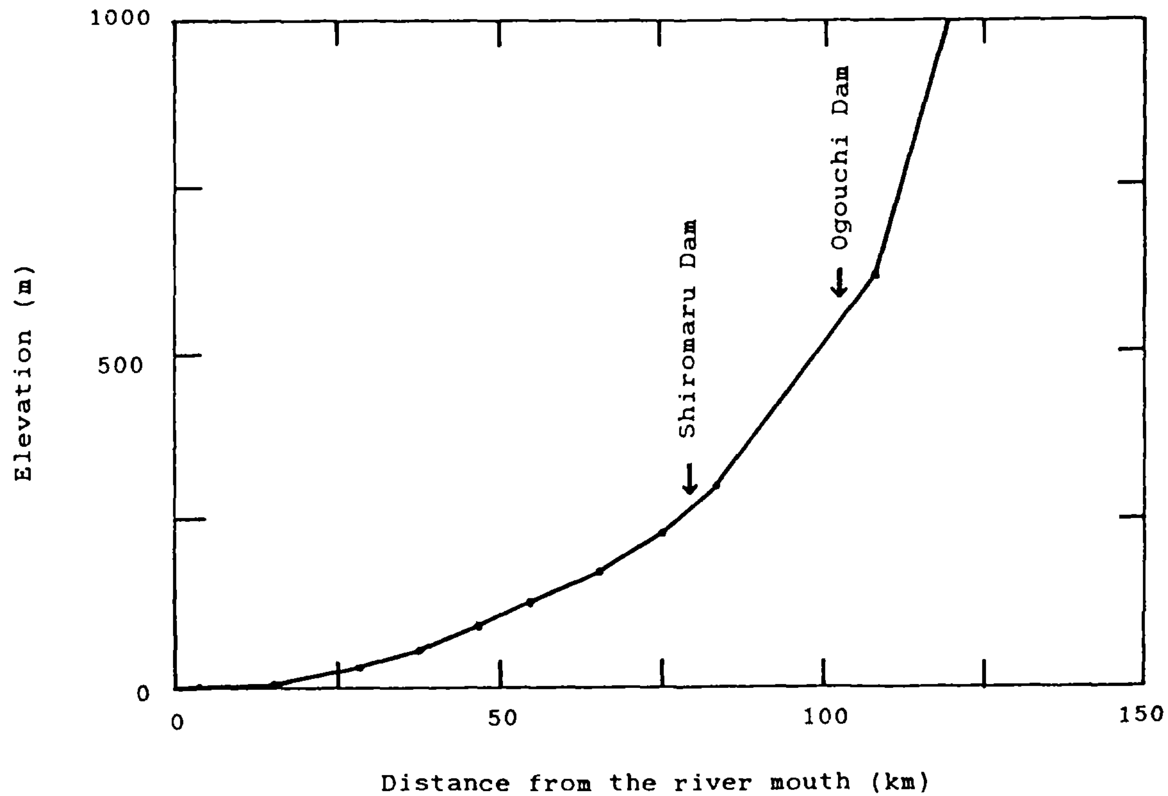

Fig. 6 Elevation of the riverbed of Tama River.

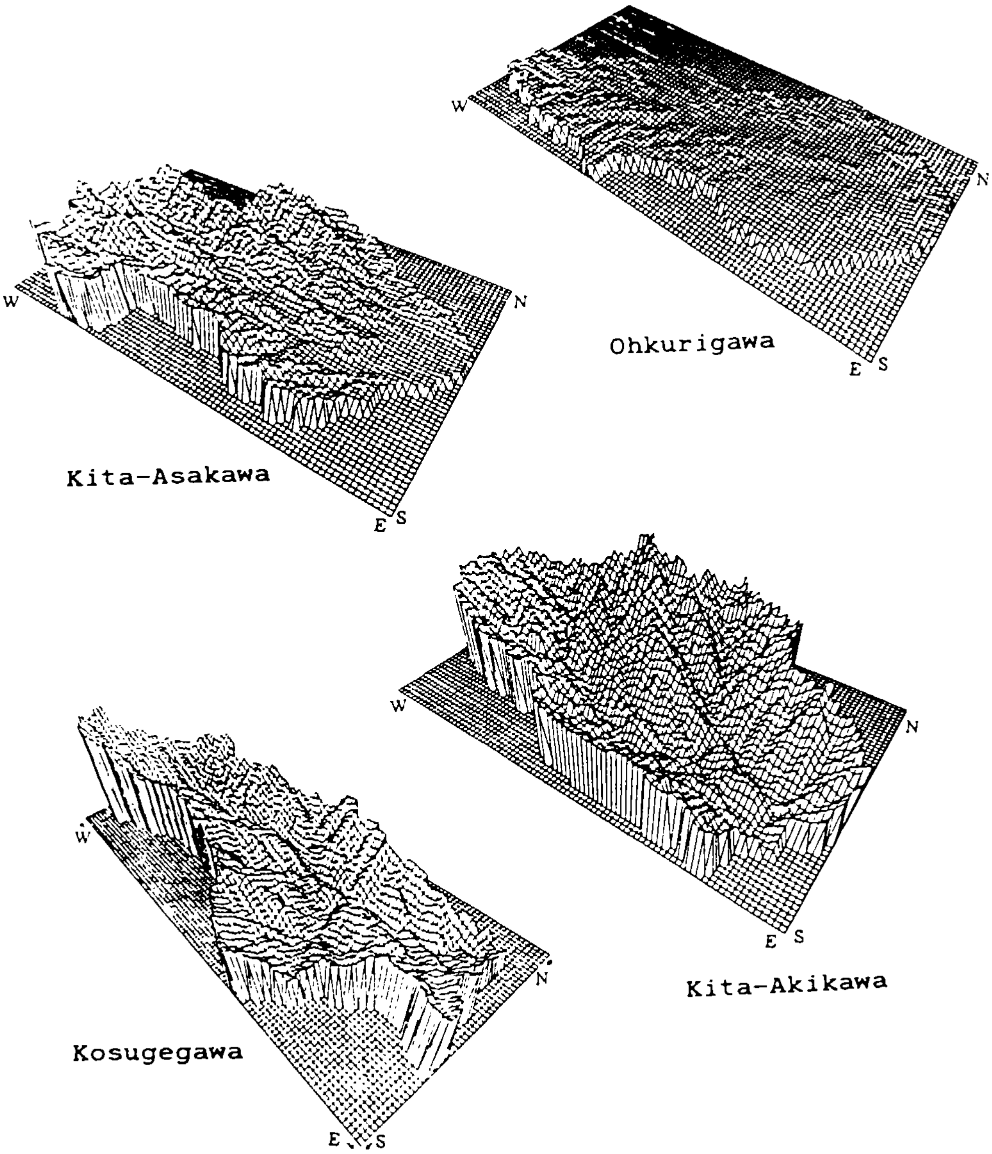

Fig.7 Morphological block diagram of tibutary watersheds of the Tama River. The vertical scale is twice of the horizontal ones.(Sakaguchi and Ohmori,(3))

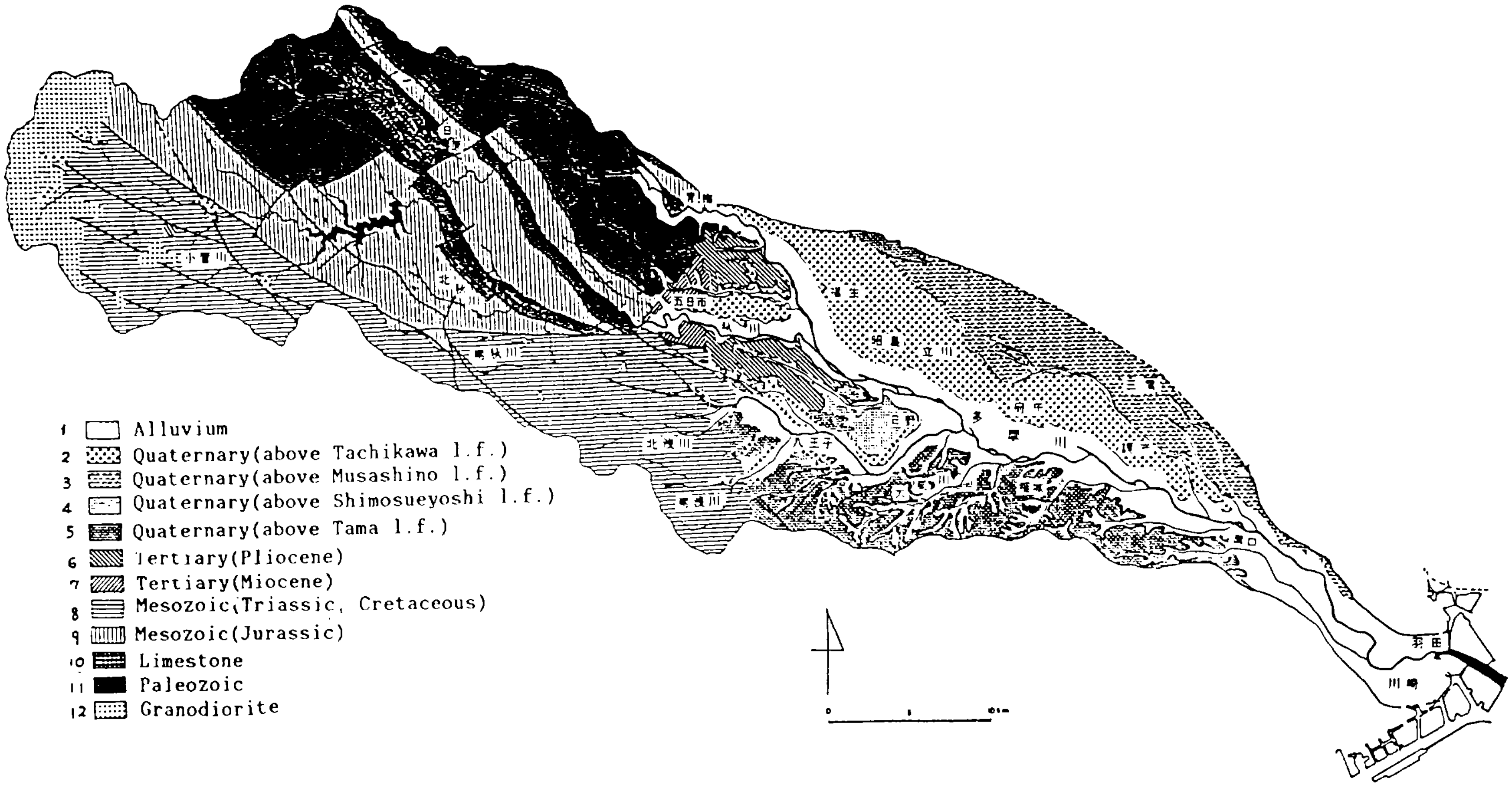

Fig.8 Surface geology of the Tama River watershed. (Sakaguchi and Ohmori, (3))
l.f.:loam formation.

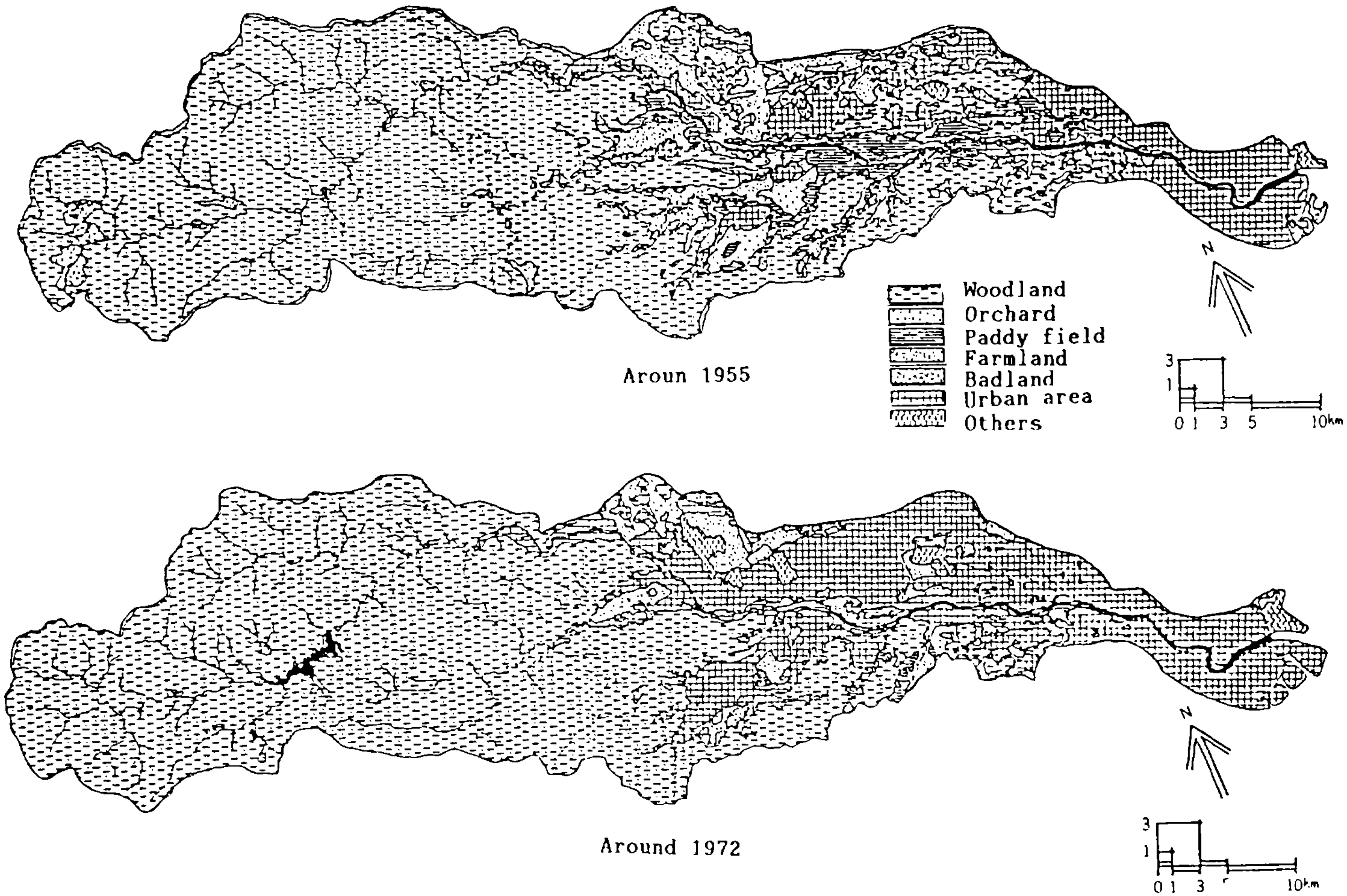

Fig.9 Landuses in the Tama River watershed.(1)

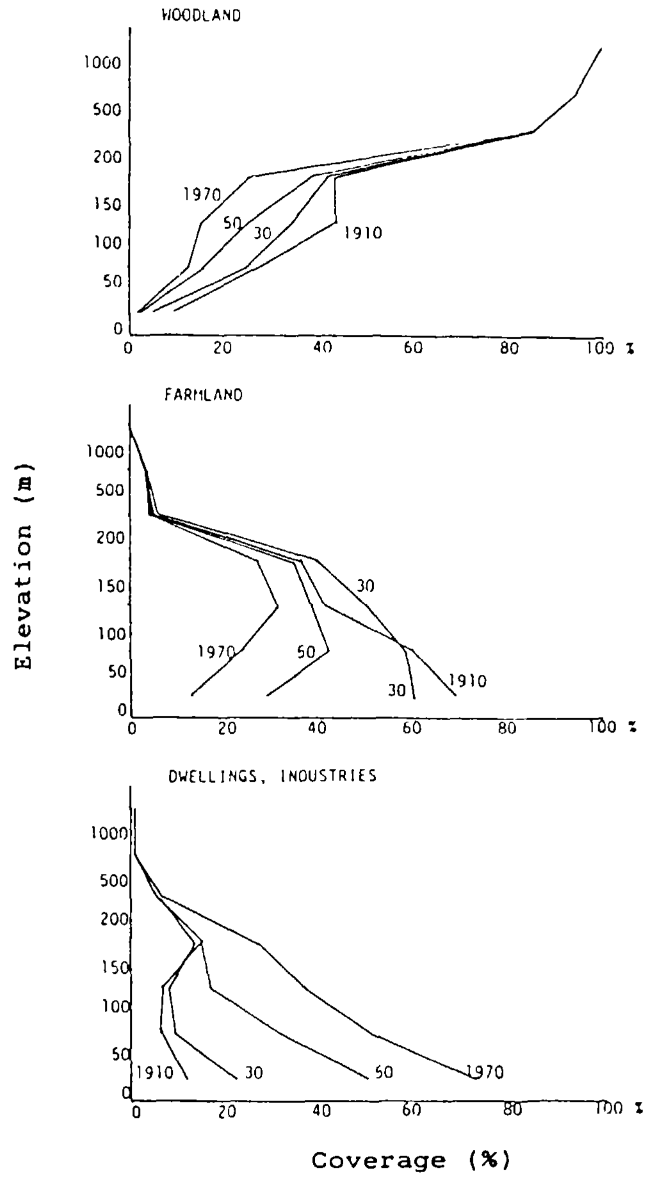

Fig.10 Elevation and landuses in the Tama River watershed.(3)

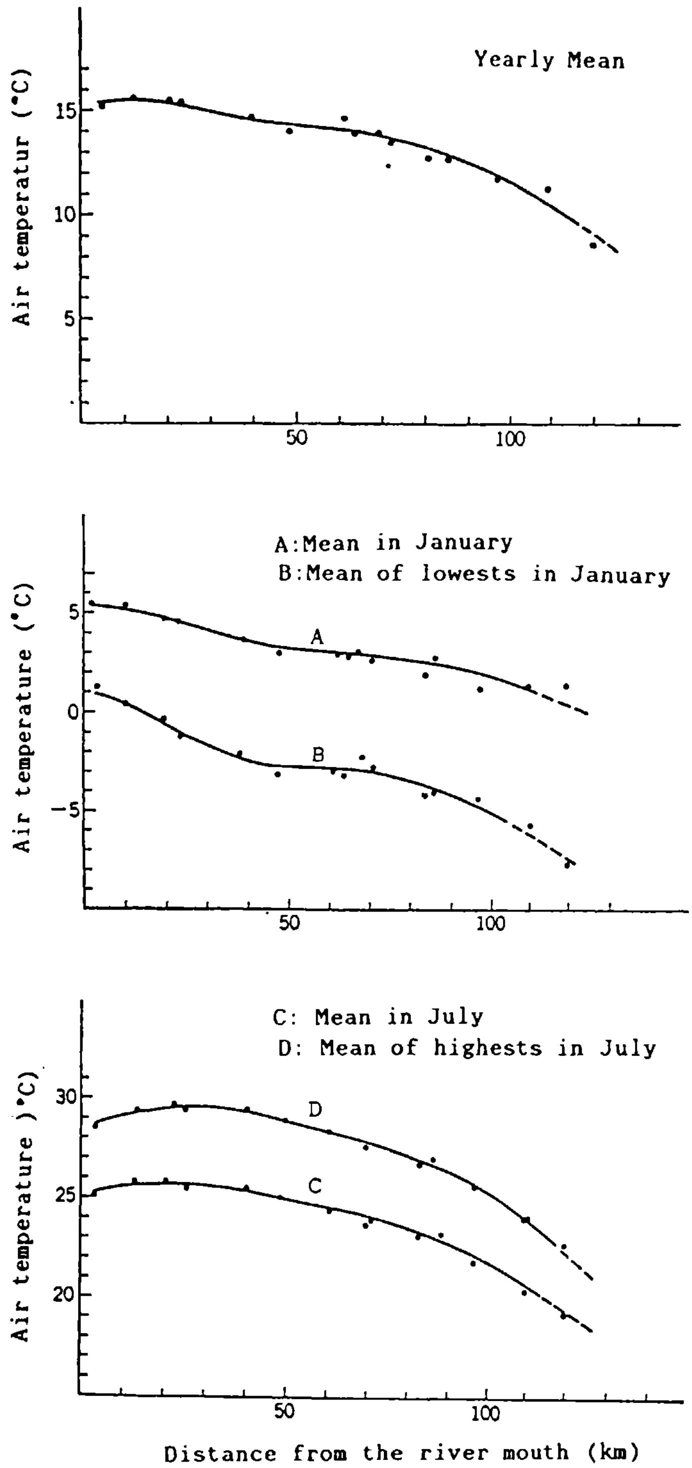

Fig.11 Mean air temperature along the Tama River from 1966 to 1980. (Kobayashi,(4))

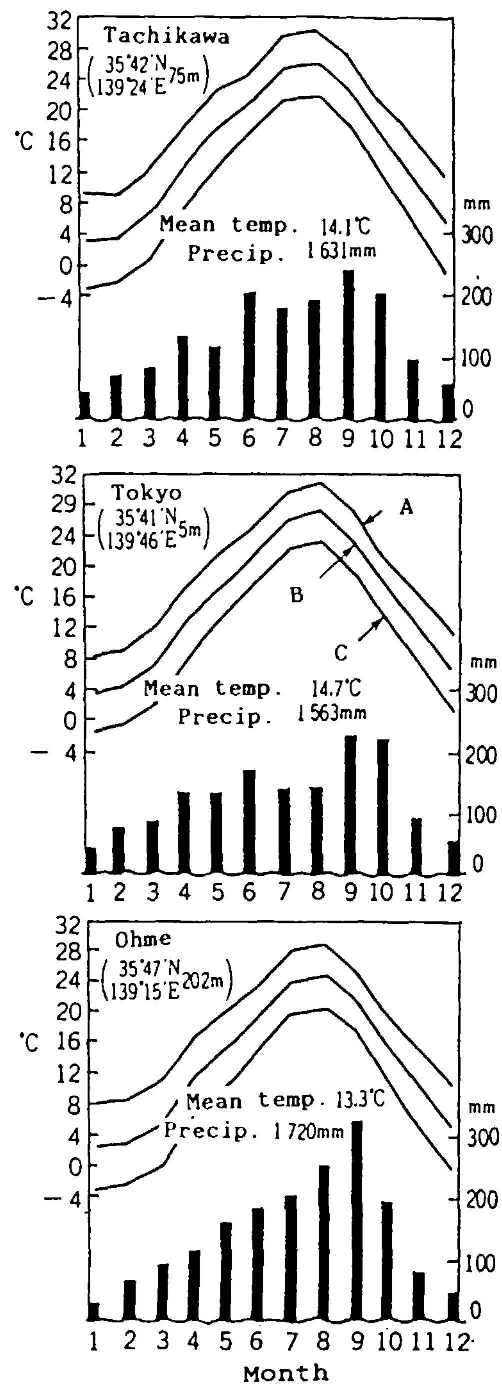

Fig.12 Monthly changes in air temperature and precipitation in the Tama River Watershed.(1)
A:Mean of daily highest temperatures, B:Mean of daily mean temperatures, C:Mean of daily lowest temperatures

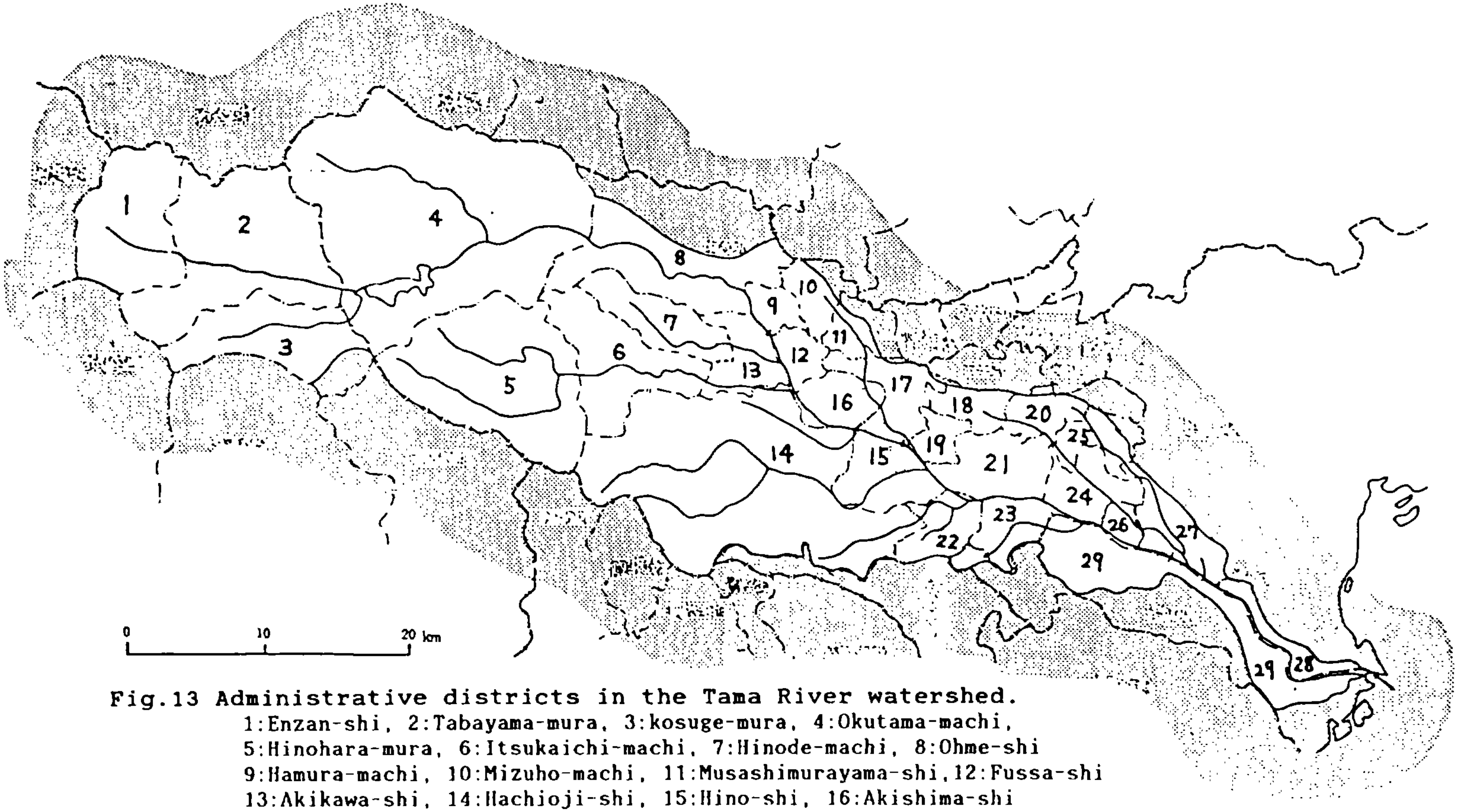

Fig.13 Administrative districts in the Tama River watershed.
1:Enzan-shi, 2:Tabayama-mura, 3:kosuge-mura, 4:Okutama-machi,
5:Hinohara-mura, 6:Itsukaichi-machi, 7:Hinode-machi, 8:Ohme-shi
9:Hamura-machi, 10:Mizuho-machi, 11:Musashimurayama-shi, 12:Fussa-shi
13:Akikawa-shi, 14:Hachioji-shi, 15:Hino-shi, 16:Akishima-shi
17:Tachikawa-shi, 18:Kokubunji-shi, 19:Kunitachi-shi, 20:Koganei-shi
21:Fuchu-shi, 22:Tama-shi, 23:Inagi-shi, 24:Chofu-shi, 25:Mitaka-shi
26:Komae-shi, 27:Setagaya-ku, 28:Ohta-ku, 29:Kawasaki-shi

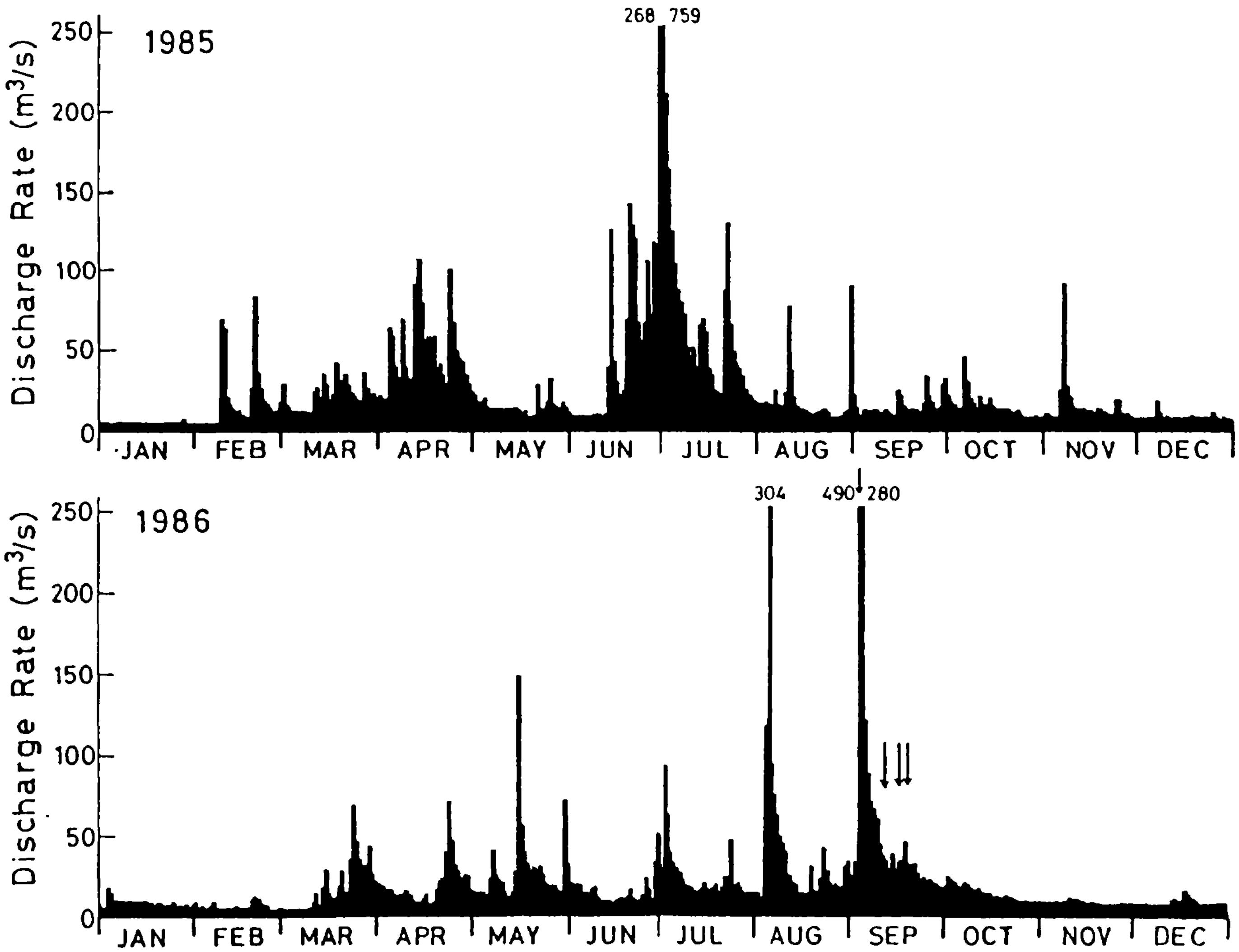

Fig.14 Discharge rate of the Tama River at the Chofu Weir in 1985 and 1986.

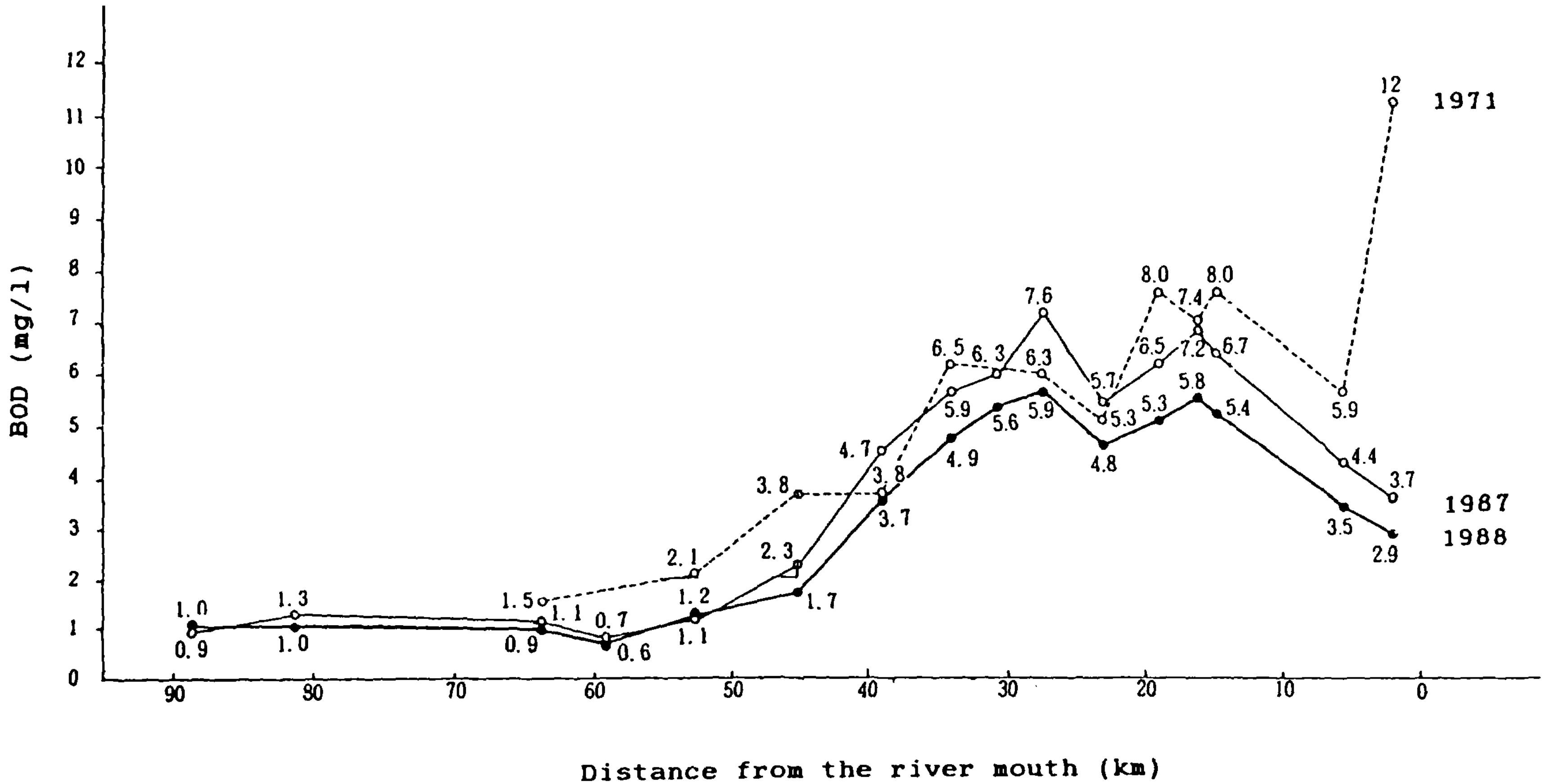

Fig.15 Changes in mean annual concentration of BOD along the
Tama River.(5)

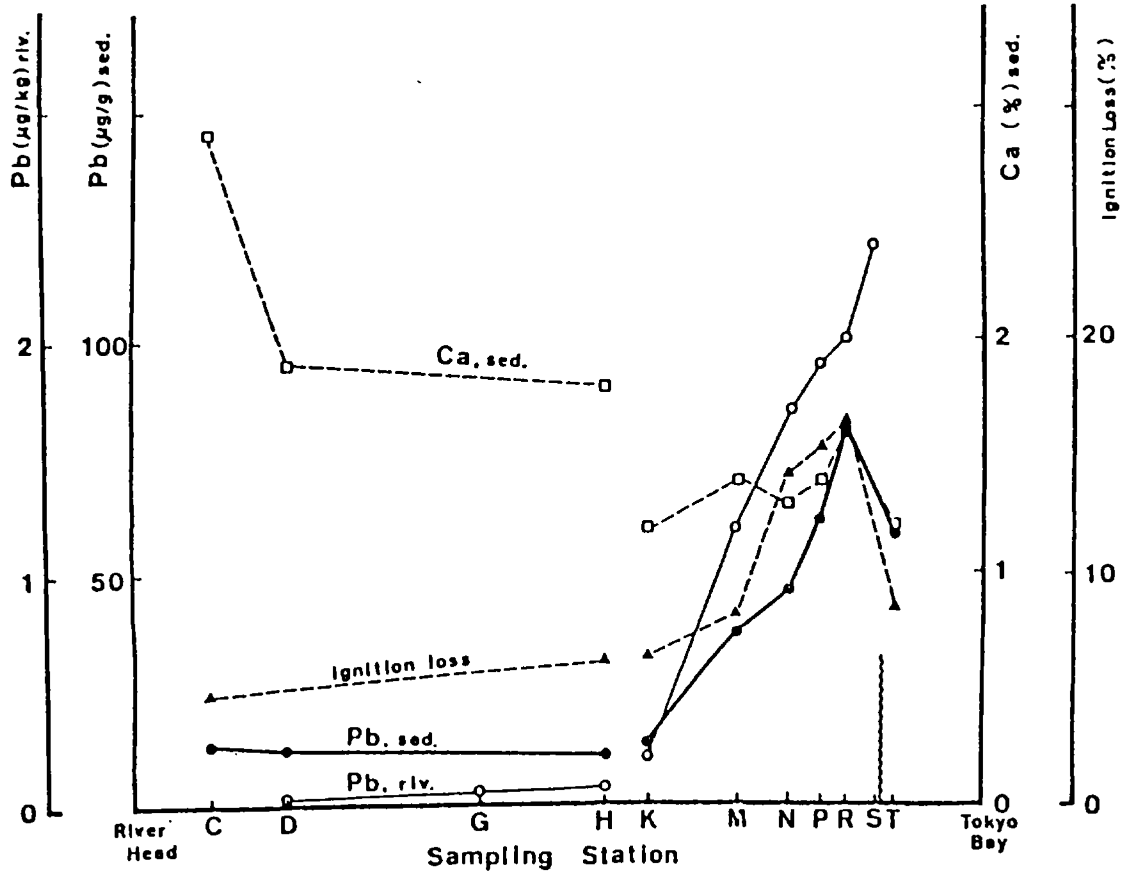

Fig.16 Changes in lead and calcium contents and ignition loss of the sediments and in lead concentration in the river water along the Tamagawa, Summer, 1980. (Hirao et al.,(6))

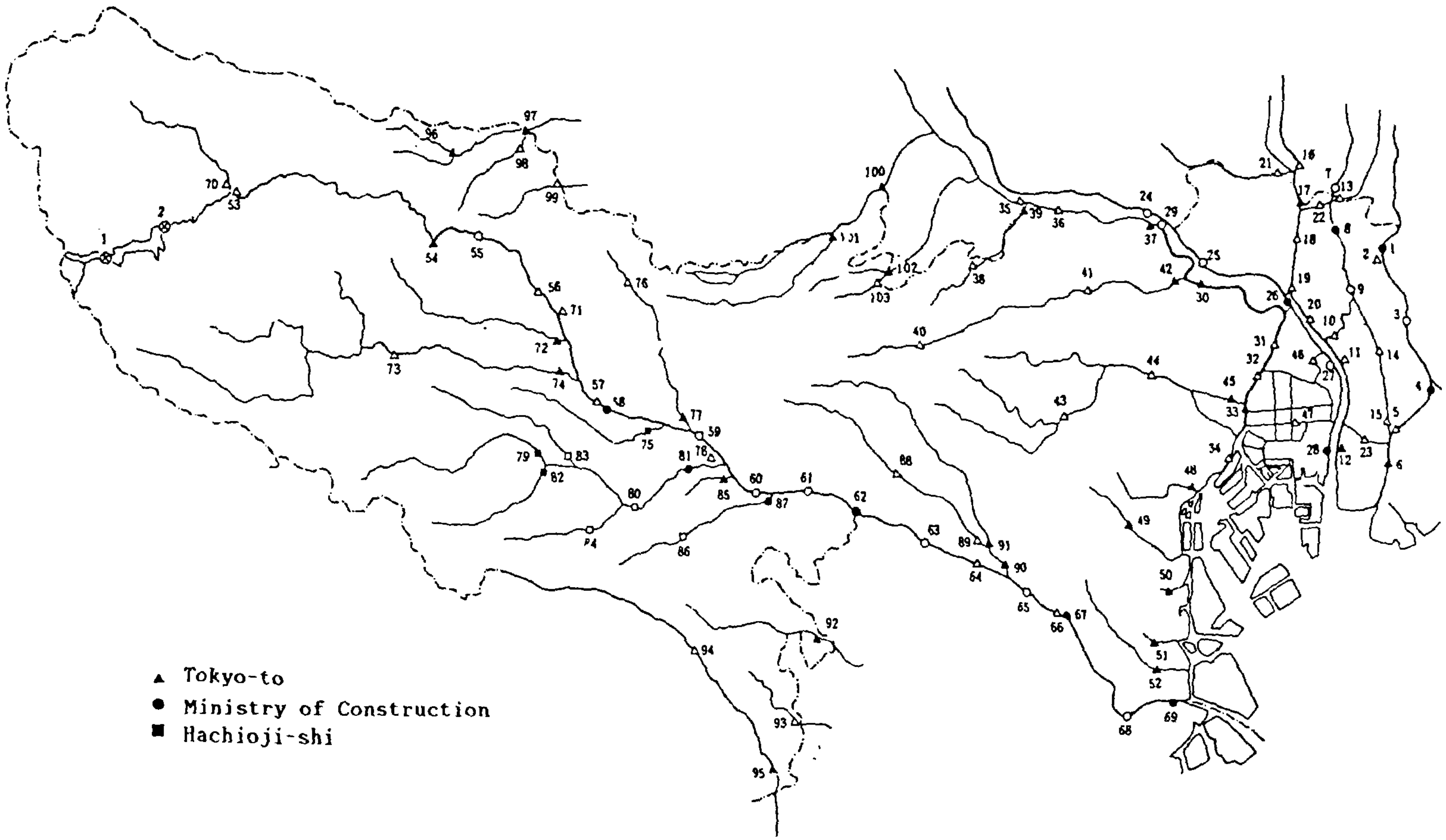

Fig.17 Monitoring stations of water qualities in rivers and lakes in Tokyo. (5)

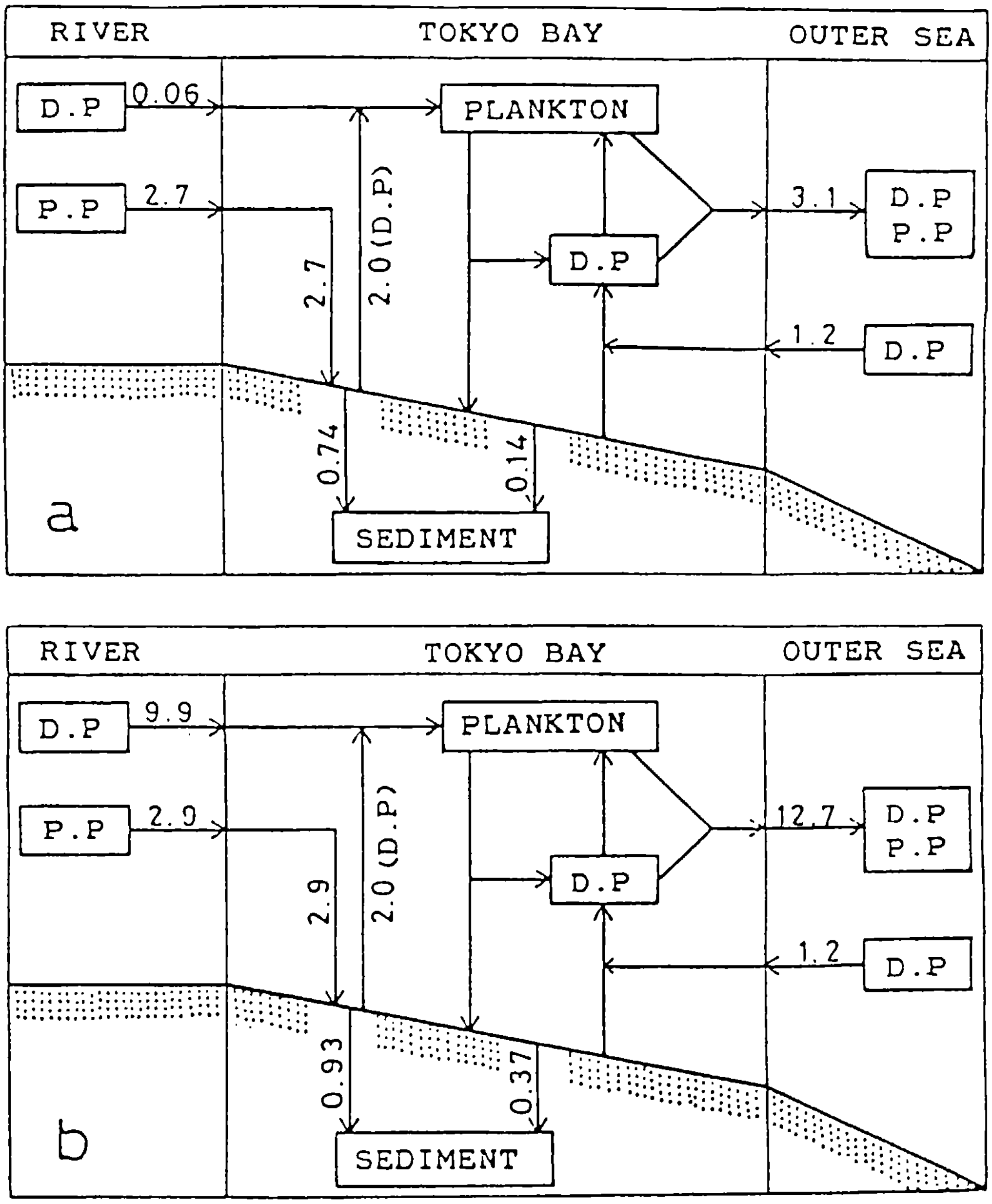

Fig.18. Budget of phosphorus in Tokyo Bay ($\times 10^9$ gP/yr)[24].

a: before 1930s (below 60 cm).

b: at present.

A COMPARATIVE STUDY OF THE TRACE METAL FLUXES OF THE BANG PAKONG AND THE MAE KLONG RIVERS, THAILAND

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ABSTRACT

Of the four major rivers draining into the Upper Gulf of Thailand, the Bang Pakong and the Mae Klong Rivers were selected for study of their inputs to the coastal zone because of their distinctive water characteristics. The Bank Pakong River drains acidic soils, while the Mae Klong is slightly alkaline and contains high concentrations of silicate and calcium. Both rivers were studied during the dry and wet seasons. It was found that, in the Bang Pakong, there appeared to be removal of some dissolved trace metals on particulates in the low-salinity region of the estuary, while this behaviour was not found in the Mae Klong River. In the Mae Klong, the high amount of particulates in the freshwater stretch of the river precipitated quickly in the low-salinity region.

INTRODUCTION

Thailand lies in Southeast Asia between latitudes 6 and 21°N in the monsoon region. The southwest monsoon season is from mid-May to October, and the northeast monsoon season lasts from November to February when the weather is cooler and dry. Generally, the weather is mild and humid. Temperature varies little during the year over most of the country except in the extreme north and northeast, which are at higher elevation. Rainfall varies from area to area, depending on topographic features. The wettest area receives 4800 mm year^{-1} and the driest $\sim$1000 mm year^{-1}. The central plain has an average rainfall of 1400 mm year^{-1}.

Of the four major rivers draining into the Upper Gulf of Thailand, the Bang Pakong and the Mae Klong Rivers (Fig. 1) were chosen for our study because of their distinctive water characteristics. The Bang Pakong River drains acidic soils while the water of the Mae Klong is slightly alkaline and contains high concentrations of silicate and calcium due to the high content of carbonate and silicate rocks in its upper watershed. The studies were conducted during both the low and high flow seasons.

THE BANG PAKONG RIVER

Soil of the Bang Pakong watershed is high in acid sulphate and poorly drained. It is mostly used for rice growing, although the yield is quite low.

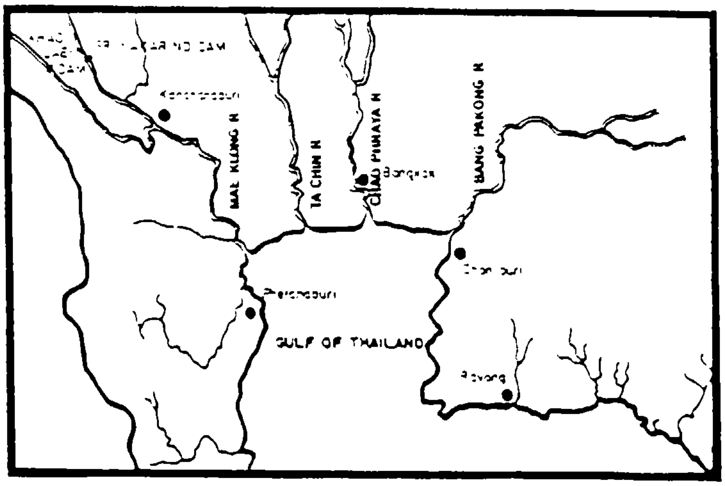


Fig. 1. Location of the Gulf of Thailand and the Bang Pakong and Mae Klong Rivers.

Further south of the central plain the soil is well-drained, and sandy to clayey; it is reddish-yellow in the low-to-medium elevation hills running from Chon Buri to Rayong Province. These soils are derived from acid rocks and are suitable for upland field crops and tree crops employing shifting cultivation practices, for example cassava and sugarcane. About 1% of the remaining forest area is of mangrove in the tidal zone and the rest are lowland and mountain forests (Chunkao et al., 1985). The lower watershed consists of alluvial deposits and sand from the Triassic Period. The upper watershed has an average rainfall of 2000 mm $year^{-1}$ and a relative humidity of 72%.

There are very few industries along this river, and the population is rather sparse in the upper regions. It is believed to be the least anthropogenic of the four main rivers draining into the Upper Gulf of Thailand. Pollution sources along this river are par-boiled rice mills, noodle factories and tapioca factories, which release starchy wastes into the river.

A water gate has been built across one of the two tributaries feeding the Bang Pakong, and this gate is closed during most of the dry season in order to conserve water for irrigation purposes and for tap water supply. This results in very low flow during the dry months of February to April. At such times, the salinity intrusion reaches up to the confluence of the two tributaries at km 122. The average yearly flow of the Bang Pakong is $\sim 99 \times 10^8 m^3$.

THE MAE KLONG RIVER

The Sri Sawad and the Sai-yoke Rivers join to become the 140-km long Mae Klong River, bringing a flow of $80 \times 10^8 m^3 year^{-1}$ to the Upper Gulf of Thailand. Several large factories, mainly sugar mills, are located on the banks of this river. The lower part of the river, ~40 km, is under tidal influence. This section is fairly densely populated and also has food-related industries. There are also pulp and paper mills in the upper section.

The Mae Klong watershed consists mainly of quartzite, sandstone and limestone with some siltstone and shales. This makes the water quality of the dam reservoirs on the two tributaries of the Mae Klong basic with high calcium and silicate contents. One of these reservoirs has a surface water calcium content of 43 mg l^{-1} and a pH of 7.8–8.3 during the dry season and half that amount of calcium and pH 7.3–7.8 in the wet season.

EXPERIMENTAL

River surveys were performed during low flow (dry season) and high flow (wet season). Samplings were carried out along the river from salinity 0 to seawater salinity when possible. A small boat was used which sometimes could not reach high salinity stations due to strong winds at the river mouth. Water parameters determined were: salinity, pH, alkalinity, dissolved oxygen, dissolved organic carbon, ammonia, nitrite, nitrate, phosphate, silicate and trace metals. For the Bang Pakong, bottom sediments were also collected with a stainless-steel, Petersen-type grab and the freeze-dried sediments were analyzed for organic carbon, nitrogen and hydrogen as well as selected trace metals. This was done to complement the water data and to obtain an estimate of metal accumulation in river sediments.

TABLE 1

Comparison of the water quality of the Bang Pakong River and the Mae Klong River (dry season)

Parameter	Bang Pakong (122 km) 5 February 1985	Mae Klong (140 km) 24 February 1986
Salinity (‰)	1.96–31.67	0–27
pH	7.1–7.7	7.7–8.0
DO (ppm)	4.6–8.0	5.1–5.8
Alkalinity (meq l^{-1})	1.71–2.24	2.12–2.79
DOC* (ppm)	3.3–4.4	1.6–14.1
Nitrite (μmol l^{-1})	3.1–22.8	0.2–0.9
Nitrate (μmol l)		10.48–21.67
Phosphate (μmol l^{-1})	1.36–5.40	0.09–0.50
Silicate (μmol l)	33.8–102.4	81.54–274.68
Suspended solids (ppm)	16–138	
Major elements at salinity 0‰		
Cl^- (ppm)	14.0	13.8
SO_4^{2-} (mg l^{-1})	8	5
HCO_3^- (mg l^{-1})	25	121
Na (mg l^{-1})	7.5	7.9
K (mg l^{-1})	1.2	2.2
Ca (mg l^{-1})	5.9	31.0
Mg (mg l^{-1})	4.0	9.8

*Data from National Environment Board.

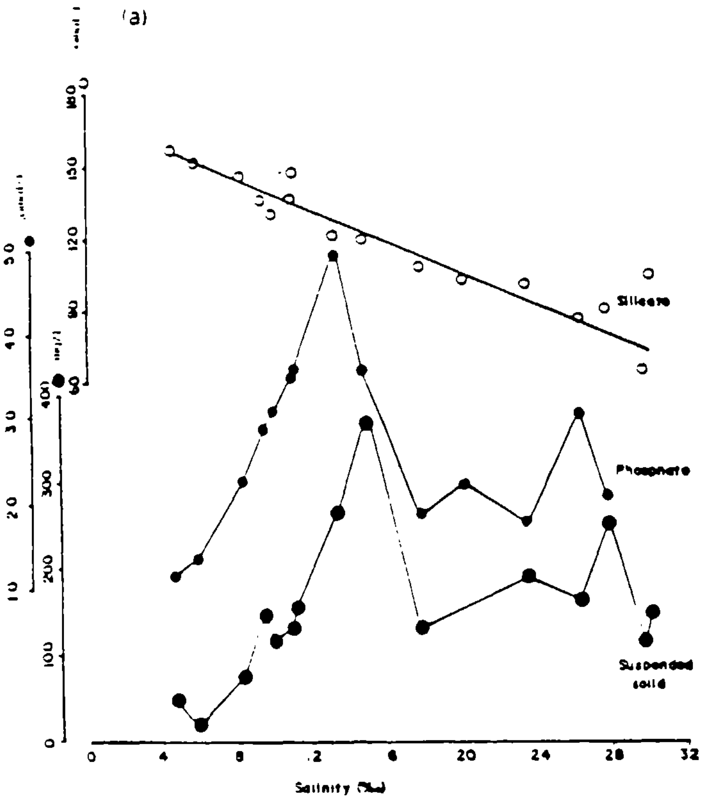


Fig. 2. (a) Dissolved phosphate, silicate and suspended solids in the Bang Pakong, March 1984 (low discharge). (Continued on pp. 93–95.)

Analysis of water samples

Alkalinity, dissolved oxygen, and nutrients were determined using the methods of Strickland and Parsons (1972). Cadmium, Cu, Pb, Fe, and Mn were co-precipitated with $CoCl_2$-ammonium pyrollidinedithiocarbamate and determined by atomic absorption spectrophotometry using a flameless graphite furnace, except for zinc which was determined in an air–acetylene flame (Huizenga, 1981).

Particulates were separated by filtration through a Nuclepore (0.4 μm) filter and digested with HF and HNO_3 in a Teflon decomposition bottle.

Sediment analysis

Trace metals were leached from the sieved sediment with 1 *N* HNO_3 for 15 min on a hot plate at 110°C, then, after cooling, the supernatant solution was filtered through an acid-cleaned Whatman No. 41 filter. The metal content was determined by atomic absorption spectrophotometry.

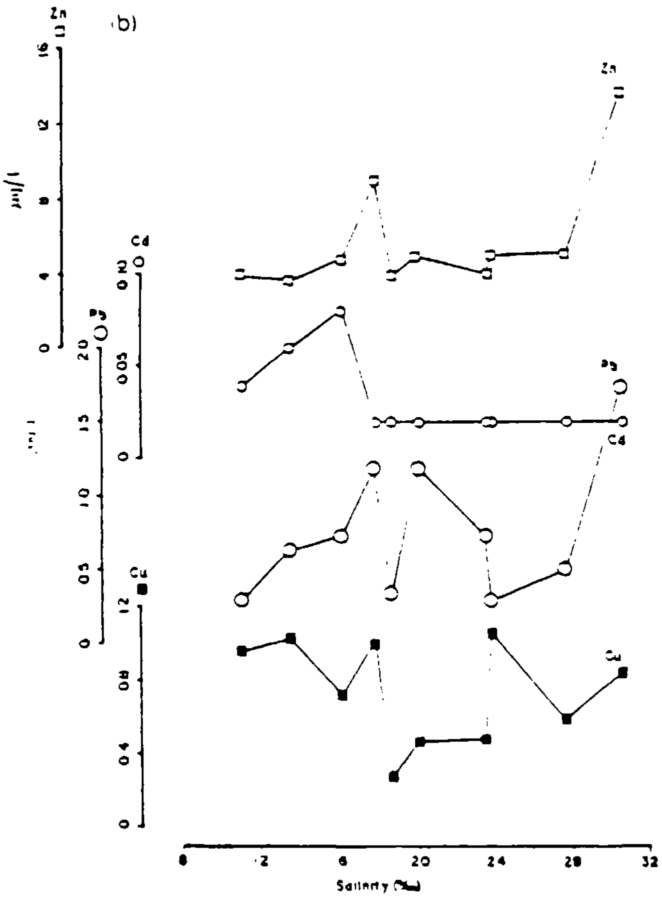


Fig. 2. (b) Particulate Cd, Cu, Pb and Zn in the Bang Pakong, March 1984 (low discharge).

The nylon-sieved (mesh size 2 mm) sediment was analyzed for readily oxidizable organic carbon (Walkey, 1947). Organic carbon, nitrogen and hydrogen contents were also determined using a C-H-N Analyzer.

RESULTS

The Bang Pakong River surveys were performed in March 1984 (dry season), September 1984 (wet season) and February 1985 (dry season). The Mae Klong River surveys were carried out in February and October 1986. Studies of the water quality of the Sri Nakarind (Fig. 1) and Khao Laem Dam Reservoir (Fig. 1) were also made for both seasons.

Typical water quality parameters for the two rivers are shown in Table 1. The Mae Klong had higher pH, alkalinity, and silicate and calcium contents. This is due to the characteristics of the Mae Klong watershed, as mentioned earlier. Study of the water in the two dam reservoirs, namely the Sri Nakarind

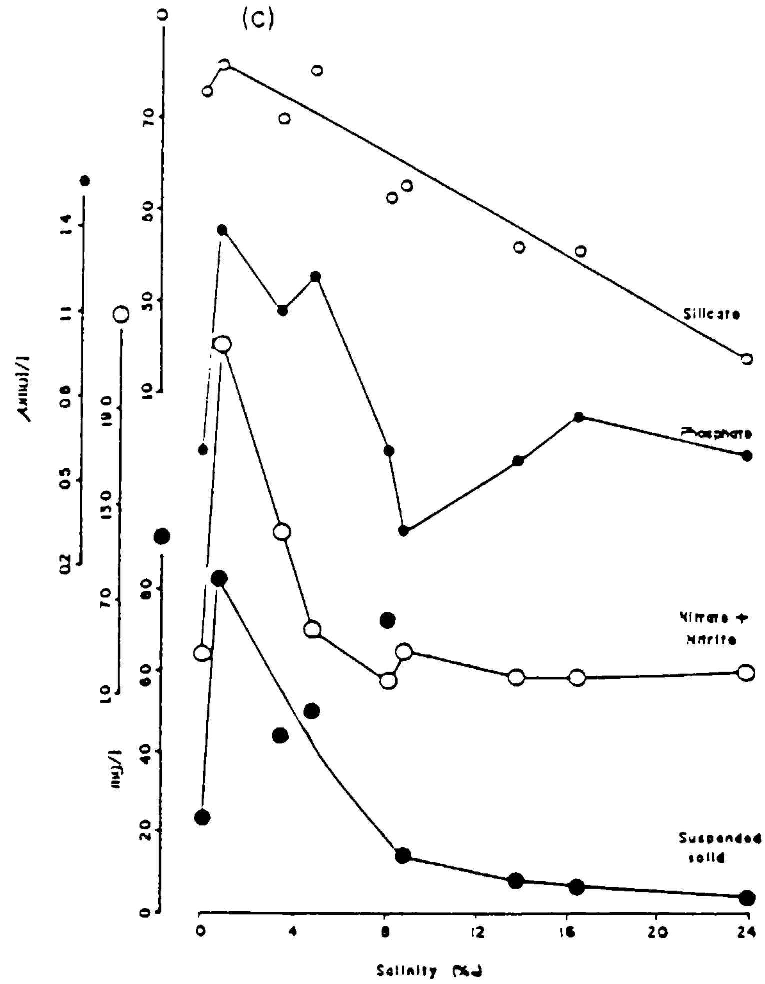


Fig. 2. (c) Dissolved phosphate, silicate, nitrate + nitrite, and suspended solids in the Bang Pakong, September 1984 (high discharge).

and the Khao Laem Dam Reservoirs of the two tributaries of the Mae Klong, showed high values for these parameters. For the Sri Nakarind, the silicate content was 336 $\mu mol\ l^{-1}$ and the calcium content 44 $mg\ l^{-1}$ in February 1985. The mean alkalinity of the Sri Nakarind was 2.86 $meq\ l^{-1}$ and the pH 8.27, while that of the Khao Laem was even higher at 3.97 $meq\ l^{-1}$. By world river standards, these two rivers were not considered to be polluted with respect to their phosphate and nitrate contents, although the mean dissolved oxygen concentration in the Mae Klong was undersaturated by about 29%.

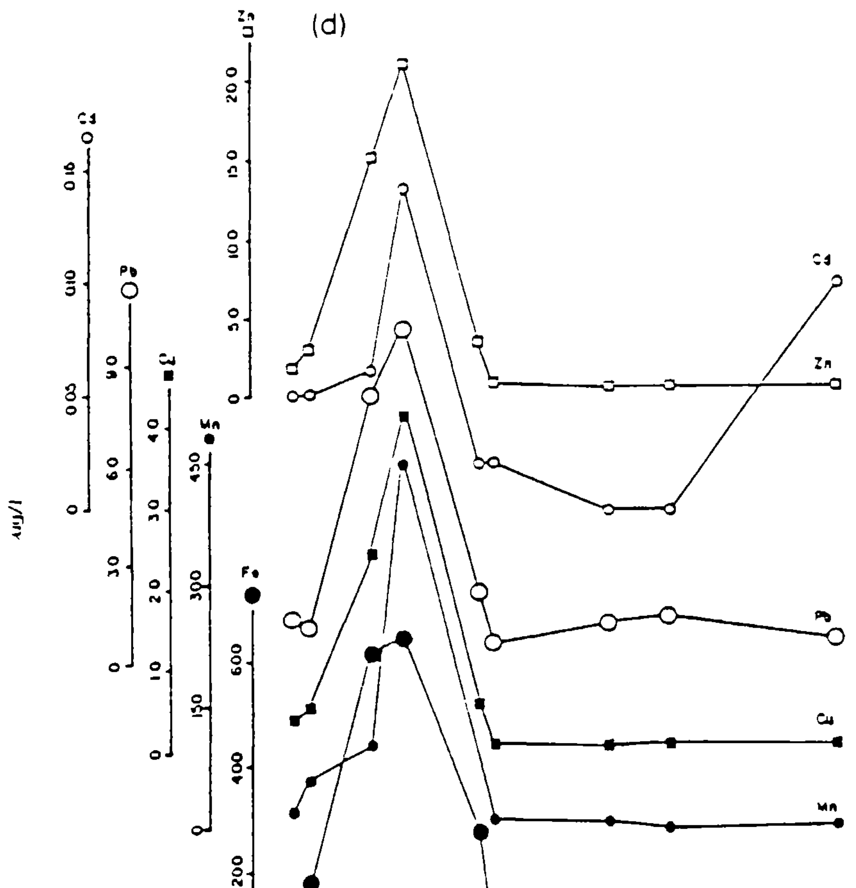


Fig. 2. (d) Particulate Cd, Cu, Pb, Mn, Fe and Zn in the Bang Pakong, September 1984 (high discharge).

The Bang Pakong River

Behaviour of nutrients

During the March 1984 (low discharge) survey (Fig. 2a), there were two dissolved phosphate maxima, one in mid-estuary at approximate salinity 10‰ and the second at the river mouth at 25‰. These maxima coincided with those for suspended solids. The National Environment Board (1983) survey also

TABLE 2

HNO_3 leached metals in Bang Pakong River sediments ($\mu g\ g^{-1}$)

Station	Salinity of water (‰)	Metal					
		Cd	Cu	Pb	Zn	Fe	Mn
Bang-Kla (km 31)	11.3	0.03	8.35	4.35	33.15	15304	1320
Sao Cha-ngoke	13.3	0.07	11.43	4.31	26.00	15137	540
Railway Bridge (km 57)	16.5	0.08	9.41	5.19	29.47	16026	1245
Tha-It (km 49.5)	19.1	0.08	11.61	4.92	24.66	15673	558
Ban Po	23.2	0.10	9.10	5.63	27.07	17500	1153
Tha-Sa-an Market	27.5	0.12	8.17	4.48	19.96	14881	613
River mouth (km 2)	29.2	0.09	6.30	5.46	26.00	16473	1074
Mean		0.08	9.20	5.05	26.66	16313	1100

found that the total coliforms curve coincided with the suspended solids curve. The September (high discharge) survey (Fig. 2c) found a similar situation with the nitrate – nitrite peak coinciding with the phosphate and suspended solid peak. Van Bennecom et al. (1978) explained the mid-estuary maximum he found in a tropical river as being the effect of salinity releasing phosphate from particulates. In our March survey, bacteria probably also played a role in nutrient release. As expected, silicate was not significantly involved and the variation of silicate with salinity was conservative except for a slight addition from salinity 0 to 2‰. In the high flow season, the nutrient peaks occurred at salinity 2‰. This is probably a result of the differences in flow and mixing rates between the seasons. In the Bang Pakong, the water gate across one of the tributaries was closed during most of the dry season in order to conserve water

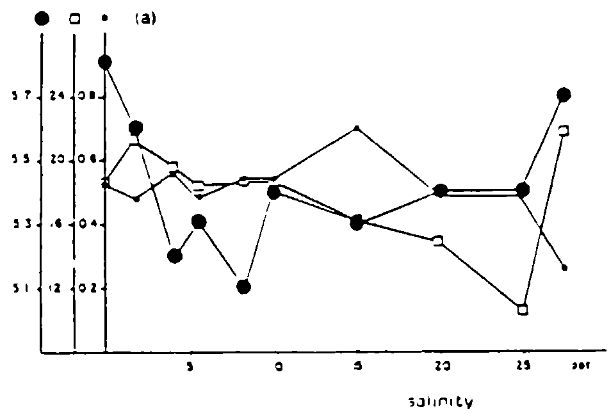
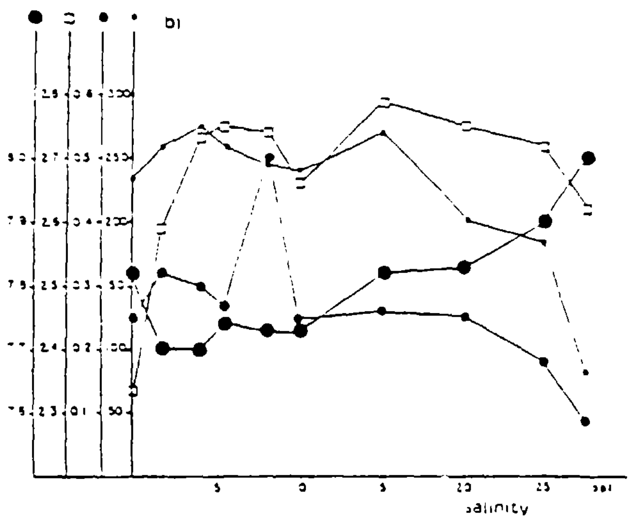
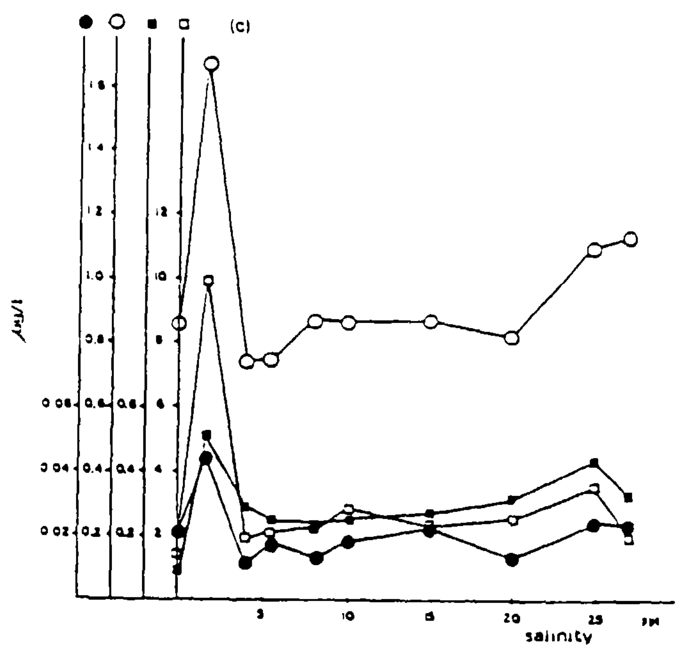


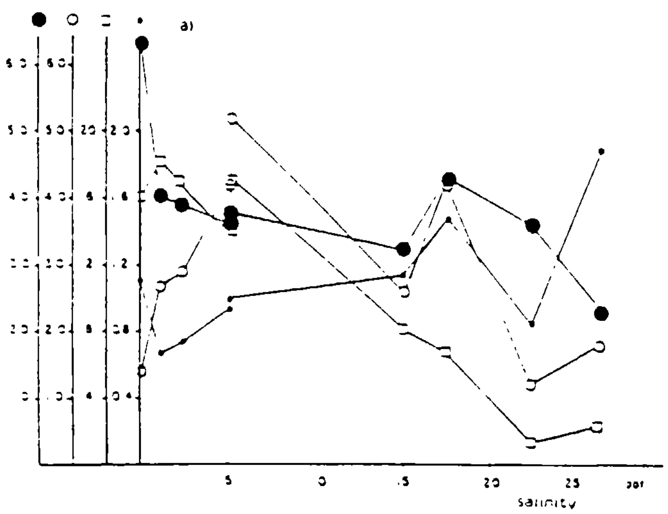
Fig. 3. (a) Dissolved oxygen, nitrate and nitrite in the Mae Klong, February 1986 (low discharge). (b) pH, alkalinity, phosphate and silicate in the Mae Klong, February 1986. (c) Dissolved Cd, Cu, Pb and Zn in the Mae Klong, February 1986.



● pH
□ Alkalinity meq/l
• phosphate µmol/l
. silicate µmol/l



● Cadmium (Cd)
○ Copper (Cu)
■ Lead (Pb)
□ Zinc (Zn)
µg/l



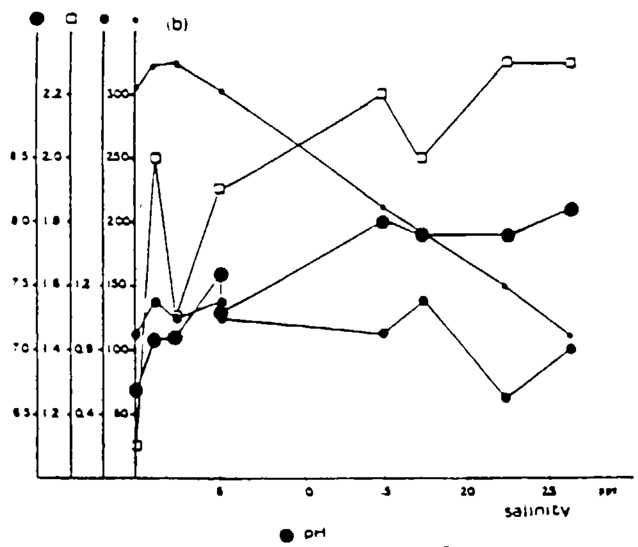
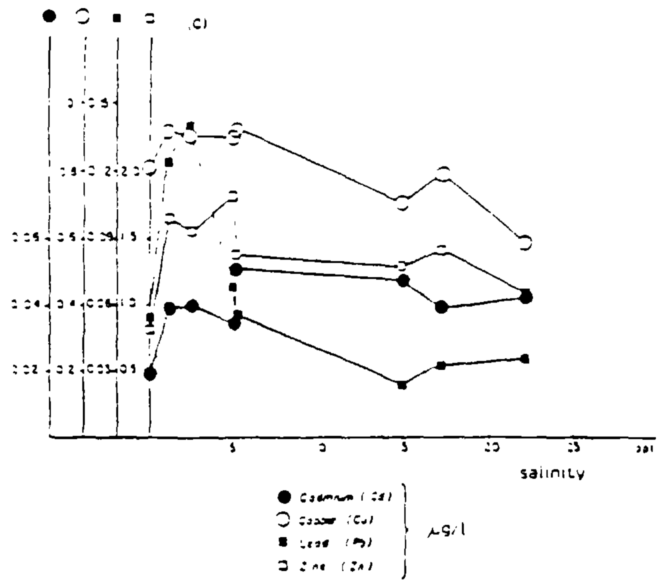
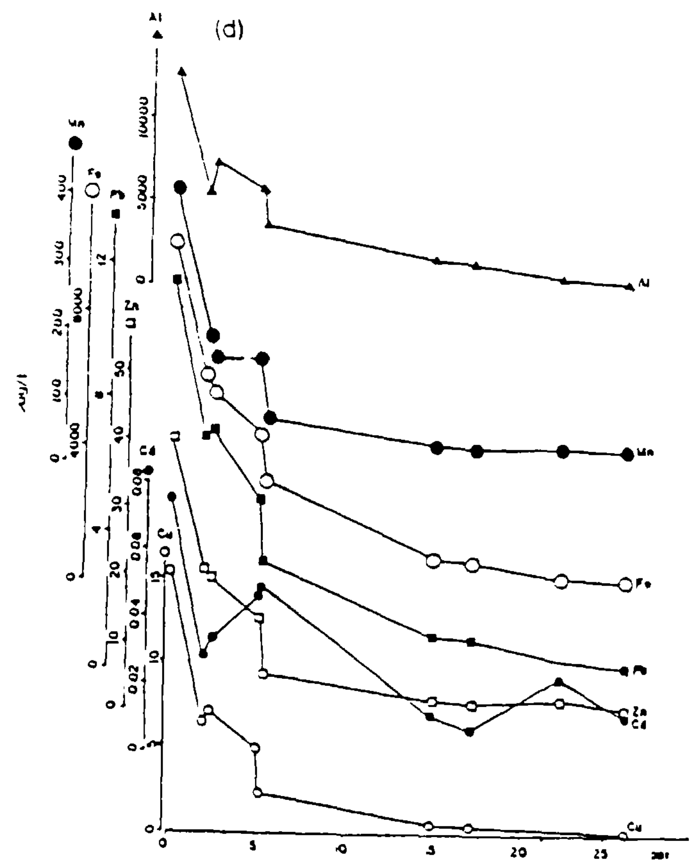


Fig. 4. (a) Dissolved oxygen, ammonia, nitrate and nitrite in the Mae Klong, October 1986 (high discharge). (b) pH, alkalinity, phosphate and silicate in the Mae Klong, October 1986. (c) Dissolved Cd, Cu, Pb and Zn in the Mae Klong, October 1986. (d) Particulate Cd, Cu, Pb, Zn, Al, Fe and Mn in the Mae Klong, October 1986.


(c)
salinity
Cadmium (Cd)
Copper (Cu)
Lead (Pb)
Zinc (Zn)
µg/l


(d)
Al
Mn
Fe
Pb
Zn
Cd
Cu
Salinity

for irrigation and domestic use, therefore runoff to the Bang Pakong consisted of only a small amount of water from the other tributary. The ratio of high to low flow rate was about 15:2.

Behaviour of trace metals

The mixing behaviour of Cd, Cu, Pb and Zn in the Bang Pakong was distinctly similar (Fig. 2b) during the high flow season (September). Removal of all four metals occurred simultaneously with iron and manganese in the salinity range 0–10‰. For the low flow (March) season (Fig. 2b), the same phenomenon occurred, but the particulate peaks were broader. It is most likely that Cd, Cu, Pb and Zn were removed by adsorption onto iron and manganese hydroxides, which precipitate on encountering seawater.

River sediments were collected along the 81-km stretch of the Bang Pakong estuary. Analysis of leachable metals showed that the concentrations of Cd, Cu, Pb, Zn, Fe and Mn were comparable along the estuary. This finding, indicating that these metals co-precipitated approximately equally within the river (Table 2), agreed with the mixing behaviour shown in Fig. 2d. The salinity regime 0–10‰ moves from the top end of the river towards the river mouth as runoff increases. In September, the mixing zone was outside the river mouth. Thus, in this river, metal transport out of the actual river will be quite small, i.e. only the dissolved metals remaining after precipitation at 0–10‰.

The Mae Klong River

Behaviour of nutrients

Figure 3(a, b) shows the results of the February 1986 (low discharge) survey in the Mae Klong, covering a distance of 40 km. The phosphate maximum occurred around salinity 5‰ and remained almost constant until being diluted by seawater, as for silicate. The silicate concentration at salinity 0‰ was 236 μmol l^{-1} in February (Fig. 3b) and 30 μmol l^{-1} in October (Fig. 4b). These concentrations are considerably higher than those in the Bang Pakong (92 μmol l^{-1} in the dry season and 76 μmol l^{-1} in the flood season). The average world river content is 173 μmol l^{-1} (Meybeck, 1981). In the lower basin of the Mae Klong, silicate behaviour was not strictly conservative as in the case of the Bang Pakong, most probably because of the effect of the adjoining canals. Anthropogenic inputs and the canal adversely affect the natural behaviour of nutrients in this river, resulting in quite different behaviour to that in the Bang Pakong.

Behaviour of trace metals

Figure 3c shows dissolved Cd, Cu, Pb and Zn concentrations in February 1986 (low flow); the four overlapping peaks at 0–4‰ salinity are probably due to anthropogenic influences, as they occur in the same region as the reduction in dissolved oxygen (Fig. 3a) and the increase in phosphate (Fig. 3b). For high flow in October, the small peak in particulate Al and Mn (Fig. 4d), as well as those for Cd. Cu. Pb and Zn. in the 2-5‰ salinity region (Fig. 4c) probably indicate small increases due to geochemical removal from the dissolved phase into particulate form. but. as the increase in pH was small. the removal was hardly noticeable. This removal was so slight that the anthropogenic increase in the dissolved form is still noticeable (Fig. 4c). Comparison of Fig. 4c and Fig. 4d shows very clearly that the concentrations of particulate metals were much larger than those of dissolved metals. The Mae Klong was always highly turbid with a reddish-brown colour. Figure 4d shows how much sedimentation occurred within the mixing regime, and only a small amount of particulates remained in the water flowing into the Upper Gulf of Thailand.

DISCUSSION AND CONCLUSION

On comparing the mixing behaviour of these two rivers, it is clear that, in the Bang Pakong, most metal inputs from the river were retained within the river along the whole of its length (122 km), except during periods of peak flood when the mixing zone moved outside the river mouth. In the dry season, due to the very small slope of the river bed, and the low flow of the river, the salinity intrusion reached the confluence of the river. Holeman (1968) estimated that only 5% of the material brought down by the river made its way to the sea. the remainder stayed in the river.

As the pH of the Mae Klong is slightly alkaline, the only big change the river water encounters on reaching the estuary is an increase in ionic strength; therefore, it seemed that there was only very small removal from the dissolved into the particulate phase (Fig. 4d). However, a very large change occurred in particulate metals. All metals studied, i.e. Al, Cd, Cu, Pb, Zn, Mn and Fe, precipitated soon after reaching the estuarine zone. Most of the Al, Cu, Fe and Zn particulates settled out above salinity 5‰, while Pb, Mn and Cd settled out above salinity 15‰. The percentages of each particulate metal remaining in the water at 26‰ were: Cd, 16%; Cu, 0.7; Fe, 1.3; Pb, 0.9; Mn, 5; Zn, 1.3; and Al, 1.6%. Iron decreased from 10044 to 128 $\mu g\,l^{-1}$. As the gradient of the Mae Klong River bed is quite steep in the upper half of the river, the salinity intrusion did not reach further than 40 km upstream. Thus sediment deposition occurred near the river mouth, in contrast to the Bang Pakong where it occurred along the length of the river.

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Variability of Riverine Nutrient Exports to the Central Great Barrier Reef, Australia

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The Great Barrier Reef is the largest single coral reef ecosystem in the world, an ecosystem of World Heritage status, and Australia's premier tourist destination. There is concern that deleterious changes m the reef system will be produced from enhanced sediment and nutrient runoff to reef waters as a consequence of development and agricultural land use practices on the adjoining mainland, particularly in nearshore regions close to rivers. Unequivocal evidence exists that high and continuous nutrient loading of reef systems produce serious, long-lived, but perhaps not irreversible changes in reefs (Smith et al., 1981). These effects are both direct and indirect through alteration of regional or local water quality. To develop realistic and defensible management practices to prevent or control such effects, it is essential to quantify the amount of nutrients and other materials reaching reef systems and separate natural from anthropogenic contributions to the total loading budget.

As part of a larger effort to budget shelf-scale nutrient sources and sinks in the shelf sea system of the Great Barrier Reef (hereafter GBR), we have been sampling dissolved and particulate nutrient and suspended sediment concentrations in the major rivers emptying into the central Great Barrier Reef province (16-20 S: Figure 1). Our aim is to develop empirical discharge-nutrient flux models for these rivers in order to quantify terrestrial nutrient inputs to the Great Barrier Reef and ultimately, to relate these inputs to land use practices. This is a time-consuming and ambitious goal.

The central GBR region encompasses a coastal region with the highest annual rainfall on the Australian continent (> 3 m p.a.) as well as inland watersheds prone to frequent multi-annual droughts and dramatic floods, following cyclones and monsoonal rain depressions (Hausler, 1991). Rivers discharging into the central GBR vary greatly in terms of catchment area, catchment type, annual discharge and inter-annual discharge variability (Table 1: Figure 2). Land use within catchments varies from virgin rainforest, sugar cane farming to dry land grazing. While instrumental records of river flow have been kept at some sites since the early 20th century, relatively little data is available on dissolved and particulate nutrient levels in North Queensland rivers and their relation to flow activity.

For the last four years, we have been sampling dissolved and particulate nutrient levels in the major rivers discharging into the northern and central GBR. Temporally intense sampling was carried out in the South Johnstone River, and to a lesser extent in the Herbert River, to assess the role of flood events on the dynamics of nutrient export. In this paper, we will focus on the data collected for the South Johnstone River during 1990 and 1991 which illustrates the nature of variability observed in North Queensland rivers with regard to nutrient discharge.

The South Johnstone River is one of the smaller catchments in North Queensland, one of the wettest, and because of the high rainfall one of the most regular, with active flow occurring throughout the year. Land use or land cover within the catchment includes virgin rainforest, second growth rainforest, wet pastureland, horticultural fruit farming and, in the lower catchment, extensive areas of sugar cane planting.

Near-surface water samples were collected from the center of a bridge near the bottom of the catchment at intervals ranging from biweekly, during low-flow periods of the winter dry season, to several times daily during major flood events, following tropical cyclones Ivor (March 1990) and Joy (December 1990). Peak daily flow rates following these cyclones were 43,000 and 19,000 megalitres, respectively. Water was filtered to obtain samples for analyses of dissolved inorganic nutrients (NH_4, NO_2, NO_3, PO_4, $Si(OH)_4$) and dissolved organic species (DON, DOP) by standard automated wet chemical methods (Ryle et al., 1981), either before or after oxidation of the organic matter in the sample by strong UV light (Armstrong et al., 1966)). Particulate nitrogen (PON) and phosphorus (POP) were determined by high temperature combustion in a commercial N analyzer and colorimetrically after hot acid-persulfate digestion (Furnas *et al.*, 1990).

Concentrations of NO_3 and PO_4 were loosely correlated with the concurrent instantaneous flow rate in the South Johnstone River (Figure 3). Soluble inorganic phosphorus concentrations were diluted during extreme high-flow episodes, reaching maximal concentrations during moderate flow peaks. Concentrations of NH_4 and NO_2 (not shown) were very low throughout the year and uncorrelated with flow rates. DON and DOP were significant contributors to total fluxes of N and P in streams, but concentrations of DON and DOP were uncorrelated with stream discharge rates (Figure 4). In contrast, concentrations of particle-associated nitrogen (PON) and phosphorus (POP) were highly correlated with instantaneous flow rate (Figure 5). This is not surprising as suspended sediment loads also increased during periods of higher flow rates (not shown) in the South Johnstone River. During low-flow periods, total water column N and P in South Johnstone River waters were in the ranges, 20-40 and 0.5-2 umol l^{-1}, respectively.

The relative distribution of N and P between dissolved inorganic, dissolved organic and particulate forms differed between wet seasons and within individual years. These distributions are likely to differ significantly between rivers as well. The relative contributions of dissolved inorganic and particulate N to total export varied within a given wet season (Figure 6, top). While particulate N concentrations exhibited peaks during both large and small flow events over the course of the wet season, increases in dissolved inorganic N concentrations, chiefly as NO_3, were greatest during the early part of the wet season. Dilution of both DIN and DON concentrations was observed following cyclone Ivor (March 1990). In contrast, very high concentrations of NO_3 were measured during the large single flow event which characterized cyclone Joy (December 1990). Immediately prior to this event, concentrations of DIN in the South Johnstone River were extremely low. This flood was also the first flush of the season, so nutrients stored in terrestrial or sediment pools were likely to be mobilized during this event. DON concentrations tended to be reduced after the first flush of the season in both years sampled.

Particulate P (Figure 6, bottom) dominated all forms of phosphorus in samples from the South Johnstone River, regardless of the year or period within the wet season. This is most likely due to the strong adsorption of P to soil particles, coupled with enhanced erosion of soil during flood events. In contrast, concentrations of silicate showed evidence of dilution during flow peak events.

Mass fluxes of nutrients from a given catchment are the product of concentration and river flow rates plus nutrients transported by bedload sediments. In the present study, only waterborne nutrients were considered. No estimate can be made of nutrient transport with sediment bedload. Given the strong correlations between PON/POP concentrations and river discharge, sediment associated transport of these species during flood events is likely to be significant. It is clear that waterborne fluxes of both N (Figure 7) and P (Figure 8) are maximal during brief episodes of high river flow. For a significant portion of the year, however, N and P export rates from the South Johnstone were relatively low because of the low flow of water in the river. With the data available to date, we estimate that approximately 350 tonnes of N (2.5×10^4 Kmol) and 35 tonnes of P (1.1×10^3 Kmol) are exported annually from the South Johnstone River catchment by river waters. These estimates are conservative as they are based on surface samples and do not include discharge added below the gauging station, groundwater fluxes into the lower river and estuary or nutrients associated with bedload sediments. In the wet seasons, approximately half of the N exported from the river is in dissolved inorganic form, principally nitrate. This form comprises <20 percent during the dry season. In contrast, only a small proportion (ca. 10 percent) of wet season P is exported as PO_4, compared to approximately 30 percent during the low-flow periods.

Summary and Conclusions

Intensive sampling of a relatively small river watershed in the North Queensland wet tropics has shown that dissolved and particulate nutrient concentrations in river waters can be highly variable over the course of an annual cycle and within the rainy season of any one year. A significant fraction of annual nutrient export from the South Johnstone River occurs during short events of only a few day duration. These events are often associated with monsoonal depressions following cyclonic storms. Any attempt to resolve nutrient budgets for this river, and likely any river in the region, must be able to resolve such events. If these events are missed, export estimates will be low.

The problem of estimating nutrient exports from north Queensland rivers is complicated by the month to month and inter-annual variability in discharge, which is of similar order to, or greater, than the mean flows. In most of the watersheds, particularly those discharging into the central and southern GBR, virtually all of the annual flow may come within one or a small number of flood events, which can be quite large. The prime example of this variability is the largest North Queensland river, the Burdekin, where the maximum and minimum annual flows differ by 180-fold and the ratio between maximum and mean annual discharge rates is 7-fold. One operational problem arising from this variability in flow rates and the role of floods is that it is often difficult, if not impossible, to sample these events unless the sampler is physically located (or trapped) next to a river as many roads in North Queensland may be blocked by smaller flooded streams and rivers.

The strong correlations between flow rate and PON or POP in the South Johnstone River mean that useful estimates of export can be derived from measurements of daily discharge rates. The poorer correlations observed for NO_3 and PO_4 or lack of correlation in the case of DON and DOP, mean that further analysis of the data and more complicated models will be required to estimate annual discharges or responses to unsampled events.

Because of the observed variability in both river discharge rates and nutrient concentrations, the data available is only sufficient to make a precise estimate for one river, the South Johnstone. The data sets for the remaining North Queensland rivers do not as yet include a sufficient number of samples from small and large flood events. Some indication of the potential variability in nutrient export between rivers may be seen from a comparison between the estimated N and P exports from the South Johnstone and Fitzroy Rivers during December 1990 to January 1991, following cyclone Joy (Brodie and Mitchell, 1991). Conservative estimates of N (11,500 tonnes) and P (2,900 tonnes) export from the Fitzroy River are 33- and 83-times the export of these elements from the South Johnstone over the full wet season. The mean catchment areas differ by 60-fold, while the averaged annual discharges differ by only 1.5-fold. The Fitzroy River catchment is considerably drier than that of the South Johnstone, with vegetation cover affected by widespread cattle grazing within the catchment. It would not be surprising therefore if the flow-nutrient export relationships for the Fitzroy River were considerably different from that of the wetter northern rivers.

What implications does the observed temporal variability in these tropical rivers have for estimating river inputs to coastal waters? The most obvious conclusions are that it is necessary to stratify sampling designs to concentrate on the seasons encompassing the highest flow rates and to maximize sampling during flood events. The observed temporal pattern of variability in both concentration and discharge is well known (e.g. GESAMP, 1987; Walling and Webb, 1985). Sampling designs which emphasize collecting samples at regular intervals from a large number of rivers are likely to miss the major events in most of them. Those samples are, of course, very useful, but the significant events are the floods. Given the difficulty in reaching many of our regional rivers during flood events, we have made considerable effort to arrange intensive sampling by individuals living in close proximity to the rivers.

The high temporal variability of nutrient concentrations and fluxes through rivers into the Great Barrier Reef system tends to focus our attention onto extreme and highly visible events such as cyclones and floods. These events are clearly the major input events for the system as a whole. However, we do not know what the long-term outcome of these events is, as nutrient materials and sediments are re-distributed within the system and cycled under non-event conditions.

Acknowledgements

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Table 1. Mean annual discharges (x 10^6 m^3) and ranges for rivers flowing into the Central Great Barrier Reef.

River	Watershed (km^2)	Number of years	Mean	Maximum	Minimum
Barron	2175	70	839	2611	203
Mulgrave	555	15	766	1537	324
Russell	1475	39	1036	2121	455
North Johnstone	1940	22	1880	3852	1059
South Johnstone	555	72	811	1574	200
Tully	1685	14	3119	4973	1632
Murray	1140	17	170	420	52
Herbert	10131	72	3582	11559	468
Ross	1815	44	279	1145	0
Haughton	3650	18	345	1204	5
Burdekin	129860	38	9941	54066	305

Figure 1. Major rivers and streams discharging into the central GBR province.

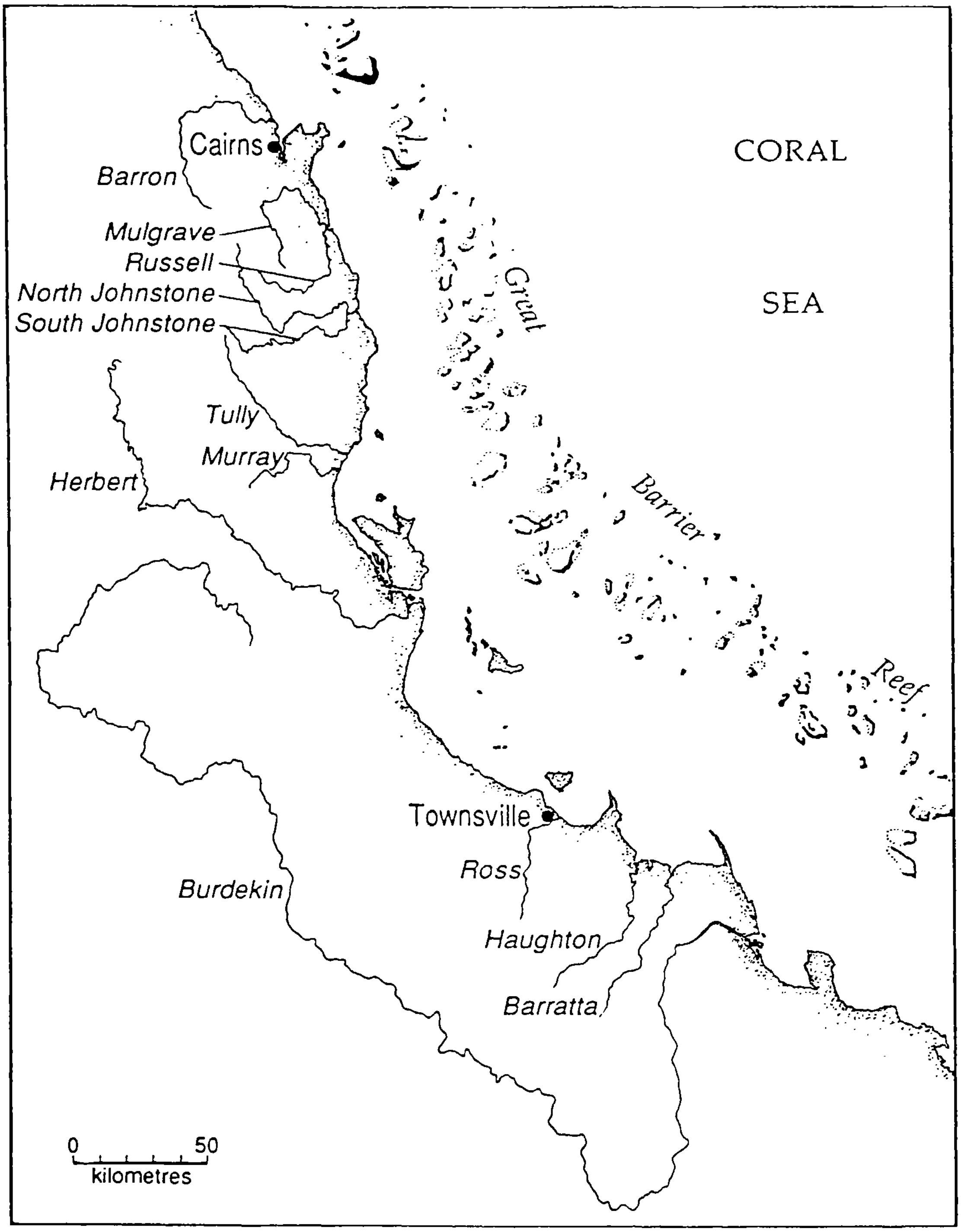


Figure 2. Time averaged discharges of water from major rivers into the central Great Barrier Reef (thick bars) and ranges of annual discharges (thin bars).

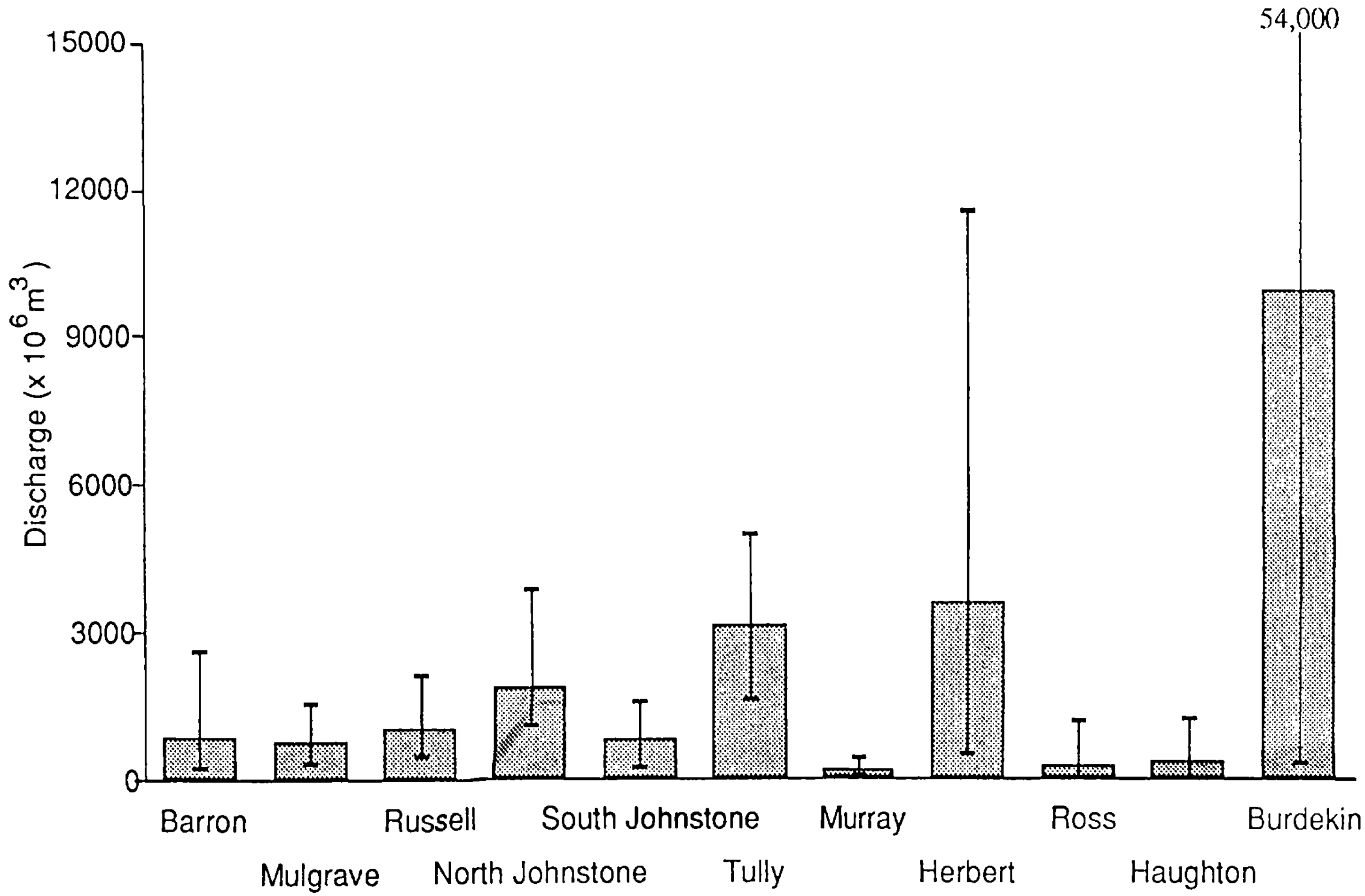


Figure 3. Top: Relationship between nitrate concentration and instantaneous discharge rate in the South Johnstone River. The line shown is:

$[NO_3] = 6.31 + 3.59e^{-2}$ x (discharge rate - cumecs), $r^2 = 0.23$, n = 314.

Bottom: Relationship between phosphate concentration and instantaneous discharge rate in the South Johnstone River. The line shown is:

$[PO_4] = 0.132 + 3.37e^{-4}$ x (discharge rate - cumecs), $r^2 = 0.125$, n = 314.

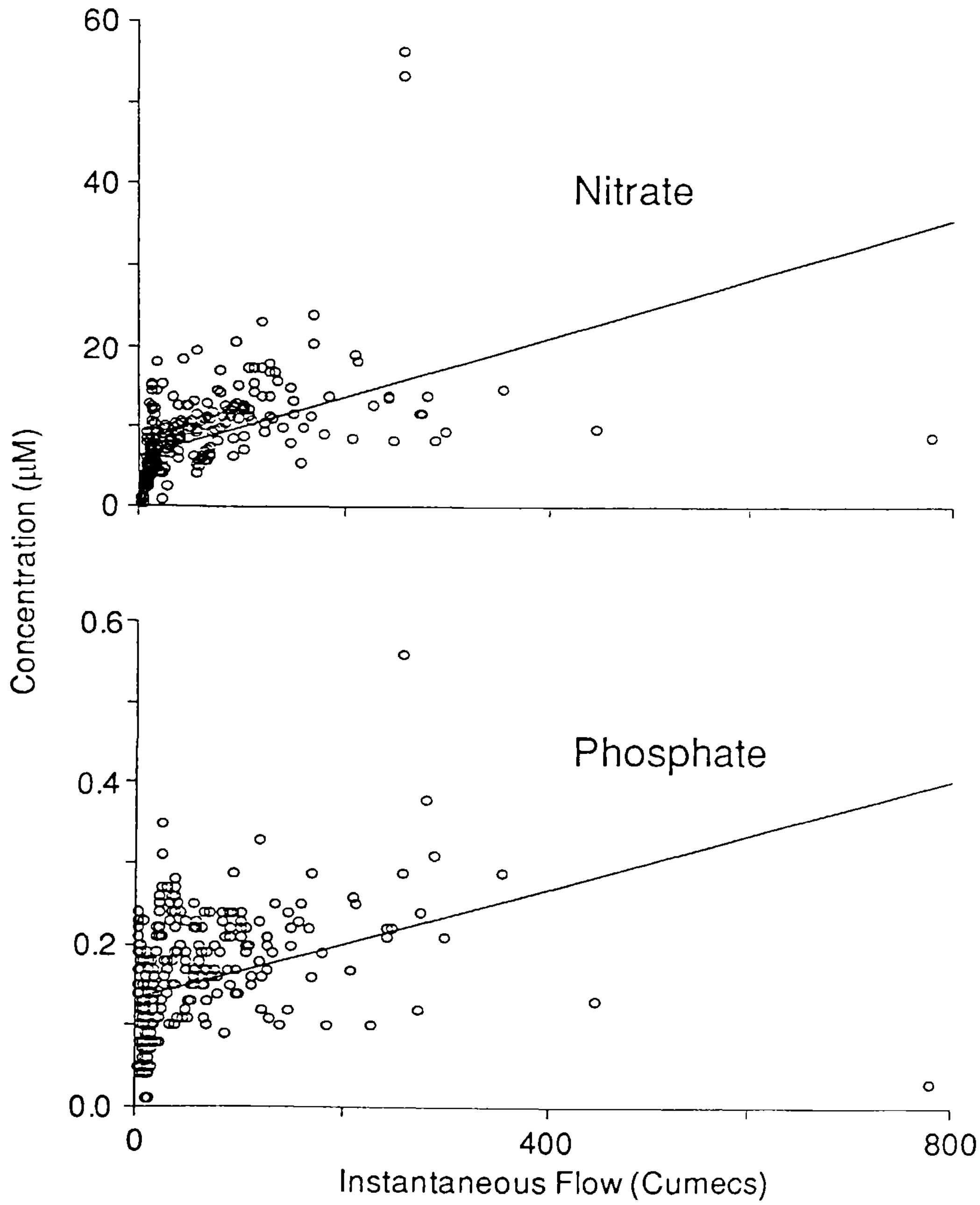


Figure 4. Top: Relationship between DON concentration and instantaneous discharge rate in the South Johnstone River. The line shown is: [DON] = 4.71 - 2.13e^{-3} x (discharge rate - cumecs), r^2 = 0.002, n = 251. Bottom: Relationship between DOP concentration and instantaneous discharge rate in the South Johnstone River. The line shown is: [DOP] = 0.177 - 2.65e^{-4} x (discharge rate - cumecs), r^2 = 0.052, n = 251.

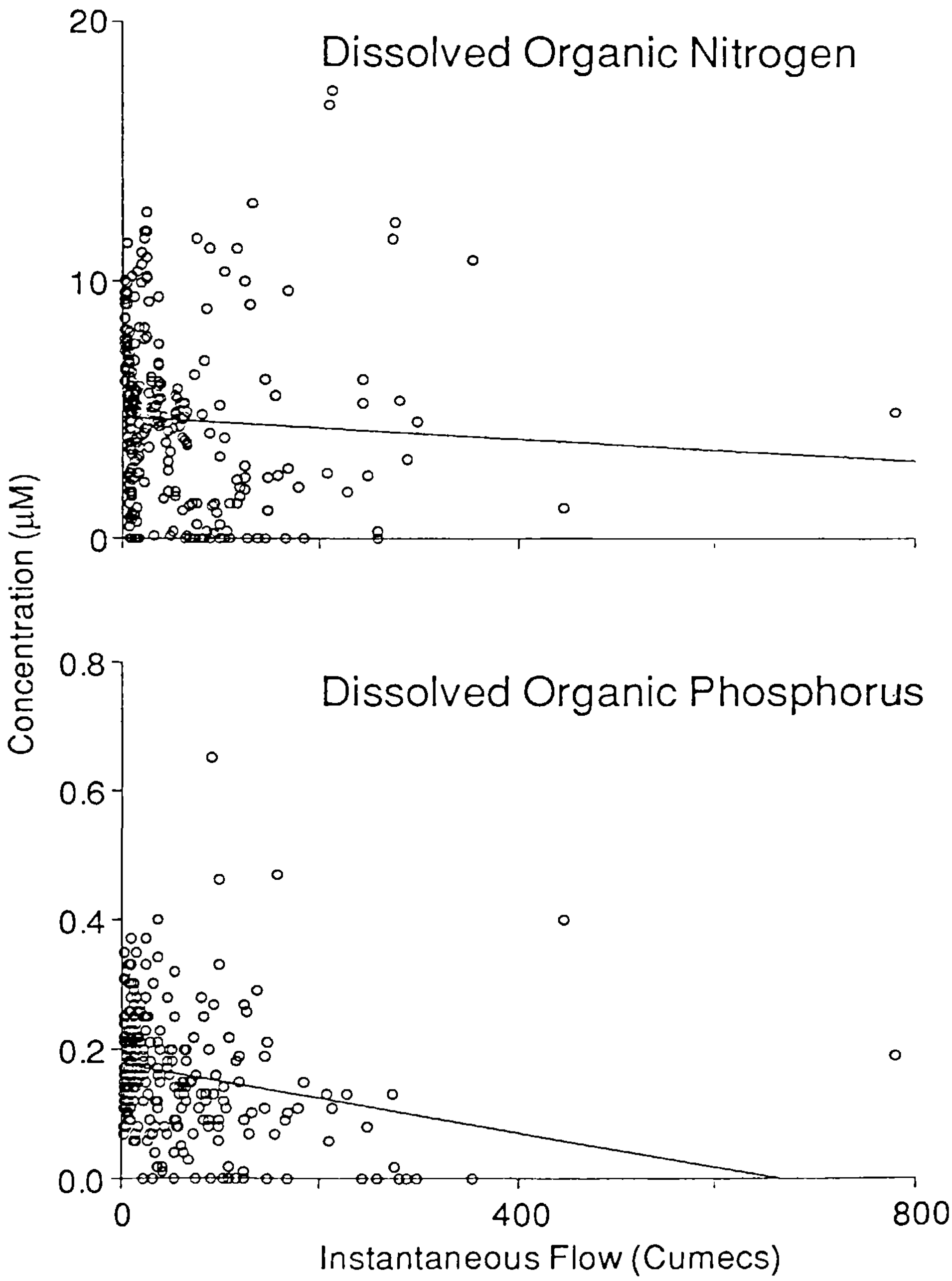


Figure 5. Top: Relationship between particulate nitrogen concentration and instantaneous discharge rate in the South Johnstone River. The line shown is: [PON] = 5.15 + 9.77e^{-2} x (discharge rate - cumecs), r^2 = 0.605, n = 304. Bottom: Relationship between particulate phosphorus concentration and instantaneous discharge rate in the South Johnstone River. The line shown is: [POP] = 0.245 + 1.03e^{-2} x (discharge rate - cumecs), r^2 = 0.671, n = 316.

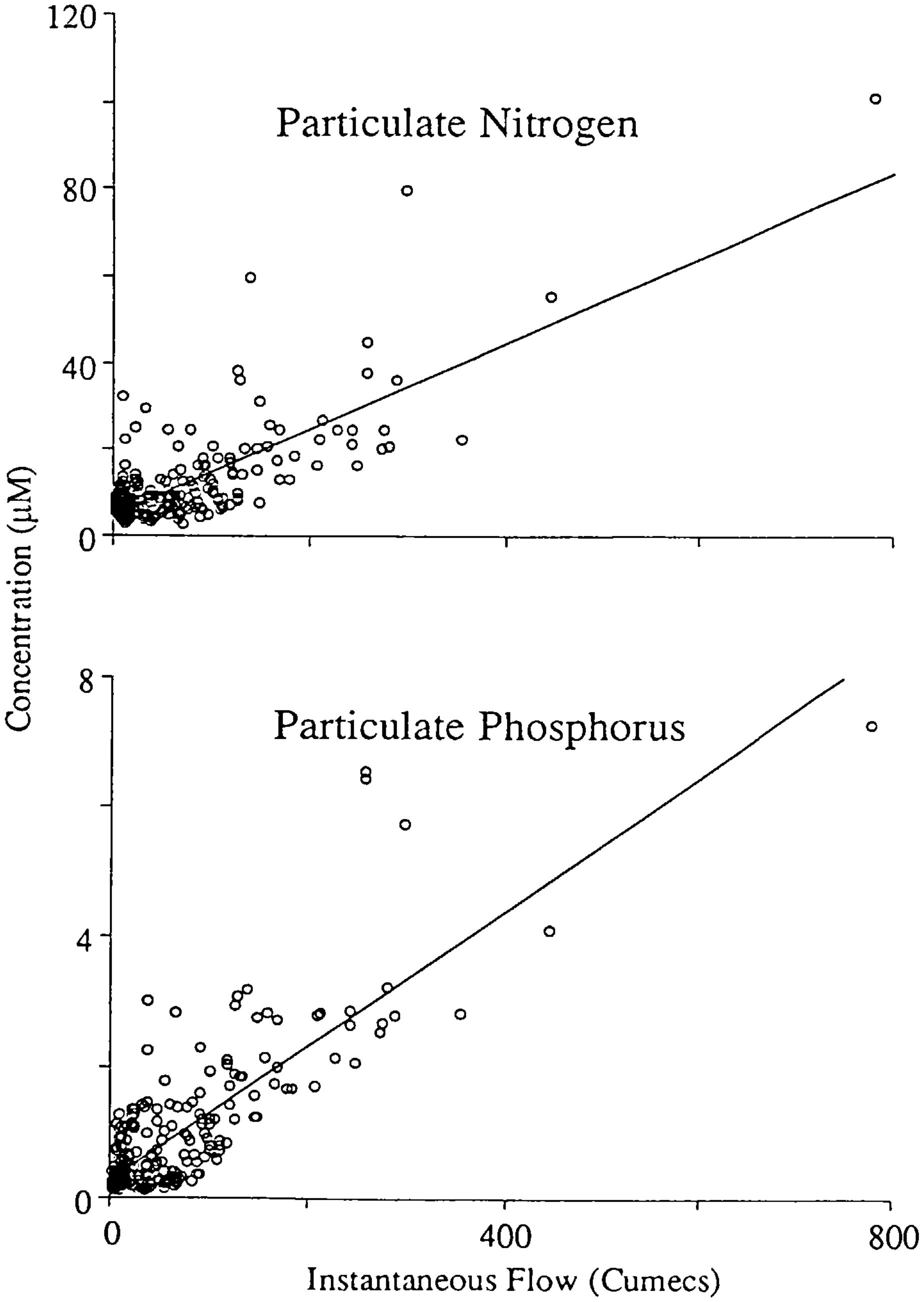


Figure 6. Concentrations and speciation of water borne nitrogen and phosphorus in the South Johnstone River during and following cyclones Ivor (March, 1990) and Joy (January, 1991).

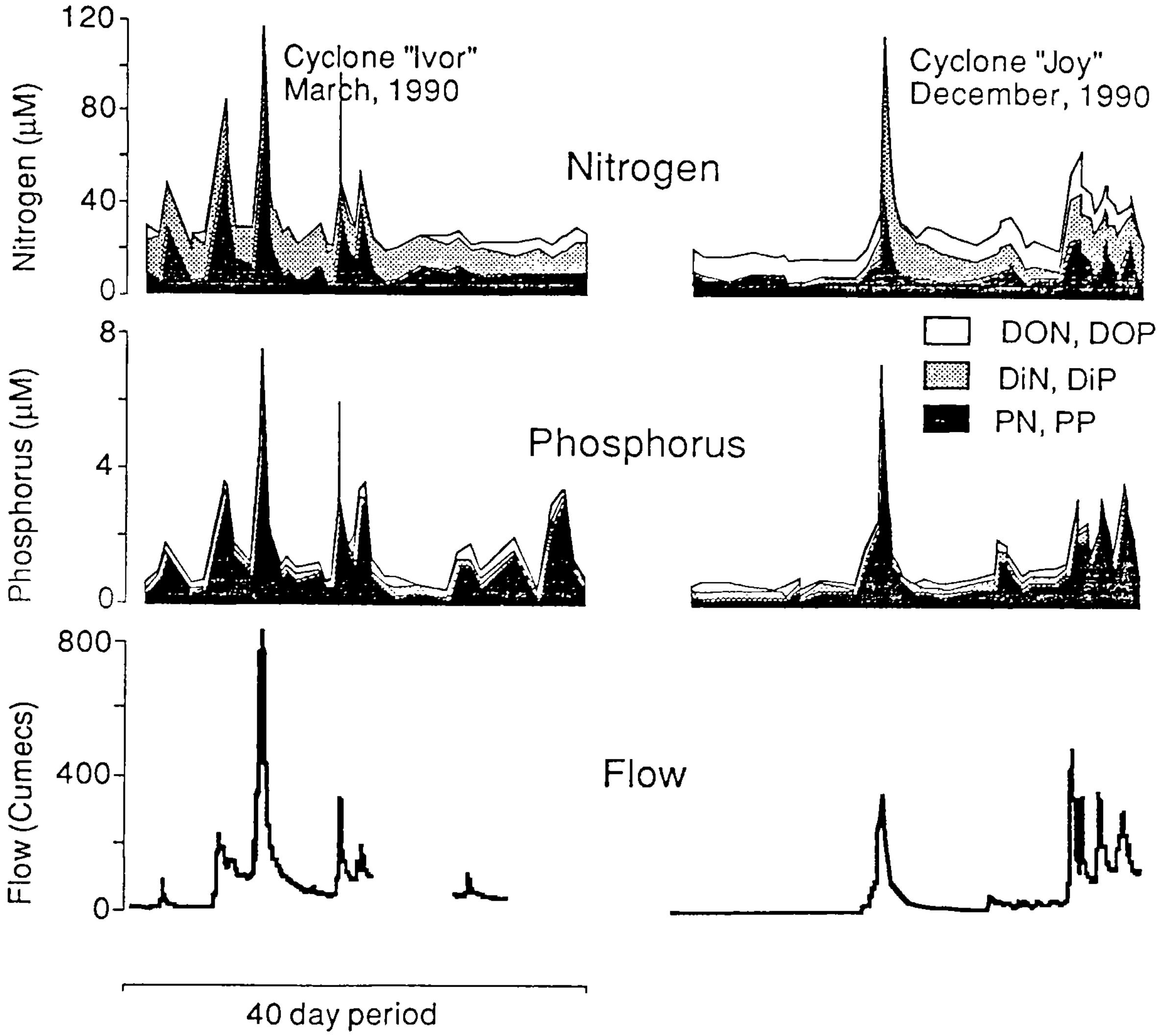


Figure 7. Concentrations and speciation of water borne nitrogenous nutrients, water discharge and cumulative nitrogen export from the South Johnstone River in the period January 1990 to August 1991.

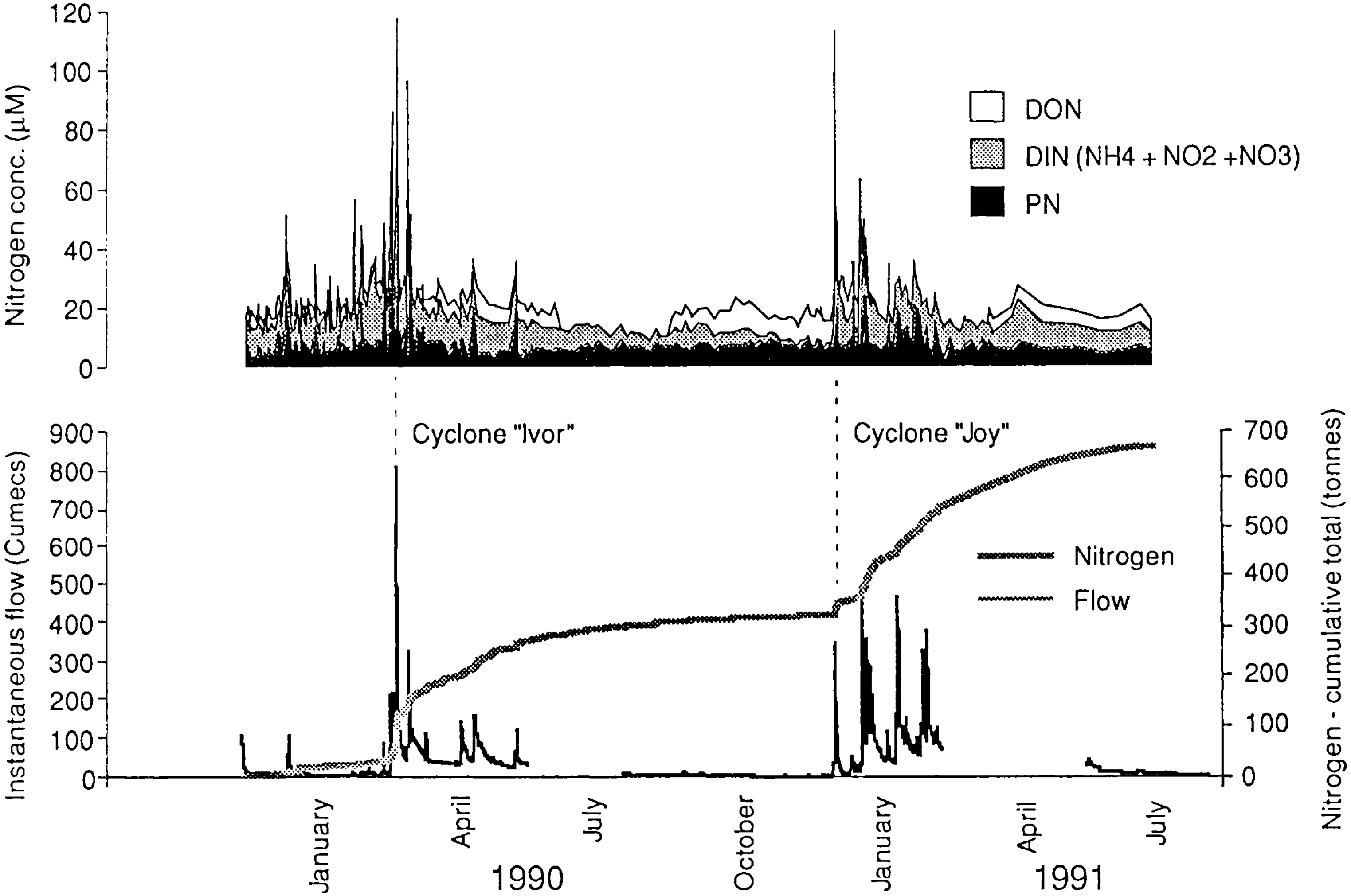
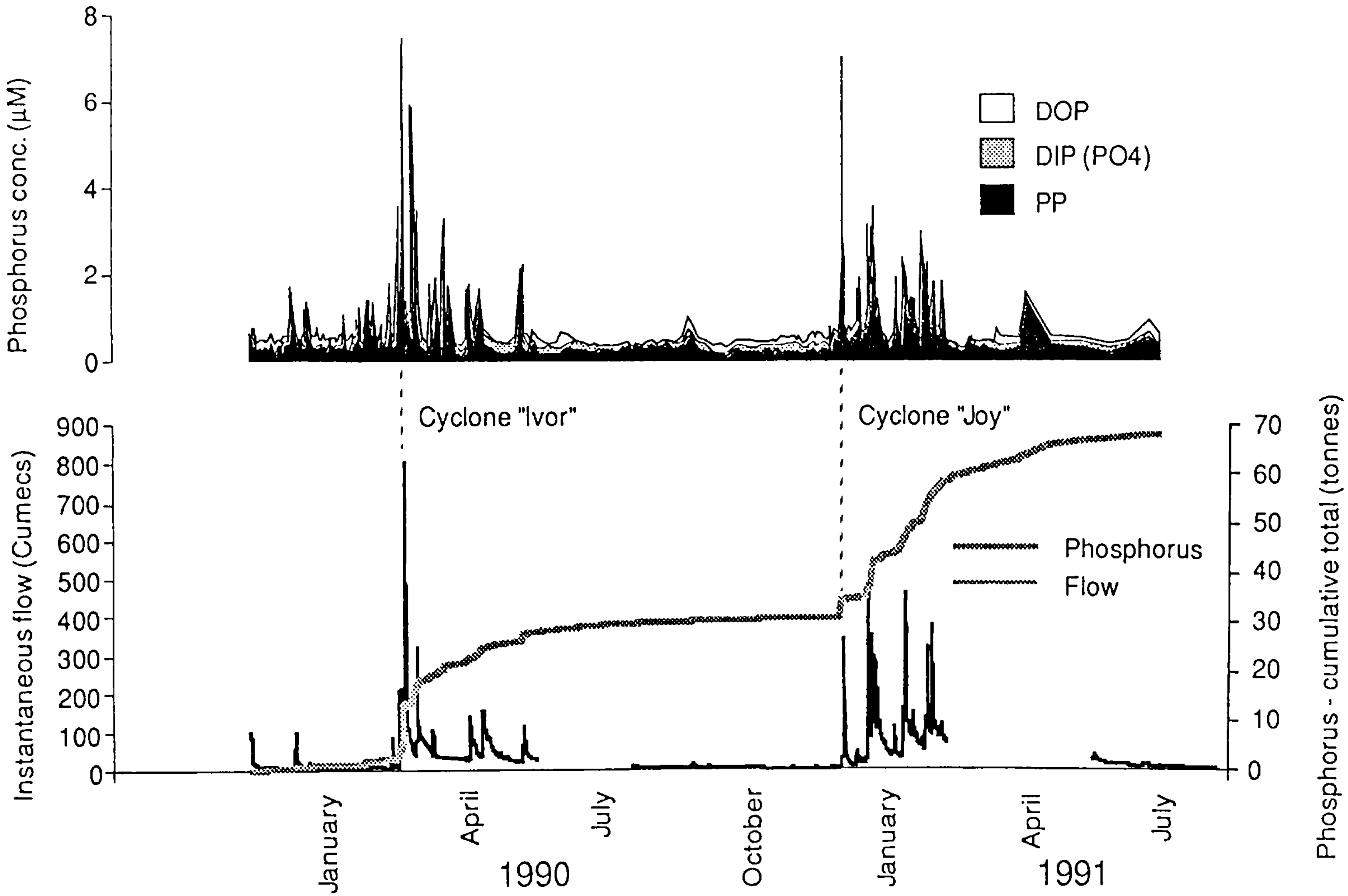


Figure 8. Concentrations and speciation of water borne phosphorus nutrients, water discharge and cumulative phosphorus exports from the South Johnstone River in the period January 1990 to August 1991.



RIVER INPUTS OF NUTRIENTS TO THE MARINE ENVIRONMENT IN FIJI AND OTHER SOUTH PACIFIC ISLANDS

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The South Pacific region represents some 30 million km^2 of ocean within which lie thousands of islands (Figure 1). The total land area is about 500,000 km^2 with over 80% of this being found in Papua New Guinea. The total population of the region is approximately 5.5 million with more than 3.5 million being residents of Papua New Guinea. Throughout the region there are major development programmes in agriculture, forestry, tourism and manufacturing which are contributing to a range of environmental problems including pollution of the marine environment. Marine pollution problems in the South Pacific have been reviewed recently by Brodie et al (1990) and Morrison (1991). Baines and Morrison (1990) have specifically addressed the issue of land use impacts on the marine environment.

This paper is in three sections. The first will briefly review the regional marine pollution assessment and control programme. Secondly some current and proposed studies in the region that could be included in an international cooperative programme will be outlined and finally information will be presented on a river system in Fiji that is being studied in some detail.

SPREP POL (the South Pacific regional marine pollution assessment and control project - a component of the South Pacific Regional Environment Programme) was formally established in 1988, although marine pollution investigations in the region had been undertaken since the early 1970's. The project has a number of components (see Table 1) but 2 are of relevance here. First is the production of a land based pollutants inventory for the region which is being developed in two inter-related activities - (i) an assessment of industry, sewage, agriculture and related discharges and (ii) an assessment of sediment movement via rivers into the South Pacific Ocean. Both have just begun and the sediments survey is being carried out by 2 research assistants (Mark Asquith and Fiona Kooge) at the University of the South Pacific. These activities will be completed before the end of 1992.

TABLE 1 SPREP POL MONITORING AND RESEARCH ACTIVITIES

MONITORING ACTIVITIES

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1. Ocean Processes and Properties: Of particular importance are variability in circulation patterns, thermal structure, salinity distributions, plankton productivity, nutrient fluxes, larval dispersion patterns.

2. Heavy Metals: Activities in this sector will concentrate on mercury, cadmium, lead and tin.

3. Pesticides: Particular emphasis will be placed on organochlorine pesticides.

4. Sewage related parameters: This section will study the problems of increased nutrients and microbiological contamination.

5. Other pollutants: including hydrocarbons and detergents.

RESEARCH ACTIVITIES

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1. Preparation of a regional status report on land-based pollutants entering the marine environment.

2. Study of the role of sedimentation in marine pollution including the transport of pollutants.

3. Development of circulation model for the main Southwest New Caledonia lagoon as a potential model system (for other Pacific island coastal areas).

4. Review of the Guam EPA coastal water monitoring programme 1978-88 to assess the appropriateness of site selection parameters determined and sampling strategy in meeting the needs of coastal area management decision makers. Guam is the only small island territory with the long-term data to carry out such an exercise. The results of this review will be made available to other governments planning monitoring programmes.

The SPREP POL monitoring activities which focus mainly on coastal environments will also produce some data on fluxes via rivers as several of the sites chosen for study in the first phase are either at or close to river mouths. It is anticipated that by the end of 1992 the data base on river inputs will be expanded significantly.

The islands of the South Pacific are basically of three types - continental, volcanic and reef limestone. Only the continental and volcanic islands have river systems.

These continental and volcanic islands are usually geographically young (Cenozoic) and many are still rugged with steep slopes dominating the land surface. The soils are frequently immature and prone to erosion. Apart from the north east section of the region (eastern Kiribati) and some rain shadow areas on the western side of the largest islands, rainfally usually exceeds 2000 mm/yr and often is over 5000 mm/yr on the windward coasts. The movement of the resultant run-off has led to the development of numerous river systems varying in catchment size from a few kilometres to over 60,000 km^2 (Fly River, PNG).

Since the rainfall occurs mostly as heavy storms with few periods of light rain, run-off and the accompanying sediment and dissolved salts vary enormously during the year. The nature of the terrain and the rainfall do indicate that the amounts of material transport/km^2/yr are likely to be high (see Figure 2 taken from Milliman and Meade, 1983). Unfortunately the data required to confirm this situation is not available in many countries. In addition, some recent evidence (e.g., Nelson, 1986) indicates that changing land use practices may be leading to significant increases in run-off and sediment transport to the marine environment.

RELEVANT CURRENT AND PROPOSED STUDIES FROM THE SOUTH PACIFIC

A number of current and proposed activities in the South Pacific islands may produce valuable information for a global picture on river inputs of nutrients to the marine environment. Although not designed specifically for this purpose, the projects listed below will generate the data that can be used to determine riverine transport of nutrients.

(a) Fly River, Papua New Guinea

This is one of the major river systems of the island of Papua with a catchment area of some 61,000 km^2. The Fly River has been studied in the past for a number of reasons. The amounts of water (2×10^{11} t/yr) discharged by the river and the associated sediments have a profound effect on the Gulf of Papua and these effects stretch as far as the northern end of Australia's Great Barrier Reef system. In addition, mining within the catchment has led and will lead to significantly greater sediment loads being moved through the river system with the subsequent impact on the Gulf of Papua (Pernetta, 1988; Harris et al., 1988). The Fly River estuary is one that is being monitored in SPREP POL in a joint project between the PNG government, Ok Tedi Mining Company, University of Papua New Guinea and PNG University of Technology.

(b) New Caledonia

ORSTOM has a major research centre based in Noumea, New Caledonia. The hydrology section of ORSTOM has been investigating river systems in the territory and studying the impacts of mining activities on the sediment and nutrient transport in several of these systems. This work is continuing and for a number of sites, there is enough long-term (>10 yrs) data to produce an assessment of nutrient movement for one or 2 rivers. The results for New Caledonia will be quite different from most of the rest of the region because of the unusual geology of the major island (effectively weathered uplifted mantle material rich in magnesium silicates).

(c) Guam

The Guam Environmental Protection Agency is probably the best endowed environmental monitoring agency in the South Pacific. With a budget of several million US dollars per year it operates an extensive monitoring and investigative programme. This includes much water quality monitoring and investigations of surface water resources including rivers.

The Talafofo river, Guam's largest, drains a catchment of about 50 km^2, and this would provide useful data from a small island location where the volcanic rocks are somewhat older and more weathered than elsewhere in the region.

(d) Tahiti (French Polynesia)

This is a rugged, relatively young, basaltic island located in the eastern sector of the region. It has a rainfall of over 3000 mm/yr and there is a large number of streams and rivers draining small catchments around the island. A number of well established research organizations are based in Tahiti (ORSTOM, Laboratoire d'Etude et de Surveillance d'Environment, L'Universite du Pacifique Sud, Ministere de la Sante et de L'Environnment) which are carrying out scientific investigations into water quality and related phenomena around the island. While there have been no specific studies on river transport of nutrients, only minor extensions of existing activities would be required to generate useful data. It had been hoped to arrange such data generation with LESE in 1991, but a change of senior scientific staff has required renegotiation of this.

REWA RIVER SYSTEM IN FIJI

Initially the intention had been to study two catchment systems in Fiji, the Rewa and the Ba rivers (see Figure 3) as joint projects between the Ministry of Primary Industries and Cooperatives and the University of the South Pacific. This approach had the advantage that the 2 rivers occur in different climate zones and have significantly different land use and management. The expected resources, however, have not become available and so it has been decided to concentrate efforts on the Rewa system. The long term intention is still to have a major study in the Ba catchment.

The Rewa catchment study has a number of complimentary activities. One is an investigation of different cropping systems on the steeplands that dominate much of the catchment. This is being done in an attempt to develop more sustainable use of land recently cleared of forest and involves a number of techniques such as agroforestry, alley cropping, mulching, grass strips. This is being done in collaboration with the International Board for Soil Research and Management (IBSRAM) as part of its PACIFICLAND project. At the major study site a climate station and run-off plots have been established together with a mini-catchment run-off study which will investigate the quantity and composition of the run-off.

The catchment/run-off study is located in the Waimanu river, one of the tributaries of the Rewa. The Waimanu river is probably the best studied in Fiji and has a reasonable data set for water and sediment load and has convenient locations for continuing this work. The third aspect of the study is to determine the sediment and nutrient output of the Rewa river system as a whole and finally the input of sediments and nutrients to Laucala Bay through the Vunidawa river is an important aspect of a long-term study of the nutrient budgets for the Bay which is now heavily impacted by urban activities of the city of Suva.

The Rewa catchment is approximately 90 km long, 50 km wide and has a total area of 2920 km^2. It occupies some 29% of the island of Viti Levu, the major island of the Fiji Group. Four river systems converge to form the Rewa as shown in Table 2 below:

TABLE 2. REWA RIVER SYSTEM - SOME BASIC DATA

River	Catchment Area (km^{2})	Discharge Range (m^3/s)
Wainibuka	706	<10-4,300
Wainimala	790	<10-6,000
Waidina	253	<10-2,900
Waimanu	165	<10-1,320
Rewa	2920	50-14,900

The average daily temperature ranges from 23-27°C near sea level and from 18-22°C on the higher ground. The maximum elevation within the catchment is just over 1200 m.

The geology of the catchment shows the dominance of volcanic and sedimentary rocks (see Figure 4, taken from Rodda and Kroenke, 1984). The northern part of the catchment is dominated by the Ba basaltic group, Pliocene (5 Ma) shoshonite or calcalkaline basaltic volcanics which includes some andesite and sedimentary materials with the volcanics. The Upper Wainimala late Oligocene (25 Ma) - mid Miocene (10 Ma) sequence occupies a major portion of the catchment. This older part is dominated by rudites and olistrostomes often polymict with basalt, dacite and minor limestone clasts. Other parts include lenses and dykes of feldspar-rich dacites and andesites, usually massive but including some breccias, lavas and tuffs (originally low -K arc tholeiite, now extensively metamorphosed to the greenshist level). Basalts are common, both pillowed and massive, similar to mid-ocean ridge basalts. Upper levels include patchy hornblende andesite dykes wades and shallow water mid-Miocene (12-15 Ma) limestones.

The Colo plutonics, intrusive into the sediments of the Wainimala series, are usually aged 10-7 Ma with the oldest pluton dated at 12.46 Ma. During the late stages of the Colo orogeny, large scale sedimentation produced groups (5-0.5 Ma) lying unconformably over Wainimala rocks. The Southern end of the catchment contains extensive areas of Suva marl (5.3-3.2 Ma). The Upper Miocene-Pliocene volcanism led to the Namosi andesite (6 Ma) occurring in the South west sector of the catchment.

Much of Viti Levu has been uplifted in the Upper Miocene and Holocene (reasons unclear but probably related to the weathering and erosion of volcanics) leading to valleys with intensive sediment infilling and terrace systems. All the Rewa tributaries exhibit these features in the wider valleys.

Like most of the Fiji islands, the catchment is dominantly steepland (70% > 18° slope) with about 15% of the land having 3-18° slope and 15% having slopes less than 3°. A complete land-use survey has not been made recently. In 1958 it was estimated that about 58% (1690 km^2) of the catchment was covered with native forest, 22% (640 km^2) in grass and regenerating forest, 7% (200 km^2) in unimproved grassland and fern, 12% (360 km^2) in permanent agriculture with a few km^2 of mangroves on the coast. A recent (1991) survey of forest cover indicates that the extent of forest and regenerating forest cover has declined to 65% with increased areas of grassland and permanent agriculture (D. Claasen and D. Watling, pers. comm.).

According to the 1986 census the population of the catchment was approximately 120,000 (representing 17% of Fiji's total population) with about 60% being indigenous Fijians, 35% of Indian descent, 5% others (Chinese, European, other Pacific Islanders). The overall population density is about 41/km^2 (compared to a national average of 39/km^2), but there is a concentration of population along the major river valleys and in the flatter land at the southern end of the catchment.

Land use in the catchment varies widely. A large amount of subsistence agriculture still occurs producing root crops, vegetables and utilizing fish and other protein resources. The delta area has extensive permanent agriculture producing rice, root crops, vegetables and there is some beef, pork and chicken production. Along the river valleys the fertile alluvial soils are widely cultivated but recent attempts to extend animal production have seen this occur on the alluvial areas with gardens being moved onto the slopes leading to significant increases in erosion there. Pressure for cash crop production and expansion of export commodities such as ginger and cocoa have seen extensive areas of forest cleared for taro, cassava, vegetables with severe impacts on many smaller catchments and the soils therein (see for example, Morrison, et al., 1990). Although legislation does exist to prevent such devastating impact on the land, it has not been effectively implemented.

Following a series of major floods between 1977-1983, the Fiji Government recognized that a problem did eixst and a system of river dredging was initiated. The costs now stand at US$6 million per year but as noted by a recent consultancy report "It would seem that Fiji is prepared to spend millions of dollars dredging sediment out of rivers, but very little to employ the staff that could prevent a significant portion of it from entering the rivers in the first place" (unpublished FAO consultants report, 1991). The Rewa catchment study began as part of an attempt to deal with the flood situation.

Although the hydrology of the Rewa catchment has received, by local standards, a reasonable amount of study, a number of information gaps and uncertainties still remain. Many of these have been highlighted by Hasan (1986) and Nelson (1987).

Rainfall in the catchment varies from 2200 mm/yr in the northern section of the catchment to over 5000 mm/yr in the south western part (Figure 5). A good series of rain gauges managed by the Fiji Public Works Department and Meteorological Service cover the catchment and these indicate an average catchment rainfall of 3590 mm/yr. Class A pan evaporation varies from about 1370 mm/yr near sea level to 880 mm/yr at higher elevations. Evapotranspiration estimates using the Penman formula gives values of about 1260 mm/yr near sea level in the southern part of the catchment and 1500 mm/yr in the northern end. Tropical cyclones enter the Fiji group at an average rate of 1.23/yr but not all seriously affect this catchment.

In addition, more localized storms, bringing heavy rain but without the cyclone force winds, affect the catchment virtually every year. These storm events obviously lead to rapid increases in run-off and river flow as outlined below.

Stream frequency is as high as $10/km^2$ in the upper reaches of the rivers but averages over 5 for the Waimanu and Wainimala rivers and over 4 for the Wainibuka, Waidina rivers and the Rewa catchment as a whole. The stream gauging density is 223 km^2/station but the data on flows has been assessed as poor due to rating curves not being updated and inadequate current metering.

Hasan (1986) reviewed most of the available data. He estimated runoff coefficients of 0.34-0.71 for storms, but the 0.34 value seems anomalously low. The Waimanu catchment has better data and the runoff coefficients for storms range from 0.49-0.92. The average value for the Waimanu (rainfall average = 4538 mm/yr, runoff average = 3170 mm/yr) is 0.70, indicating that the average value is close to that found for many storms.

The total average rainfall entering the Rewa catchment is 1.05×10^{10} m^3/yr (2920 km^2 x 3.59 m). Estimates of discharge and average annual discharge are given below:

TABLE 3. AVERAGE ANNUAL DISCHARGE ESTIMATES FOR THE REWA RIVER

Runoff Coeff.	Discharge (m^3/yr)	Aver. Ann. Disch. (m^3/s)
0.5	5240×10^6	166
0.6	6290×10^6	199
0.7	7338×10^6	233

Hasan (1986) preferred a value of 160 m^3/s while Harris (quoted in Penn, 1983) estimated the average flow of 156 m^3/s.
Measured flows in the river have varied from 30-17,000 m^3/s (the latter relating to a 50 year return storm). Studies on the river delta system have indicated that 15% of the total flow moves into Laucala Bay (Figure 6) through the Vunidawa River.

Few measurements have been made on the chemistry of the Rewa river water or on the amounts and composition of the suspended solid. This work began only in mid-1991. Using data from the Waimanu and Waidina rivers, plus information available for the Vunidawa river, some estimates have been made. Hasan (1986) using a range of formulae relating discharge to sediment load estimated that the average sediment load was approximately 10^7 t/yr (equivalent to a soil loss of 34 t/ha which according to Morrison (1981) is not unreasonable). Glatthaar (1988) in studies on the Waimanu river showed that there was little variation in suspended load with river depth and also that the bedload represented about 10% of the total sediment load. The average erosion rate for the Waimanu catchment as determined by Glatthaar (1988) was 53.2 t/ha/yr made up of 44.7 t suspended sediment, 5 t of bedload and 3.5 t of dissolved material.

The data above have been used together with appropriate compositional data to estimate nutrient fluxes but recent dredging and other river works **may** have increased the discharge of water and sediment from the Rewa river. This is being investigated as part of the ongoing project. The nutrient flux via sediment is given in Table 4 and as dissolved material in Table 5, with Table 6 giving the total fluxes.

TABLE 4. NUTRIENT FLUX VIA SEDIMENTS FROM THE REWA RIVER

Element	Av. Sed. Comp.* (%)	Sed. Flux (t/yr)	Nutrient Flux (t/yr)
C	5	10^7	5×10^5
N	0.5		4×10^4
P	0.02		2×10^3
K	0.2		2×10^4
Ca	0.7		7×10^4
Mg	1.1		1.1×10^5
Si	7.5		7.5×10^5

*Data derived from analyses of a range of catchment topsoils

TABLE 5. NUTRIENT FLUX AS DISSOLVED MATERIAL FROM THE REWA RIVER

Element	Av. Conc*	Water Flux (m^3/yr)	Nutrient Flux (t/yr)
C	5 mg/L	6 x 109	3×10^7
N	2.5 mg/L		1.5×10^4
P	55 ug/L		330
K	0.6 mg/L		3600
Ca	20 mg/L		1.2×10^5
Mg	3 mg/L		1.8×10^4
Si	7.5 mg/L		4.5×10^4

*Data derived from unpublished data

TABLE 6. NUTRIENT FLUX FROM THE REWA RIVER

Element	Particulate Flux (t/yr)	Dissolved Flux (t/yr)	Total Flux (t/yr)	Total Flux (t/km^2/yr)
C	5×10^5	3×10^7	3×10^7	1×10^4
N	4×10^4	1.5×10^4	5.5×10^4	19
P	2×10^3	330	2.33×10^3	0.8
K	2×10^4	3600	2.36×10^4	8
Ca	7×10^4	1.2×10^5	1.9×10^5	65
Mg	1.1×10^5	1.8×10^4	1.3×10^5	45
Si	7.5×10^5	4.5×10^4	8.0×10^5	274

There are few data from tropical islands with which to compare the numbers in Tables 4, 5 and 6. Since the numbers are derived at least partially from estimates rather than direct measurements care should be exercised when drawing conclusions. It is clear, however, that substantial quantities of material/unit area are being exported from Pacific Islands into the ocean. The impact of these is felt primarily in coastal areas and this requires urgent attention.

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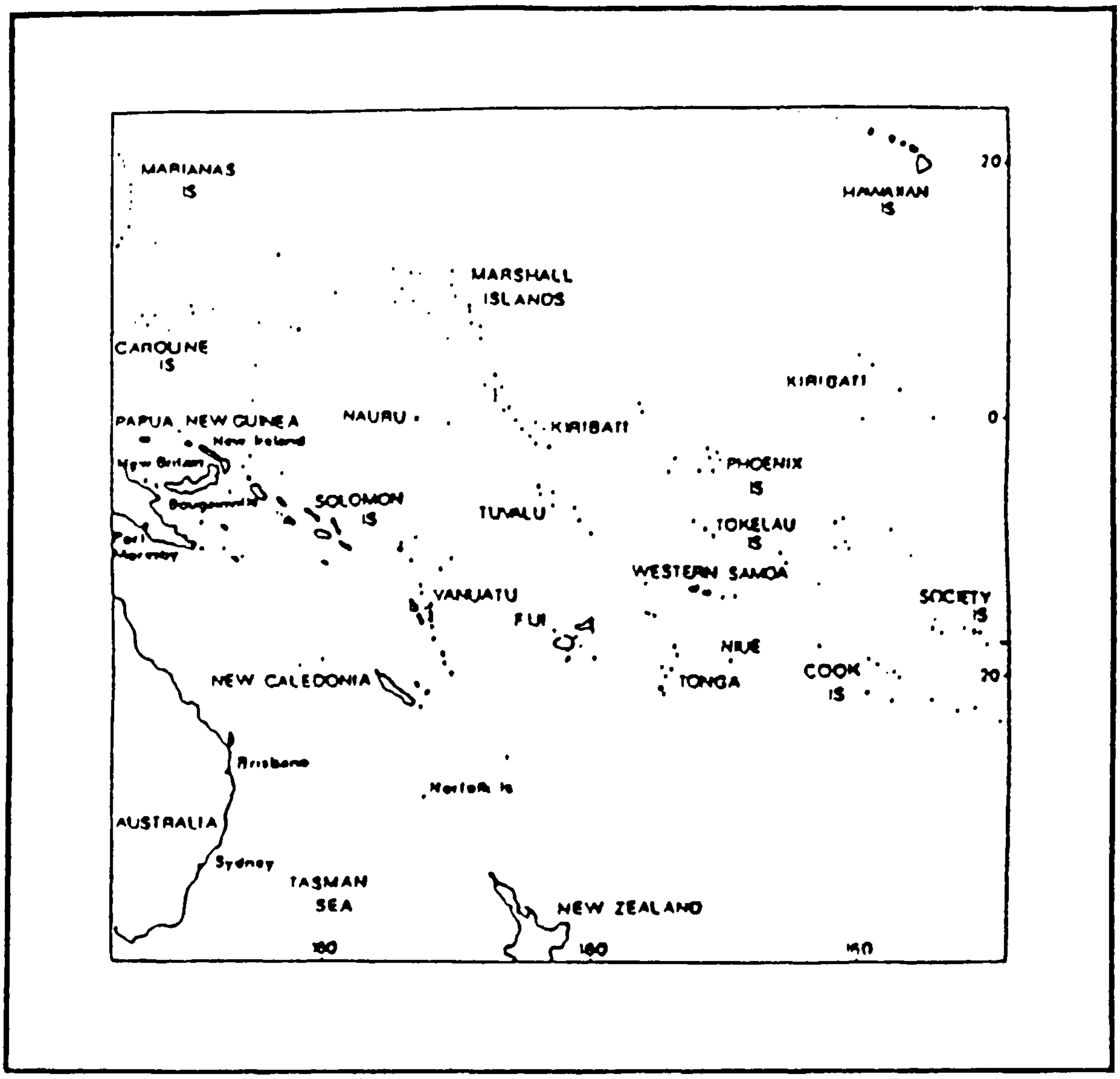
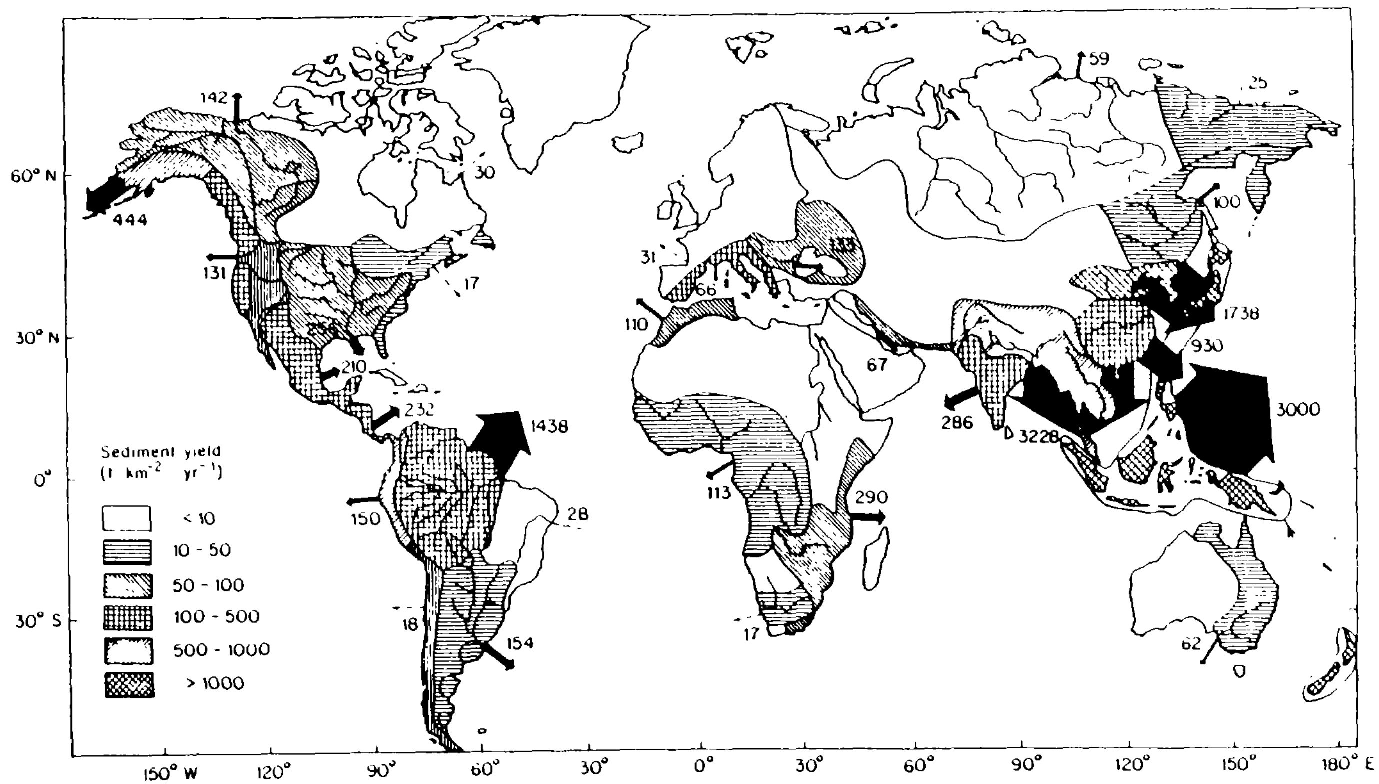


Figure 1. The Oceania Region

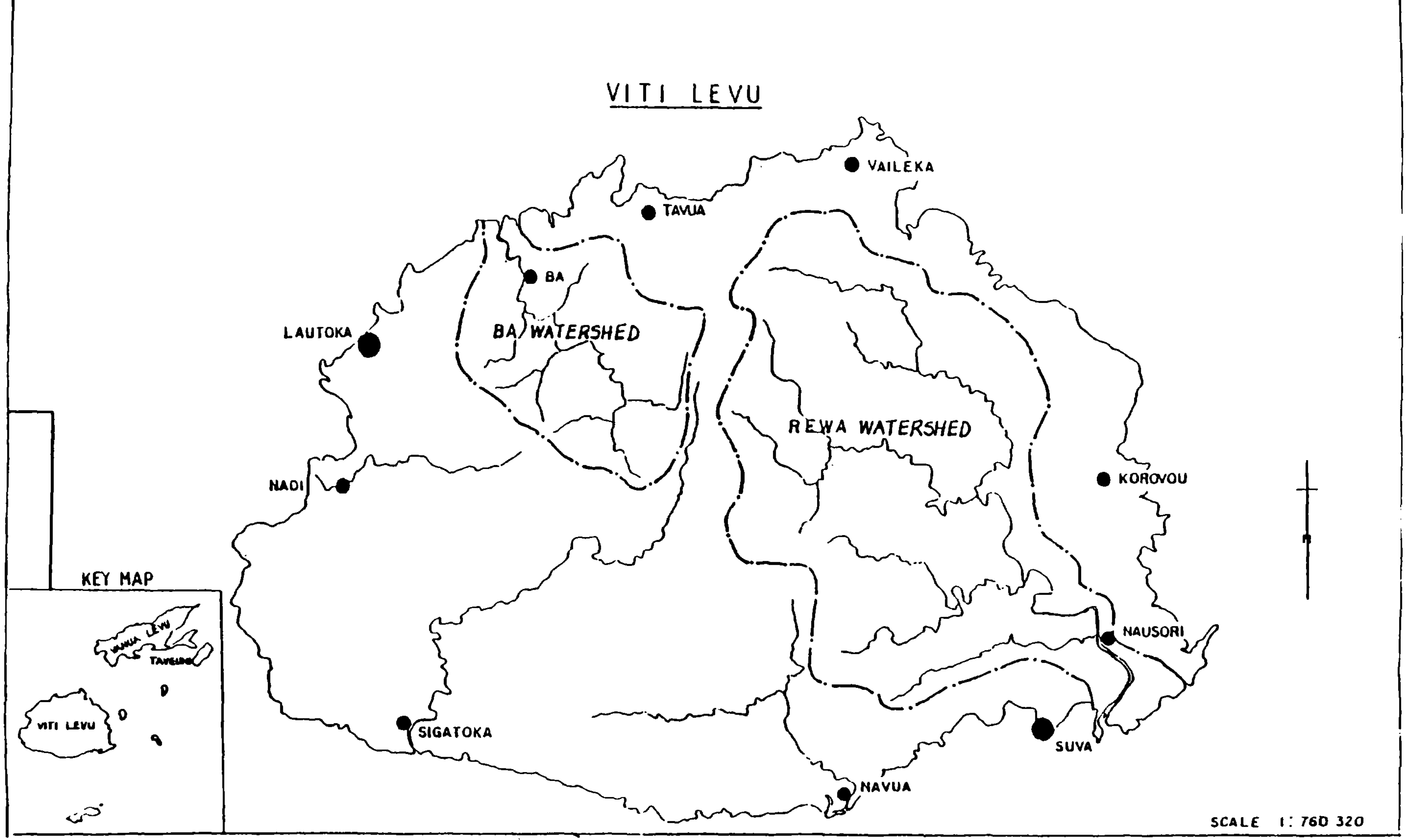
FIGURE 2



Annual discharge of suspended sediment from the drainage basins of the world. Numbers are average annual input in 10^6 tons. *From Milliman and Meade, 1983,* J Geol., *91, 1-21. Reproduced by permission of the University of Chicago Press*

FIJI

FIGURE 3



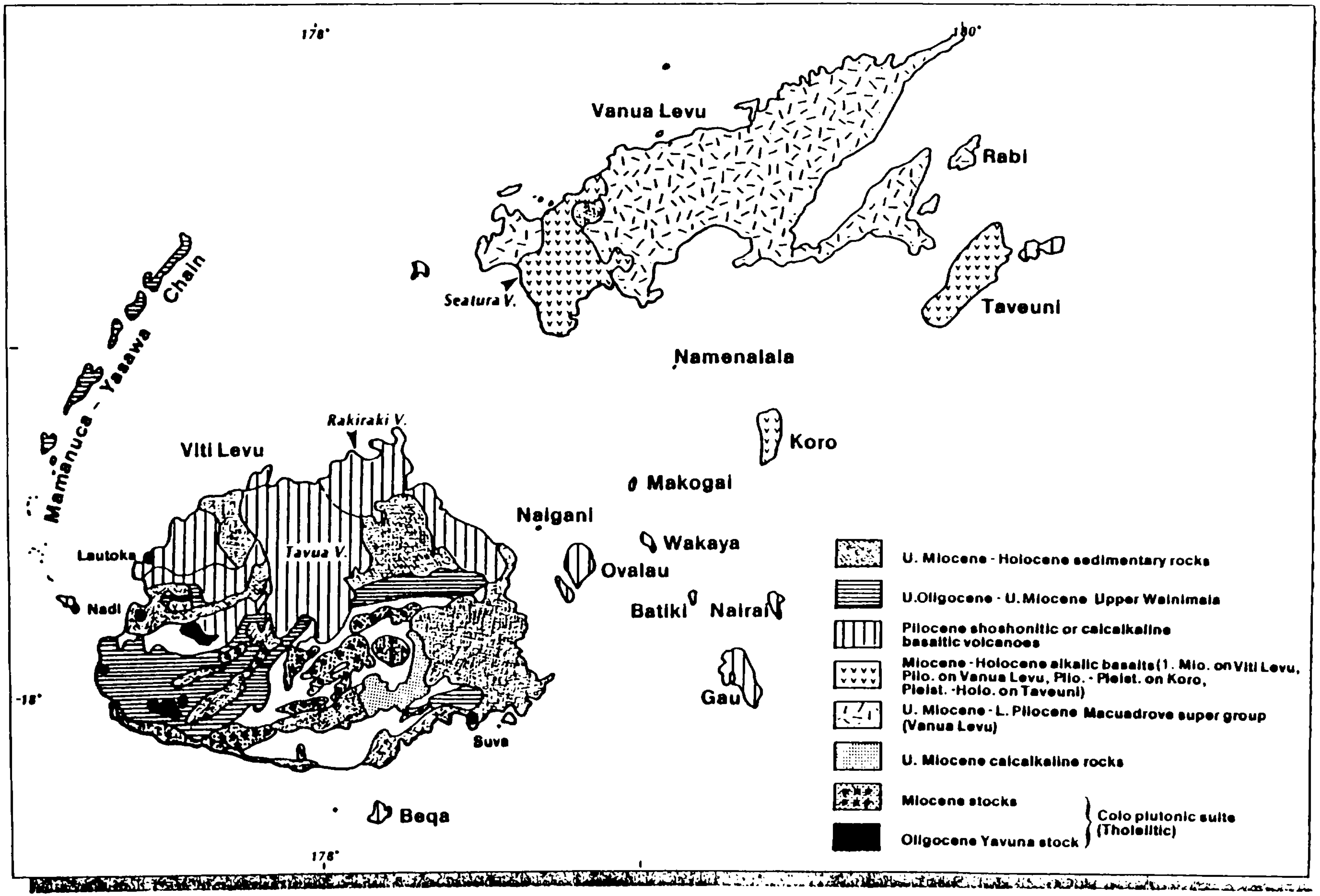


FIGURE 4 *Generalized Geology of Fiji (after Rodda in Kroenke, 1984).*

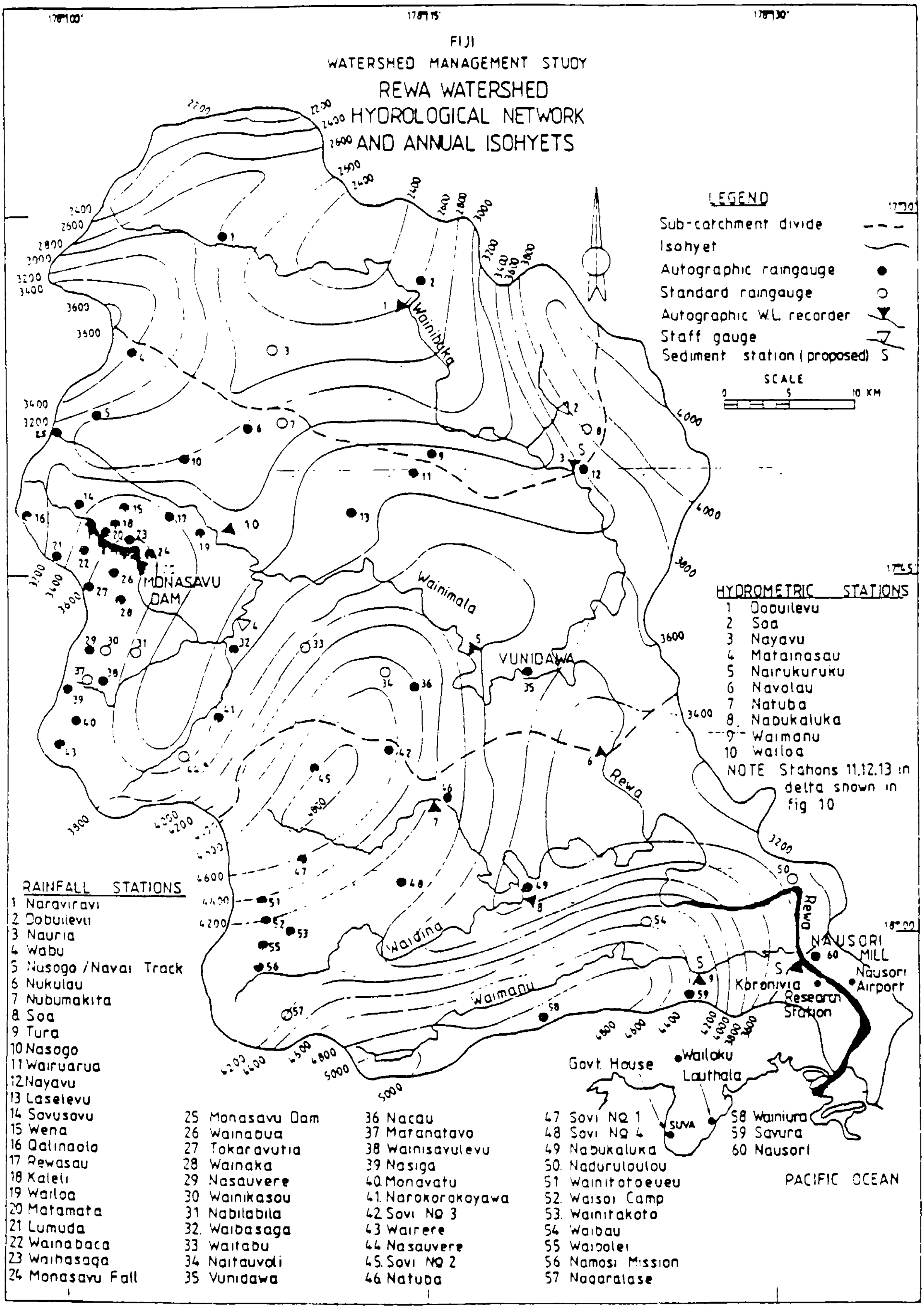

FIJI
WATERSHED MANAGEMENT STUDY
REWA WATERSHED
HYDROLOGICAL NETWORK
AND ANNUAL ISOHYETS
LEGEND
Sub-catchment divide
Isohyet
Autographic raingauge
Standard raingauge
Autographic W.L. recorder
Staff gauge
Sediment station (proposed) S
SCALE
0 5 10 KM
HYDROMETRIC STATIONS
1 Dobuilevu
2 Soa
3 Nayavu
4 Matainasau
5 Nairukuruku
6 Navolau
7 Natuba
8 Naboukaluka
9 Waimanu
10 Wailoa
NOTE Stations 11,12,13 in delta shown in fig 10
RAINFALL STATIONS
1 Naraviravi
2 Dobuilevu
3 Nauria
4 Wabu
5 Nasogo / Navai Track
6 Nukulau
7 Nubumakita
8 Soa
9 Tura
10 Nasogo
11 Wairuarua
12 Nayavu
13 Laselevu
14 Sovusovu
15 Wena
16 Qalinaolo
17 Rewasau
18 Kaleli
19 Wailoa
20 Matamata
21 Lumuda
22 Wainabaca
23 Wainasaqa
24 Monasavu Fall
25 Monasavu Dam
26 Wainabua
27 Tokaravutia
28 Wainaka
29 Nasauvere
30 Wainikasou
31 Nabilabila
32 Waibasaga
33 Waitabu
34 Naitauvoli
35 Vunidawa
36 Nacau
37 Matanatavo
38 Wainisavulevu
39 Nasiga
40 Monavatu
41 Narokorokoyawa
42 Sovi NO 3
43 Wairere
44 Nasauvere
45 Sovi NO 2
46 Natuba
47 Sovi NO 1
48 Sovi NO 4
49 Nabukaluka
50 Nadurutoutou
51 Wainitotoeueu
52 Waisoi Camp
53 Wainitakoto
54 Waibau
55 Waibolei
56 Namosi Mission
57 Nagaralase
58 Wainiura
59 Savura
60 Nausori
Wainibuka
Wainimala
Waidina
Waimanu
Rewa
MONASAVU DAM
VUNIDAWA
NAUSORI MILL
Nausori Airport
Koronivia Research Station
Govt. House
Wailoku
Lauthala
SUVA
PACIFIC OCEAN

FIGURE 5

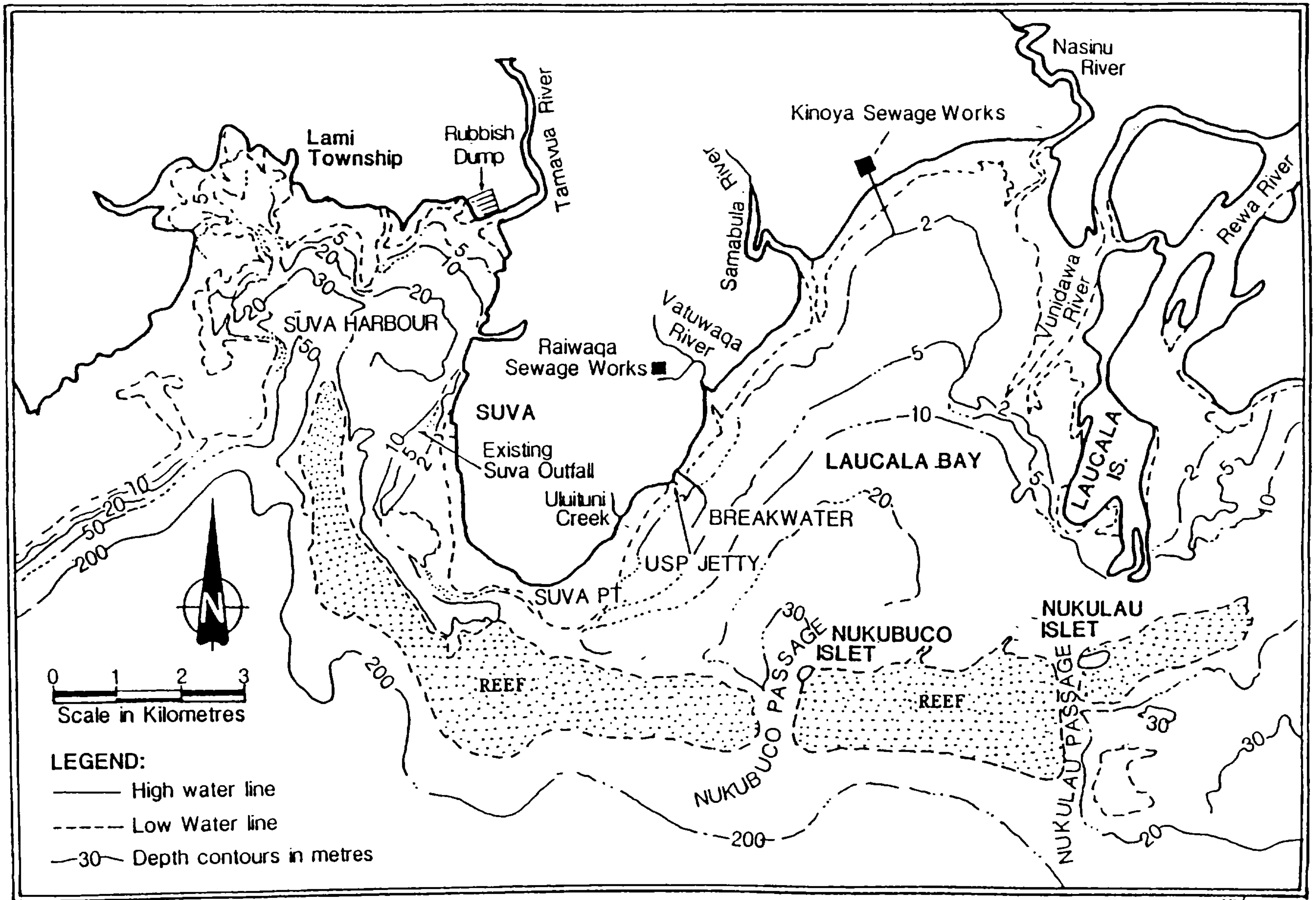


FIG. 6 : LAUCALA BAY/SUVA HARBOUR AREA

NUTRIENTS INPUT FROM JIULONGJIANG RIVER

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INTRODUCTION

In response to the proposal, suggested by the Experts Consultation on River Input project of WESTPAC (Dalian, April 1990), on an joint study of river nutrients input into the sea in WESTPAC region, two riverS in China have been proposed by State Oceanic Administration (SOA) as the candidates to take part in this cooperative program. One of the selected river is the Jiulongjiang River system, which discharges into the sea at Xiamen Bay, where the Third Institute of Oceanography is located. The study on the nutrient inputS into the sea from Jiulongjiang River will be carried out by the Institute.

Following the instruction of the workshop coordinators, the presentation is going to provide some basic information on the Jiulongjiang River system and includes three parts: 1) a background description of Jiulongjiang River system; 2) a brief review of previous studies on nutrients in this area; 3). preliminary results of an ongoing research.

1. BACKGROUND OF JIULONGJIANG RIVER SYSTEM

Jiulongjiang River is situated in the southern Fujian Province, between 116°50'-118°08' E and 24°12'-26°44' N, and is the second longest river in the Province. The river system is composed of three branches: Beixi(north branch), Xixi(west branch) and Nanxi(south branch), and discharge into Xiamen Bay (Fig.1). Beixi and Xixi combined together at the downward sedimentary plane and rush into the estuary. Some basic features of the river system are summarized in Table 1. The total length of the river is 1148 Km with a drainage area of 14741 Km^2 and annual runoff of $14.9x10^9$ m^3. The average suspended particulate matter SPM amounts to 210 mg/L and the annual SPM loading of the river is about $3x10^6$ T. Being the main branch, Bexi is 274 Km long mainstream with a drainage area of 9640 Km^2 and an annual runoff of $8.4x10^9$ T. Xixi has a mainstream length of 171.5 Km, a drainage area of 3940 Km^2 and annual runoff of $3.76x10^9$ T. Since Nanxi is quite small, when Jiulongjiang river is refereed, generally only Beixi and Xixi are considered.

The Jiulongjiang watershed is a major agriculture ground of the province and about 3.76 million population is accommodated in this area. The annual precipitation ranges between 1000 to 1700 mm. The change of river runoff follows essentially the annual distribution of the precipitation (Fig.2) suggesting that the runoff of the river is regulated by the rainfall. Along the river, there is 1820 Km^2 cultivative area, 73% of which (1340Km^2) is for rice planting. The agriculture is the major anthropogenic activity in the watershed. There only a few cities scatters along the river, such as Zhangping, Huaan and Zhangzhou. Among them only Zhangzhou is relatively large and its industrial waste may exert considerable effect on the river. Moreover, since China takes the reformation and open policy, many small-sized factories have ground up everywhere. Their sewage may have significant effect on the local water quality. However, the agriculture activities and domestic discharge are still the major sources of the nutrients in the river water. High nitrogen content has been frequently recorded in Jiulongjiang River water.

In the estuary, river water runs into the sea through a few channels. The southern one is the main channel and effect of freshwater mainly extends along the south bank. River water and sea water mix in the open region of the estuary. In addition to the tidal current, there is a downward residual current on the surface in the south part and an upward bottom residual current. An anti-clock residual current is detected around Jiyu Island. The current pattern certainly affects the nutrients transportation in the area.

Sediment studies indicate that the estuary is principally separated into two distinguished parts. The upper one is quite shallow and dominated by river sediment and the lower one is dominated by marine effect. The salinity is usually higher than S=20 most of the time in the lower part. However, even at the mouth of Xiamen Bay, a salinity of as low as S=15 has been recorded during flood period.

2. PREVIOUS STUDIES ON NUTRIENTS IN THIS AREA

Since 1960, Jiulongjiang river and its estuary have been an area of a number of studies conducted by institutions in Xiaman, such as the Third Institute of Oceanography (SOA), Xiaman University and Fujian Oceanography Institute.

From 1960 to 1962, the First General Survey of Chinese National Coastal Sea Area was carried out. Work has been done in Jiulongjiang Estuary and Xiamen Bay. However, since the primitive methods for nutrients analyses were used during the survey, the reliability of the results is suspentable.

From 1961 to 1965, a group of scientists headed by the late Professor Li Faxi in Xiamen University comprehensively studied the behavior and remove mechanism of silicate during the estuarine mixing of Jiulongjiang river water. The temporal and spatial distribution of silicate in river, estuary and sea waters was determined. A chemical remove of silicate during estuarine mixing has been confirmed by the in situ investigation and simulation experiments, and effecting factors have been studied (Li et al., 1964; 1978).

Between 1980 and 1981, a comprehensive annual investigation of Xiamen Bay was conducted by the Third Institute of Oceanography. Unfortunately, this program was mainly concentrated on the sea area around Xiamen Island and only part of the estuary was covered.

In 1986, Dr. Hong Huasheng and her students (Hong et al., 1989; Guo et al.,1989) carried out a study on phosphorus in Jiulongjiang Estuary and Xiamen Bay. Her work extended to where a salinity of about S=3 is common even in low tide period.

The only work by now reported on nutrients in river and sea water, which extended to the fresh water end in this area, was conducted by Fujian Oceanography Institute in 1983 (Chen et al., 1985) and conclusions are briefly introduced as follows.

The temporal variation of nitrate, phosphorus and silicate at river water end and sea water end has been redrawn from Chen's paper and show in Fig.3. It is unfortunate that they missed the data in May and June, the two higher runoff months, which are curious for nutrients transportation.

In general, the nitrate content is high in this area. The concentration of nitrate is higher in river water and low in seawater and their annual changes are quite similar except in autumn. The nitrate in river water ranges between 22.5 and 65.4 ugat/L with a mean content of 38.4 ugat/L. At seawater end, it changes between 3.6 and 20 ugat/L. From the relations between the nitrate concentration and salinity in each month, they concluded that the nitrate behaves essentially a conservative mixing in the estuary. In contrary, the phosphorus is low in this area and lower in river water than in seawater whole year long. From the distribution of phosphate concentration along the increase of salinity in each month, no general tendency or relationship was found. Their data seem hard to confirm an input of phosphorus from river to the sea, at least as dissolved phosphate. Silicate in the river and estuary is quite high and is much higher in river water than in seawater. A chemical removal from water body is obvious, especial in where salinity is lower than S=4. The memoval ratio ranges between 4 and 32%.

By using Boyle's mode $Qc=Qw(C-S*dc/ds)$, they estimated that annual fluxes of nitrate and silicate were 5.7 KT and 125 KT respectively. They also proposed an annual phosphate flux of 57 to 109 T.

Some general knowledge on nutrients in this area can be summarized from the previous studies.

(1) The nutrients in Jiulongjiang river water show a seasonal variation, which is governed by the river runoff. The concentration of nutrients is lower in wet season and high in arid season.

(2) Nitrate is high in this area, that may overweight the biological requirement and the dilution may dominate its distribution in estuarine mixing. However, linear regression may conceal some chemical and biological changes especially in low salinity region.

(3) Studies in this area have indicated that the phosphorus is the limiting nutrient in Xiamea Bay. The behavior of phosphorus must be complicated chemically and biologically. In studying phosphorus input from Jiulongjiang river, not only the dissolved phosphate should be considered. The particulate phosphorus and its transfer during estuarine mixing may be essential in river phosphorus input to the sea.

(4) The content and behavior of silicate in Jiulongjiang river and its estuary have

been studied and a chemical removal has been confirmed by various studies.

3. PRELIMINARY RESULTS OF AN ONGOING RESEARCH

In order to examine the design for further river nutrients input study, two cruises were made in Agu. and Oct. 1991. The main differences of this design to the previous individual studiesare: particulate and dissolved forms were separated and organic and inorganic forms were distinguished, and sampling was
conducted based on water salinity.

The abbreviation and definition of forms and species are listed in Table 2.

The dissolved nitrogen content is high in whole the study area and decreases from river water to seawater (Fig.4). Nitrate is the dominate species in dissolved nitrogen and governs the distribution of dissolved nitrogen. Both nitrite and ammonia are low and do not change evidently. Dissolved organic nitrogen changes unregularlly and has a considerable effect on the distribution of dissolved nitrogen. Particulate nitrogen is very low compared to dissolved nitrogen and is neglectable in flux estimation. The complication of nitrogen in salinity less than S=5 should be further verified.

The concentration of dissolved phosphorus is low and quite even, but a slight increase from river water to seawater can still be distinguished (Fig.5). However, particulate phosphorus is very high, especially in salinity less then S=5. From this results, river input and a removal of phosphorus from mixing of river water and seawater are evident and significant. The input of phosphorus from Jiulongjiang to the sea is governed by particulate form. The increase of dissolved phosphorus from river water end to seawater end can reasonably be explained by the release of phosphorus from particles and sediment.

Dissolved phosphorus can be divided into inorganic and organic forms. The data show (Fig.6)that phosphorus increases while organic phosphorus decrease as salinity increase. Studies of the behavior of both organic and inorganic phosphorus in salinity less then S=10 may be useful in our understanding of the transportation of dissolved phosphorus.

Particulate phosphorus decrease rapidly in low salinity and behaves principally a conservative dilution in high salinity. Its concentration and distribution are governed by organic form (Fig7.). Particulate inorganic phosphorus is operatively divided into three species: seawater soluble, Al/Fe combined and Ca combined (Fig.8 Most of PIP is in P-Al/Fe and P-Ca forms. Seawater soluble phosphorus release during early mixing (Fig.8) and its decrease may be responsible for the increase of phosphate in water body.

As a summary, there are some considerations:

(1) An input of nutrients from Jiulongjiang River to the sea is obvious and significate, but in different form: nitrogen is mainly in dissolved nitrate and phosphorus in particulate organic form.

(2) Different species of nutrients can present in water environment,especially phosphorus. Although determination of all the possible species and study on their transfer are difficult, reasonable selection of key species is essential in river nutrients input studies.

(3) All of the nutrients exhibit great variation during early mixing in low salinity, usually less than (S=5). It is an active geochemical region, which should be considered separately in the studies.

(4) Our results are only preliminary and a continuing investigation for a longer period is needed to confirm the observation.

(5) Some additional biological parameters and simulation experiments may be necessary to address the biological effect on nutrients transfer in estuary.

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Table 1. Some basic features of Jiulongjiang River

	mainstream length (m)	drainage area (Km^2)	annual runoff ($x10^8T$)	mean SPM concen. (mg/L)	annual SPM load ($x10^6T$)
Beixi	274.0	9640	84.0	206	1.70
Xixi	171.5	3940	37.6	212	0.77
J.L.	*1148.0	14741	149.0	210	3.00

* total length

Table 2. Abbreviation and definition of measured nutrient species

SPM: suspended particulate material
TDN: total dissolved nitrogen
TDP: total dissolved phosphorus
DIN:[1)] dissolved inorganic nitrogen
DON:[2)] dissolved organic nitrogen
NO_3 : nitrate
NO_2 : nitrite
NH_4 : ammonium
DOP[3)]: dissolved organic phosphorus
TPN: total particulate nitrogen
TPP: total particulate phosphorus
PIP[4)]: particulate inorganic phosphorus
POP[5)]: particulate organic phosphorus
P-solubed: seawater-soluble phosphorus from TPP
P-Al/Fe: phosphorus combined with Al and Fe in TPP
P-Ca: phosphorus combined with calcium in TPP

1) calculated DIN = $NO_3 + NO_2 + NH_4$
2) calculated DON = TDN - DIN
3) calculated DOP = TDP - DIP
4) calculated PIP = P-soluble + P-Al/Fe + P-Ca
5) calculated POP = TPP - PIP

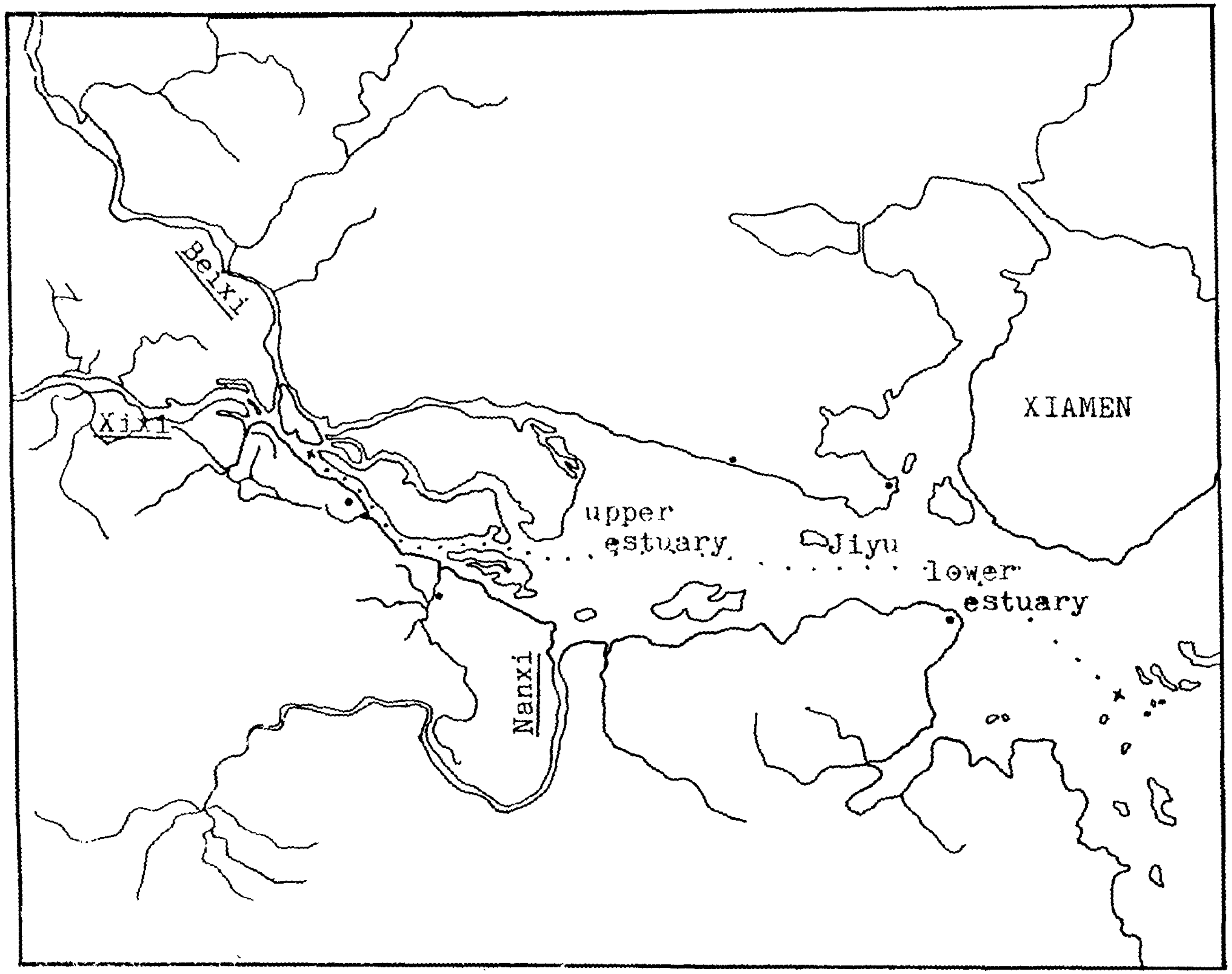

Fig. 1 Jiulongjiang river system and its estuary

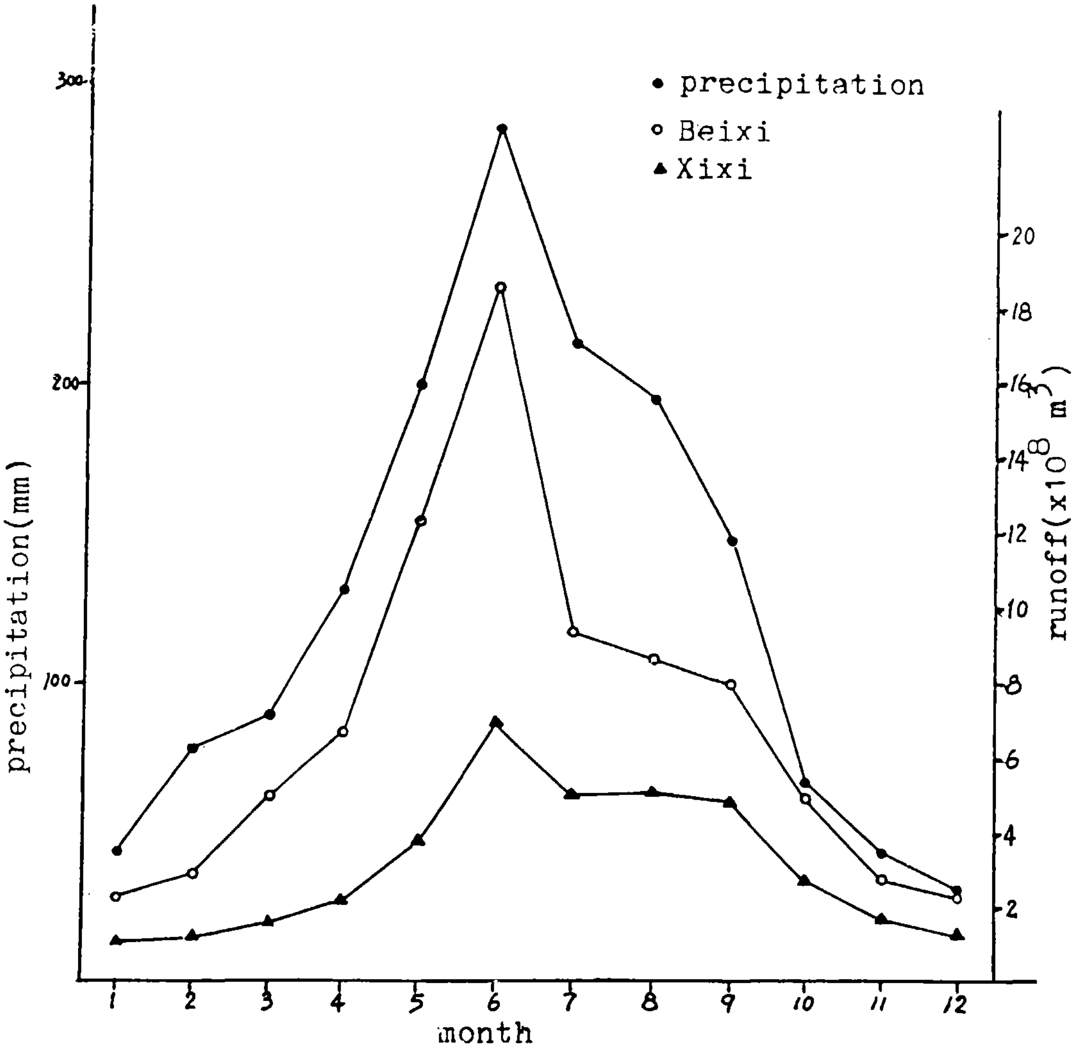

Fig. 2 Annual distribution of precipitation and runoff

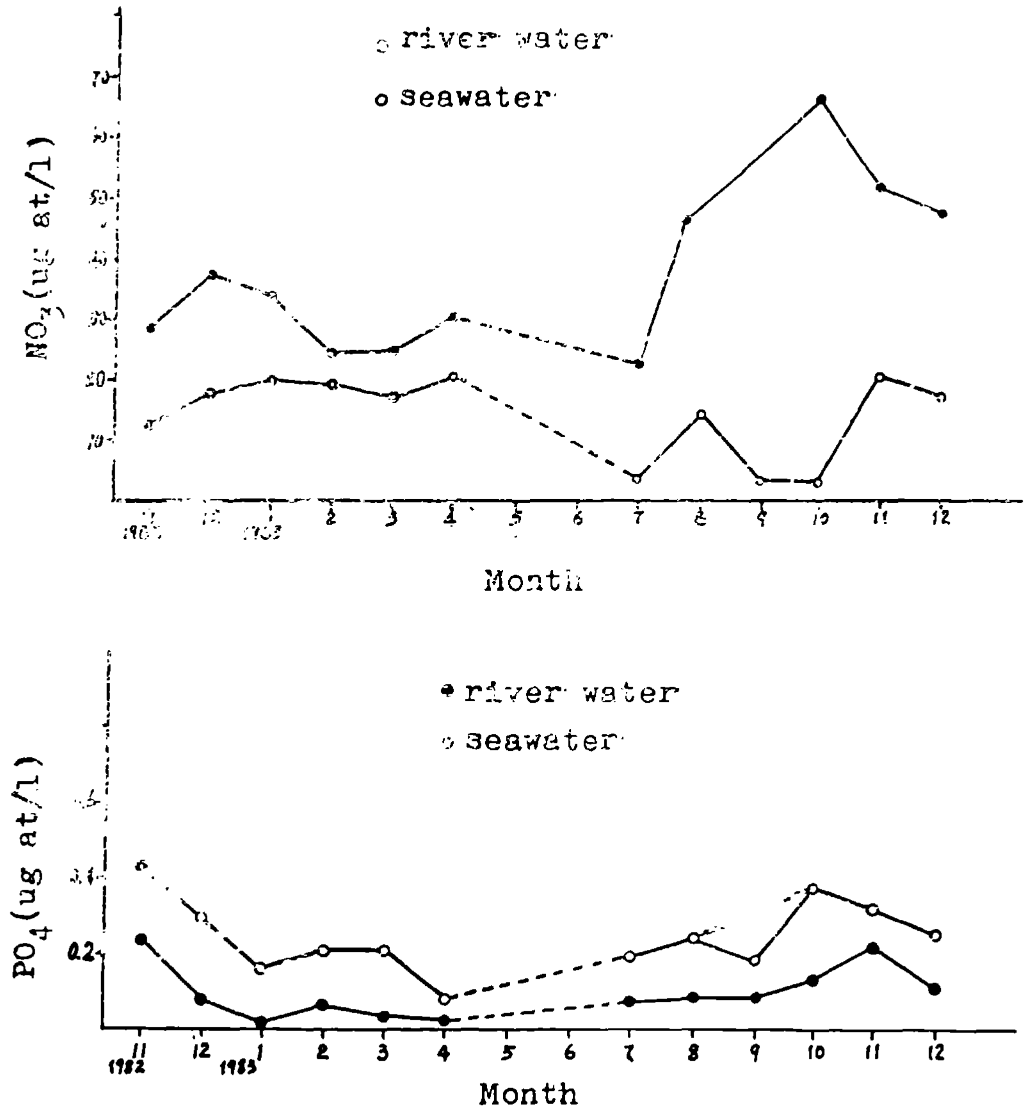

Fig. 3a Temporal variation of NO_3 and PO_4 at river- and sea- water ends

(redraw from Chen Shuitu et al., 1985)

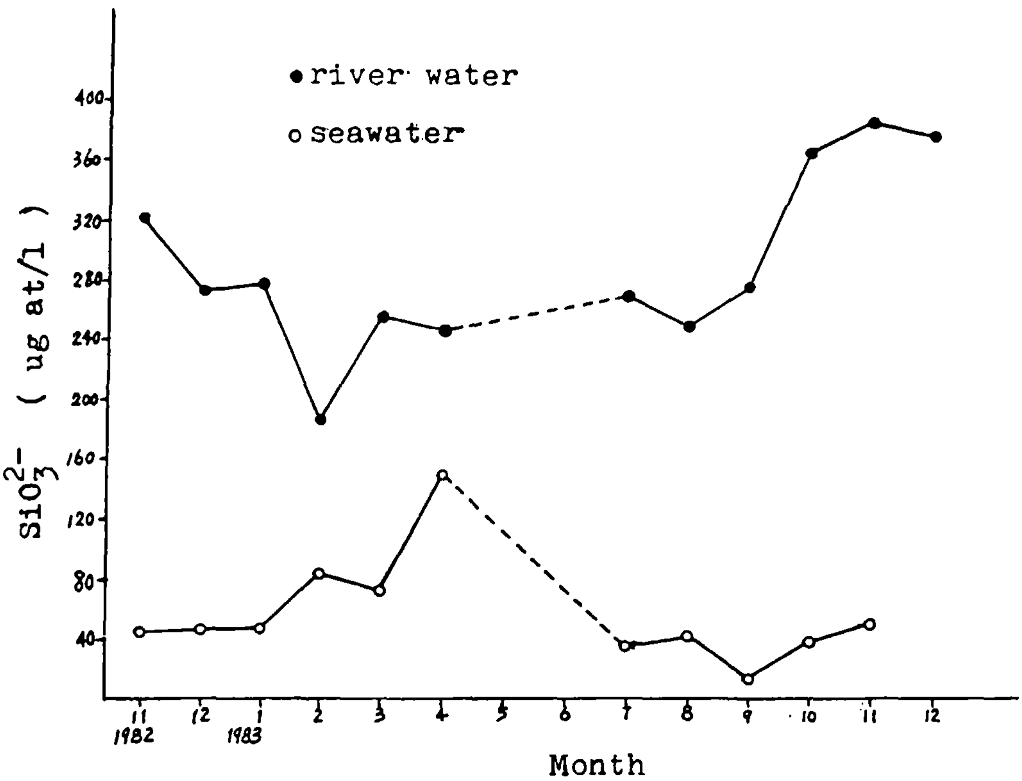

Fig. 3b Temporal variation of SiO_3^{2-} at river- and sea-water ends

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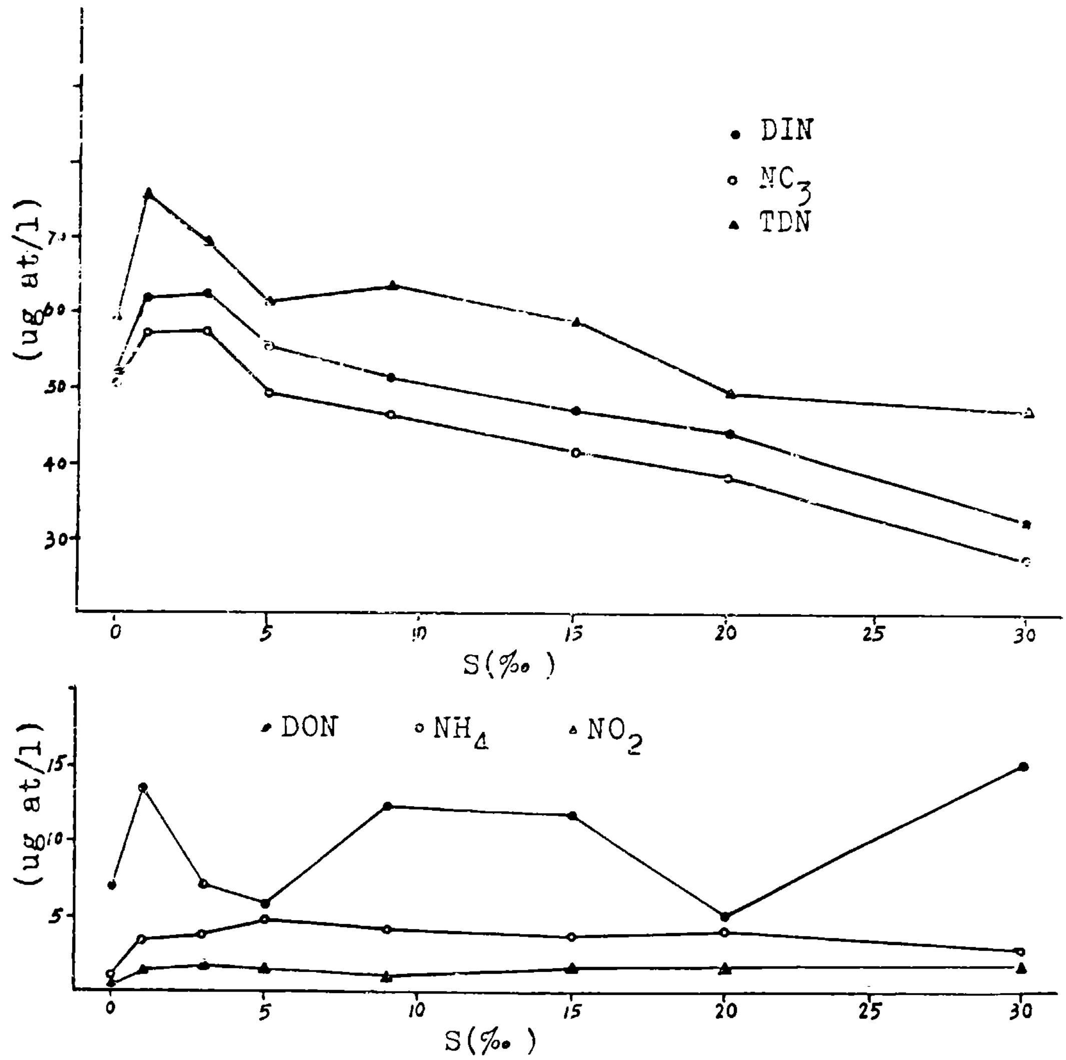

Fig. 4 Species of dissolved nitrogen in Jiulongjiang Estuary waters

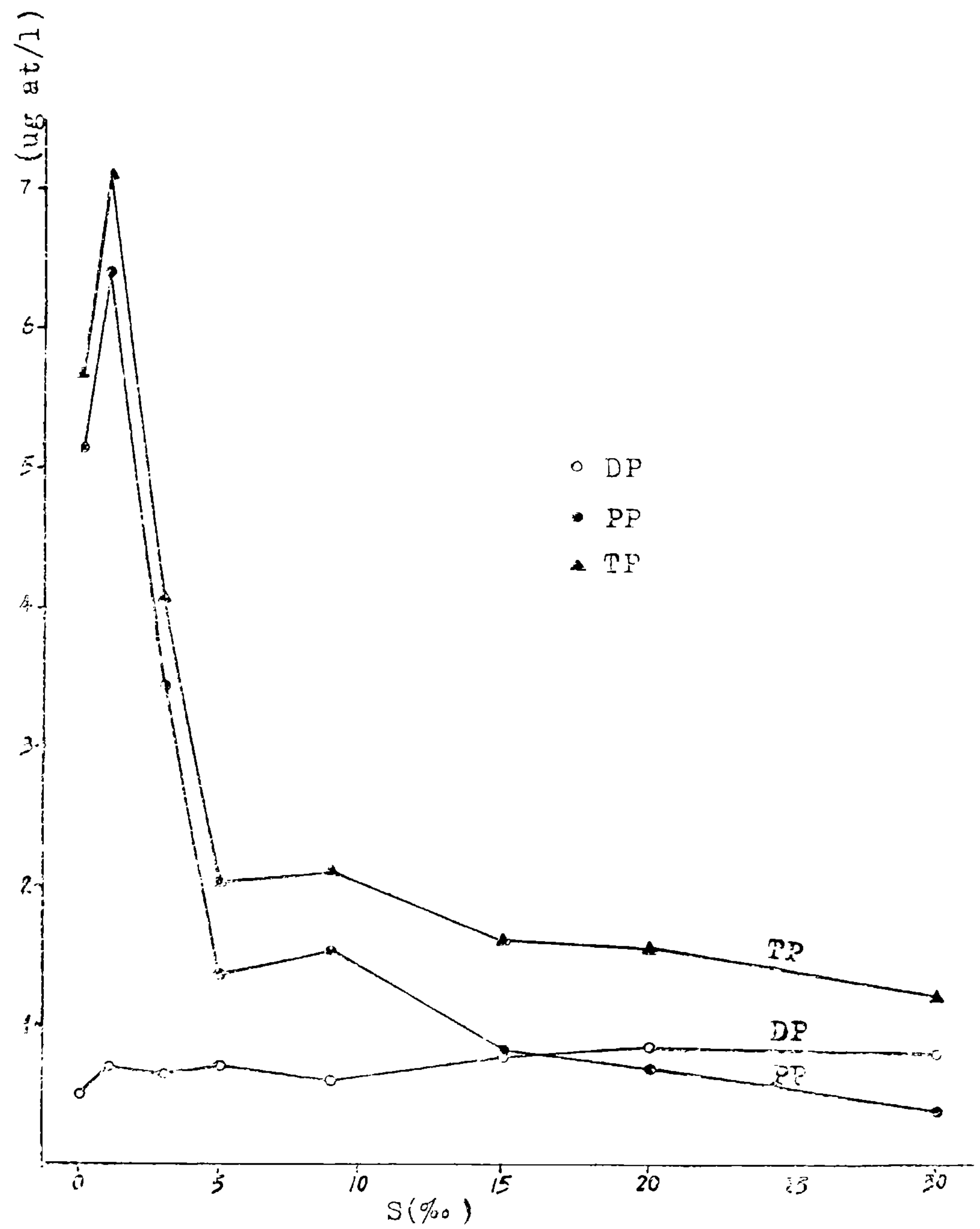

Fig. 5 Composition of phosphorus in water of different salinity

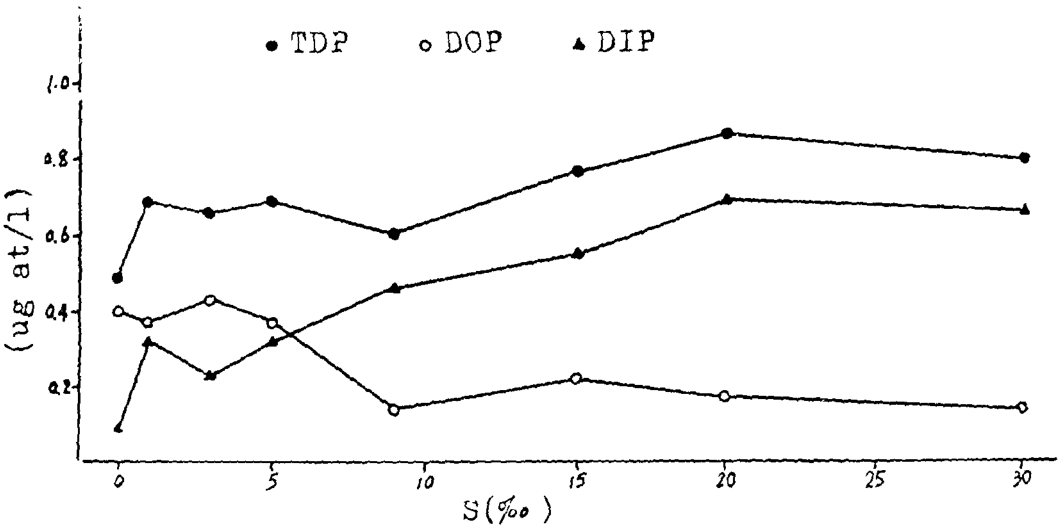

Fig. 6 Composition of dissolved phosphorus in Jiulongjiang Estuary waters

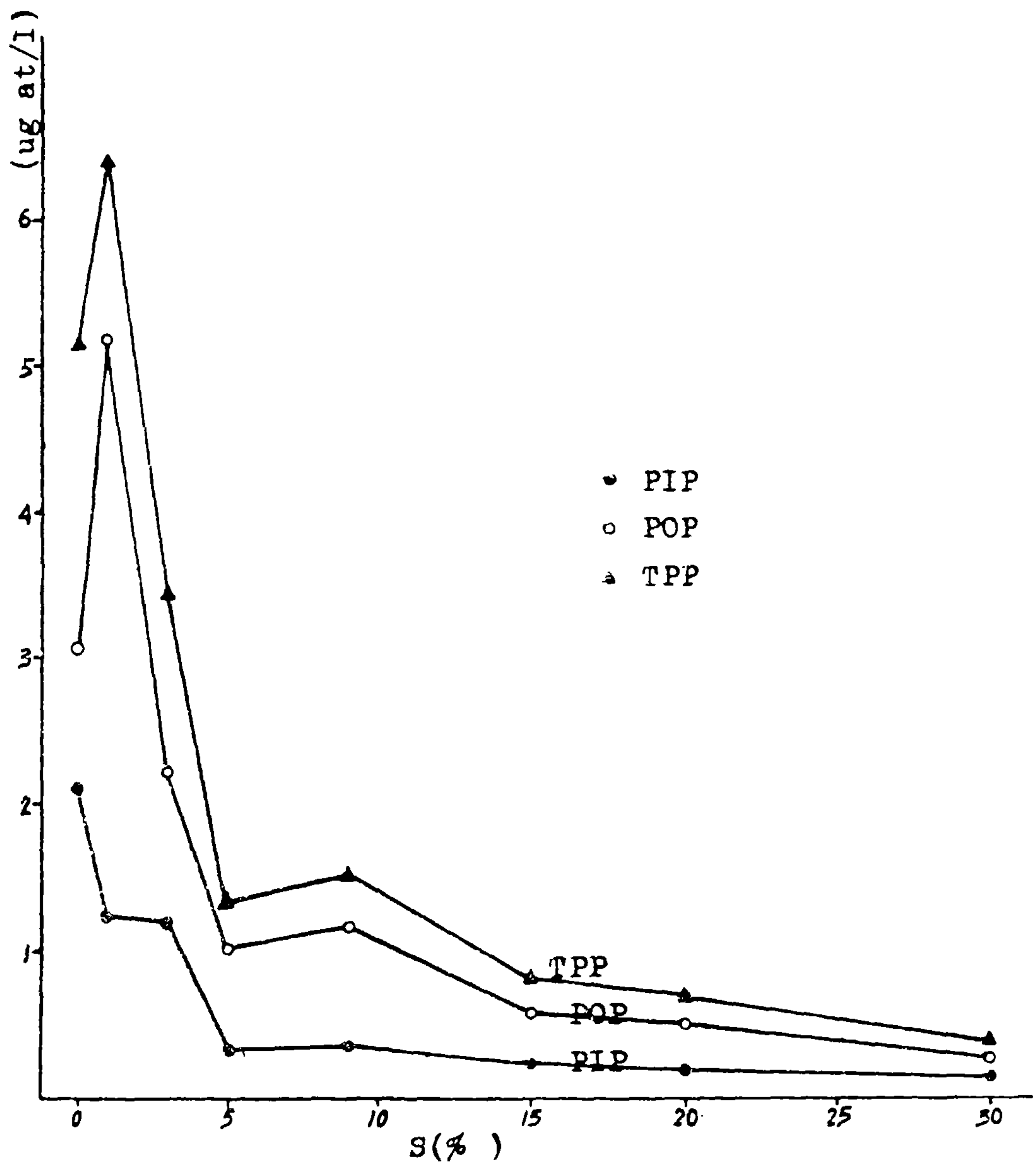

Fig. 7 Composition of particulate phosphorus in Jiulongjiang Estuary waters

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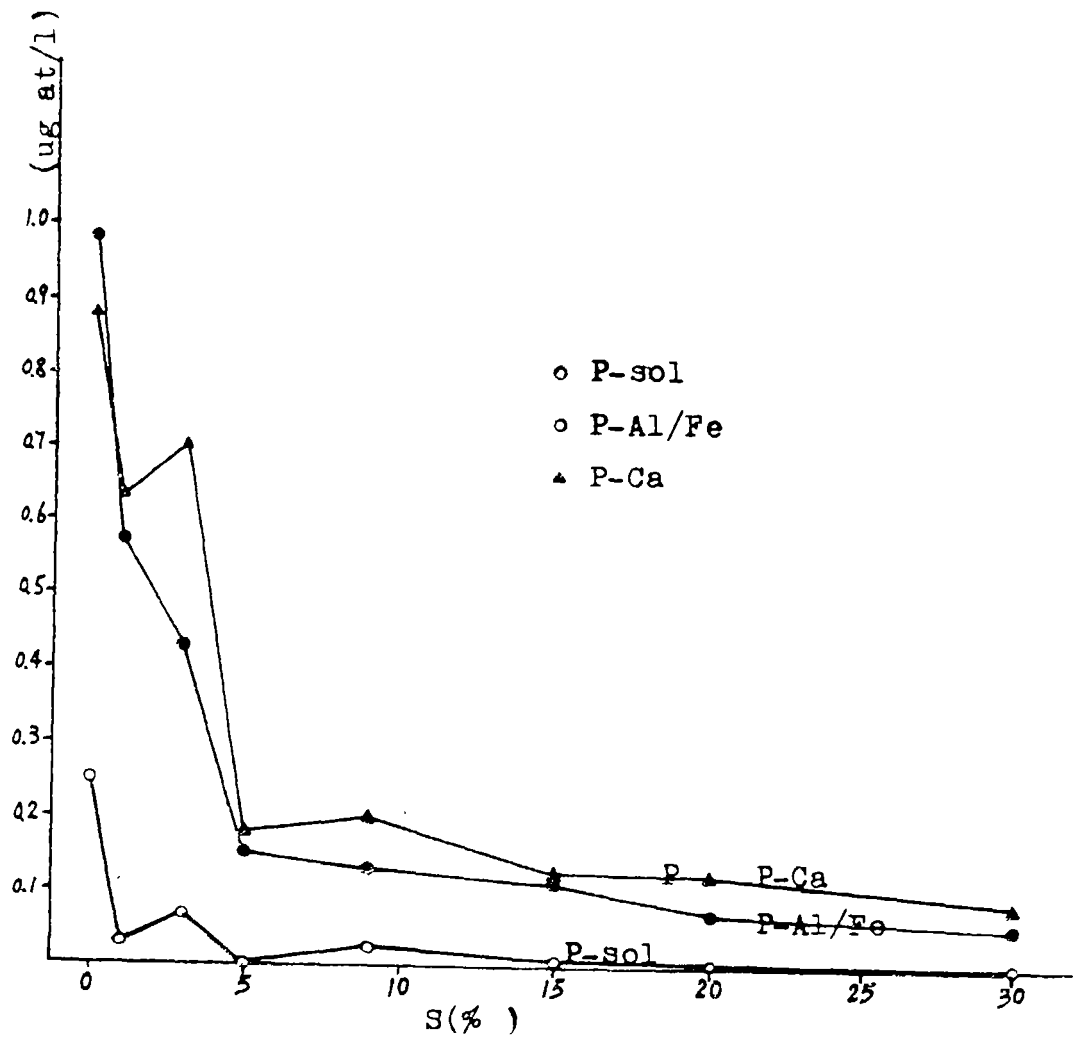

Fig. 8 Species of particulate inorganic phosphorus in Jiulongjiang Estuary waters

Characteristics of River Systems and Nutrient Sources in Korea

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ABSTRACT

Korea is a rugged country, being by about 70 percent a mountainous terrain. The land surface of the western slope is typified by an old-age terrain with a gentle slope traversed by highly sinuous meandering rivers. Alluvial plains are mostly developed along these rivers. Climate in the southern part of Korea is temperate. Annual mean temperature lies normally between 10 and 14 degree Celcius except the Cheju Island. Mean annual precipitation in Korea is 1,159 mm of which 50 percent is concentrated in July and August of summer monsoon period. Vegetation in the southern part of Korea can be grouped into four categories; North, Middle and South temperate zone and Subtropical zone. Igneous rocks are widely distributed in Korea. Mesozoic layer is found in the southeastern region and paleozoic layer is localized to the mid-eastern section. Use of land surface in the watershed becomes more and more extensive due to high density of population and continuing industrialization.

Five major river systems are proposed for study. Mean discharge rates of Naktong, Kum, Yongsan, Somjin and Man-gyong River are 102.0, 73.6, 15.4, 26.9 and 11.0 m3/sec respectively. TKN contents showed high variability in the mid-streams ranging from 394 to 6,964 g/l. Harmful algal blooms are occasionally reported in the narrow inlets receiving freshwater discharge.

1. INTRODUCTION

Rivers are a major mean of transport of material including nutrients and organic matter to the coastal zone.

Delivery of dissolved materials, including inorganic nutrients and contaminants, depends on riverine geochemical and hydrological processes. River geochemistry varies considerably with the types of lithology, topography, hydrology, agricultural development, and vegetation cover of the river system (Meybeck, 1982). Understanding this variability in relation to changes in climate, land use, hydrology, etc., will be critical to the prediction of nutrient budgets for coastal zones.

Soil-leaching and surface runoff are the principal sources of dissolved and particulate nitrogen in natural waters. Deforestation, soil fertilization, animal production, discharge of industrial and domestic wastewaters have considerably increased the concentration of dissolved and particulate nitrogen in rivers.

Recent reports have documented the significance of of the transport of nutrients to ocean margins by rivers. It has suggested that one of the most pressing concerns regarding the quality of the marine environment is coastal eutrophication. In factregional concern regarding toxic algal blooms in various coastal areas are growing. Eutrophication of the coastal zone by altered land use and waste disposal practices of man affects the productivity and structure of coastal ecosystems as a result of absolute or relative changes in abundances of nutrients.

Also, concern over global climate changes and the role of the carbon cycle on this has resulted in increased attention to the input of nutrients to coastal oceans, particularly those due to man's activities.

The purpose of this paper is to describe a general characteristics of Korean river systems proposed for study before beginning a Progream on River Input of Nutrients.

2. GENERAL CHARACTERISTICS OF WATERSHEDS IN KOREA

Korea is a rugged country, being by about 70 percent a mountainous terrain. The mountains are, however, not so high averaging 482 m in altitude. Mt. Halla of Cheju Island is the highest one in the southern part of Korea. The land surface of the western slope is typified by an old-age terrain with a gentle slope traversed by highly sinuous meandering rivers. Relatively long rivers with complicated dendritic drainage patterns flow westward into the Yellow Sea. Alluvial plains are mostly developed along these rivers. On the contrary eastward from the divide mountain slopes dive steeply to the East Sea.

Climate in the southern part of Korea is temperate. Annual mean temperature lies normally between 10 and 14 degree celcius except the Cheju Island. Mean annual precipitation in Korea is 1,159 mm of which 50 percent is concentrated in July and August of summer monsoon period. Vegetation in the southern part of Korea can be grouped into four categories; North temperate zone (Elm, Nettle tree), Mid-temperate Zone (Hornbeam, Japanese oak), South temperate zone (Bamboo, sp. of Hornbeam) and Subtropical zone (Bramble, Cone pine). Igneous rocks are widely distributed in Korea. Mesozoic layer is found in the southeastern region and paleozoic layer is localized to the mid-eastern section.

Aluvial soil predominates major river valleys. Western region of Korea is mostly covered with redyellow podzolic soil. Limestones and Brown forest soil are found in the mid-eastern region. Most dominant type of soil in Korea is lateritic which covers large mountainous area. Soils of volcanic origin prevail in the subtropical island of Cheju.

3. CHARACTERISTICS OF WATERSHEDS

Major river systems of Korea are shown in Fig. 1. Five major river systems are chosen for study. Watershed size, mean flow, population and pollutant dischare are summarized in Table 1.

Naktong River

Eastern boundary of the watershed is Taebak Mountain Range and 71 percent of this watershed is mountainous area. Geological characteristics in this watershed is quite susceptible to weathering processes(E.P.A., Korea, 1982). So extensive erosion after heavy rainfall is likely to occur. Mesozoic sedimentary rocks occupies two thirds of the watershed. Relief of this river at the lower and mid-stream is 1/2000 - 1/7000 and relatively steep at the upper stream.

Kum River

Watershed size is about one tenth of Korea. This stream beginning from Dukyusan (1594m) flows down the mountainous watershed. Geological characteristics are quite complicated. Granite gneiss prevails in eastern and western extremeties of this watershed. Mesozoic layer in this watershed is mainly consisted of conglomerate and sandstone. Quartenary layer including both alluvial and diluvial soil occupies 34 percent of this watershed. Vegetative cover is very poor in this watershed. Relief at upper and mid-stream is 1/1000 - 1/3000. Large rice paddy fields are located around the lower reaches of this stream.

Yongsan River

Relief of this river ranges from 1/5000 to 1/1000. Precambrian metamorphic rocks are found in the eastern region while sedimentary rocks are dominant in southeastern area. Wide igneous layer dominates the central part. Rapid industrialization is taking place in this watershed.

Somjin River

Watershed of this river is in relatively pristine condition. 19.3 percent of terrain is used for agricultural purpose. Precambrian gneiss, jurassic and cretaceous granite, and sedimentary rocks are found in this watershed. But in the river valleys, alluvial layer of silt, sand and clay is about 30 meter thick.

Man-gyong River

Relief at the lower stream is 1/2000. Agriculture is the most important industrial activities in this region. Precambrian metamorphic rocks, paleozoic and mesozoic sedimentary layer are dominant in this watershed.

4. NUTRIENT SOURCES

The amount of nutrients originated from fluvial erosion is porrly understood in Korea. Fluvial erosion rate is a function of rainfall, slope length, vegetative cover and a soil erodability factor. Each is a function, to some degree, of other aspects of climate, geological substrate, weathering rate, regional geomorphology, fire frequency and land use.

Wastewater discharges from major river systems are shown in Table 2. Nutrient contents in the korean rivers reflect the the influence of very dense population and, perhaps the effect of rice culture. Major form of wastewaters from korean rivers is domestic. Amount of industrial wastewaters entering the Somjin River is relatively small due to poor industrial activities. Non-point source inputs are excluded in Table 2. However, use of fertilizers will be decreased due to continuing urbanization and industrialization.

Nutrient Contents in mid-stream are shown in Table 3. All forms of nutrients show high contents in Naktong River. Chemical oxygen demand is relatively high in Yongsan and Man-gyong River probably due to the non-point source input of agricultural wastes. High contents of ammonia and TKN could also be found in Yongsan River. Nitrate contents are relatively high in Man-gyong River. Phosphate contents show its maximum at mid-stream of Yongsan River.

Nutrient Contents at the mouth of the Korean Rivers are shown in table 4. More than 1 mg/l of nitrate are found at the mouth of Yongsan River

(E.P.A., Korea, 1991). At the mouth of Somjin River, though nitrate and ammonia contents were low, 44 g/l of phosphate is recorded. Highest phosphate content is found at the mouth of Yongsan River as is the case of mid-stream. Silicate contents are high at the at the mouth of of Naktong River where fluvial erosion can be easily occurred due to geological characteristics.

5. CONCLUSION

Natural waters acquire the chemical characteristics by dissolving and by chemical reactions with solids, liquids and gases through the various parts of the hydrological cycles. The headwater stream chemistry based on weathering geochemistry and erosion is essential to assess man-made perturbation in the lower reaches of the river.

The nutrient cycle is now greatly modified by human activities and is no longer at steady state. Examples of increase in nitrogen levels of rivers are now numerous. The per capita loadings are highly variable and some what reflect the state of development of each country and water uses in each watershed. Nitrogen and phosphorus in precipitations have been studied for a long time, but data are not available for korean watersheds. As for rivers the influence of pollution on nutrient levels in precipitation is great, and a careful screening of data sholud be done to eliminate the most obviously contaminated stations.

Increases in the frequency and intensity of phytoplankton blooms in coastal waters have been widely reported in Korea(Yang, 1992). Many bloom-forming flagellates are strong sources of DMS, and in cases where the degradation of large quantities of algal matter lead to oxygen depletion enhanced production of N2O is likely. Export rates of TOC are closely related to river runoff. Relative proportions of of dissolved and particulate organic carbon in rivers is a debated question.

River transport of nitrogen, phosphorus, silicate and organic carbon are poorly investigated in Korea. New projects on river inputs of nutrients to the marine environment would provide overall informations on river inputs and carbon burial in the estuary.

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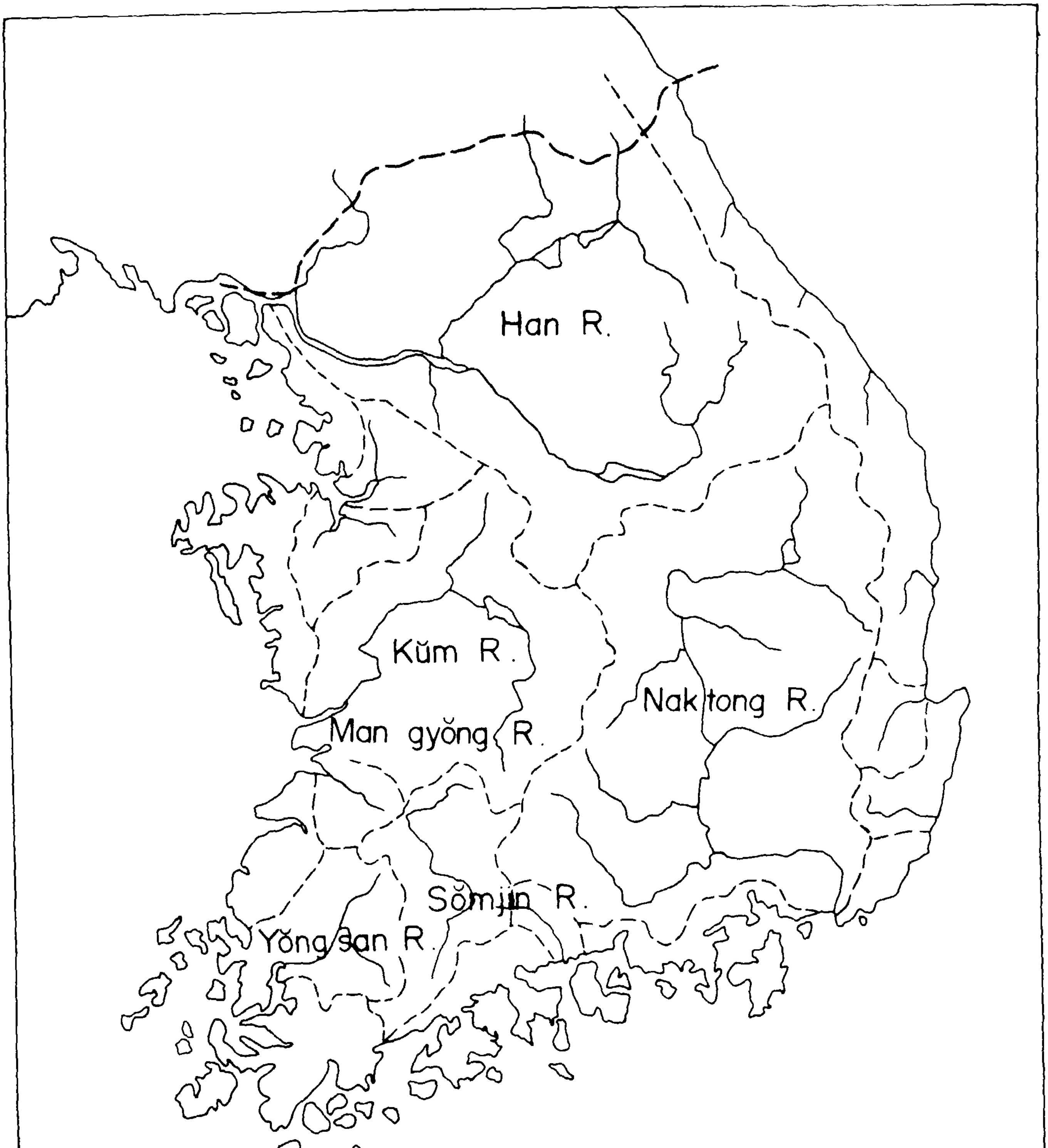

Fig. 1. Major Rivewr Systems in Korea.

Table 1. Major River Systems proposed for study

Main Stream	Total Length (km)	Watershed (km^2)	Annual Precipitation (mm)	Mean Flow (m^3/sec)	Population (1,000)	Pollutants Discharge (BOD, kg/d)
Naktong R.	521.5	23,860	1,079.0	102.0	6,548	716,969
Kŭm R.	395.9	9,886	1,206.8	73.6	3,068	334,352
Yŏngsan R.	136.0	2,861	1,386.9	15.4	1,906	126,375
Sŏmjin R.	74.1	2,143	1,287.2	26.9	572	91,392
Man-gyŏng R.	212.3	1,602	1,404.1	11.0	963	94,733

Table 2. Wastewater Discharge from major river systems

(m^3/day)

Main Stream	Total	Domestic	Livestock	Industrial
Naktong R.	1,738,453	1,553,121	63,149	122,183
Kŭm R.	494,037	422,919	21,224	49,895
Yŏngsan R.	250,441	223,063	11,454	15,924
Sŏmjin R.	76,068	68,188	6,812	1,068
Man-gyŏng R.	167,953	133,945	6,254	27,754

Table 3. Nutrient contents at mid-stream 1983

Main Stream	COD(mg/l)	Ammonia (μg/l)	TKN (μg/l)	Phosphate (μg/l)	Nitrate (μg/l)
Naktong R.	2.1 - 8.3	60-1946	1066-6246	8-141	207-1133
Kŭm R.	1.7 - 4.4	89- 282	1771-2500	14- 51	723-2351
Yŏngsan R.	4.7 -20.1	151-4975	1578-6964	33-542	316-1099
Sŏmjin R.	1.6- 6.3	79- 108	394- 632	11- 38	281- 646
Man-gyŏng R.	1.1-23.8	14-1037	1938-2211	13- 50	387-2767

Table 4. Nutrient Contents at the mouth of Korean Rivers (μg/l)

Main Stream	Nitrate	Ammonia	Phosphate	Silicate
Naktong R.	136	56	22.6	477
Kŭm R.	419	244	18.3	270
Yŏngsan R.	1446	272	92.0	
Sŏmjin R.	40	7	44.0	168

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CONCENTRATION LEVEL OF NUTRIENTS IN PASIG RIVER

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ABSTRACT

This study was undertaken to determine the concentration of nutrients in one of the major river systems in Metro Manila that drains into Manila Bay, the Pasig River.

Result of findings revealed that nutrient concentrations vary due to seasonal changes and amount of rainfall. Nutrient parameters such as ammonia, nitrates, orthophosphate and total phosphates were found to increase in average concentration from dry to wet season.

Anthropogenic inputs through varied human activities i.e. domestic activities, heavy industrialization and urbanization influenced the variability in nutrient concentrations. This study revealed that phosphate concentrations were relatively high at Total P, 0.606 - 0.057 mg/L and ortho P. 0.397 - 0.106 mg/L in sampling sites near residential areas. While ammonia at 0.648 - 0.072 mg/L 7 "' was observed high near industrial plants.

River tributaries were also shown to affect the nutrient concentration. It was found that average nutrient concentrations were even higher in areas at the confluences of Marikina and San Juan Rivers (NH_3 - N 0.868 - 0.062 mg/L, Total P. 0.662 - .008 mg/L).

Other water-quality parameters were also taken and showed a general improvement during the rainy months. However, it was found that dissolved oxygen, a factor necessary for aquatic life propagation and survival had further deteriorated from 1989 to 1990.

1. INTRODUCTION

River nutrient inputs have become the concern of coastal and estuarine environmentalists because of problems of eutrophication of this ecosystem. (UNESCO Report No. 29, 1984). Nutrient sources does not only come from the natural hydrological cycle but also from anthropogenic inputs, high population density, industrialization, urbanization and intensive agricultural practices.

In Pasig River, the nutrient inputs not only affect the nearby estuarine and marine environment i.e. Manila Bay but also the adjacent freshwater body i.e. Laguna Lake through Pasig River's complex water flow direction which is mainly influenced by the tidal condition.

Marine research studies have shown that increased river nutrient inputs may have caused frequent red tide outbreaks (Yang & Hong, 1982). Quantifying the extent of this nutrient impact however, is hampered by the fact that the distribution of this planktonic organism as well as the associated environmental factors vary tremendously in time and space.

The Bureau of Fisheries and Aquatic Resources (BFAR) reported the occurrence of pyrodinium red tide in Manila Bay in August 1988 (Ordonez, 1988) where a total of 66 poisoning cases with 4 deaths due to ingestion of green bay mussels (Perna viridis) or locally known as "Tahong" became a major cause for alarm among health officers and local government officials. Red tide incidences did not only cause harm to the general public health but also to the economy since millions of pesos from the "Tahong" aquaculture were lost in less than four months of its occurrence (Ordonez, 1988)

2. OBJECTIVES

A. General Objective

To assess the extent of eutrophication of Pasig River by studying the concentration levels of nutrients and other water-quality parameters.

B. Specific Objectives

1. To determine the concentration level of nutrients, i.e. total phosphate, orthophosphate, ammonia and nitrate.

2. To determine the concentration level of water-quality parameters such as dissolved oxygen, pH, water temperature and water depth.

3. LITERATURE REVIEW

Nutrient as defined by Webster is the substance that provides nourishment to any life form. In terms of water-quality, it refers to the chemical species that are biogeochemically reactive compounds required to sustain aquatic life (GESAMP Reports and Studies No. 32, 1987).

Nutrients are composed of compounds of nitrogen phosphorus, carbon and silicates. They enter the water system in varied forms, mostly as particulates which are gradually released as ions through biodegradation.

Nitrogen exists in many different oxidation states from - 3 to + 5 as inorganic constituents (ammonia, nitrogen gas, nitrite & nitrate) or organic compounds as shown in Figure 1. Under oxygenated conditions, Nitosomonas bacteria convert simple ammonia compounds into nitrite which is then oxidized to nitrate ions by Nitrobacter bacteria (Odum, 1971). Plants readily absorb nitrate ions although some algaes are also capable of utilizing ammonia. Dissolved organic nitrogen is dominant in humid tropical rivers.

Soil leaching and surface run-off are the principal sources of dissolved and particulate nitrogen in natural waters (GESAMP Reports and Studies No. 32, 1987). However,human activities such as deforestation, intensive agricultural practices, livestock farming, industrial waste effluents specifically from food processing industry, and domestic waste effluents have increased the concentration of dissolved and particulate nitrogen.

Phosphorus compounds commonly occur as phosphate which are composed of simple ionic orthophosphate and total phosphate (also referred to as bound phosphate) (UNESCO Reports in Marine Science No. 42, 1984). Its mobility and availability in water are highly dependent on metallic iron. In oxygenated conditions ferric oxides and hydroxides sequester phosphate componends in water and locks them into a complex which is then precipitated in the sediments. However, with the deoxygenation of the water system iron is reduced from ferric

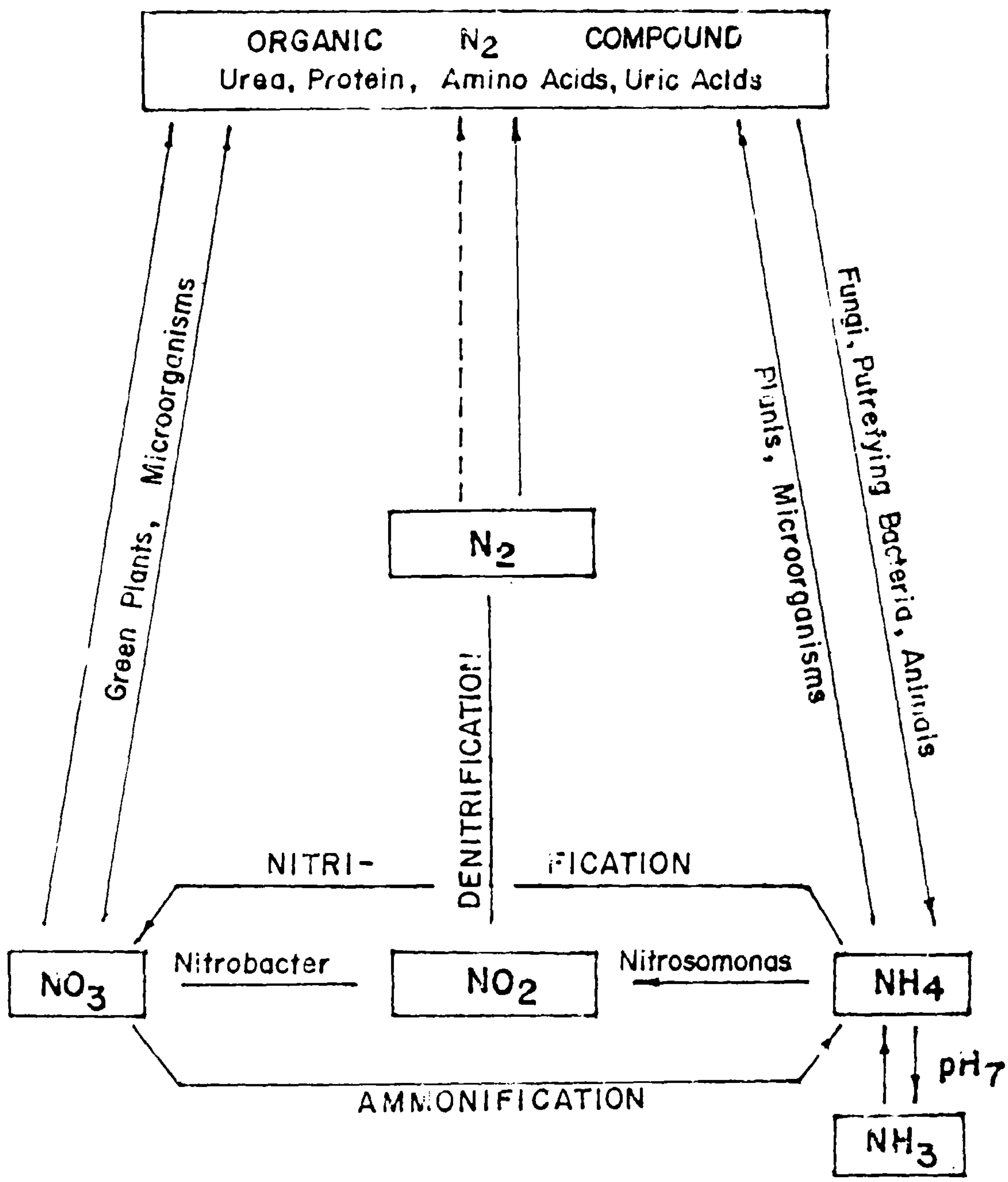


Figure-1, MAJOR-TRANSFORMATION IN THE NITROGEN CYCLE to ferrous and consequently release phosphate compounds into the water.

Carbon is the main component of natural organic carbon. Riverine carbon compounds consist of dissolved organic carbon (DOC) and particulate organic carbon (POC). (UNESCO Report in Marine Science No. 42, 1984).

The dissolved organic carbon is quite important and is a highly dynamic component of the global carbon cycle, and however it is still poorly defined. (Likens, et. al, 1981)

Rivers contain organic matters that are both synthesized and mineralized biogeochemically in both terrestial and aquatic ecosystems. Almost 80% of DOC is composed of humic acids (insoluble acides) and furic acids (soluble acids) (Ertel, et. al., 1986) while the rest of the DOC pool consist of carbohydrates, polypeptides, and fatty acids (Degens and Ittekott, 1983).

On the other hand, in the study of Amazon River particulate matter, Hedges et al (1986) found that vascular plant debris and soil humic material constitute the bulk of the POC transported in the lower river. They also concluded that degradation takes place primarily in the terrestial environment yielding refractory material comprising most of the particular input.

Silicon is a dissolved constituent and represents approximately 10% of the dissolved solids in an average river system (GESAMP Report and Studies No. 32, 1987). It originates from the natural degradation of minerals which is highly influenced by the temperature, amount of rainfall and relief.

Dissolved silicon is significantly removed from the river water system by biological processes and activities of the diatoms. This is, however, limited in unpolluted or clean rivers due to low biological productivity. The proliferation of diatoms is favoured in large rivers with relatively low water velocities. Silicon removal is likewise not discernible in unpolluted estuaries. In eutrophic estuaries, increased planktonic activity may be responsible for the total removal of dissolved silicon during summer while the extent of biological removal is almost absent in winter (GESAM Report and Studies No. 32, 1987).

Of the four nutrient components, only nitrogen and phosphorus compounds are of prime importance since they exhibit limiting effects on the growth of aquatic flora and fauna.

4. STUDY AREA

Pasig River is approximately 18.5 km. from Buting, Taguig to the mouth of Manila Bay. It is 80 - 100 meters wide and has varying depths from 2 - 7 meters depending on topography, season and tidal conditions (see Fig. 2).

It is geologically composed of volcanic tuff adobe to the east and west which are alluvial deposit of gravel, silt, clay and sand. The benthic bed is generally permeable, allowing water infiltration and formation of ground water.

This river follows quite a straight course except for the meandering curve at Sta. Anna, Manila, and practically cuts across the metropolis.

It has three (3) main river tributaries namely: Marikina, San Juan and Napindan Rivers and other smaller ones are composed of creeks and esteros.

The catchment area is approximately 366.8 km2 composed mainly of the major cities of Manila and Quezon, and several municipalities of Makati, Mandaluyong, Montalban, Marikina, Pateros, Pasig, San Juan, San Mateo and Taguig.

NATIONAL CAPITAL REGION

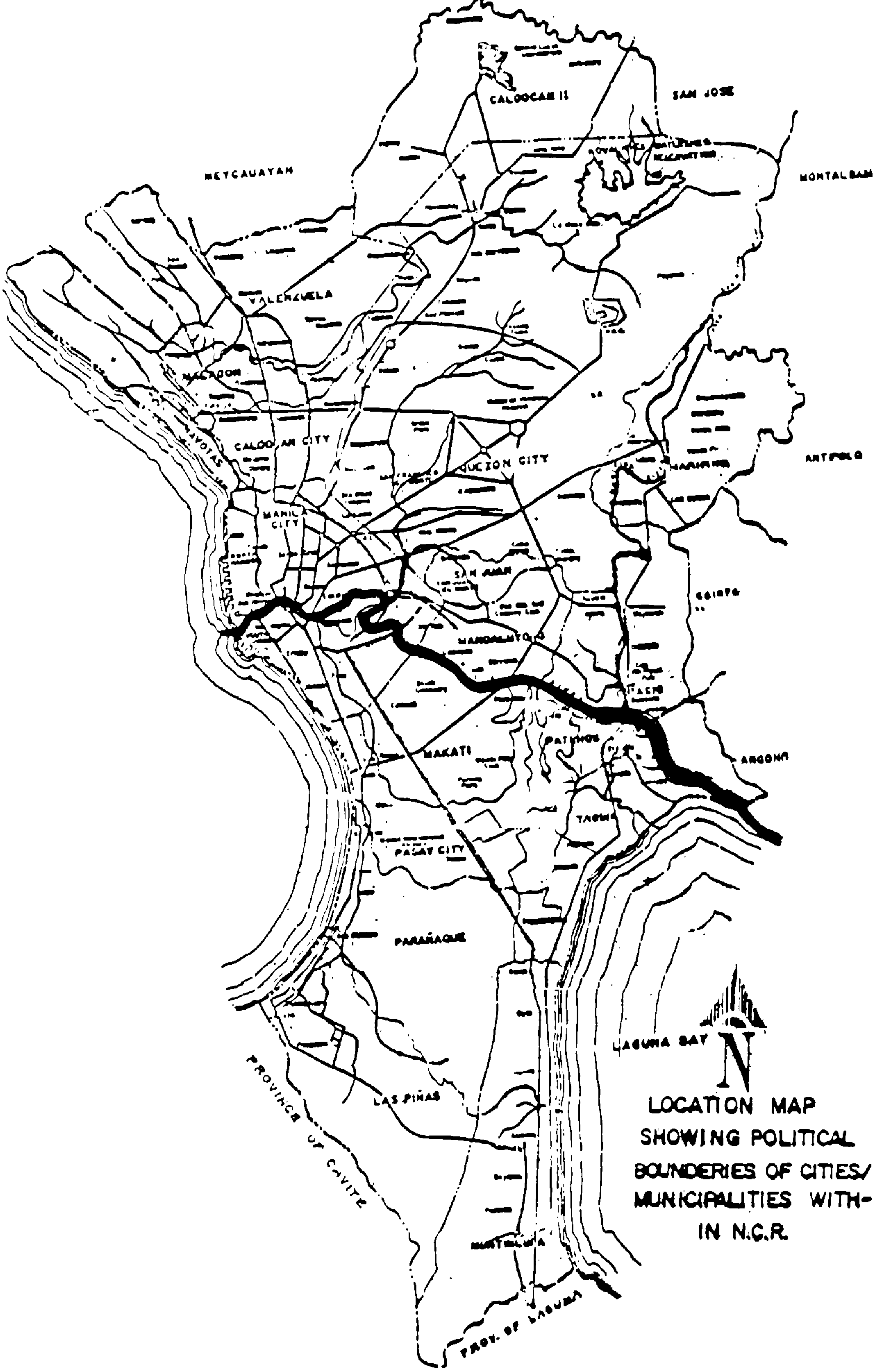
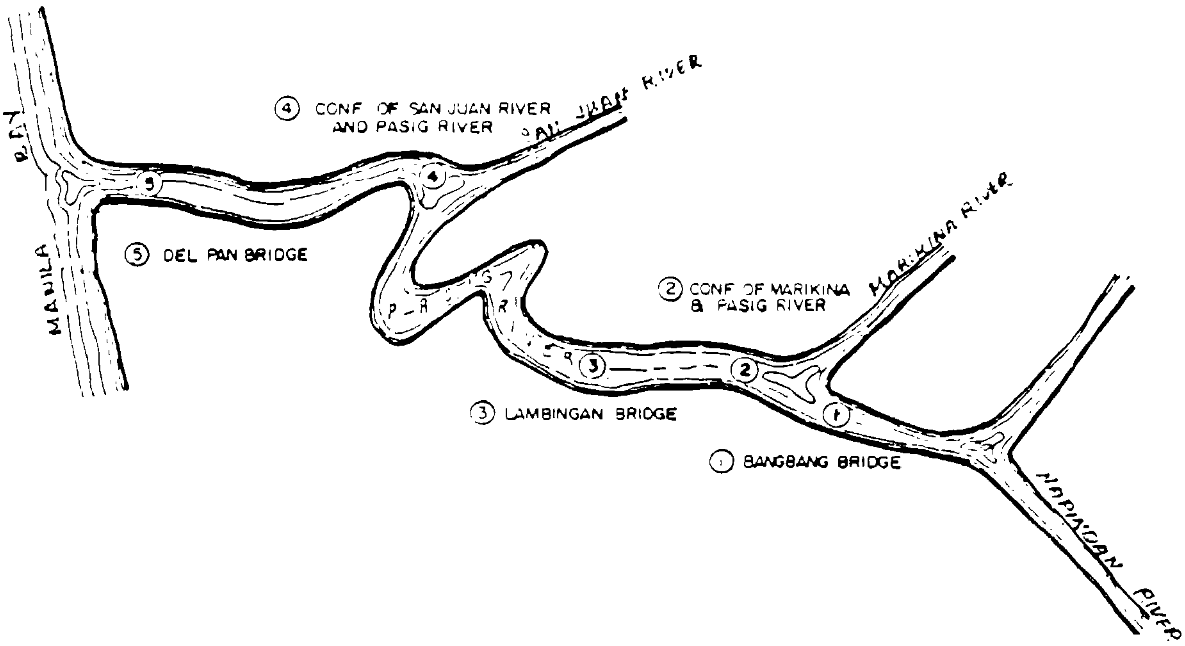


Table 1. Sampling Sites in Pasig River (1989)

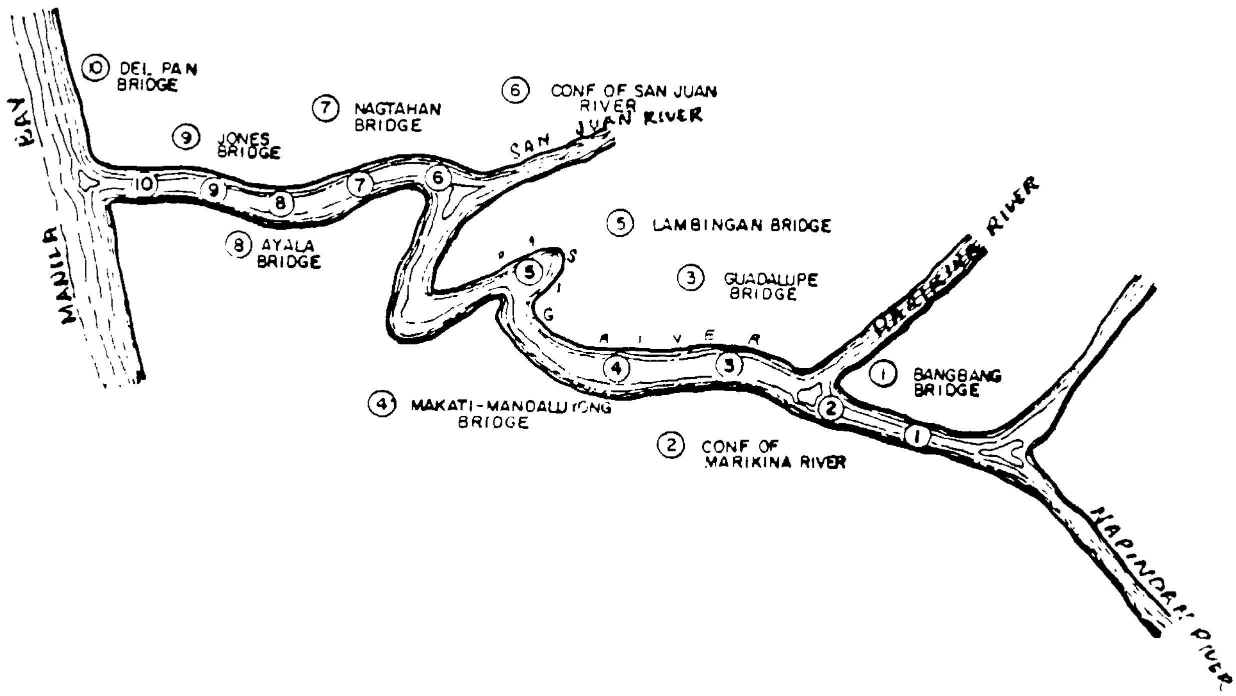
Station No.	Sampling Sites
Sta. 1	50 m. N. 40 00 E. from Bambang Bridge
Sta. 2	30 m. S. 10 00 E. Confluence of Marikina-Pasig River
Sta. 3	60 m. N. 80 00 E. from Guadalupe Bridge
Sta. 4	120 m. N. 40 00 E. from Makati-Mandaluyong Bridge
Sta. 5	120 m. S. 40 00 E. from Lambingan Bridge
Sta. 6	50 m. S. 40 00 W. Confluence of San Juan-Pasig River
Sta. 7	60 m. S. 70 00 E. from Nagtahan Bridge
Sta. 8	70 m. N. 35 00 E. from Ayala Bridge
Sta. 9	50 m. S. 65 00 E. from Jones Bridge
Sta. 10	30 m. S. 80 00 E. from Del Pan Bridge

Table 2. Sampling Sites in Pasig River (1990)

Station No.	Sampling Sites
Sta. 1	Bambang Bridge
Sta. 2	Confluence Area of Marikina and Pasig Rivers
Sta. 3	Outfall of Colgate-Palmolive Inc.
Sta. 4	Confluence Area of San Juan and Pasig Rivers
Sta. 5	Del Pan Bridge



SAMPLING SITES AT PASIG RIVER 1990



SAMPLING SITES AT PASIG RIVER 1989

The water-quality of Pasig River is highly affected by human activities and land-usage of the densely populated Metro Manila. The Metropolis present population is now 7.8 million (NCSO Census, 1990). Of these, 5.2% live 150 meters adjacent to the riverbank. Furthermore, there are about 250 industrial firms found without wastewater treatment facilities (Report, DENR-NCR, EMS, 1989). These are mainly composed of food processing, chemical manufacturing, glass and electroplating plants, soap and detergent, paper mills, textile mills, crude oil processors, petroleum and oil depots, distilleries and breweries, wood and lumber/steam laundry, cigar and cigarette facotries (Appendix C).

5. METHODOLOGY

Grab-sampling technique was used to obtain (1) liter samples at the surface (one meter below) and at the bottom (one meter above) with the aid of an improvised water sampler at the designated sampling sites shown in Tables 1 and 2.

There were 15 samplings made from March 1989 till October 1990. Activities were scheduled to cover both dry and wet season.

Samples taken were preserved by cooling in an ice chest and were brought to the laboratory for immediate analysis of the nutrient parameters, i.e. ammonia, nitrate orthophosphate and total phosphate.

General water-quality parameters such as dissolved oxygen, temperature and water depth were determined **in situ**. Laboratory procedures used in the analysis of nutrients were adopted from the Standard Methods for the Examination of Water and Wastewater. (American Public Health Association 15th edition). (See Appendix B).

The data gathered were statistically analyzed through the aid of the computer program called Statistical Analysis System (SAS) that generated the data on annual mean nutrient concentration, Analysis of Variance and Duncan's Multiple Range Test (Appendix A).

6. DISCUSSION OF RESULTS

The selection of sampling location was given primary consideration due to its effects on the water-quality condition of the river system as influenced by the varied activities of men. The sampling sites were categorized according to the anthropogenic inputs of nutrient, i.e. areas predominantly influenced by domestic wastewater and solid waste discharges and areas influenced by main river tributaries. Data found in Tables 3-5 were the mean concentrations for the above areas.

Based on the data gathered, the annual mean concentrations of ammonia and total phosphates were found high (NH_3 0.868 ± 0.062 mgN/L, and Total P 0.662 ± 0.008 mgN/L) at the confluence areas of the main river tributaries.

The study revealed that the main river tributaries contributed heavily to the increase in ammonia and total phosphate concentration in the iver system due to heady silation and garbage waste disposal.

Total and ortho-phosphates were found high (Total P, 0.606 ± 0.057, ortho P 0.397 ± 0.100) at areas with heavy domestic waste water discharge. The analysis of variance (Appendix A) showed that values obtained from each sampling station was significantly different from each other at __ = 0.05.

The general water-quality parameters i.e. dissolved oxygen water

Table 3. Mean Nutrient Concentration in areas in Pasig River with Heavy Domestic Waste Water Discharge.

STATIONS\ PARAMETERS	NH3 mg/L	NO3 mg/L	TOTAL P mg/L	ORTHO P mg/L
1. Bambang Br.	0.559	0.472	0.551	0.335
2. Guadalupe Br.	0.558	0.428	0.676	0.553
3. Makati-Mand. Br.	0.507	0.473	0.628	0.365
4. Lambingan Br.	0.542	0.380	0.568	0.335
X ± SD	0.541 ± 0.024	0.438 ± 0.044	0.606 ± 0.057	0.397 ± 0.106
Range	0.507 - 0.559	0.380 - 0.473	0.551 - 0.676	0.335 - 0.553

Table 4. Mean Nutrient Concentration in areas of Pasig River with Heavy Industrial Wastewater Discharge

STATIONS\ PARAMETERS	NH3 mg/L	NO3 mg/L	TOTAL P mg/L	ORTHO P mg/L
1. Nagtahan Br.	0.575	0.423	0.682	0.360
2. Ayala Br.	0.720	0.455	0.596	0.348
3. Jones Br.	0.693	0.400	0.520	0.360
4. Del Pan Br.	0.584	0.425	0.551	0.353
X ± SD	0.648 ± 0.074	0.426 ± 0.022	0.587 ± 0.070	0.355 ± 0.005
Range	0.584 - 0.720	0.40 - 0.455	0.520 - 0.682	0.348 - 0.360

Table 5. Mean Nutrient Concentration of the Confluence areas of the main river tributaries.

STATIONS\ PARAMETERS	NH3 mg/L	NO3 mg/L	TOTAL P mg/L	ORTHO P mg/L
1. Confluence of Marikina River	0.825	0.340	0.667	0.387
2. Confluence of San Juan River	0.912	0.413	0.656	0.381
X ± SD	0.868 ± 0.062	0.377 ± 0.052	0.662 ± 0.008	0.384 ± 0.004

Table 6. Water-Quality parameters in areas of Pasig River with heavy domestic wastewater discharge

STATIONS\ PARAMETERS	DO mg/L	Temp, C	pH, units	Depth, m
1. Bambang Br.	6.317	28.833	7.283	4.317
2. Guadalupe Br.	5.250	28.833	7.283	5.500
3. Makati-Mand. Br.	4.431	29.038	7.362	4.200
4. Lambingan Br.	4.633	29.375	7.142	5.683
X ± SD	5.158 ± 0.848	29.019 ± 0.256	7.268 ± 0.092	4.925 ± 0.775
Range	4.431 - 6.317	28.83 - 29.38	7.14 - 7.36	4.20 - 5.68

Table 7. Water-quality parameters in areas of Pasig River with heavy industrial wastewater discharge.

STATIONS\ PARAMETERS	DO mg/L	Temp, C	pH, units	Depth, m
1. Nagtahan Br.	3.508	28.792	7.092	5.017
2. Ayala Br.	3.533	29.208	7.050	7.100
3. Jones Br.	3.150	29.125	7.133	6.450
4. Del Pan Br.	3.017	29.000	6.750	6.650
X ± SD	3.302 ± 0.258	29.031 ± 0.181	7.006 ± 0.174	6.304 ± 0.90
Range	3.017 - 3.533	28.79 - 29.21	6.75 - 7.13	5.017 - 9.10

Table 8. Water-quality parameters at the confluence of the main river tributaries.

STATIONS\ PARAMETERS	DO mg/L	Temp, C	pH, units	Depth, m
1. Confluence of Marikina River	3.85	28.917	7.233	3.367
2. Confluence of San Juan River	3.950	28.0	7.175	5.117
X ± SD	3.90 ± 0.07	28.958 ± 0.059	7.204 ± 0.041	4.242 ± 1.237
Range	3.85 - 3.95	28.0 - 28.92	7.18 - 7.23	3.37 - 5.12

Table 9. Mean nutrient concentration at Pasig River areas influenced by heavy domestic during wet and dry season.

STATIONS\ PARAMETERS	NH3 mg/L DRY	WET	NO3 mg/L DRY	WET	TOTAL P mg/L DRY	WET	ORTHO P mg/L DRY	WET
1. Bambang Br.	0.42	0.68	0.28	0.61	0.61	0.57	0.39	0.43
2. Guadalupe Br.	0.41	0.68	0.27	0.55	0.66	0.76	0.49	0.65
3. Makati-Mand. Br.	0.37	0.61	0.29	0.61	0.57	0.73	0.43	0.56
4. Lambingan Br.	0.35	0.59	0.27	0.46	0.59	0.55	0.43	0.28
X ± SD	0.39±0.03	0.64±0.05	0.28±0.01	0.56±0.07	0.61±0.04	0.65±0.11	0.44±0.041	0.48±0.16
Range	0.35-0.42	0.59-0.68	0.27-0.29	0.46-0.61	0.57-0.66	0.55-0.76	0.43-0.49	0.28-0.65

Table 10. Mean nutrient concentration at Pasig River areas influenced by industrial wastewater discharge during wet and dry season.

STATIONS\ PARAMETERS	NH3 mg/L DRY	WET	NO3 mg/L DRY	WET	TOTAL P mg/L DRY	WET	ORTHO P mg/L DRY	WET
1. Nagtahan Br.	0.57	0.59	0.34	0.49	0.78	0.59	0.43	0.30
2. Ayala Br.	0.62	0.75	0.30	0.52	0.54	0.67	0.35	0.39
3. Jones Br.	0.62	0.75	0.28	0.42	0.41	0.68	0.33	0.55
4. Del Pan Br.	0.50	0.80	0.34	0.51	0.35	0.79	0.79	0.39
X ± SD	0.59±0.07	0.74±0.09	0.31±0.04	0.485±0.05	0.52±0.19	0.68±0.08	0.37±0.04	0.408±0.104
Range	0.50-0.62	0.59-0.80	0.28-0.34	0.042-0.52	0.35-0.78	0.59-0.79	0.33-0.79	0.30-0.55

Table 11. Mean nutrient concentration at Pasig River area influenced by the main river tributaries.

STATIONS\ PARAMETERS	NH3 DRY	WET	NO3 DRY	WET	TOTAL P DRY	WET	ORTHO P DRY	WET
1. Confluence of Marikina River	0.87	0.66	0.24	0.46	0.81	0.56	0.55	0.29
2. Confluence of San Juan River	0.76	0.70	0.22	0.54	0.74	0.54	0.55	0.28
X ± SD	0.82±0.08	0.68±0.03	0.23±0.01	0.50±0.06	0.78±0.05	0.55±0.05	0.00	0.29±0.01
Range	0.76-0.87	0.66-0.7	0.22-0.24	0.46-0.54	0.74-0.81	0.54-0.56		0.28-0.29

Table 12. Water-Quality Parameters at Pasig River Area with Heavy Domestic and Solid Wastes Discharges During Dry and Wet Seasons.

STATIONS\ PARAMETERS	DO, mg/L		Temp, C		pH		Depth, m	
	SEASON		SEASON		SEASON		SEASON	
	DRY	WET	DRY	WET	DRY	WET	DRY	WET
1. Bambang Br.	5.30	7.20	30.4	27.6	7.3	7.2	3.9	4.8
2. Guadalupe Br.	4.40	5.80	30.4	27.4	7.5	7.1	5.0	6.0
3. Makati-Mand. Br.	3.50	5.90	30.8	27.3	7.5	7.2	3.8	4.6
4. Lambingan Br.	3.60	5.50	31.4	27.5	7.2	7.0	5.9	5.5
X	4.20	6.10	30.75	27.45	7.375	7.125	4.65	5.225
SD	± 0.837	± 0.753	± 0.473	± 0.129	± 0.15	± 0.095	± 0.995	± 0.645
Range	5.30-3.50	7.20-5.50	31.4-30.4	27.6-27.5	7.5-7.2	7.0-7.2	5.9-3.8	6.0-4.6

Table 13. Water-Quality Parameters of Pasig River area with Heavy Industrial Wastewater Discharge During Dry and Wet Seasons.

STATIONS\ PARAMETERS	DO, mg/L		Temp, C		pH		Depth, m	
	SEASON		SEASON		SEASON		SEASON	
	DRY	WET	DRY	WET	DRY	WET	DRY	WET
1. Magtahan Br.	2.4	4.5	30.2	27.5	6.4	7.1	5.6	4.6
2. Ayala Br.	2.4	4.5	30.8	27.7	7.1	7.2	6.9	7.3
3. Jones Br.	1.7	4.1	30.6	27.7	7.0	7.0	5.8	7.1
4. Del Pan Br.	2.0	3.7	30.4	27.6	7.1	6.9	5.0	7.7
X	2.125	4.2	30.5	27.625	6.9	7.05	5.825	6.675
SD	± 0.340	± 0.383	± 0.258	± 0.096	± 0.337	± 0.129	± 0.793	± 1.406
Range	1.7-2.4	3.7-4.5	30.2-30.8	27.5-27.7	6.4-7.1	6.9-7.2	5.0-6.9	4.6-7.7

Table 14. Water-Quality Parameter at Pasig River area influenced by main river tributaries during dry and wet Seasons.

1989

STATIONS\ PARAMETERS	DO, mg/L		Temp, C		pH		Depth, m	
	SEASON		SEASON		SEASON		SEASON	
	DRY	WET	DRY	WET	DRY	WET	DRY	WET
1. Confluence of Marikina River	3.6	4.1	30.6	27.4	7.2	7.2	2.9	3.9
2. Confluence of San Juan River	2.4	5.5	30.8	27.2	7.3	7.1	5.6	4.7
X	3.0	4.8	30.7	27.3	7.25	7.15	4.25	4.3
SD	± 0.848	± 0.99	± 0.141	± 0.141	± 0.071	± 0.071	± 1.909	± 0.565

1990

STATIONS\ PARAMETERS	DO, mg/L		Temp, C		pH		Depth, m	
	SEASON		SEASON		SEASON		SEASON	
	DRY	WET	DRY	WET	DRY	WET	DRY	WET
1. Confluence of Marikina River	0.893	6.40	29.625	27.10	7.30	7.425	2.768	4.0
2. Confluence of San Juan River	0.97	5.25	28.30	28.738	7.319	7.375	3.925	5.1
X	0.932	5.825	28.963	27.919	7.309	7.40	3.347	4.55
SD	± 0.054	± 0.813	± 0.937	± 1.158	± 0.013	± 0.035	± 0.818	± 0.78

Fig. 2 Monthly Variation of DO

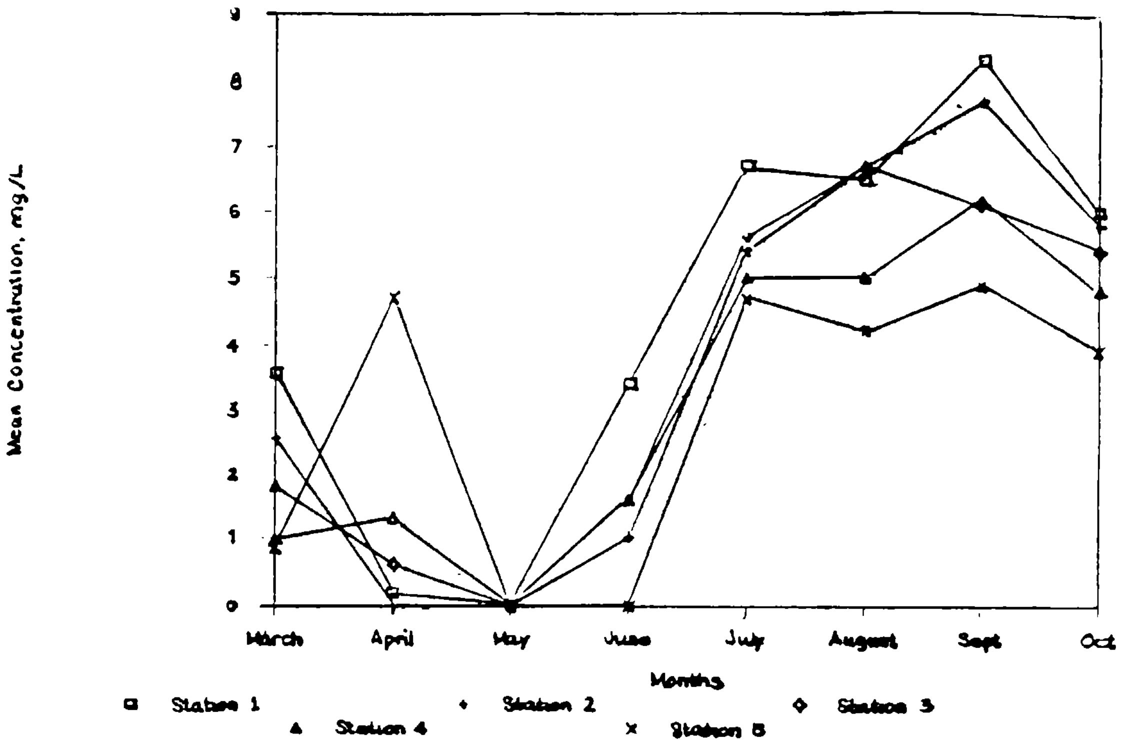


Fig. 3. Monthly Variation of Temperature

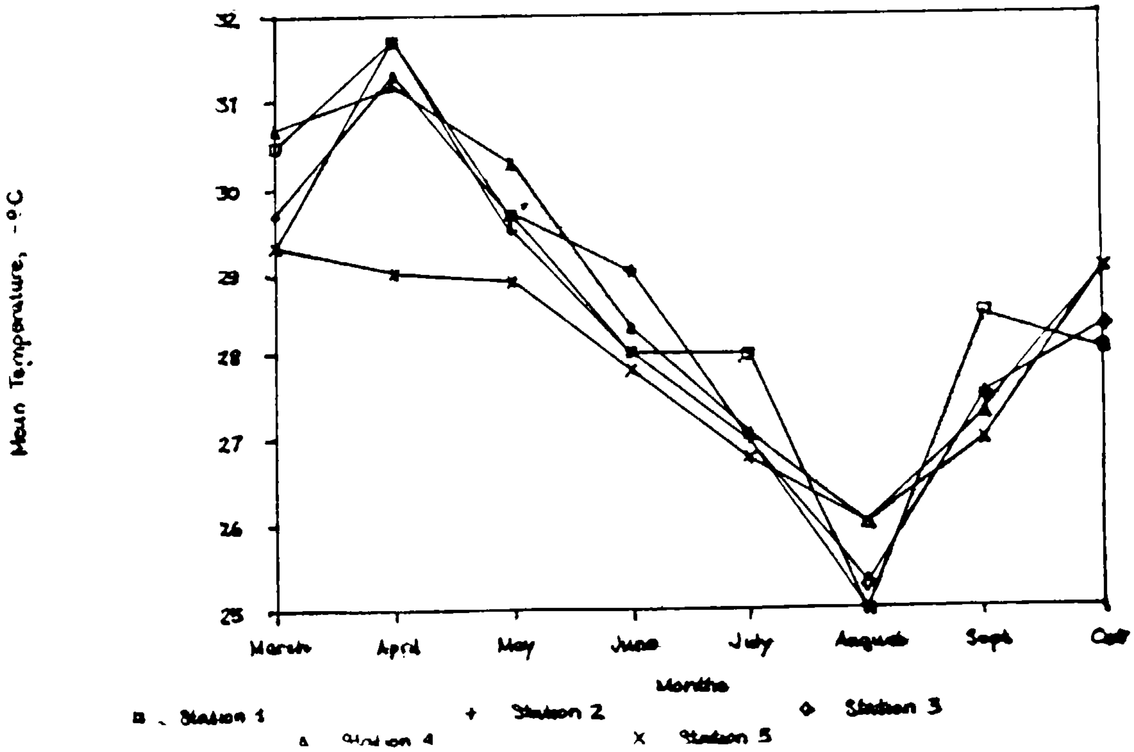


Fig. 4. Monthly Variation of pH

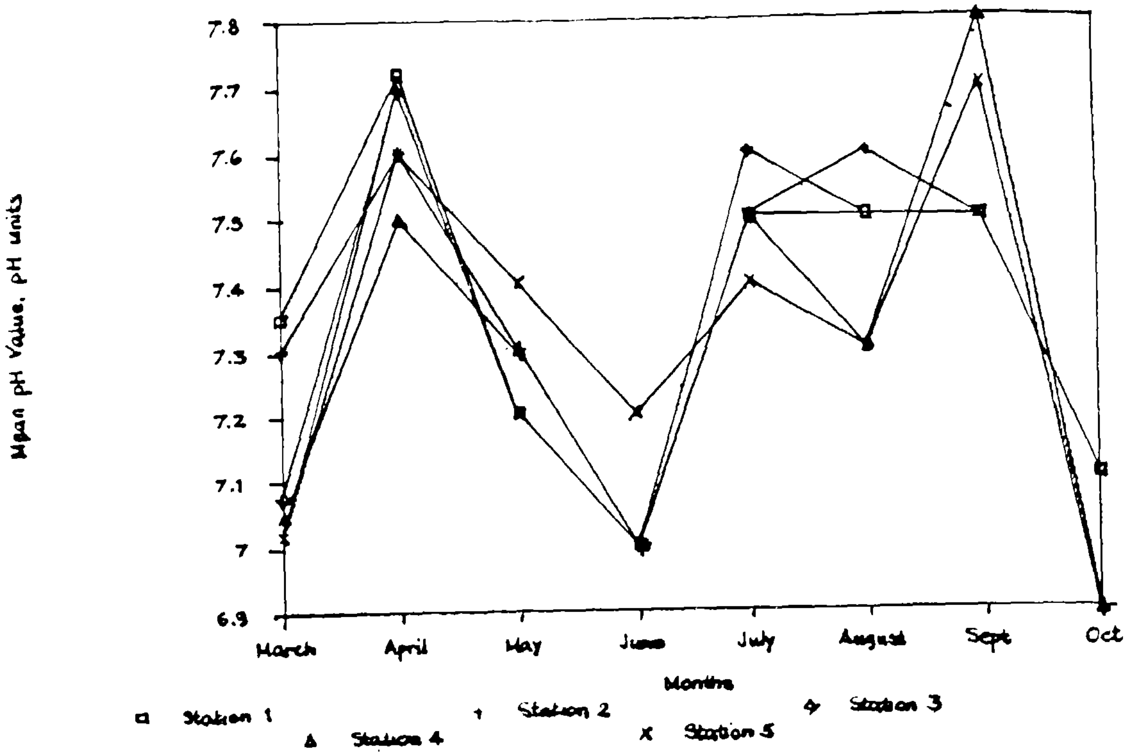


Fig. 6. Monthly Variation of Water Depth

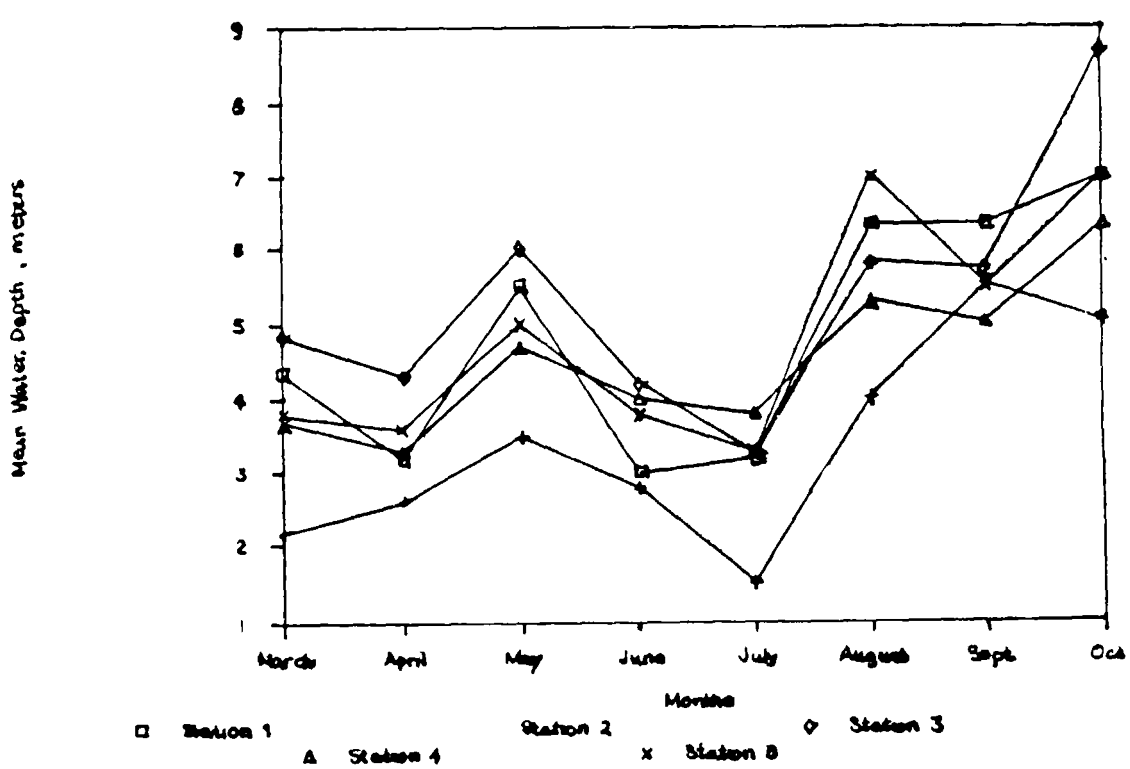


Fig. 6. Monthly Variation of Nitrate

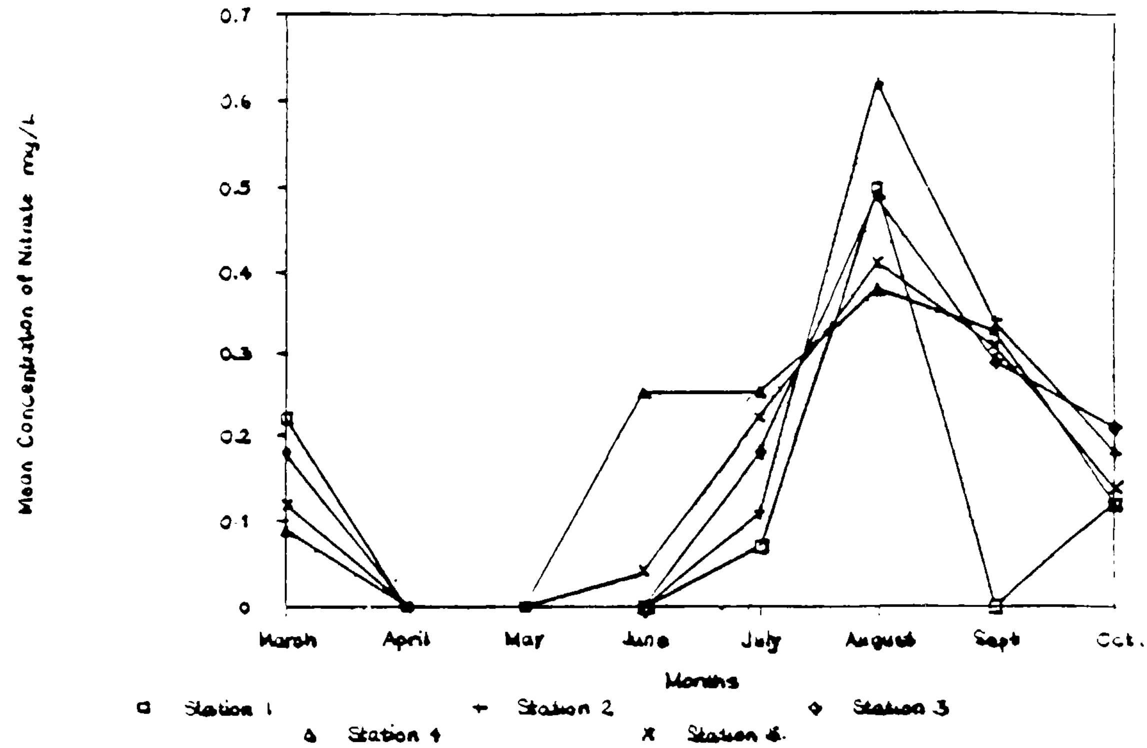


Fig. Monthly Variation of Ammonia

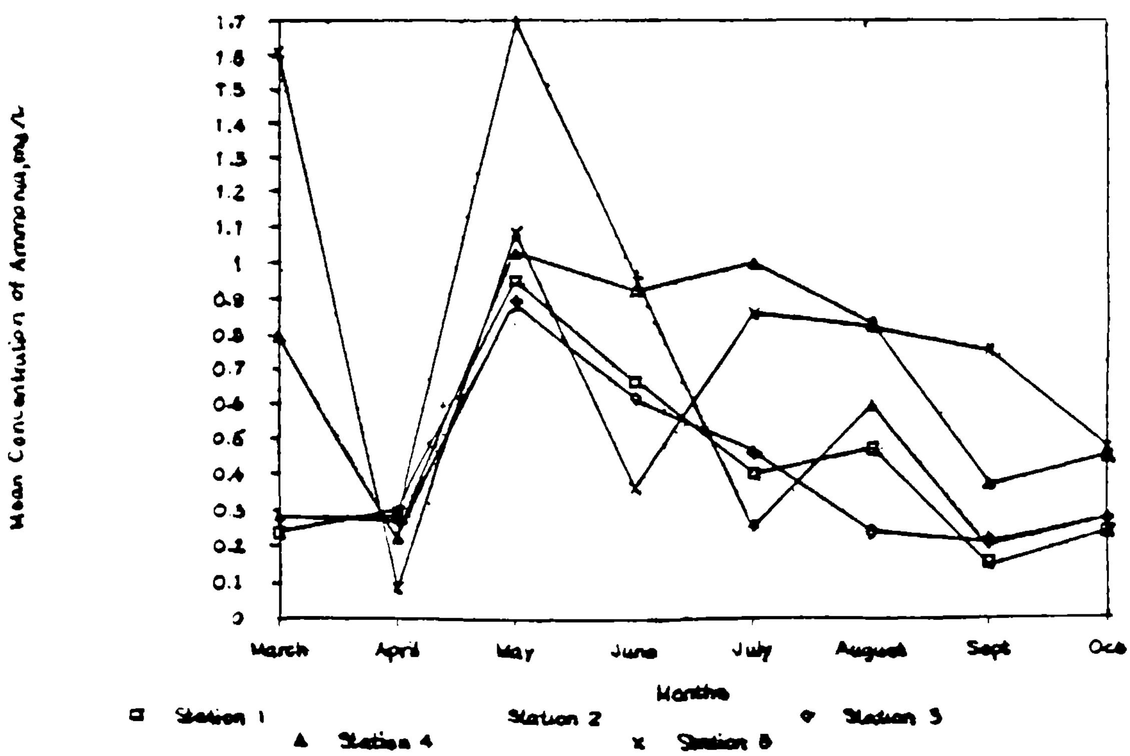


Fig. 8. Monthly Variation of Total Phosphorus

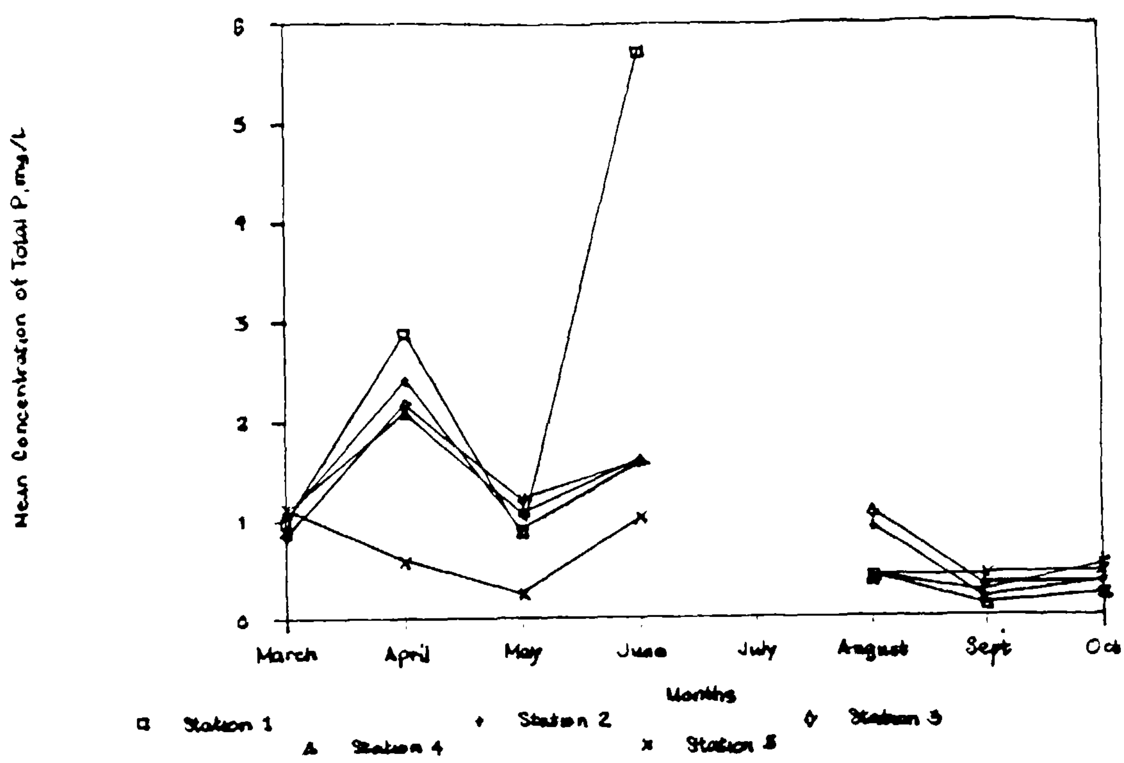


Fig. 9. Monthly Variation of Orthophosphate P

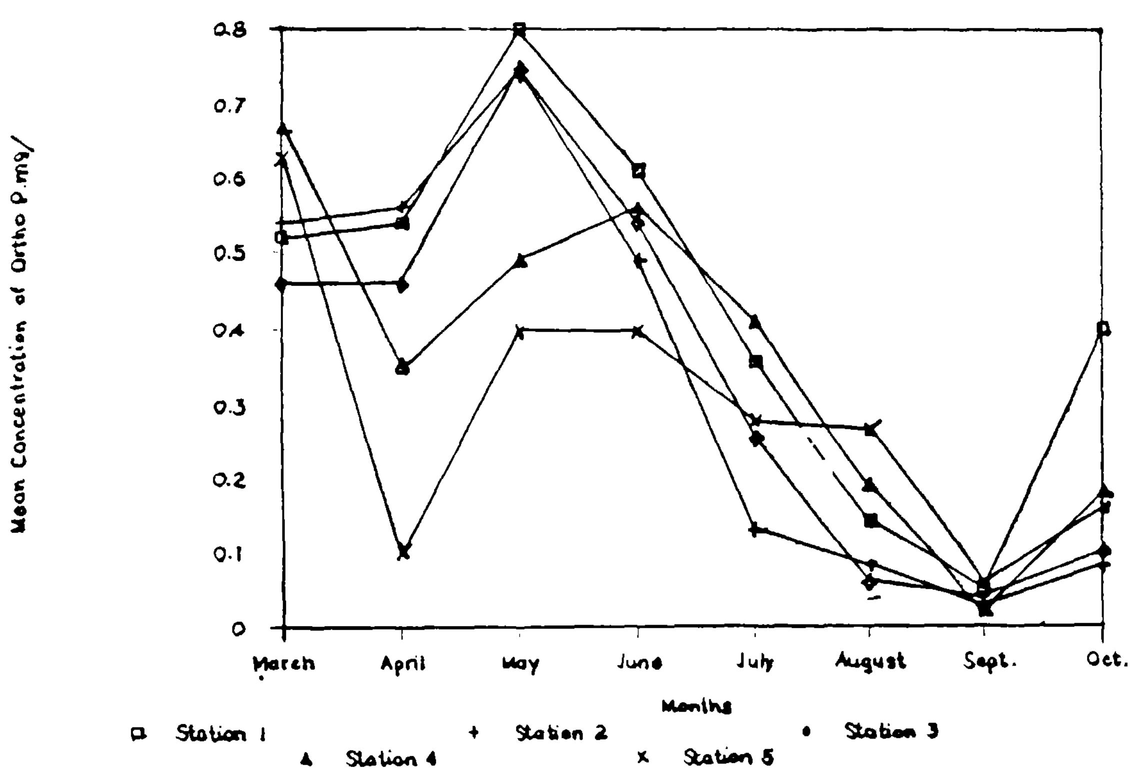


FIG. 10 MONTHLY AVE. RAINFALL (inches)

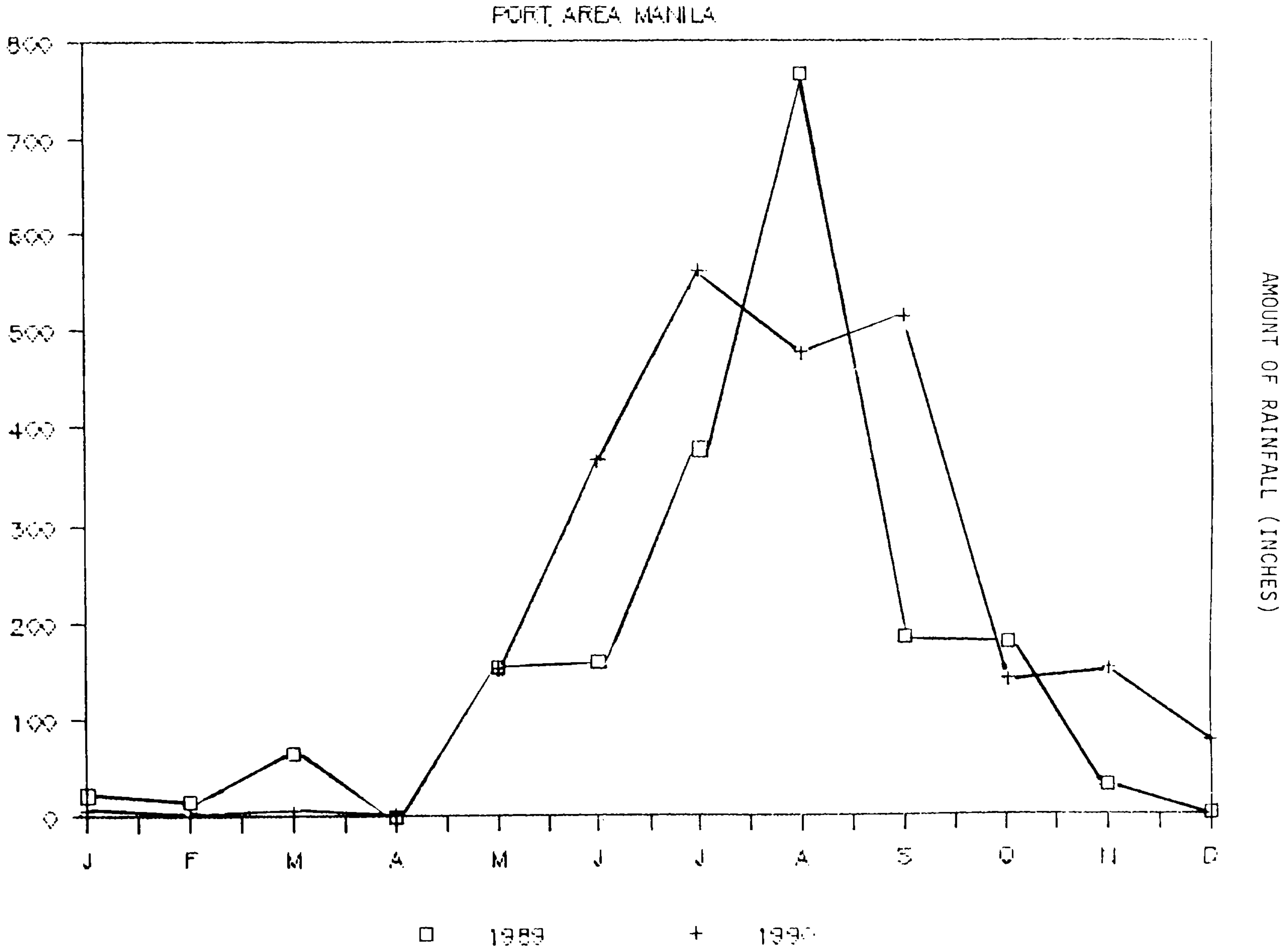


Table 15. Mean Nutrient and Water-quality Concentrations at the Transect Points of Pasig River.

STATIONS\ PARAMETERS	20 m Right of Midstream	Midstream	20 m Left of Midstream
NH3, mg/L	0.640	0.554	0.538
NO3, mg/L	0.130	0.187	0.196
Total P, mg/L	1.00	0.976	0.924
Ortho P mg/L	0.359	0.334	0.315
DO mg/L	3.048	3.751	3.751
Temp, C	28.45	28.48	28.52
pH, units	7.32	7.32	7.30
Depth, m	3.813	5.52	4.47

From the analysis of variance, however it was revealed that the transect point to the right of midstream showed relative increase in concentration of NH3, total and ortho-phosphates but relative decrease in DO and water depth. These variabilities were all found to be significantly different at α =0.05 from the other two (2) points. The existence of the main river tributaries at this portion of the river may be a significant factor to consider.

Annual mean concentrations from 1989 to 1990 are shown in Table 16.

Table 16. Annual mean nutrient and water-quality parameters from 1989 and 1990.

STATIONS\ PARAMETERS	1989	1990	% Increase/Decrease (1989 - 1990)
NH3, mg/L	0.720	0.569	20.97
NO3, mg/L	0.413	0.173	58.11
Total P, mg/L	0.606	0.964	37.13
Ortho P mg/L	0.364	0.317	12.91
DO mg/L	4.283	3.747	12.51
Temp, C	28.94	28.50	1.52
Depth, m	4.88	5.21	6.71

temperature, pH and water depth also showed variability as shown in Tables 6 - 8.

Dissolved oxygen concentrations in Pasig River were observed below the minimum requirement of 5.0 mg/L DO, i.e. 3.302 ± 0.258 mg/L and 3.9 ± 0.07 mg/L at areas influenced by industrial plants and main river tributaries, respectively. Other water-quality parameters i.e. water temperature were found

to be average at 29.0 C and pH at 7.10. Water depth was observed to vary depending on topography and amount of silted material deposited in the riverbed.

Another factor considered was the impact of seasonal variability to the nutrient concentration. In Tables 9 - 11, the variations of nutrient concentration were shown in relation to climatic/seasonal changes and anthropogenic activities within the watershed.

Ammonia, nitrate, total and ortho-phosphates showed relative increases from dry to wet seasons in areas influenced by domestic and industrial activities. However, in areas affected by the river tributaries there was a decrease by 17%, 29% and 47% for the nutrient parameters of NH_3, Total P and ortho P, respectively, from dry to wet season. Nitrate, however, was observed to increase by 54% with the change in season. The analysis of variance showed that values obtained were at ___ = 0.05 during dry and wet season.

In Table 12, the general water-quality parameters improved with the onset of the rainy months, specifically in the case of dissolved oxygen concentration.

The graph of monthly variations of nutrient and water-quality parameters (Figs. 2-9) showed the months of April and May exhibited relatively low mean values of NO_3, Total P, ortho-P and DO. The dissolved oxygen and nitrate concentration, as a matter of fact, were observed to be zero in these months at all sampling points in 1990. While August and September showed relative increases in the mean values of the above parameters. This may be attributed to the heavy precipitation received within the watershed area with accompanying fast flow of water current that flushed the pollutants from the mainstream. Even the physical qualities of the riverwater were observed to improve in color from murky black to brownish hue and the smell of the water apparently diminished.

The amount of precipitation shown in Fig. 10 may explain the cause of these variabilities in concentrations since rainfall is also considered to be one of the major sources of nutrients.

Data obtained at the transect points of the designated sampling sites (Table 15) showed that Pasig River is well mixed at some points due to its turbulence and water depth.

From the analysis of variance, however it was revealed that the transect point to the right of midstream showed relative increase in concentration of NH_3, total and ortho-phosphates but relative decrease in DO and water depth. These avariabilities were all found to be significantly different at ___ = 0.05 from the other two (2) points. The existence of the main river tributaries at this portion of the river may be a significant factor to consider.

Annual mean concentrations from 1989 to 1990 are shown in Table 16.

Based on the above data, it is implied that the water-quality of Pasig River had gradually deteriorated from 1989 to 1990. The dissolved oxygen was decreased by an average of 12.5%, nitrate by 58.11%, and ammonia by 20.9%.

While the total phosphate concentration on the otherhand, was increased by 37.1%. Heavy accumulation of wastes during prolonged dry seasons seem to cause the above condition in Pasig River.

7. CONCLUSIONS

From the results of this study the following inferences were made:

1. The primary source of nutrients in Pasig River comes from the main river tributaries of San Juan and Marikina Rivers which was observed to be heavily polluted with domestic and solid waste discharges, and industrial wastewater effluents.

2. Dissolved oxygen, a basic factor for aquatic life propagation and survival, was observed below the minimum requirement of 5.0 mg/L at areas near industrial plants and confluences of main river tributaries.

3. During summer months, the worst condition were observed in April and May. DO were found to be zero at all sampling stations in May, 1990.

4. The water depth varied depending on topography and amount of silted material deposited on the river bed.

5. Nutrient parameters (NH_3, Total P and ortho P) increased during rainy season due to turbulence and scouring of river beds at the mainstream. However, nutrient concentration showed marked decrease at the confluence of river tributaries.

6. Nitrate, a nitrogen form which is readily absorbed by algae and plants, increased during the wet season which may be attributed to the increased oxygenation of water.

7. The general water quality condition of Pasig River showed marked improvement at the onset of the rainly season. The months of August and September exhibited the best condition of river system.

8. The transect point to the right of the midstream (flow direction towards Manila Bay) showed faster deterioration due to the heavy siltation and transport of organic pollutants from the two (2) main river tributaries found at this location.

9. The water-quality of Pasig River areas was observed to gradually deteriorate based on the data analyzed for two (2) successive years of observation.

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NUTRIENT FLUXES OF A MALAYSIAN MANGROVE ESTUARY

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ABSTRACT

The Sungai (River) Merbok in Kedah, Malaysia (5°30'N, 100°25'E) is the subject of an ongoing, long-term study (started in 1980) that focuses on the exchange of organic matter and mineral nutrients between the estuary and adjacent coastal waters. Most of the parameters required for discussion at this Workshop have been recently documented by Ong et al. (1991). The abstract of the paper is as follows:

"The Sungai Merbok estuary, in wet tropical Peninsular Malaysia, borders the Straits of Malacca. Tide, current and salinity data are used to describe the salient hydrographic features of the mangrove-fringed system. The Sungai Merbok estuary is characterised by a 1.7 m semidiurnal tide with a 0.16 form number, peak currents of 1.3 m s^{-1}, and mean freshwater discharge of 20m^3 s^{-1}. The system is classified as 2a/2b estuary (Hansen & Rattray, 1966) or 1a/1b during periods of low runoff. Gravitational circulation is highly variable (but coincides with neap stratification) and vertical stratification varies from 10^{-2} to 1. The estuary displays a pronounced fortnightly neap-spring stratification- destratification cycle. The effective longitudinal dispersion coefficient is approximately 100 m^2 s^{-1}."

A number of data sets (including one of 31 continuous cycles involving 4 Stations and tidal-hourly measurements of currents, salinity and nutrients) has been collected and analysed/computed using the method described in Kjerfve (1979). Estimates appear to be about an order of magnitude too high and this problem is being investigated.

Whilst problems with nutrient analyses are surmountable the problem with computing fluxes is perhaps less so, especially in stratified estuaries. In this respect, we suggest that the project looks into mathematical and ecological modelling.

1. INTRODUCTION

The understanding of the quantitative relationship between the productivity of mangroves and the fisheries of the adjacent coastal waters is vital to the rational management of the mangrove ecosystem. Although there are now a number of very convincing studies that statistically link the areal extent of mangroves to shrimp or prawn landings (e.g. Martosubroto & Naamin, 1977, Turner, 1977 and Gedney, Kapetsky & Kuhnhold, 1982) the causal effects are less convincing. With increasing pressures by increasing numbers of users of the mangrove ecosystem, this link has to be quantified.

The question of "outwelling" (Odum, 1968) is a complex one and has been addressed in some detail for the salt marsh ecosystem. Nixon (1980) has very ably reviewed this question with respect to salt marshes and there appears to be no simple solution.

The Mangrove Ecosystem Research Group at Universiti Sains Malaysia, with generous funding from the IDRC of Canada, Intensification of Research in Priority Areas (IRPA) funding of the Government of Malaysia and infrastructural support of the Universiti Sains Malaysia has been working on this complex problem since 1984. Our group has focussed on the Sungai Merbok, a mangrove fringed estuary with a single opening into the sea. This single opening into the sea means that fluxes of materials like carbon or plant nutrients may be more easily monitored. The physical characteristics of the Sungai Merbok including the "physiographic characteristic of the river system such as watershed size, relief, discharge, geology, vegetative cover, and major agricultural activities" have been described in some detail recently by Ong et al. (1991). Basic details of the hydrodynamics were also described. We will thus not repeat the description in Ong et al. (1991) which will be made available to the Meeting.

Data sets covering 48 tidal cycles have been collected (from 4 to 9 stations across the mouth of the estuary (this includes a unique set from 4 stations and covering 31 continuous tidal cycles). The procedure used is essentially that described by Kjerfve (1979). This essentially involves measuring current velocities and collecting water samples for salinity and nutrient analysis (at different depths, tidal hourly over one or more tidal cycles). The discharge and nutrient fluxes were then computed using the programmes described by Kjerfve (1979).

Some of the discharge and nutrient flux patterns are presented and discussed. There appears to be an order of magnitude over estimate of discharge. We discuss the problems associated with using this approach to measure discharge and nutrient fluxes from the Sungai Merbok estuary.

We also briefly discuss the methods used in determining currents, salinity, and nutrients (N, P, Si & C).

2. DISCHARGE

The Sungai Merbok unfortunately is not gauged. Our estimate of the mean annual discharge of the river is about 20 $m^3 s^{-1}$. This is based on rainfall, size of catchment and evapotranspiration. The figures we obtained from measuring currents and using the computational method described in Kjerfve (1979) is on the average about an order of magnitude larger (than the calculated 20 $m^3 s^{-1}$). These computations have been very carefully checked a number of times and we are sure this discrepancy is not a computational error. We have also had three very eminent physical oceanographers look at (and work with) our data sets and computations and, to date, we have been unable to pinpoint the reason for this discrepancy. One weakness may be that we use the very simple (but also inexpensive) current vanes to measure current velocities and these may not give accurate enough readings. This, coupled with the stratified nature of the estuary during neap tides (Uncles, Ong & Gong, 1990) may be responsible for part of this problem. We are also unable to balance the salt budget for the estuary from our data (Dyer, Gong & Ong, in press) which is the main reason why we are not confident of our estimates! We are still looking into the problem. We just like to emphasise however that the hydrodynamics of estuaries are far from understood and existing methods may not be good enough for accurate estimates of fluxes of nutrients especially in stratified estuaries. This is our point of view as ecologists who have worked with some of the leading coastal physical oceanographers on this problem over the last 7 years.

Yet, Wolanski et al. (1980) and Wolanski & Ridd (1987) have been able to estimate material fluxes from their mangrove estuaries in Australia. But we must emphasise that there is one important caveat: their estimates were based on measurements in the dry season when there was no freshwater flow (and thus no problems with stratification?). In the really wet tropics we do not or rarely get this zero freshwater input situation. Even if we do, we can only arrive at fluxes during the dry season: what happens when it rains is a completely different matter.

We may thus have to resort to 3 dimensional mathematical modelling which is not an easy task. At the same time, it will be useful to look into ecological models (this requires the right type of data but is easier to handle than 3 dimensional mathematical models). In this respect, we suggest that this project may do well by bringing in experts in estuarine physical oceanography as well as mathematical and ecological modelling.

3. NUTRIENT FLUX

Since we cannot get a proper handle on discharge, we are also not able to obtain reliable figures of nutrient fluxes. There are also added problems in the determination of the various nutrients in estuaries where salinity fluctuates from 0 to 30 or so parts per thousand. Most method manuals are written either for seawater or freshwater so one has to be careful of salt effects with brackish waters. The methods we use are described in Ong et al. (1985). We usually only measure total P and total N and not their various redox species (e.g. total N rather than ammonia, nitrite and nitrate) because we do not have the facilities to measure huge numbers of samples over a short time and storage could result in conversion from one form to another depending on redox state as well as presence or absence of microorganisms. For N and P we use an alkaline persulphate method (Koroleff, 1983) to oxidise both N and P. This cuts down considerably on time. For N, the oxidised form is reduced to nitrite using cadmium-copper columns (Wood, Armstrong & Richards, 1967) and determined as nitrite. Our experience is that cadmium-copper columns can be extremely fickle in their ability to reduce nitrate to nitrite. We certainly like to hear from others who have used this method. We do not have any real problems with the molybdate method to determine P except for the occasional problem with the reducing agent (less than fresh ascorbic acid or partly oxidised stannous chloride).

We use the method of Strickland & Parsons (1972) with some modifications (Fanning & Pilson, 1973) for Si. The method is tedious but we do not encounter any insurmountable problems although preparing the standards may be a problem. One way to solve this problem is to beg for some from a good laboratory. This method allows for salinity correction which is vital for estuarine work.

Whilst it is relatively easy (though tedious) to determine particulate organic carbon (POC), dissolved organic carbon (DOC) has been a pain for us.

We determine POC by difference in weight after combusting total suspended sediments (TSS) collected by filtration of glassfibre filters at 450°C. Variability is high so at least 3 (but preferably 5) samples are almost always required. Nonetheless the method is simple, does not require complex equipment and the results are reasonably reliable, with the usual care.

DOC on the other hand requires complex equipment. We use an instrument based on oxidation and acid digestion to liberate CO_2 which is then mesured with an infrared gas analyser. We have encountered many problems. This is partly due to working with estuarine samples where the salinity changes from sample to sample. Chloride in seawater interferes with the digestion chemistry so it is necessary to obtain standards of different salinities and then make the necessary corrections. Liberated chlorine must also be scrubbed from the system to prevent damage to the infrared gas analyser. It is also necessary to extend the period of digestion as well as increase the amount of digest for water with a high chloride content. We have not fully solved this problem and would like to hear from others who have.

One very useful thing that this project can do is to have a good laboratory prepare standards and make these available to all participants. This will provide participants with checks for their analytical methods and ensure that data from the project are reliable.

4. SAMPLING DESIGN

We have to look at both the spatial and temporal aspects. Kjerfve et al. (1981) have considered the spatial aspect in some detail. For our 900 m cross-section we have used up to 9 stations. This allowed us to determine the lateral variability of the estuarine cross-section and the eventual number of stations we pick would then depend on resources available and the precision we require. It is usually possible to get away with just three or even two stations when the hydrodynamics of the cross-section is better known. Apart from stations in the cross- section it is usually useful to have at least one more station upstream (e.g. to calculate dispersion coefficient and modelling).

For currents we sampled at metre depths and for nutrients we sampled at surface, mid-depth and bottom. Again, the intensity of sampling is dependent on resource availability and logistics but sampling at three depths would be a minimum, unless the estuary is very shallow or very well mixed.

Temporally, we sample every tidal hourly (1 hr 2 min) but it is possible to get away with sampling every 2 hours. The minimum period of sampling is over at least 1 tidal cycle. We routinely do a minimum of 3 tidal cycles since our semi-diurnal tides are not equal. This does not take into account the spring-neap cycle so we have done a 31 tidal cycle series to include this. Such a long series involves massive logistics. 4 (stations) X 3 (depths) X 12 (samplings per tidal cycle) X 31 (tidal cycles) = 4,464 (data points). This is just for one parameter (e.g. salinity) and does not take into account replications. If 3 replicates are necessary (e.g. for TSS / POC) then the number becomes 13,392 i.e. one has to dry, weigh, wrap and label 13,500 glass fibre filters before the actual field trip. We are thus dealing with a highly labour intensive exercise. Samples have also to be carefully labelled and packed so that they do not spill, break or lose their labels. Preservation problems arise if analyses cannot be carried out immediately. All in all there is a need for very careful planning. We suggest that a pilot 1 (certainly not more than 3) tidal cycle exercise be first carried out to iron out any bugs in the logistics. The numbers become more and more daunting but with a good understanding of the estuarine hydrodynamics, it is possible to rationally reduce the number of samples needed.

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AMUR RIVER AS A RIVER POTENTIALLY SUITABLE FOR INCLUSION IN THE IOC/WESTPAC RIVER INPUT PROGRAM

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INTRODUCTION

Pollution is the introduction of matter and energy into the marine environment which can have negative consequences [1].

We have to consider pollutant transport into coastal and marine environment as a result of action of physical, chemical, biological and geological processes taking into account natural and man-made sources and possible ways of the migration of material into the sea such as river input, atmospheric transport, coast erosion, bottom - seawater underwater fluxes, etc. and in homogeneous distribution of matter and energy fields at the boundary: Asian continent - Western Pacific Ocean [1,2].

River input is an important source of material (including pollutants) for marginal seas of Western Pacific. Consideration of riverine systems of this region led us to recommend to include a set of USSR rivers in the IOC/WESTPAC river input program. The Amur River is the most important among these rivers due to large discharge and drainage area characteristics.

MAIN AMUR RIVER CHARACTERISTICS

Amur River is one of the largest rivers of East Asia and the largest river of the Soviet Far East (Table 1). The length of Amur River (jointly with rivers Ingoda and Shilka) is about 4444 km (second place between rivers of USSR). Its catchement area is about 1,856,000 km^2 (fourth place between rivers of the Soviet Union) [3].

Table 1. Main Characteristics of the Amur River System

Total Length	4444 km
Drainage Area	1856000 km^2
Average Discharge	8360 m^3/sec
SPM Concentrations	
Upper Amur	~ 1 mg/l
Ussury Basin	20-60 mg/l
Lower Amur	50-80 mg/l
Mineralization	
At Winter	103-150 mg/l
At Summer (flood)	35-75 mg/l
At Autumn	60-80 mg/l
Rain Precipitation	
Upper Amur	400-500 mm/yr
Lower Amur	700-800 mm/yr
Ice Cover	November-April

Physiographic and Geological Description

On the USSR territory one can see 3 major parts of the Amur River watershed:

(1) Upper and Middle Amur River (Chita and Amur administrative regions);

(2) Watershed of the largest southern tributary - Ussury River, covering considerable part of the Primorye administrative region;

(3) Lower Amur River - from Khabarovsk (after Ussury tributary) to the mouth (Nikolaevsk-na-Amure).

The upper part of the watershed of Amur River is mainly mountain country (latitudes 1000-1500 m). Mountain ridges are represented by acid magmatic and metamorphic rocks (granite rocks of different ages mainly). Mountain valleys are filled by silty (sandy) materials and by clays, covered by alluvium. Watershed area in Primorye region (Ussury drainage Basin) is represented by mountains Sikhote-Alin with altitudes up to 1000-2000 m and by west Primorian plain, very humid and covered by water at considerable extent. Disolcated sedimentary rocks, metamorphic and volcanic rocks of different composition and genesis with granite intrusions are typical here.

Lower Amur is mainly mountain country with the contribution of plains ~ 30-35% of total drainage area. Mean altitudes of mountains are up to 1000 m, maximal altitude - 2500 m. All types of geological formations are found here: sedimentary and volcanogenic sedimentary rocks with intrusions of basic and acid composition, effusives of acid, middle and basic composition.

Major part of the watershed area of Amur River on the territory of USSR is covered by forest ("taiga") and only southern part of the drainage basin is represented by grassland and dry grassland of mongolian type.

Climate, Rainfall and Discharge Characteristics

In monsoon zone of the South East Asia the catchement area of the Amur River takes northern position.

Influences of marine tropical air (main element of summer monsoon) and arctic air are typical for this area [4]. Possibility of interaction of these contrasting air masses is main distinguished feature of the Amur River Basin compared with other zones of East Asia monsoon circulation [4]. Namely, these conditions cause the most large floods on rivers of Amur River Basin. As a result of this fact, main water origin for rivers of Amur watershed is connected with rains. Snow melting and groundwater sources are not so important.

Major amount of rainfall is observed at summer period. At the limits of upper and middle Amur River watershed annual rainfall varies from 400-450 mm to 200-300 mm from the north to the south. For Primorye territory it accounts 700-1000 mm per year. On the watershed of Lower Amur, it is equal to 700-800 mm per year.

90-year-long observations of Amur River discharge near Khabarovsk showed 10 year periods of homogeneous values of water discharges [3,4]. The largest floods were registered at 50-th years of XX century. 80th years of this century are characterized as period of approximately continuous floods. Solar activity changes possibly cause this catastrophic consequence [3,4]. Amur River discharge distribution is also extremely variable during the year due to rainfall changes. Major part of Amur River discharge is observed during warm period of the year (up to 90-95%). After small spring flood (April-May) the decrease of the discharge takes place in June - first half of July. The discharge of Amur River becomes the larges in the middle of second half of the summer (July-August) as a result of intensive rains connected very often with taiphours [4].

From November to April rivers of Amur Basin usually are covered by ice. Small tributaries may be frozen from the surface to the bottom.

Chemical Composition and Input of Materials, Mineralization and Main Constituents

Mineralization of Amur River water at winter period accounts 103-150 mg/l. During flood period it decreases to 35-75 mg/l and later (at autumn) increases to 60-80 mg/l [5].

The mineralization and chemical composition of Amur River water between Lhabarovsk and Nikolayevsk-na-Amure has only small changes (some decrease of mineralization to the lower part of the river). Water composition is hydrocarbonate-calcious [5]. Seasonal changeability of the mineralization and of concentrations of major constituents of chemical composition of amur River water is characterized by Mordovon *et al.* [6].

During ice cover of the Amur River surface at some sites (665 and 560 km from the mouth) the change of chemical composition of water from hydrocarbonate-calcious to hydrocarbonate-sodium was found due to input of groundwater enriched by Na^+ and SO_4^{2-}-ions. It leads to extremely variable distribution of Na^+, SO_4^{2-}, and Cl^--ion concentrations in water from Khabarovsk to the point situated at the distance 465 km from the mouth [6].

Influence of waste water discharges of large cities (Khabarovsk, mursk and Komsomolsk-n-Amure) was revealed in the study of Cl^-, SO_4^{2-} seasonal distributions in Amur River water [6].

Nutrients

The review of nutrient and organic matter data obtained by standard observations at stations of USSR State Committee for Hydrometeorology in 1939 - 85 years for river waters of Amur River Basin is given by Pogadaev (1988) [7].

Maximal content of NH_4^+ ions and NO_2^--ions (in elemental nitrogen units) in river water changes correspondingly from 0.420 to 4.464 mg/l and from 0.002 to 0.045 mg/l. Self-purification of water from ammonium and nitrite-nitrogen was found to be expressed the most intensely during floods, being conditioned not only by fast flow of rivers but also by presence of considerable amounts of dissolved oxygen in waters [7].

Maximal contents of nitrate (in elemental nitrogen units) being 0.018-0.835 mg/l were typical for winter time and spring flood, when the consumption of nitrogen compounds by vegetation water organisms is stopped. For summer due to this consumption of nitrogen may lead to full disappearance of nutrients in water [7].

Maximal concentrations of phosphorous in Amur River water are changing from 0.131 to 0.261 mg/l in the part of the river between Chernyaevo and Blagoveshchensk and from 0.083 to 0.193 mg/l between Khabarovsk and Nikolaevsk-na-Amure. The largest concentration of phosphates (up to 0.441 mg/l) was found during cold season [7].

Silicon concentrations in river water of Amur River and tributaries varies from 0.2 to 18.0 mg/l. High concentrations of Si in waters are conditioned by enriched groundwaters in some sites [7].

During spring flood content of Si-containing compounds decreases to 0.2-11.5 mg/l, but during summer flood period a considerable increase of the content of this element up to 12-18 mg/l was registered, possibly due to elevated weathering of silicium from the soil in comparison with cold seasons [7].

Considerable variations of nutrient concentrations in Amur River water were found, especially for nitrogen and phosphorus near cities due to domestic waste water discharges [7].

Organic Matter

Only first estimates of organic matter distribution in Amur River water were accomplished [6,7]. Mean concentration of total organic matter was found to be 22-32 mg/l. During spring flood it was 9.2-53 mg/l and during summer flood it accounted 8.5-50 mg/l [8]. Seasonal dynamics of organic matter in Amur River water near the mouth (Bogorodskoye Hydrometerological Station) was estimated [6].

Input of Amur River Water Constituents into Marine Environment

Data of long term observations of the river discharge and of content of major ions and some other constituents in Amur River water were used to estimate input of dissolved and solid materials by Amur River into the estuarine and marine environment [9]. It was shown that a major part of salts goes to the sea in summer period with distribution maximum in August and September [9].

Mobilization ($t/km^2 \cdot yr$) of dissolved constituents for Amur River watershed and for total river watersheds of the far eastern coast of the USSR is shown in Table 3.

Ratios of inputs of total dissolved and total suspended materials of Amur River and for total input of rivers of far-eastern coast of USSR into Pacific Ocean are given in Table 4.

One can see that Amur River gives a large contribution in total river input of Soviet far-eastern rivers into the marine environment [9]/cp 1/3 of riverine dissolved substances and about 50% of suspended substances.

These data [9] on inputs of suspended solids of the area of interest are more reliable than data published before [10].

First estimate of river input of some minor constituents from Pacific coast and Sakhaline Island of USSR into the marine environment (Table 5) demonstrate also important contribution of Amur River in total riverine input from this catchement area (more than 60% of Fe, 40% of Mn, >70% of Zn and cp 32% of Cu)[11].

Mobilization of metals from different watersheds of the far-eastern coast of the USSR is approximately characterized also (Table 6).

Transport of Water and Materials in Estuary of Amur River

Major part of Amur River water discharges into the Okhotsk Sea at summer, as for winter transport of water into the Sea of Japan prevails [12]. Pecularities of water circulation of this area are determined by river discharge, by ratios of levels of Okhotsk Sea and Sea of Japan, by tidal phenomena and wind fields. It was shown that transformed Amur River waters are transferred mainly in destination of northern Sakhalin [13,14].

Due to large differences of summer and winter Amur River discharges at the mouth (22,500 and 1,100 m^3/s) major part of solids (95%) is transferred into the Okhotsk Sea [15].

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Table 2. Inputs of Dissolved Constituents ($\times 10^3$ t/yr) of Amur River in Comparison with Total Riverine Input from Far-Eastern Soviet Coast to the Pacific Ocean [9].

	Ca^{2+}	Mg^{2+}	$Na^+ + K^+$	HCO_3^-	SO_4^{2-}	Cl^-	Σi	Nutrients	Organic Substances	Total Value
Amur River	1.3	0.4	0.9	5.6	1.1	0.6	9.9	0.08	3.0	13.8
Total River Input	2.1	0.6	1.4	7.8	2.2	1.0	15.1	0.13	4.2	20.9

Table 3. Mobilization ($t/km^2 \cdot yr$) of Dissolved Constituents for Amur River Watershed and for Total Watershed of Rivers of Far-Eastern Coast of USSR [9].

	Ca^{2+}	Mg^{2+}	$Na^+ + K^+$	HCO_3^-	SO_4^{2-}	Cl^-	Σi	Nutrients	Organic Substances	Total Value
Amur River	2340	740	1630	10400	2110	1080	18300	141	5510	25463
River of Soviet Far-Eastern Coast	6667	1860	4362	24916	6984	3046	47834	414	13184	66501

Table 4. Inputs of Solid (R_s) and Dissolved (R_d) Material and Annual Mobilization of Solid and Dissolved Material per Unit of area (M_s and M_d) by Amur River and Totally by Rivers of USSR Pacific Coast [9].

	Input, ml a t/yr		Ratio,		Specific Loss of Material, t/km^2 · yr		
	R_s	R_d	R_s	R_d	M_s	M_d	M_Σ
Amur River	25.7	25.4	1	0.99	13.9	13.8	27.7
Rivers of USSR Pacific Coast	57.6	66.5	1	1.16	18.2	21.0	39.2

Table 5. Input of Metals from Far-Eastern Coast of USSR into Pacific Ocean from Different Areas (t/yr) [11].

Area	Fe		Mn		Zn		Cu		Ni		Pb		Cd	
	part.	diss.	part	diss.	part.	diss.	part.	diss.	part.	diss.	part.	diss.	part.	diss.
I. Watershed of Amurzsley and Ussuryisky Bays of the Japan Sea	20000	364	653	73	536	264	61.0	9.2	52	-	52.5	-	1.8	-
II. Eastern Sikhote-Alin (mountain area)	31400	852	1032	130	1420	1960	146	45.0	64	-	319	-	9.4	-
III. Sakhalin Island	23900	1338	3782	503	1696	1505	294	59.8	288	-	256	-	15.4	-
IV. Amur River	1079000	8052	29700	1751	31600	15264	642	700	1722	-	694	-	25.7	-
V. Kamchatka Peninsula	567000	5321	31900	1416	2369	6508	1058	1091	680	-	731	1.5	63.6	-

Table 6. Metal Mobilization from Different Watersheds of the Far-Eastern coast of the USSR ($kg/km^2 \cdot yr$) [11].

Area	Fe		Mn		Zn		Cu		Ni		Pb		Cd	
	part.	diss.	part	diss.	part.	diss.	part.	diss.	part.	diss.	part.	diss.	part.	diss.
I. Watershed of Amurzsley and Ussuryisky Bays of the Japan Sea	772	14.0	25.2	2.8	20.7	10.2	2.35	0.35	2.0	-	2.0	-	0.07	-
II. Eastern Sikhote-Alin (mountain area)	334	9.1	11.0	1.4	15.1	20.8	1.55	0.48	0.68	-	3.4	-	0.10	-
III. Sakhalin Island	306	17.2	48.5	6.4	21.7	19.3	3.8	0.77	3.7	-	3.3	-	0.19	-
IV. Amur River	583	4.4	16.1	1.0	17.1	8.3	0.35	0.38	0.93	-	0.38	-	0.013	-
V. Kamchatka Peninsula	1200	11.3	67.5	3.0	5.0	13.8	2.2	2.3	1.5	-	1.5	-	0.13	-

The Distribution Features and fluxes of Dissolved Nitrogen, Phosphorus and Silicon in Hangzhou Bay

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ABSTRACT

The distribution features and temporal and spatial variations of nitrate, phosphate and silicate in Hangzhou bay and its adjacent waters are described and their estuarine behaviours are discussed based on the data obtained in recent years. The river fluxes of dissolved nitrogen, phosphorus and silicon are estimated to be about 68×10^3 tons/yr., 1.8×10^3 tons/yr. and 163×10^3 tons/yr., respectively.

INTRODUCTION

River input is a major source of nutrients to the marine environment. The nutrients transported from river provide with essential support for the reproduction of the plankton in the estuarine environment. However, the excess input of nutrients may cause eutrophication, or occurrence of red tide in coastal waters, thus doing harm to the marine living beings. Because of rapid development of industry and great increase of population along Hangzhou bay as well as wide utilization of nitrogenous fertilizer and farmyard manure in cultivated land of that area during the last two decades, the pollution of nitrogen, phosphorus and organic matters has been becoming a serious environmental problem in Hangzhou bay and its adjacent areas. Since 1972, red tide has been observed frequently in the coastal waters off Hangzhou bay and it has had a great influence on the fisheries production of the coastal areas[1,2]. Understanding the distribution, variation and the process of transfer of nutrients in Hangzhou bay and its adjacent waters together with fluxes is, therefore, vital in the assessment of the pollution problems and the study of marine ecology of that area.

The primary purpose of this paper is to describe the distribution features and temporal and spatial variation of dissolved nitrogen, phosphorus and silicon in Hangzhou bay and its adjacent waters and to estimate their outfluxes mainly based on the data obtained by our institute during recent years[3,4.].

GENERAL CHARACTERISTICS OF STUDIED AREA AND ANALYTICAL METHODS OF NUTRIENTS

Hangzhou bay is located on the northern part of the East China Sea. The northern side of the bay mouth is adjacent to the Changjiang river mouth and the southern side is linked up with the Zhoushan islands. Outside the bay mouth, there is a famous fishing ground——Zhoushan fishery. The annual runoff, directly entering the bay, is mainly from

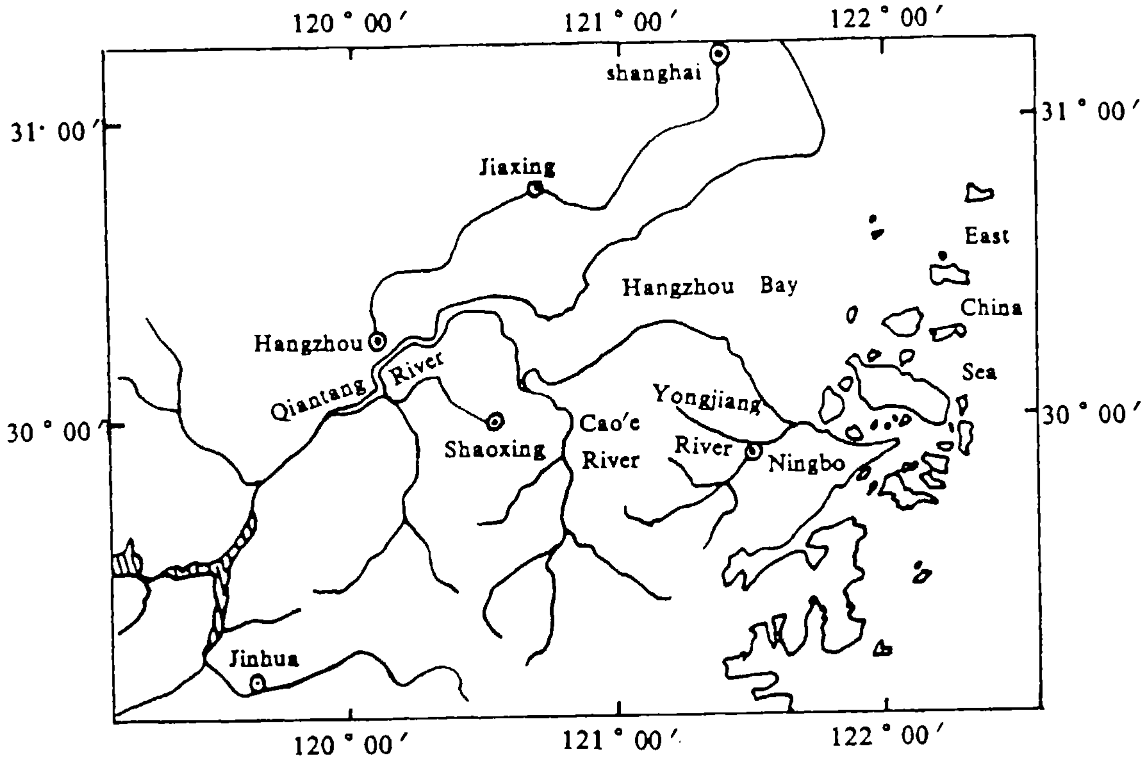

Fig.1. Physiographic Positions of Qiantang River, Cao'e River and Yongjiang River.

Qiantang river, Cao'e river and Yongjiang river with gross runoff 4.4×10^4 million cubic meters (3.7×10^4 million cubic meters from Qiantang river) and the annual sand load 8.3×10^6 tons (6.6×10^6 tons from Qiantang river).

Table 1. General Characteristics of Main Rivers Emptying into Hangzhou Bay

description	Qiantang River	Cao'e River	Yongjiang	Total
Length, Km	494	192	121	
Drainage Area (km^2)	54349	6050	4300	64699
Average Flow (m^3/ sec.)	1182	135.7	90.7	
Mean Annual Discharge ($\times 10^9 m^3$)	37.3	4.28	2.86	44.44
Mean Annual Load ($\times 10^6$ tons)	6.587	1.287	0.359	8.233

Hangzhou bay is a typical funnel shaped estuary. It is of semi–diurnal tide with mean tidal range 2.5 m near the bay mouth and it is amplificated rapidly towards the bay head. The amplification produces a famous Qiantang tidal bore at the Qiantang estuary with average tidal range 5.45 m (the greatest range 8.87 m).

Hangzhou bay area has a sub–tropical monsoon climate with humid temperate climate and four distinct seasons. The average temperature is about 16.1 ℃ and the annual rainfall is about 1300 mm, 50% of which is in the months between May and August.

The studied area is between 29°48′ N——31°00′ N and 120°50′ E——122°25′ E. Four cruises near the bay mouth and its adjacent area (December, 1981 and May, July and October, 1982) and in the upper bay (April, July and October, 1989 and January, 1990) were carried out (sampling stations in Fig.2).

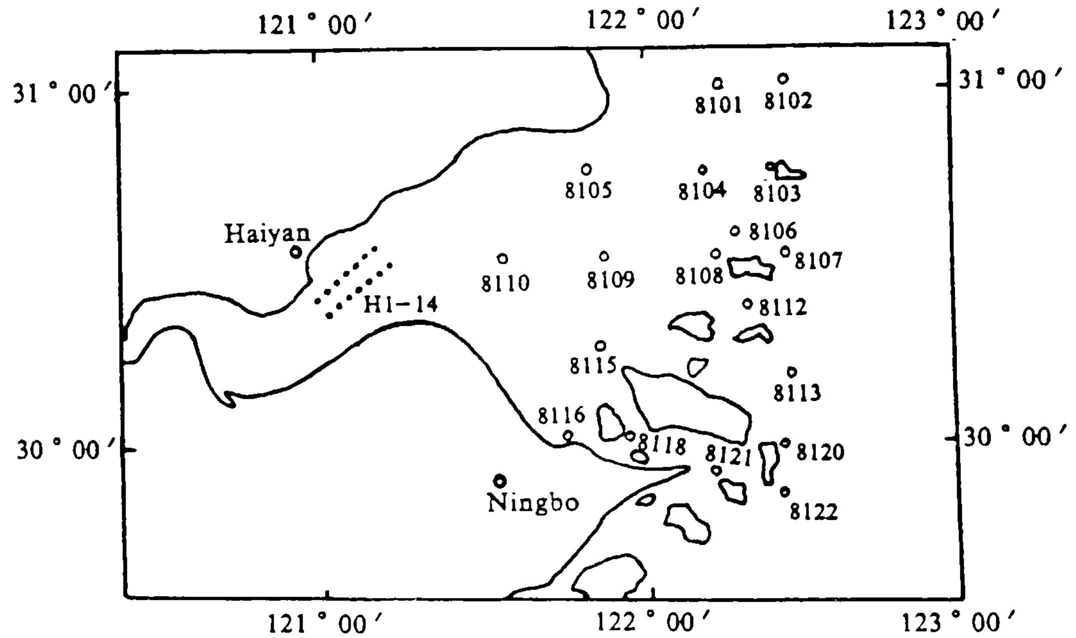

Fig.2. Station Positon Investigated.
O: December, 1981–October, 1982. ●: April, 1989–January, 1990.

Water samples were filtered with 0.45 μm millipore filter immediately after collection. Nutrients were analyzed using silco– molybdenum yellow for silicate, phosphor–molybdenum blue for phosphate, zinc–cadmium reduction method for nitrate, diazo–azo method for nitrite and sodium hypobromite oxidation–diazo–azo method for ammonia[5]. All nutrients were measured in situ.

DISTRIBUTIONAL FEATURES OF NUTRIENTS

1. Concentration range of nutrients: The results of nutrients and N / P ratios are given in Tab.2. It shows that the concentrations of nutrients and N/ P ratios in the upper bay

Table. 2. Concentrations of Nutrients and ΣN / P Ratios

Element	Season	Upper bay			Lower bay			out off bay		
		N	concentration range	concentration mean	N	concentration range	concentration mean	N	concentration range	concentration mean
Phosphate (μM)	Spring	40	0.59–2.84	1.07 ± 0.40	13	0.59–1.18	0.80 ± 0.20	48	0.31–1.08	0.66 ± 0.19
	Summer	38	0.21–2.49	1.00 ± 0.38	13	0.76–1.29	1.00 ± 0.14	48	0.33–1.05	0.64 ± 0.17
	Autumn	42	1.48–2.92	2.02 ± 0.37	12	0.67–1.56	1.12 ± 0.34	41	0.29–3.13	0.83 ± 0.50
	Winter	39	1.08–3.12	1.92 ± 0.62	11	0.72–1.52	1.16 ± 0.30	37	0.50–2.10	1.07 ± 0.51
Silicate (μM)	Spring	40	74.4–95.3	81.3 ± 5.1	13	35.7–70.2	54.5 ± 14.6	48	17.1–54.1	30.7 ± 10.2
	Summer	38	109.0–143.0	119.0 ± 8.7	13	51.6–88.7	70.3 ± 13.8	48	4.8–88.9	36.8 ± 23.2
	Autumn	42	111.0–127.9	117.7 ± 4.0	12	50.9–101.8	79.4 ± 24.4	41	24.7–94.0	49.7 ± 20.9
	Winter	39	81.0–102.0	90.9 ± 5.8	11	13.6–41.3	29.6 ± 9.6	37	28.0–66.0	45.0 ± 9.9
Nitrate (μM)	Spring	40	33.1–95.4	63.2 ± 13.7	13	22.3–62.0	47.3 ± 13.8	48	14.6–46.2	26.8 ± 8.8
	Summer	36	34.8–123.9	93.0 ± 19.8	13	14.9–52.0	35.8 ± 14.1	48	2.8–67.7	19.0 ± 12.6
	Autumn	42	62.1–118.2	79.1 ± 12.2	12	7.2–53.7	34.2 ± 12.0	41	8.6–44.4	19.9 ± 7.8
	Winter	39	60.6–94.1	78.4 ± 8.8	11	19.6–52.8	37.7 ± 8.4	37	11.2–33.8	23.8 ± 6.6
Nitrite (μM)	Spring	40	0.00–1.26	0.30 ± 0.34	13	0.07–0.64	0.18 ± 0.17	48	0.05–0.46	0.16 ± 0.10
	Summer	38	0.60–2.85	1.87 ± 0.55	13	0.06–0.42	0.17 ± 0.13	48	0.14–0.80	0.39 ± 0.20
	Autumn	42	0.11–0.86	0.31 ± 0.16	12	0.05–0.55	0.22 ± 0.17	41	0.04–0.93	0.33 ± 0.21
	Winter	39	0.32–1.72	0.81 ± 0.32	10	0.07–0.36	0.19 ± 0.10	37	0.00–0.23	0.09 ± 0.05
Ammonia (μM)	Spring	40	0.02–5.24	1.83 ± 1.61	13	0.00–2.22	0.34 ± 0.82	48	0.00–4.25	0.89 ± 0.73
	Summer	38	0.61–9.59	3.96 ± 2.22	13	0.68–7.18	1.94 ± 1.66	48	0.00–5.89	2.01 ± 1.23
	Autumn	42	0.28–6.91	1.22 ± 1.20	12	0.25–4.17	1.41 ± 1.20	41	0.46–5.19	1.85 ± 1.38
	Winter	39	1.30–3.11	2.58 ± 0.32	10	0.03–4.83	2.70 ± 1.28	36	0.19–6.18	1.92 ± 1.44
Salinity (‰)	Spring	40	7.90–12.78	11.26 ± 1.34	13	13.3–24.4	18.1 ± 5.0	48	17.0–30.5	26.0 ± 3.3
	Summer	37	2.86–5.72	3.98 ± 0.77	13	7.6–23.0	17.2 ± 4.9	48	9.7–32.4	23.8 ± 5.4
	Autumn	42	5.54–6.21	5.95 ± 0.17	12	5.4–20.7	13.2 ± 6.4	41	9.0–26.1	20.8 ± 4.9
	Winter	41	6.34–10.65	9.19 ± 1.13	11	9.7–19.4	15.1 ± 4.2	37	19.6–30.4	24.4 ± 3.3
ΣN / P	Spring	40	28.1–101.3	65.0 ± 17.2	13	21.6–100.9	66.3 ± 30.0	48	22.8–91.9	43.2 ± 10.8
	Summer	36	37.3–257.1	103.8 ± 45.6	13	16.6–57.8	38.6 ± 15.5	48	6.2–101.6	34.6 ± 22.4
	Autumn	42	22.2–69.9	41.4 ± 10.7	12	10.8–52.4	33.0 ± 11.5	41	10.8–57.9	29.9 ± 10.5
	Winter	39	23.3–84.6	47.5 ± 17.3	11	20.3–56.4	37.2 ± 14.4	37	10.1–48.1	27.0 ± 8.6

are higher than those in the lower bay, and they are all higher than those outside the bay in any season, reaching 78.4 μM, 1.50 μM and 102.2 μM respectively. Comparing with the global mean values[6,7], the silicate level in Hangzhou bay is corresponding to the global mean value while the contents of dissolved nitrate (the large part of total inorganic nitrogen) and phosphate in Hangzhou bay are as four and two times respectively as the global mean values. The high values of nutrients in Hangzhou bay are rarely seen among the estuaries in China.

As for N / P ratios in Hangzhou bay and its adjacent waters, the magnitude of variation is greatly linked with time and space, ranging from 27 to 104 on the average for regions and seasons. They are much higher than that of normal sea water (N / P = 16). The cause for this particularly high value of nitrate or great N / P ratio in that area is probably related to the utilization of nitrogenous fertilizer in the paddy fields and the increasing discharge of industrial and domestic wastes. It was estimated that the average applied intensity of nitrogenous and phosphate fertilizer was about 390 kg N / ha. and 60 kg P / ha. respectively. The farmland areas of Zhejiang province only makes up 1. 85% of total farmland in china, whereas the applied quantity of synthetic fertilizer accounted for about 10% of total fertilizer used in china.

2. Horizontal distribution of nutrients: The general features of the horizontal distributions of the dissolved nitrate, phosphate and silicate in Hangzhou bay and its adjacent waters are rather similar and they present an analogic tendency with salinity (Figs.3–6), with opposite variation in magnitude. The contour of nutrient distribution runs from the west to the east in a tongue shaps. The tongue contour becomes more obvious in spring and summer, which shows that the sea water off the coast flows into Hangzhou bay along both sides of

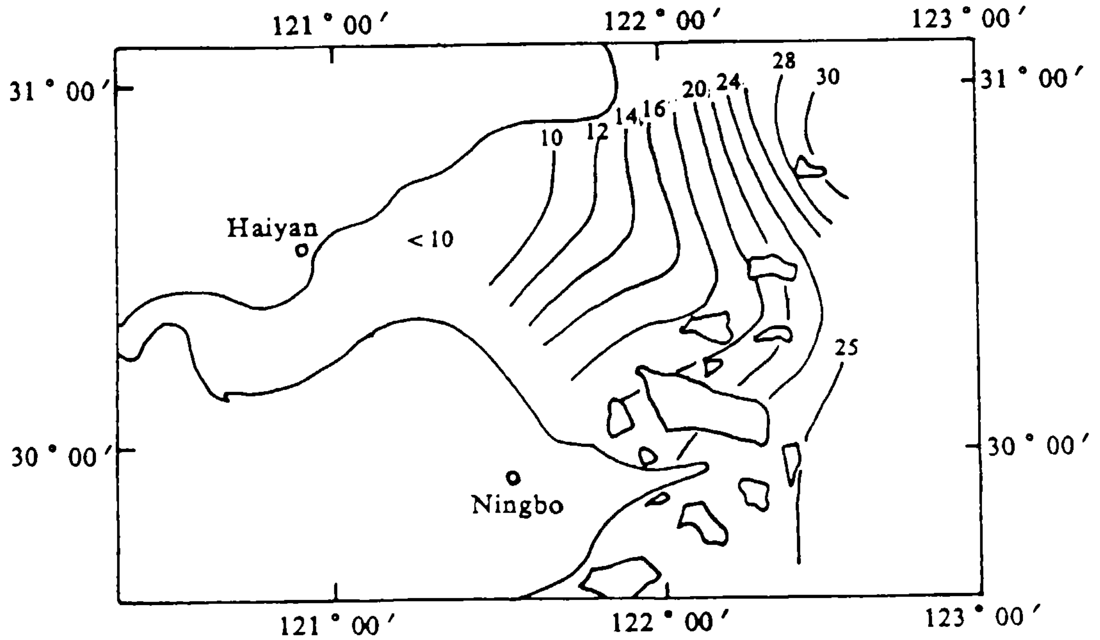

Fig.3a. Horizontal Distribution of Salinity (July, 1982)

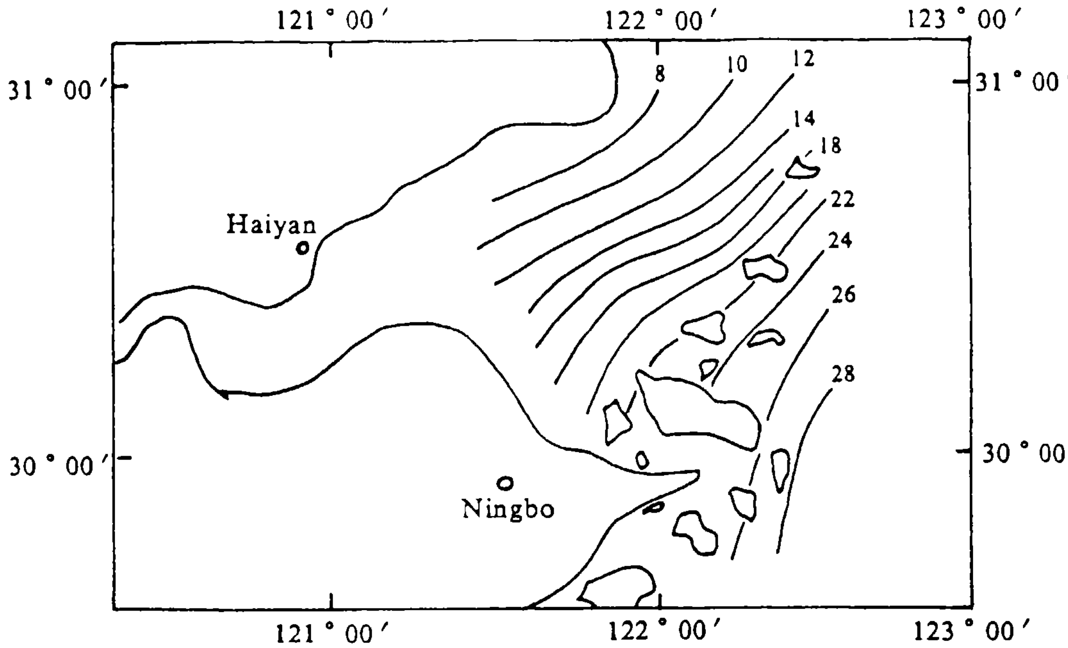

Fig.3b. Horizontal Distribution of Salinity (December, 1981)

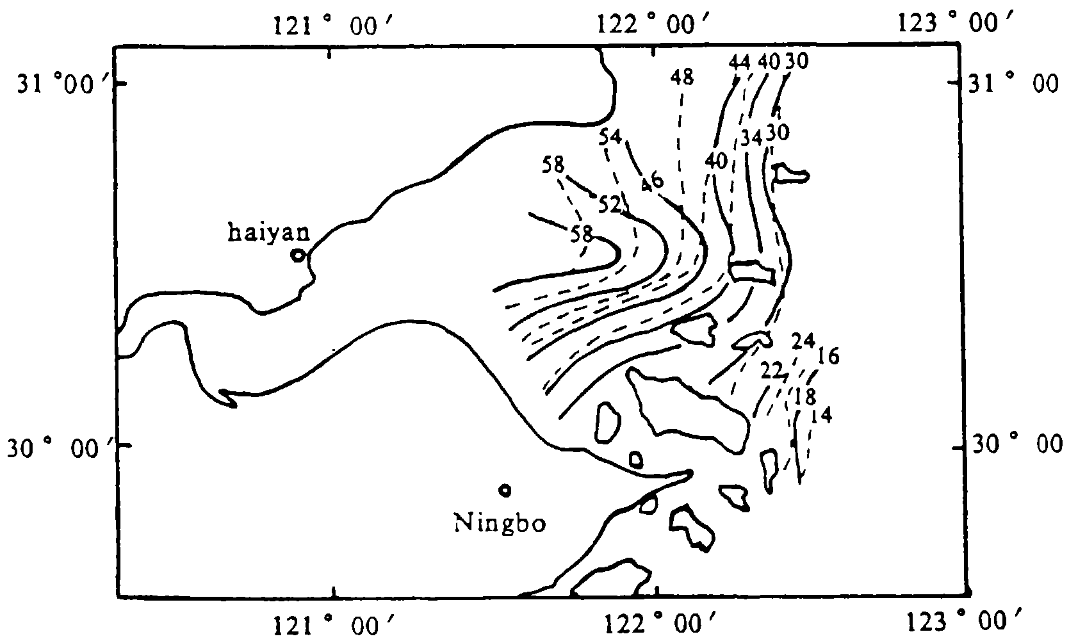

Fig.4a. Horizontal distribution of Nitrate: May 1982.
——surface, ••••••bottom.

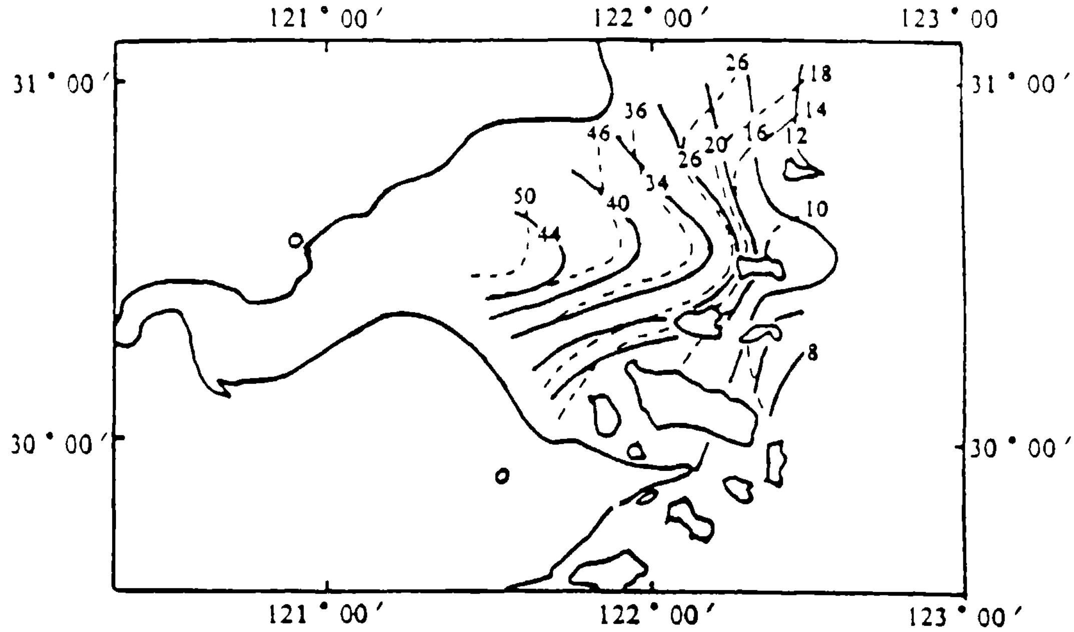

Fig.4b. Horizontal distribution of Nitrate: July 1982.
——surface, ······bottom.

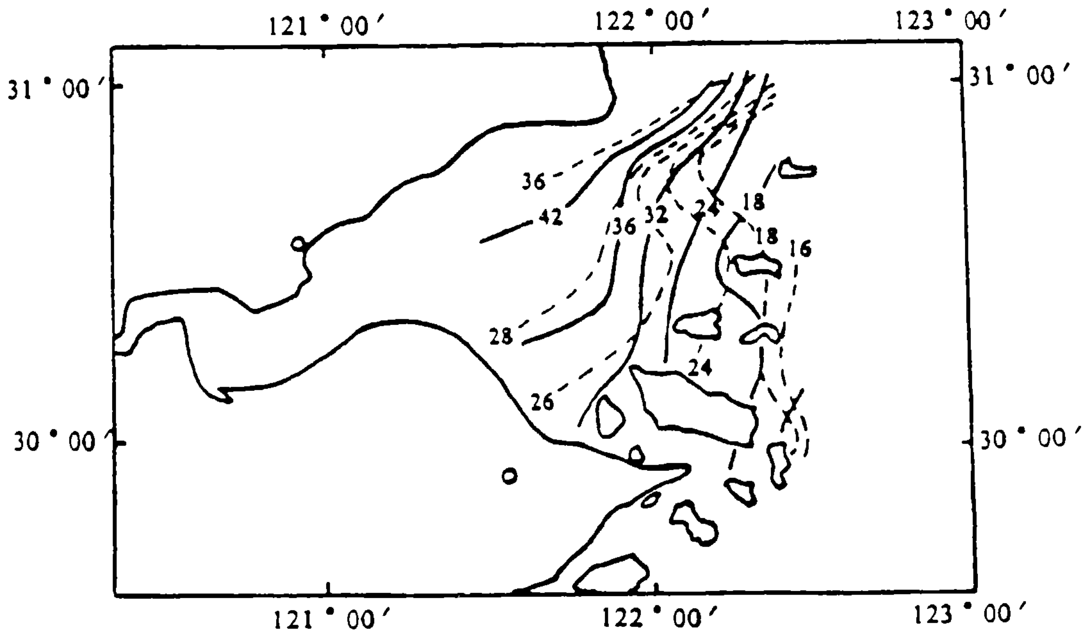

Fig.4c. Horizontal distribution of Nitrate: October 1982.
——surface, ······bottom.

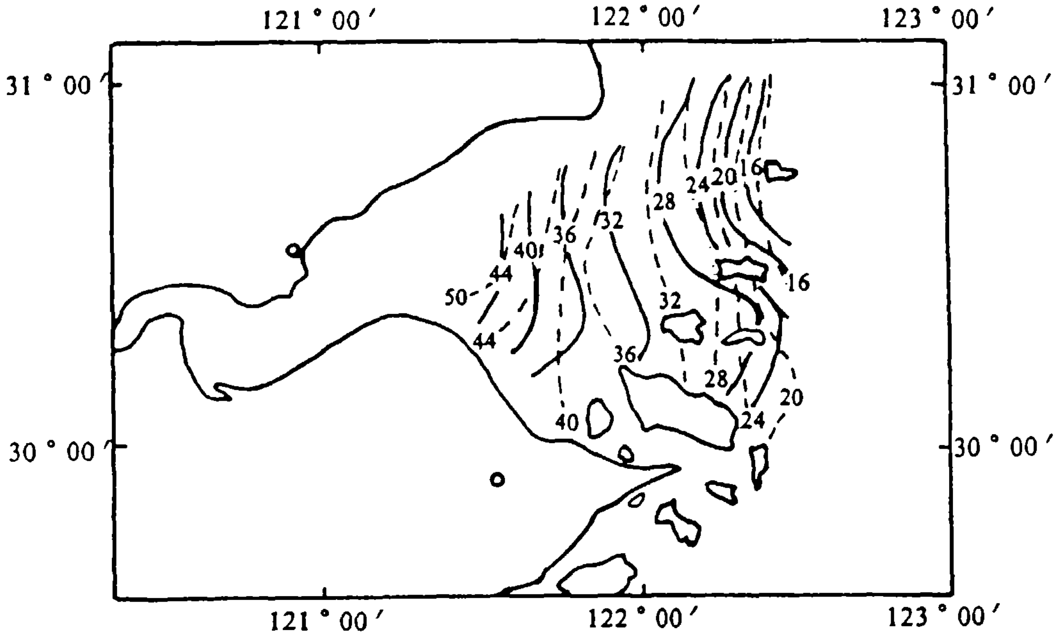

Fig.4d. Horizontal distribution of Nitrate: December 1981.
——surface, ······bottom.

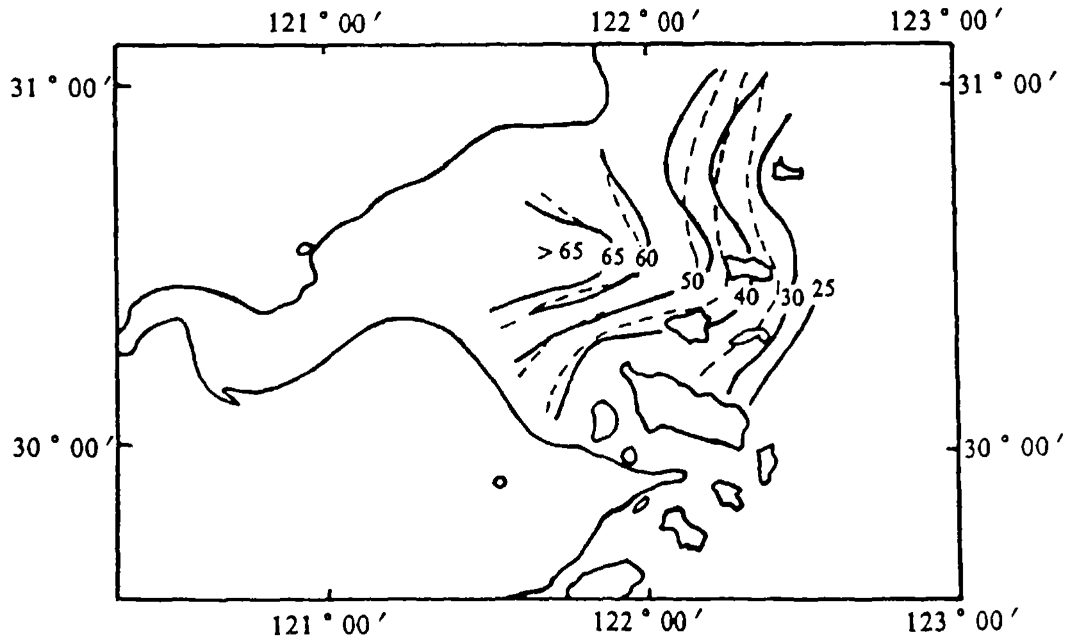

Fig.5a. Horizontal distribution of silicate: May 1982.
——surface, ······bottom.

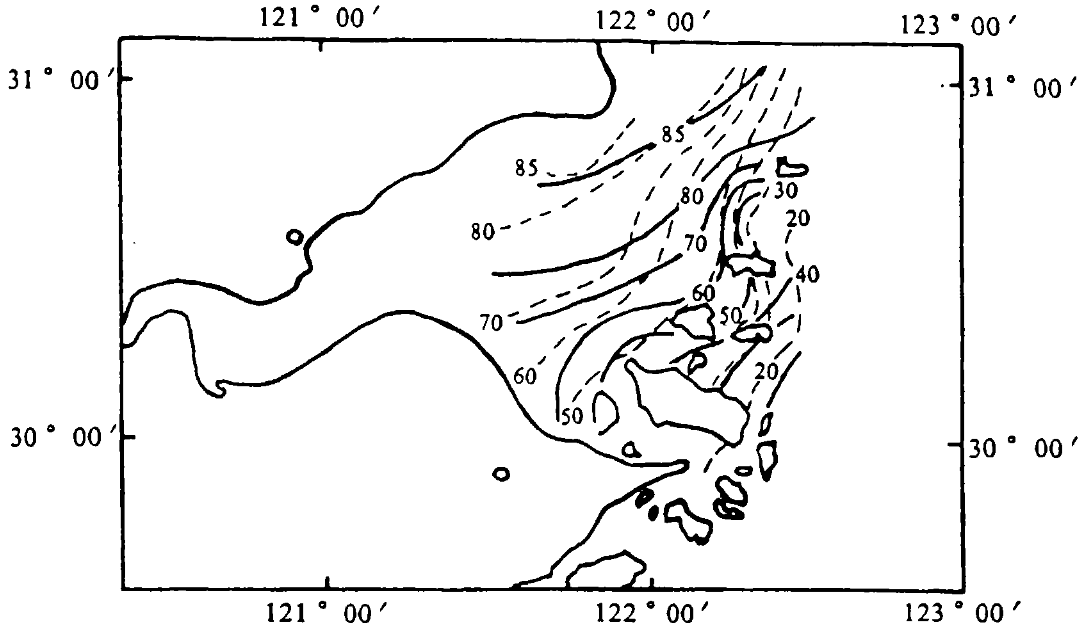

Fig.5b. Horizontal distribution of silicate: July 1982.
——surface, ······bottom.

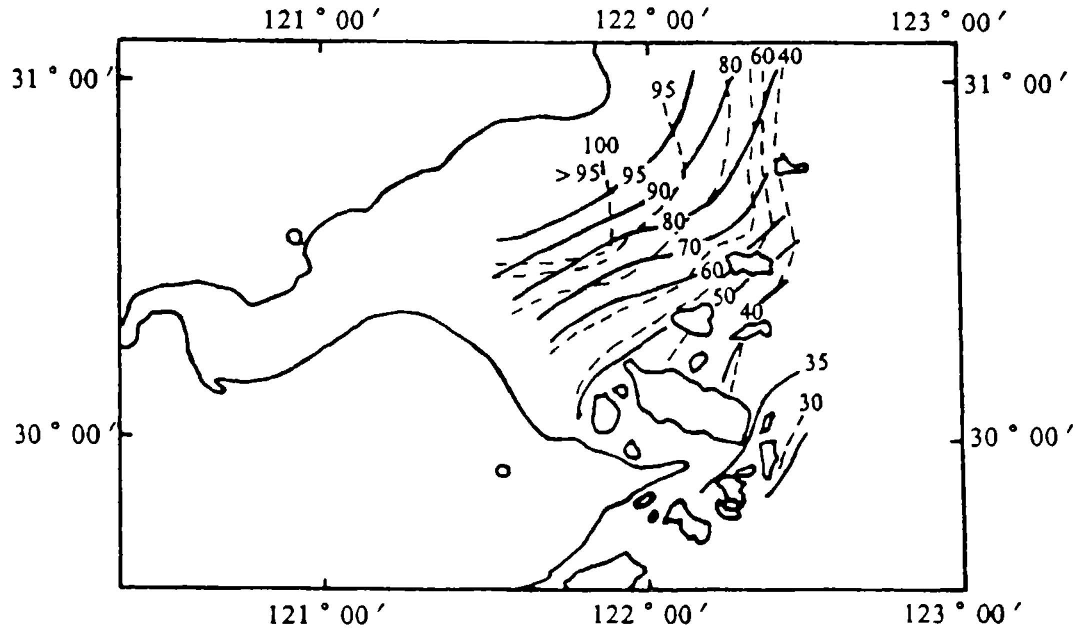

Fig.5c. Horizontal distribution of silicate: October 1982.
——surface, ······bottom.

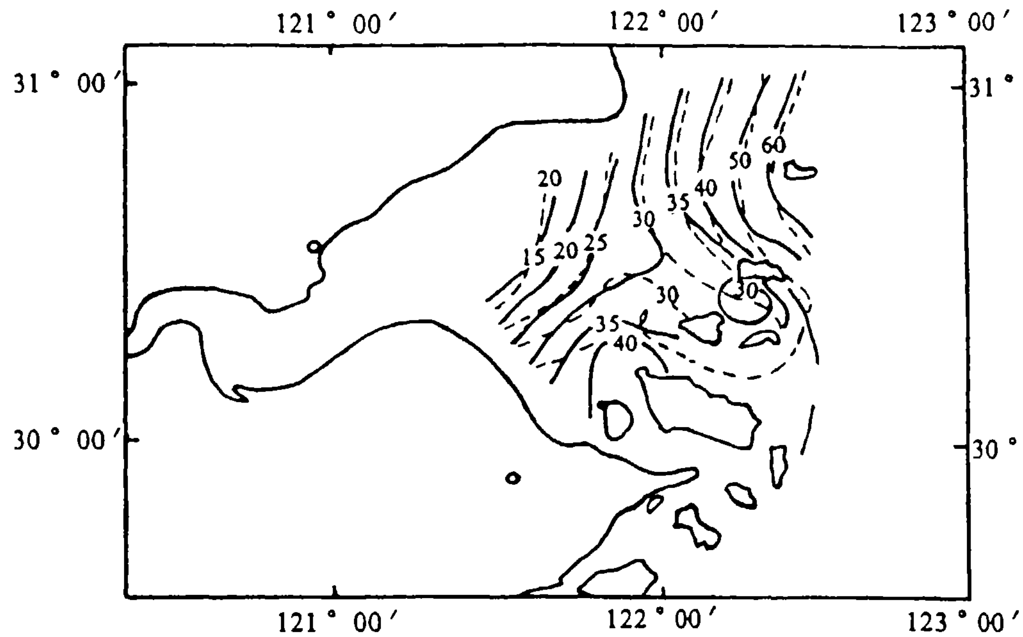

Fig.5d. Horizontal distribution of silicate: December 1981.
——surface, ······bottom.

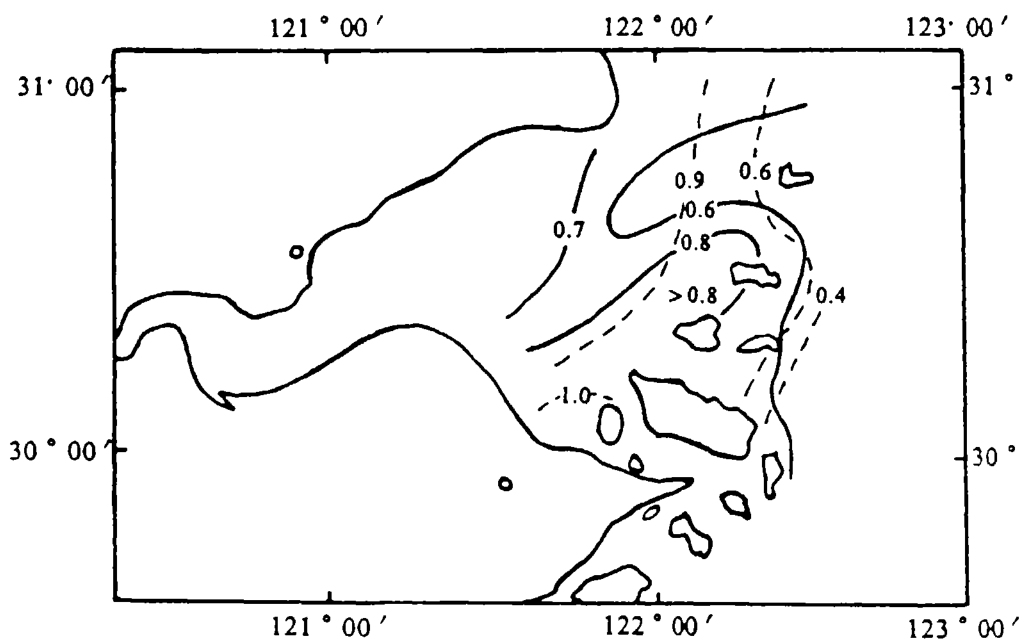

Fig.6a. Horizontal distribution of phosphate: May 1982.
——surface, ······bottom.

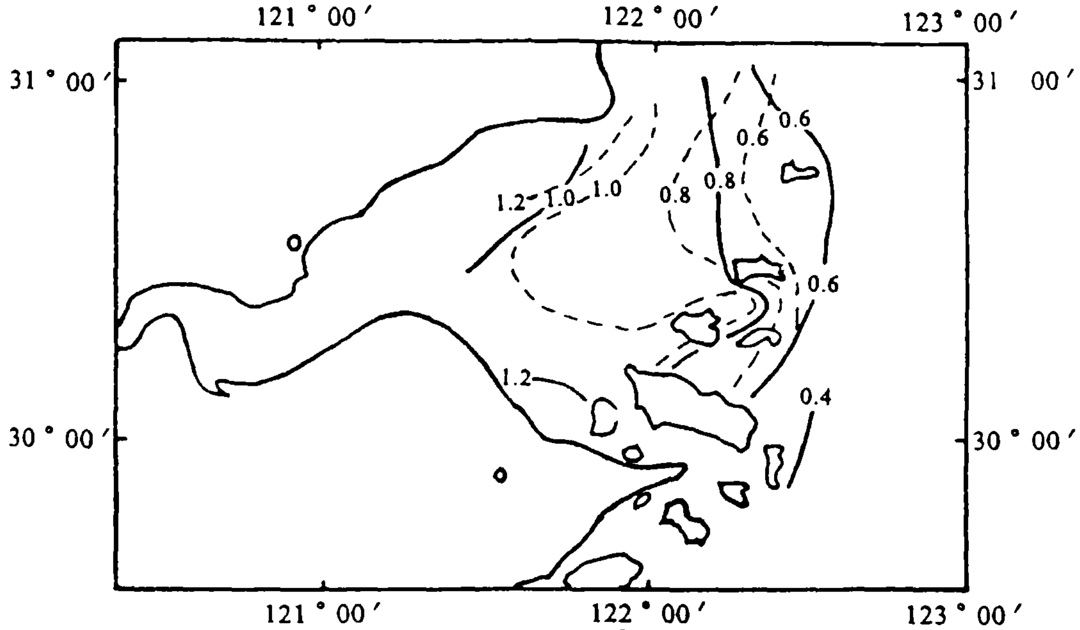

Fig.6b. Horizontal distribution of phosphate: July 1982.
——surface, ······bottom.

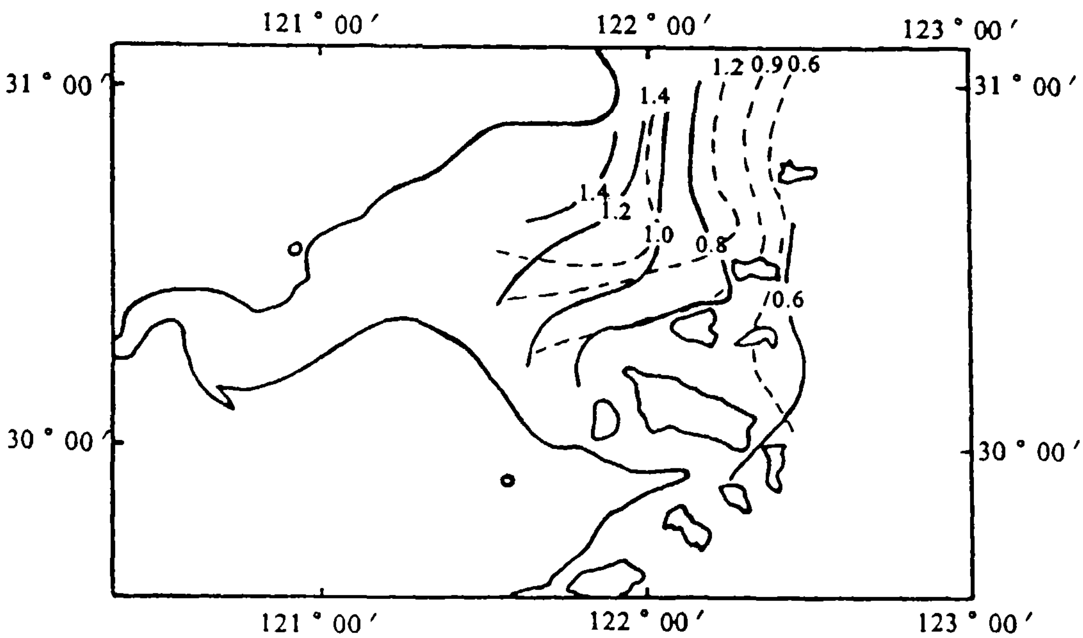

Fig.6c. Horizontal distribution of phosphate: October 1982.
——surface, ······bottom.

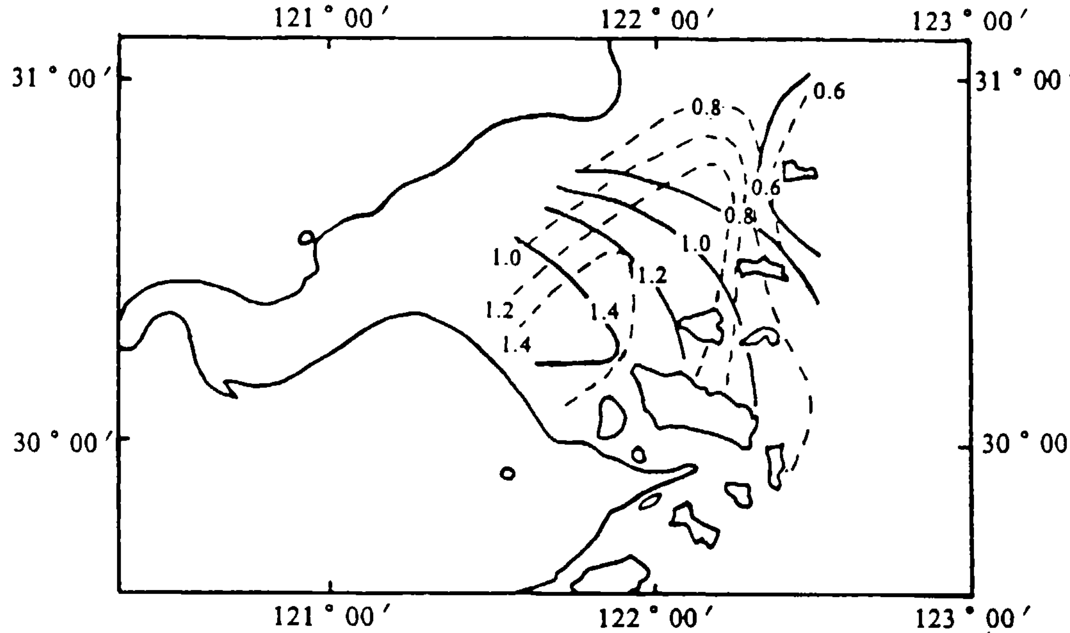

Fig.6d. Horizontal distribution of phosphate: December 1981.
——surface, ······bottom.

Zhoushan Islands and mixes strongly with the river runoff in the frontal zone, and the river runoff mainly flows out from the middle of the Hangzhou bay mouth.

All the contents of nutrients decrease gradually from the inner bay to the outer bay, but silicate content in winter is contrary to that in the other seasons (Fig.5d). This is probably related to the influence of the runoff of Changjiang river because the flow direction of the runoff in Changjiang river to the sea has a obvious periodicity. In the dry season (between November and April), the runoff of Changjiang river mainly flows south along the shore, mixing with the runoff of Qiantang river and sea water near the bay mouth. Since the runoff of Changjiang river is as 25 times as that of Qiantang river and the silicate level in Changjiang river is higher than that in Qiantang river[3], also because the water of Changjiang river is only partially mixed with the runoff of Qiantang river, Cao'e river and Yongjiang river in this area, it is inevitable that the distribution of silicate near Hangzhou bay mouth is influenced by the rich–in–silicate water of Changjiang river in winter. In flood period (between May and October), the influence of Changjiang river on this area decreases because it flows towards northeast, while the effect of Qiantang river increases relatively in other seasons. Therefore, the distributions of nutrients in Hangzhou bay and its adjacent waters are certainly affected by these factors and show obvious seasonal variation.

3. Cross–section and vertical distribution of nutrients: The cross–section distributions of dissolved nitrate, phosphate and silicate from the inner bay to the outer bay at 30 ° 30′ N are showen in Figs. 7 and 8. They show clearly that the contents of nutrients decrease

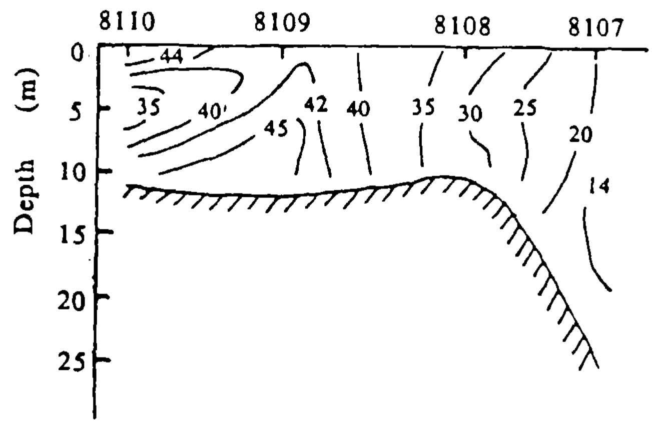

Fig.7a. Cross-section distribution of Nitrate (July 1982).

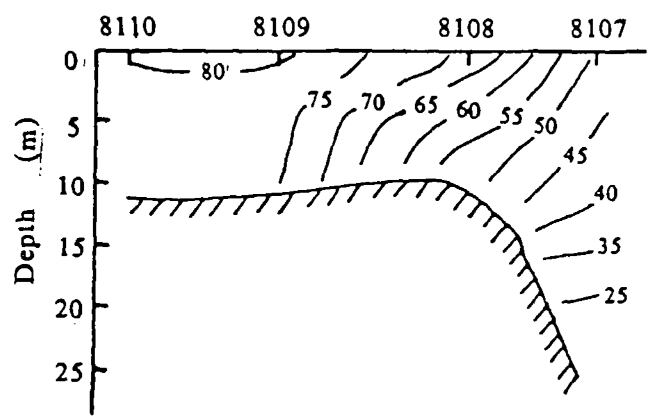

Fig.7b. Cross-section distribution of Silicate (July 1982).

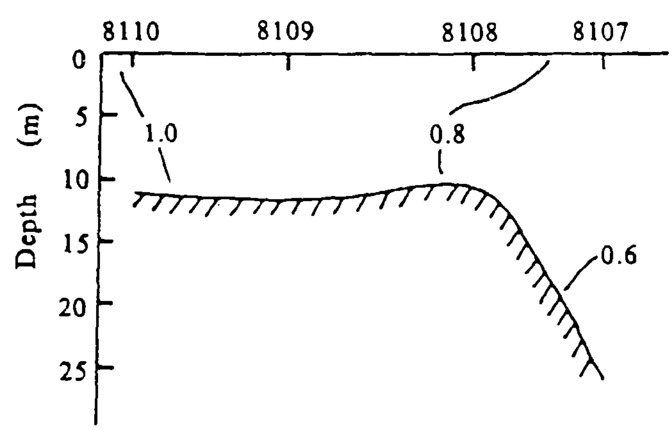

Fig.7c. Cross-section distribution of Phosphate (July 1982).

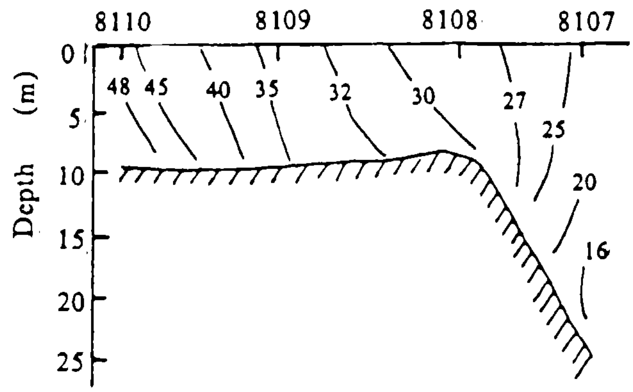

Fig.8a. Cross-section distribution of Nitrate (December 1981).

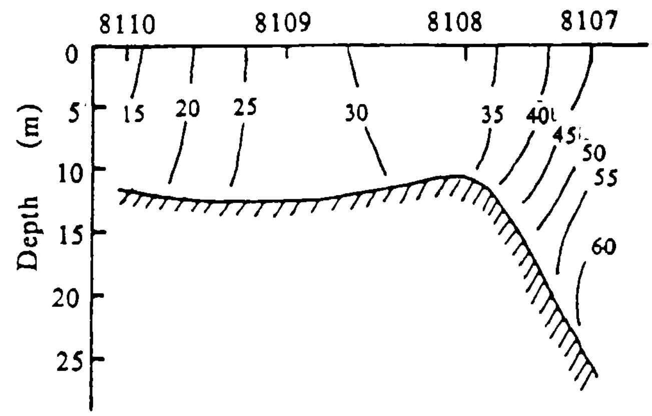

Fig.8b. Cross-section distribution of Silicate (December 1981).

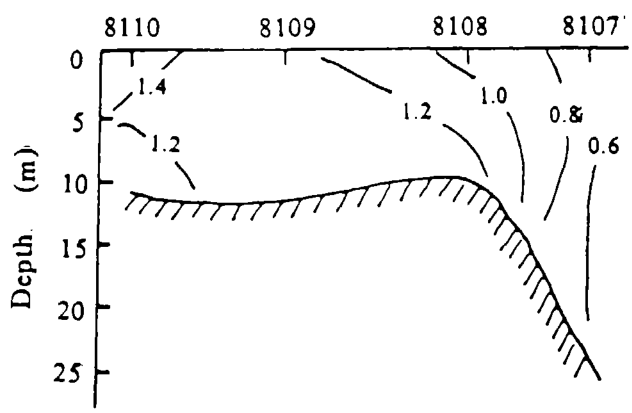

Fig.8c. Cross-section distribution of Phosphate (December 1981).

gradually from the inner bay to the outer bay and decrease slightly with the augment of the depth except for silicate in winter. The uncommon distribution of silicate, which shows that its concentration is higher outside the bay than that inside the bay and the levels in bottom water are over that in surface water, may be resulted from the decrease of runoff in Qiantang river and the runoff of Changjiang river runing towards south directly in winter, as mentioned above.

The vertical distribution of nutrients is generally even in the shallow waters (less than 10 m), but there is obvious stratification in some stations outside the bay mouth. However,

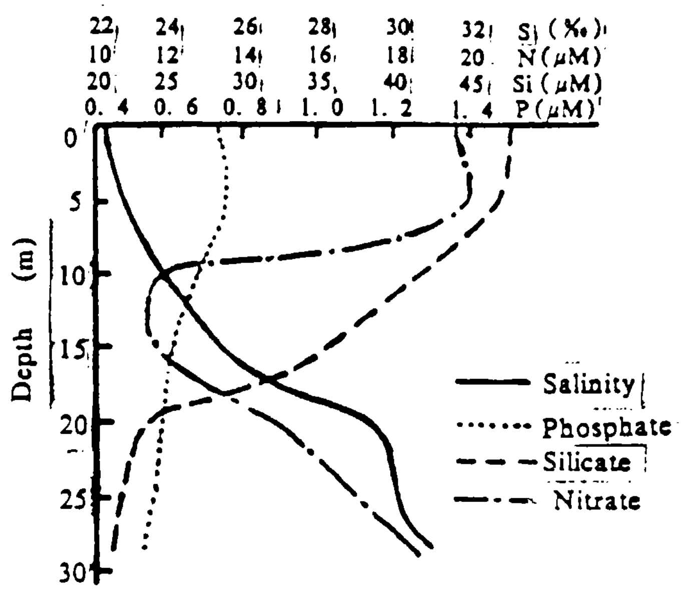

Fig.9. Vertical Variation of nitrate, silicate, phosphate and salinity in station 8107(July,1982).

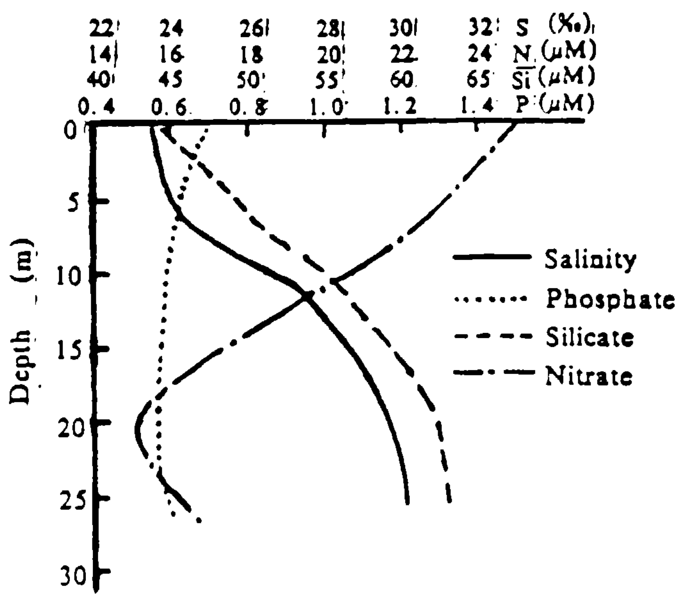

Fig.10. Vertical Variation of nitrate, silicate, phosphate and salinity in station 8107 (December, 1981).

the vertical distribution of nutrients in station 8107 is rather complex (Figs.9 and 10). This special distribution may be contributed not only by the intrusion of the sea water off shore from bottom layer, but also the specific structure of cyclosis around Zhoushan Islands gives a certain effect[3].

4. Variation of nutrients with time: The seasonal variations of dissolved nitrate, phosphate, silicate and salinity in the water of upper bay as well as the flow of Qiantang river are showen in Fig. 11. It can be seen that the seasonal variations of nutrients are related

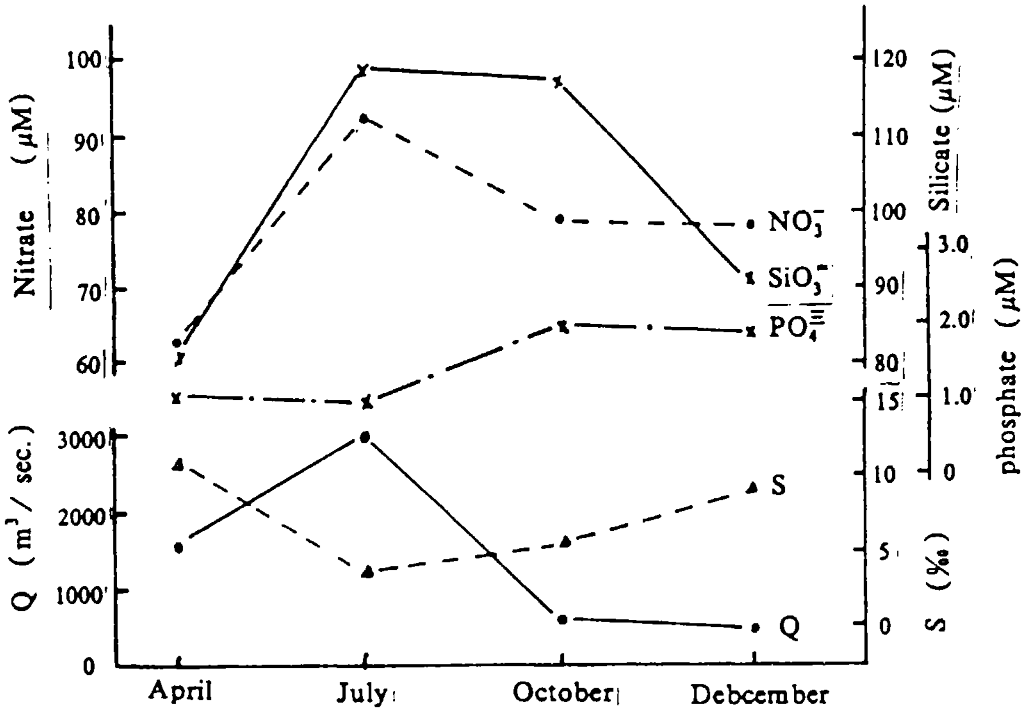

Fig.11. Seasonal variation of dissolved nutrients and salinity in the upper of Hangzhou bay and discharge of Qiantang river. S: Salinity (‰). Q: Discharge (m^3/sec.).

closely to the variation of the flow of Qiantang river. The contents of dissolved nitrate and silicate in the upper bay increase with the augment of discharge of Qiantang river and decrease with the augment of salinity, while the concentration of dissolved phosphate seems to be contrary to that of nitrate and silicate. This indicates to some extent that the contents of nitrate and silicate are closely related to the rainfall, and mainly contributed by the soil leaching and surface run-off as well as the loss of fertilizer, while the concentration of phosphate seems to be diluted by runoff. The levels of phosphate may be influenced by the discharge of industrial and domestic wastes greatly due to the application of quantities of detergent polyphosphate. Additionally, because the biomass of phytoplankton is higher in spring and summer than that in other seasons and the contents of phosphate are much lower than those of nitrate and silicate, biological removal of phosphate is more obvious than that of nitrate and silicate.

The darily variations of nutrients, salinity and water level at station 8109 are showen in Fig.12. It can be seen that the contents of nutrients are obviously affected by the change of

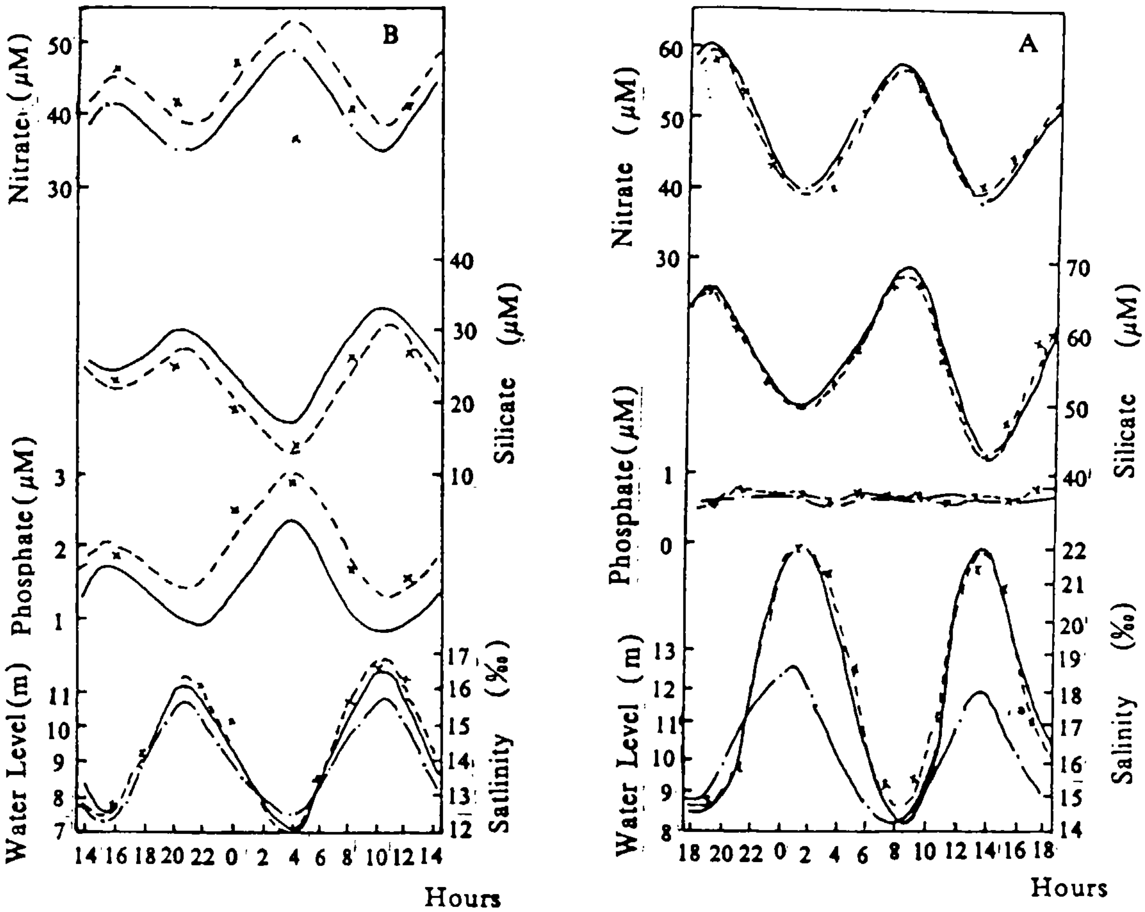

Fig.12. Darily variation of dissolved nutrients, salinity and water level in station 8109. A: May, 1982. B: December, 1981.

tide. The variation pattern is just opposite to that of salinity except for silicate in winter which presents the same pattern as salinity.

TRANSFER AND FLUXES OF NUTRIENTS

1. Relationship between nutrients and salinity: The relationships of dissolved nitrate, phosphate and silicate versus salinity in Hangzhou bay and its adjacent waters are showen in Figs. 13–15 and their regression equations are given in Tab.3. It can be seen that the relationships of dissolved nitrate, phosphate and silicate versus salinity show negative correlation, except for silicate in winter which presents positive correlation. There are

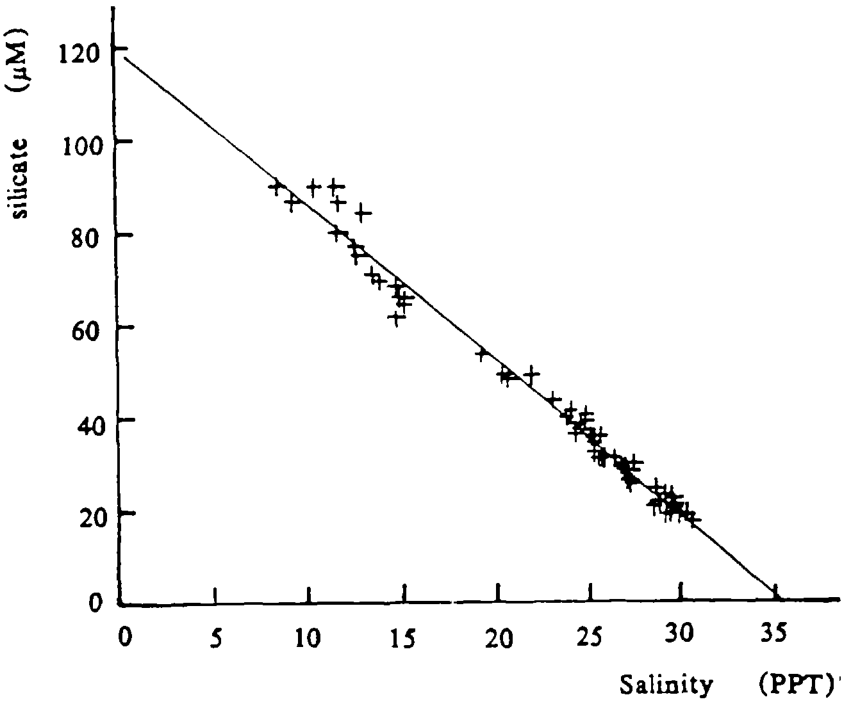

Fig.13a. Silicate versus salinity: May 1982.

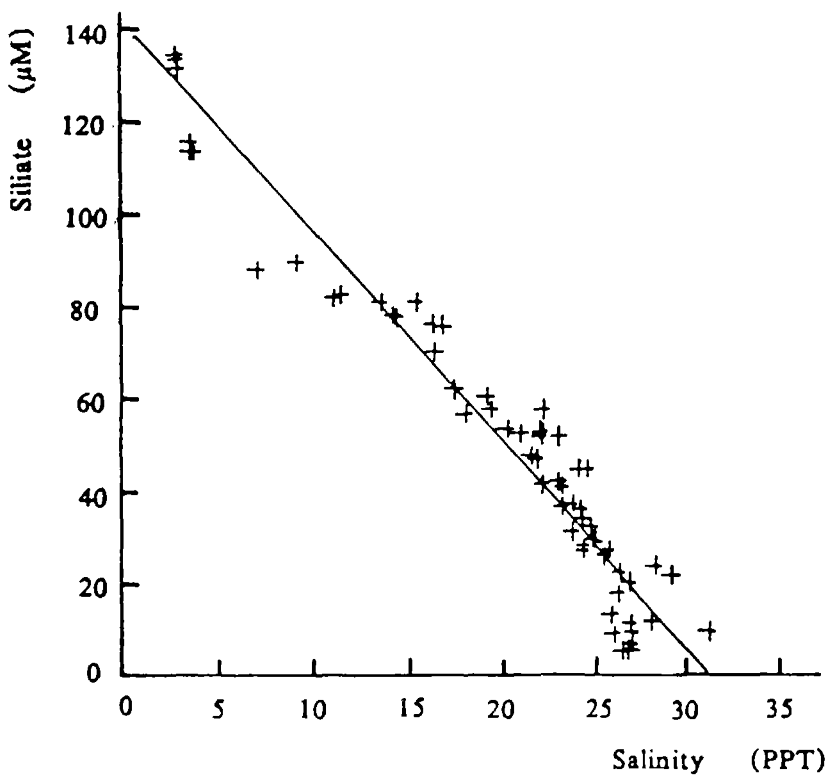

Fig.13b. Silicate versus salinity: July 1982.

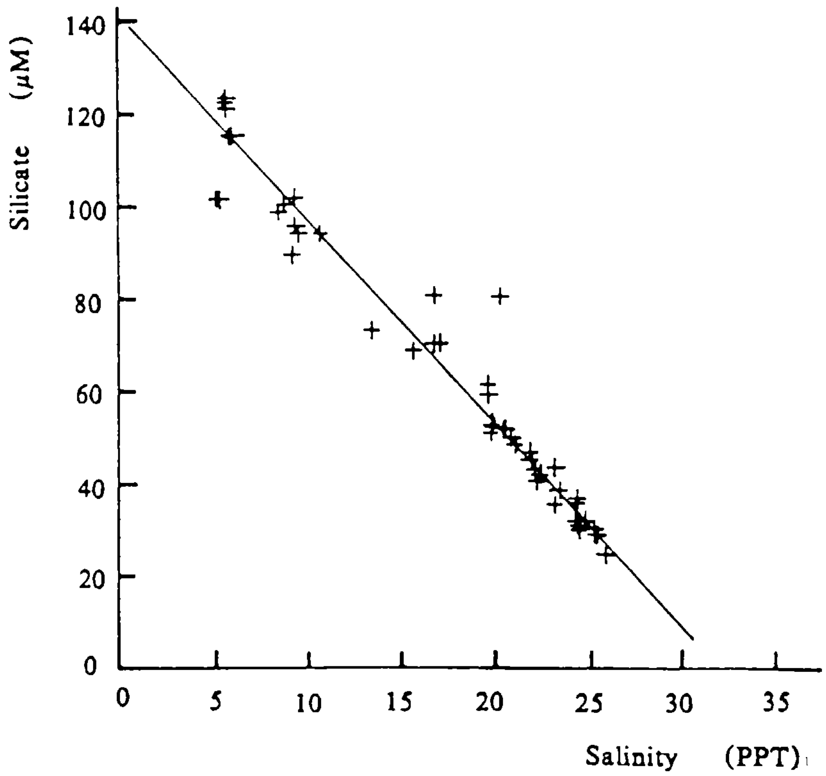

Fig.13c. Silicate versus salinity: October 1982.

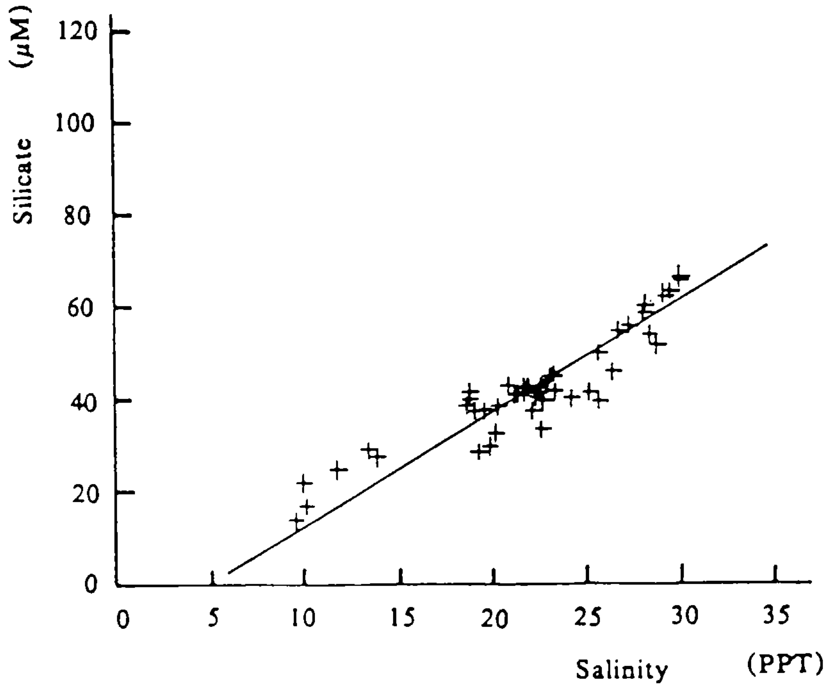

Fig.13d. Silicate versus salinity: December 1981.

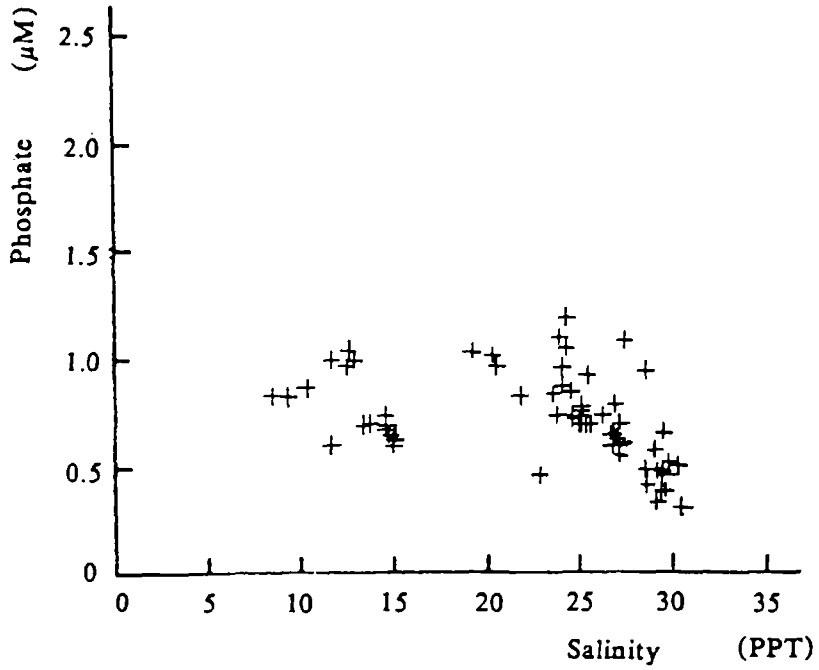

Fig.15a. Phosphate versus salinity: May 1982.

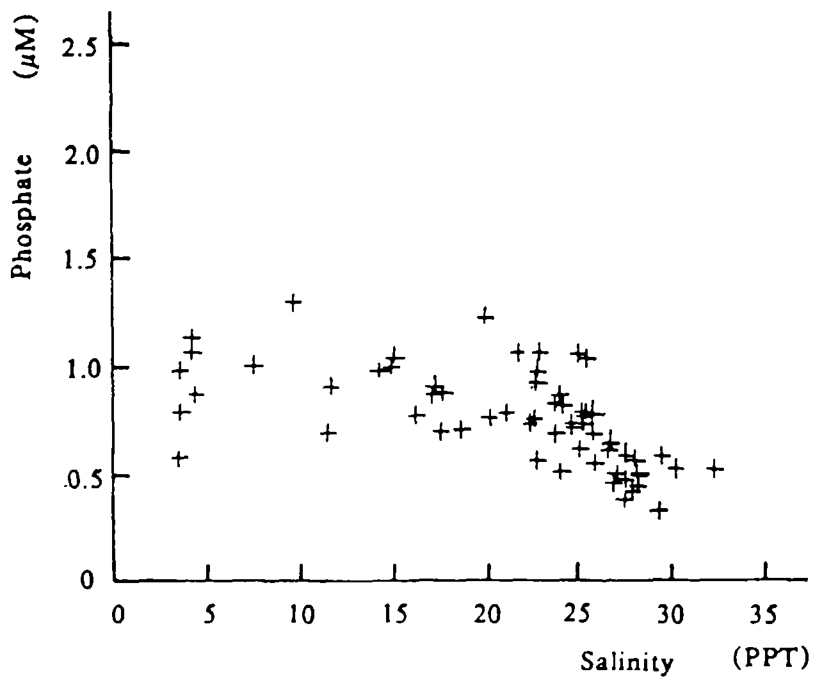

Fig.15b. Phosphate versus salinity: July 1982.

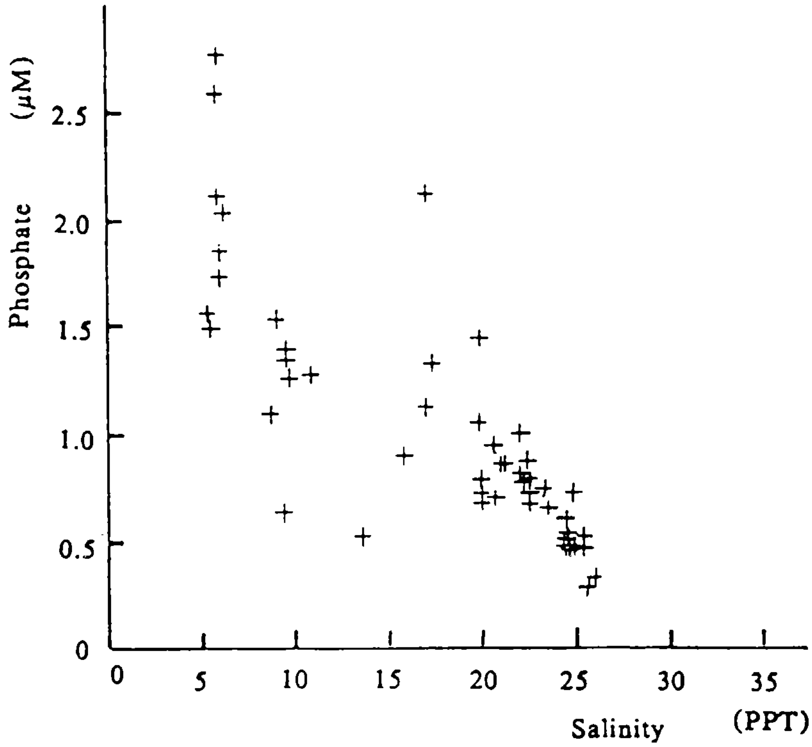

Fig.15c. Phosphate versus salinity: October 1982.

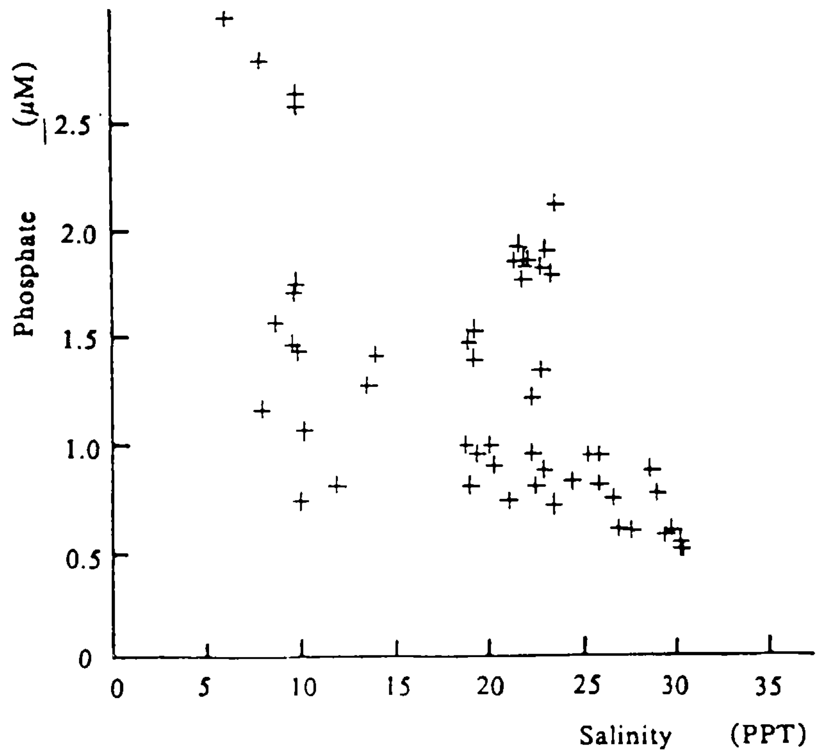

Fig.15d. Phosphate versus salinity: December 1981.

Table 3. The Regression Equations of Nutrients Versus Salinity

element	season	regression equations	n	r
nitrate	Spring	C = 94.9–2.62 S	65	–0.984
	Summer	C = 117.0–4.07 S	62	–0.871
	Autumn	C = 103.7–4.01 S	54	–0.808
	Winter	C = 102.3–3.33 S	53	–0.885
silicate	Spring	C = 118.9–3.38 S	65	–0.990
	Summer	C = 144.9–4.50 S	62	–0.970
	Autumn	C = 142.4–4.45 S	54	–0.979
	Winter	C = –12.2+2.41 S	48	0.921
phosphate	Spring	C = 2.77–0.090 S	65	–0.447
	Summer	C = 1.79–0.049 S	62	–0.580
	Autumn	C = 3.36–0.128 S	54	–0.698
	Winter	C = 4.47–0.160 S	53	–0.551
Note	C: concentration of nutrients (μM), S: salinity (‰)			

good correlations for nitrate and silicate in any season and the correlation for phosphate is varied in different seasons. The good linear relationships of dissolved nitrate and silicate versus salinity may reflect that the transportation of dissolved nitrate and silicate in studied areas are mainly controlled by physical dilution process.

Since Bien et al.[8] discovered that dissolved silicate was transfered during the mixing process of river water with sea water, oceanographers in many countries have undertaken a lot of studies on relationship of dissolved silicate versus salinity [9–12]. Nevertheless, different results have been obtained in different estuaries. Liss [10] summarized the previous data and advanced a buffering mechanism that the transfer of silicate would occur when dissolved silicate level was higher than 14 mg/l (SiO_2), and below this level, the transfer wouldn't take place. All the observed values of silicate in the waters of Hangzhou bay are below 143 μM (less than 8. 6 mg/ l (SiO_2)) and transfer of silicate hasn't been observed obviously. This result is basically in agreement with Liss's conclusion.

The good correlations of the concentrations of dissolved silicate and nitrate versus salinity is presumably due to strong tide, high concentration of suspended sediments and low transparency in the waters of Hangzhou bay, which is neither favourable for the reproduction of plankton in large quantities nor for chemical removal of silicate and nitrate[3]. However, although the concentration of dissolved nitrate is very high and the condition of water quality is not benefit for reproduction of plankton in large quantities, the standing crop of plankton is distinct in different stations. In addition, Yongjiang river empties at the mouth of Hangzhou bay and the concentration of dissolved nitrate in Yongjiang river is not the same as that in Qiantang river. Therefore, the data of dissolved nitrate versus salinity show rather scatter and in intermediate salinity , there is some depletion in the values.

The correlation of dissolved phosphate versus salinity is rather poor and the data show that phosphate behaves in a non-conservative manner. As for the behaviour of phosphate in estuaries, Edmond et al. [13] reported the biological removal in the study of Amazon plume, while Simpson et al. [14] observed that biological activities had little effect on the distribution of phosphate in Hudson estuary. Stefansson and Richards [15] discovered that the concentration of phosphate was buffered in a wide salinity range in the study of Columbia estuary, maintaining its level at 37 $\mu g/l$. Butler and Tibbits[16] made the same conclusion as Stefansson and Richards in the study of the Tamar estuary . From the data of Hangzhou bay, the biological removal is presumably insignificant because of low existing biomass of phytoplankton ($32.3 \times 10^4 - 123 \times 10^4$ unit / m^3). Nevertheless, the data set there show no obvious dilution trend in spring and summer, varying within a relatively narrow range (Figs.15a and 15b). This behavior is strongly indicative of buffering mechanism, as reported in Columbia estuary by Stefansson and Richards. In autumn and winter, the phosphate levels in intermediate salinity region show considerable scatter from 0.6 μM to 3.0 μM (Figs.15c and 15d) and they are much higher than those in spring and summer. This phenomenon may result from that the exchange of phosphorus between bottom water and surface water is sped up due to low water level in autumn and winter.

From above discussion, the concentrations and distributions of dissolved silicate and nitrate are mainly controlled by physical mixing of river water with sea water and their biological removal is relatively insignificant, whereas phosphate shows buffering mechanism by the suspended materials besides physical mixing process.

2. Outfluxes of dissolved nitrogen, phosphorus and silicon: Quantities of nitrogen , phosphorus and silicon from Qiantang river, Cao'e river and Yongjiang river is inputed into Hangzhou bay continuously. But most of the nutrients entering Hangzhou bay are transported out of the bay, except for the removal of a small amount of nitrogen, phosphorus and silicon by biological, chemical and physical processes in Hangzhou bay[3,4]. Since there are linear relationships of dissolved silicate and nitrate versus salinity in Hangzhou bay and its adjacent waters, they could be considered as conservative or closely conservative elements. According to their regression equations (Tab.3), the concentrations of dissolved silicate and nitrate of each season in the rivers could be calculated respectively. However, because of the uncommon distribution of dissolved silicate near Hangzhou bay mouth in winter, we would calculate its concentration in the river from the slope of the mean concentration of silicate and salinity in the upper bay to the mean concentration of silicate and salinity off the bay. The concentrations of nitrite and ammonia in river water would be calculated based on the proportions of their mean concentrations to the average content of nitrate in the upper bay . Nevertheless, phosphate is a non-conservative element in Hangzhou bay, we would consider the mean concentration of phosphate in the upper bay as the corresponding concentrations of phosphate of each season in the river here.

The fluxes of nutrients could be estimated based on the following equation[3,12]:

$$F = \sum_{i=1}^{4} Qi \times Ci$$

where i is season, Q is mean runoff of each season and C is mean concentration of nutrients of each season in river water. The fluxes f dissolved nitrate, nitrite, ammonia, phosphate and silicate are given in Tab.4.

Table 4. Evaluation of River Fluxes of Dissolved Nitrogen, Phosphorus and Silicon

	Discharge ($\times 10^9 m^3$)	Nitrate		Ammonia		Nitrite		Phosphate		Silicate	
		conc. (μM)	flux (tons)	conc. (μM)	flux (tons)	conc. (μM)	flux (tons)	conc. (μM)	flux (tons)	conc. (μM)	flux (tons)
Spring	16.68	94.9	22161	2.75	642	0.45	105	1.07	553.2	118.9	55531
Summer	15.38	117.0	25192	4.98	1072	2.35	506	1.00	476.8	144.9	62400
Autumn	6.40	103.7	9292	1.60	143	0.41	37	2.02	401	142.4	25518
Winter	5.98	102.3	8564	3.37	282	1.06	89	1.92	356	118.6	19858
Total	44.44		65209		2139		737		1787		163307

The fluxes considered here didn't take into account the estuarine processes affecting each element in detail. Nevertheless, the nutrients in estuaries are extensively involved in biological , chemical and physical process which can affect their transfer from river to the open ocean. Thus, the estimation of multiplying the average river concentration by the mean river dischage in each season may be a simple estimative method.

As for organic nitrogen and phosphorus compounds and for the particulate forms which have to be considered for flux estimations, it is difficult to estimate their fluxes for Hangzhou bay now due to the limited data. This work remain to be done in future.

ASSESSMENT OF EUTROPHICATION IN HANGZHOU BAY

The general feature of eutrophication is that excess nutrients and organic matters cause the ecological structure to be changed greatly in the coastal waters. Thus, many environmental researchers usually consider the concentrations of COD, dissolved nitrate. phosphate and primary productivity as the indexes of eutrophication of water[17−20]. In order to take precautions against eutrophication of waters, many countries stipulated the maximum allowable concentrations for dissolved nitrate, phosphate and COD in sea water.

According to 《The sea water quality criteria》 and 《The water quality criteria for marine fishery》 of china (COD: 3 mg/l; $NO_3^- - N$: 0.1 mg/l and $PO_4^{3-} - P$: 0.015 mg/l), it can be seen from Tab.2 that mean concentration of dissolved nitrate in Hangzhou bay and its adjacent waters (0.68 mg / l)exceed the criterion by 5.8 times and the mean value of dissolved phosphate (0.034 mg / l) is as 2.2 times as the criterion. COD varies in different seasons. In spring and winter, COD in the inner bay is beyond the criterion, while the levels in summer and autumn are less than the critical value.

According to the equation of eutrophicational index proposed by Tomotoshi Okaichi[19]:

$$\frac{COD\ (mg/l) \times DIN\ (mg/l) \times DIP\ (mg/l)}{4500} \times 10^6 \geq 1$$

The exponential values in Hangzhou bay and its adjacent waters (Tab. 5) are all beyond

Table 5. The Exponential Values of Eutrophication of Hangzhou Bay in Each Season

	Upper bay	Lower bay	Out off bay
Spring	24.8	2.6	0.98
Summer	26.2	3.3	1.2
Autumn	45.5	4.4	2.0
Winter	56.6	22.0	6.7

the critical value, except for the area off the bay in spring . This indicates that most of waters in Hangzhou bay and its adjacent areas are eutrophicated in different degree and the water in the upper of Hangzhou bay is hypertrophicated because its exponential value is higher more than 25 in any season.

Hangzhou bay and its adjacent areas is one of the most heavily eutrophicated estuaries and bays in china. In fact , the most important environmental problem in Hangzhou bay and surrounding area is eutrophication now, as it has been provided with material support for red tide. However, because the water in the inner bay is in good exchange with the water off the bay and the contents of dissolved oxygen are generally within normal range, also because of strong tide, high concentration of suspended sediments and low transparency in the waters of Hangzhou bay , which is unfavourable for the reproduction of plankton in large quantities, there is no large—scale red tide appearing in Hangzhou bay up to now. But red tides have been observed frequently in the coastal waters around Zhoushan Islands off Handgzhou bay in recent years and the area ranging 30° 05′ ——31° 51′ N, 122° 15′ ——123° 10′ E has become a frequently—occurring region for red tide. It has had a great influence on fisheries production and ecological featrue of this area.

The cause for eutrophication of the coastal waters of Hangzhou bay and its adjacent area is mainly due to the river input of Qiantang river, Cao'e river and Yongjiang river, which contain quantities of nitrogen, phosphorus and organic matters, and the increasing discharge of domestic and industrial wastes along Hangzhou bay. In addition, the runoff of Changjiang river, which is 21 times more than the total runoff of Qiantang river, Cao'e river and Yongjiang river and runs south directly during dry season, has made certain contribution to the eutrophication of Hangzhou bay and its adjacent waters and extended the eutrophication area.

CONCLUSIONS

1. The average concentrations of nitrate, phosphate and silicate in the upper of Hangzhou bay are 78.4 μM, 1.50 μM and 102.2 μM respectively. The content of silicate is corresponding to the mean of world estuaries, while the values of nitrate and phosphate are much higher than the mean of world estuaries. It is presumably due to wide utilization of synthetic fertilizer in the rice paddies and the increasing discharge of industrial and domestic wastes in this area.

2. The distributions and variations of nutrients in Hangzhou bay and its adjacent area are influenced not only by the runoff of Qiantang river, Cao'e river and Yongjiang river, but also by Changjiang river plume, tide and their estuarine processes. The distributions of nutrients show obvious seasonal variation.

3. The biological removal of nutrients in Hangzhou bay is presumably insignificant because low standing crop of plankton is observed in any season. The linear relationships of silicate and nitrate versus salinity indicate that they are mainly controlled by physical dilution, while the values of phosphate show no obvious dilution trend in this area.

4. The fluxes of dissolved nitrogen, phosphorus and silicon to the ocean from the river are estimated to be about 68×10^3tons / yr., 1.8×10^3 tons / yr. and 163×10^3 tons / yr. respectively.

5. Hangzhou bay and its adjacent areas is one of the most heavily eutrophicated estuaries and bays in china. Although there is no large-scale red tide appearing in Hangzhou bay up to now, there is every probability of the occurrence of red tide in this area.

ACKNOWLEDGEMENTS

We sincerely thank Mr. Dong Henglin, Jiang Guochang and Wang Zhengfang for providing the data and information.

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ASSESMENT OF RIVER INPUTS TO THE SEAS IN WESTPAC

A CASE STUDY OF THE CHAO PHRAYA RIVER, THAILAND

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Office of the National Environment Board

1. INTRODUCTION

Thailand is an agriculture oriented country which depends largely on her natural water resources. The country, fortunately enough, locates in the lower basin where rivers and canals provide abundant of water for agriculture and other uses. Developments in economic and population growth number leads to higher use of water in both quantity and variations. Problems that the country now facing at are decreasing of water quality and quantity. The degradation in water quality of some water ways is so critical that the government had to put urgent measures in order to alleviate situation. Of all water ways in Thailand, the Chao Phraya has been named as King of the River due to its large volume of discharge and its importance to the country's economic development.

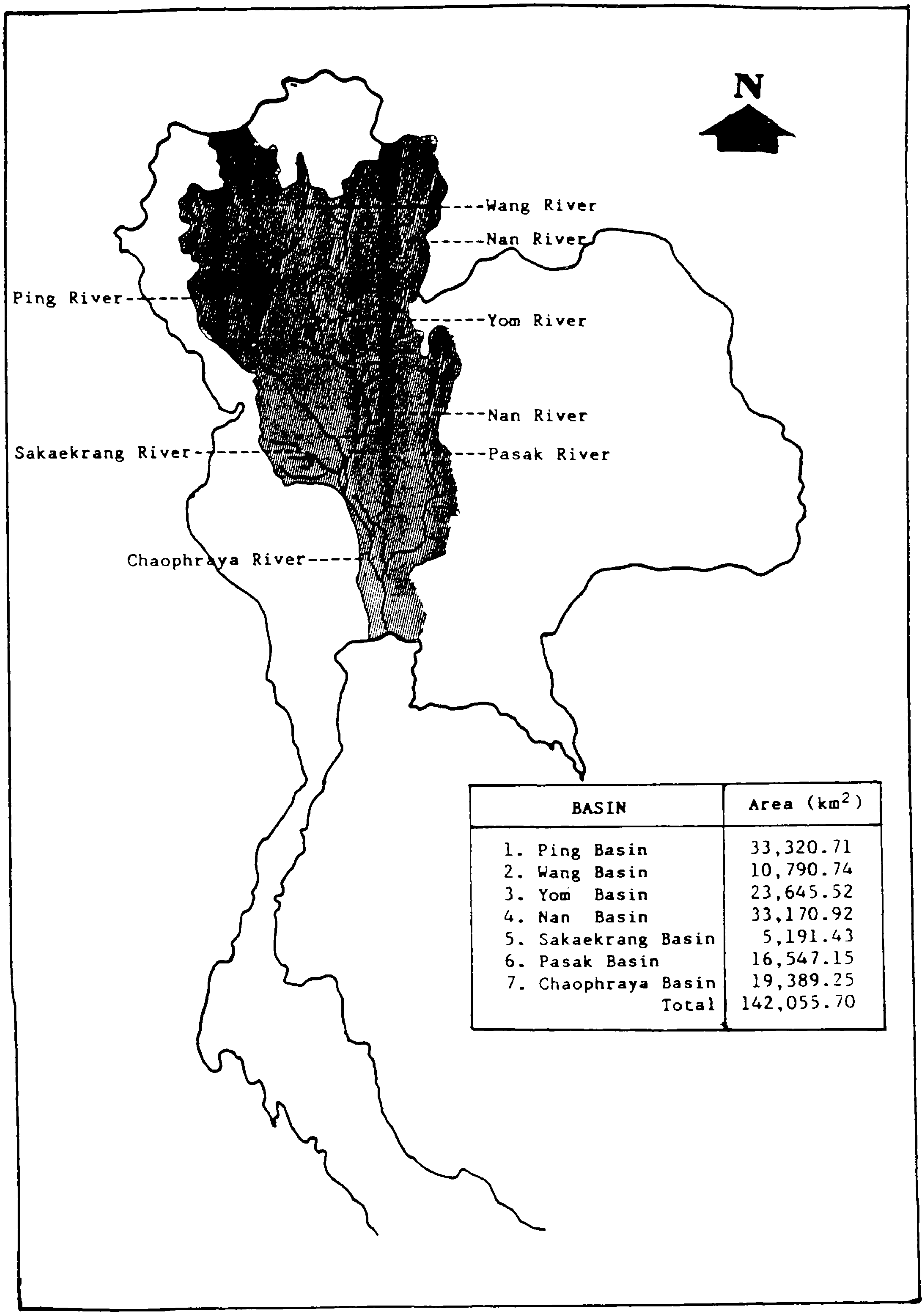
2. THE CHAO PHRAYA'S CHARACTERISTICS

The Chao Phraya River originates in the north of the country where four rivers namely, Ping, Wang, Yom and Nan, join together to become the great river. The overall river basin is totally estimated at 142,055.70 square kilometers (Fig. 1). This number includes all of its tributaries which comprise 7 basins altogether.

The Chao Phraya River itself is 380 kilometers long which start from Nakornsawan Province to the Gulf of Thailand in Samut Prakarn Province and its basin is 19,389.25 square kilometers (Fig. 2). The river flows past 9 provinces along its banks, and serves almost 8 million population (Fig. 3) and the lower part of the river, 60 km., is condensed of industries, especially in Samut Prakarn Province.

There are 3 seasons in this basin which are summer season (February-April), rainy season (May-October) and winter season (November-January). The mean monthly air temperature, wind, evaporation and rainfall for the period 29 years (1961-1990) at Nakorn Sawan and Bangkok Metropolis station which are located at the northern and southern part of the river respectively are presented in Table 1. The mean monthly rainfall in the basin ranges from 7.3 - 334 mm. and the yearly discharge is about 30,000 million cubic meters. The high discharge period is in May to November, while the low discharge is in December to April (Fig. 4).

The Chao Phraya basin is lain on the Lower Central Plain which occupies the central part of Thailand. The elevation of the plain ranges from 25 meters above the mean sea level at Nakorn Sawan in the north to less than 4 meters at Ayutthaya, and to about 2 meters in the vicinity of Bangkok. The Chao Phraya basin is a geological depression filled with alluvial and detail sediments. Soils associated with the flood plain deposits are mostly made up of sandy clay and are formed throughout the northern half of the plain. Because of its geological composition and the characteristic of the Chao Phraya basin's sediments, the basin has been used for paddy field and is a major source of rice production of the country.



BASIN	Area (km^2)
1. Ping Basin	33,320.71
2. Wang Basin	10,790.74
3. Yom Basin	23,645.52
4. Nan Basin	33,170.92
5. Sakaekrang Basin	5,191.43
6. Pasak Basin	16,547.15
7. Chaophraya Basin	19,389.25
Total	142,055.70

Fig. 1 Area of Chaophraya River Basin and other related rivers basin

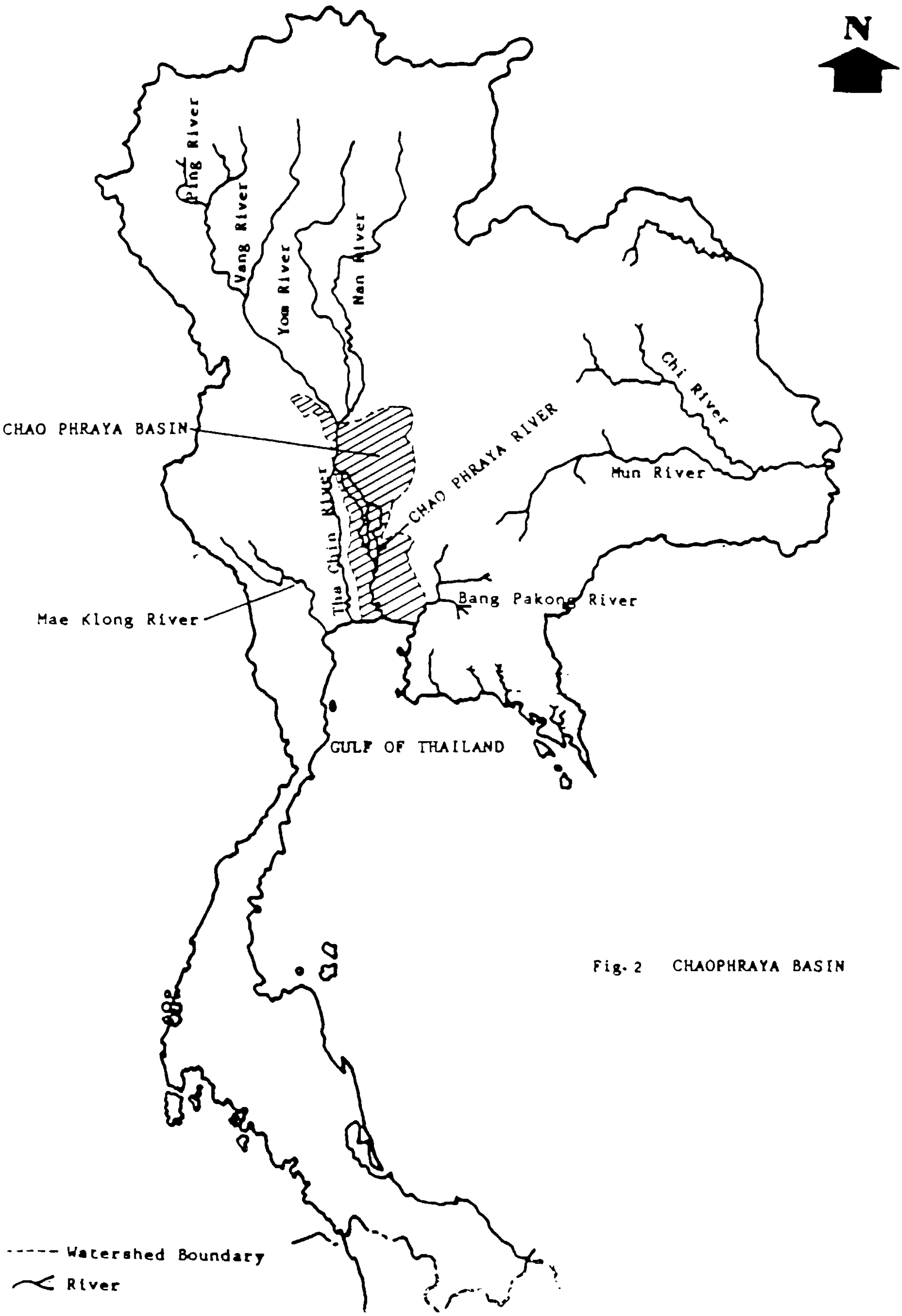


Fig. 2 CHAOPHRAYA BASIN

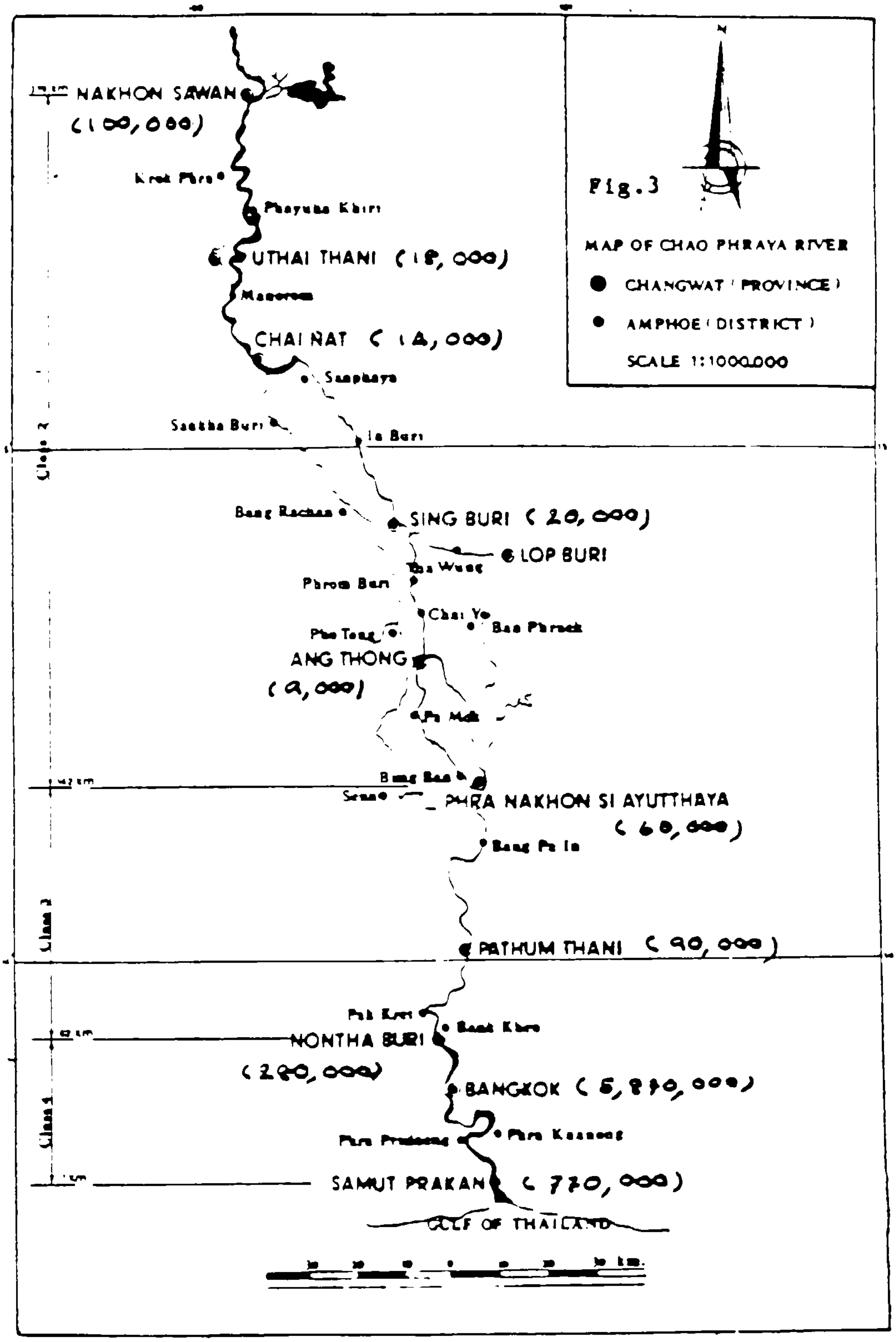
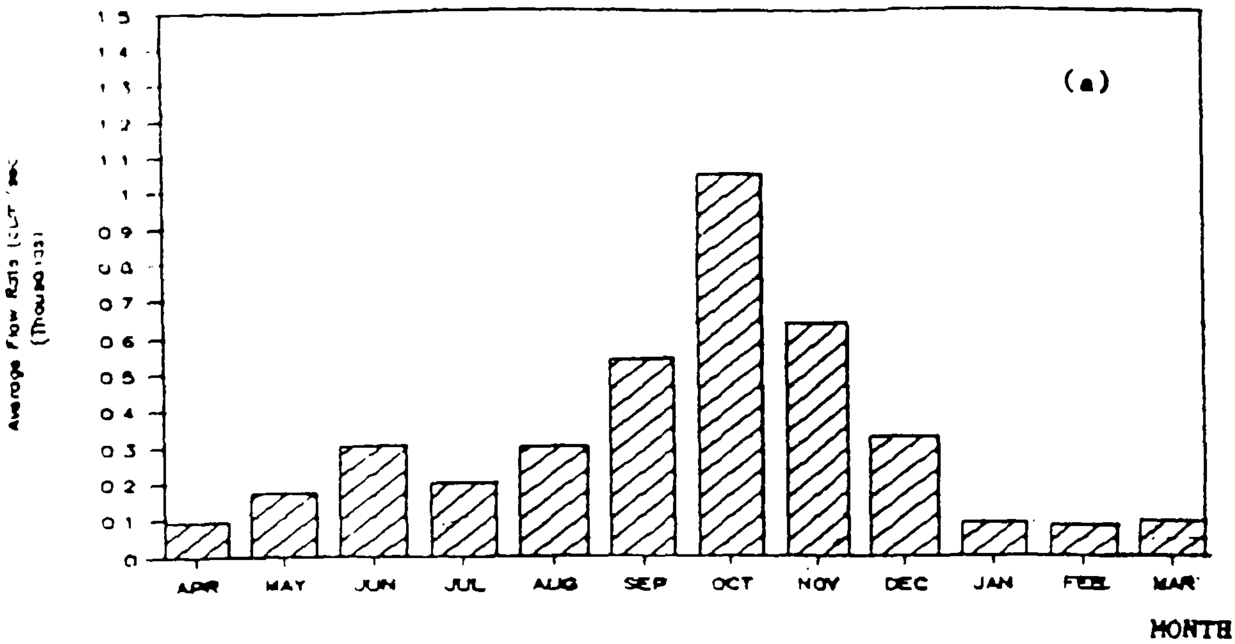


Fig 3 Population in Municipal (1990) along the river



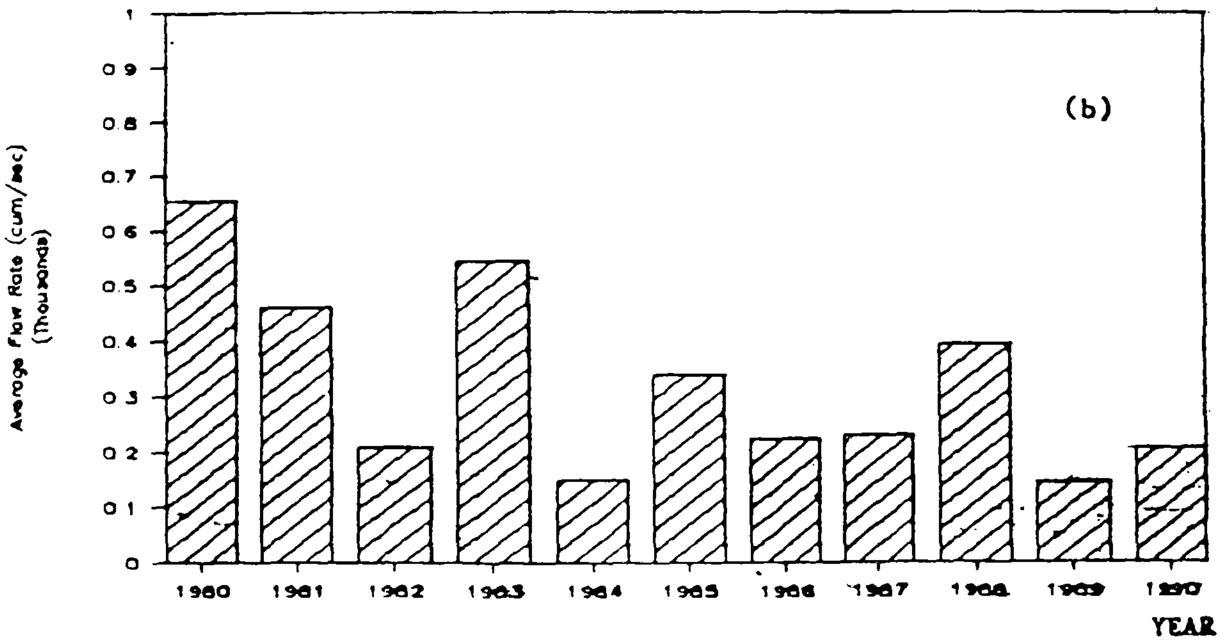


Fig. 4 (a) Monthly variation of average flow rate at CHAOPHRAYA DAM during year 1980 - 1990.

(b) Annual variation of average flow rate of CHAOPHRAYA RIVER at CHAOPHRAYA DAM from 1980 - 1990.

3. PROBLEMS CONCERNING THE RIVER

Because the number of large population which the river serves to, the Chao Phraya river is now under critical condition that its water quantity and quality becomes critical.

3.1 PROBLEMS ON WATER QUANTITY

Deforestation has affected water volume of most rivers in Thailand and the Chao Phraya River is one of the victim. Flow volume in the Chao Phraya River decreases significantly in the last decade. The low flow begins to affect irrigation, power supply, and most of all water supply. Farmers are requested to cut down their cropping areas while authority starts to look for other sources of water supply to substitute the water shortage in the river.

3.2 PROBLEMS IN WATER QUALITY

Other than shortage of water, the Chao Phraya also faces with degradation in its water quality. Sources of pollution which are responsible for polluting the river include community, industry and agriculture. Community discharges most of organic and nutrient into the river while industry discharges various kinds of toxic substance which may be harmful to water users. Agriculture, on the other hand, releases pesticides and nutrients into the water body as well. The Chao Phraya water quality in some sections, particularly to the section which passes the Bangkok Metropolitan Region (BMR), are so severe that impacts to water utilization and ecology become evidence. Dissolved Oxygen, the most important parameter, reaches nearly close to zero in dry season. High number of coliform bacteria exists in sections close to towns (Fig. 5, 6).

Nutrients such as Nitrogen and Phophorous continuously increase. Though impacts of high nutrients content in the river are not clearly identified, the wide spread of water hyacinth is mentioned that caused from such high level of nutrientss in water ways. From monitors, carried out be Office of the National Environment Board (ONEB), nutrients content in the river vary from section to section (Fig. 7, 8). The yearly discharge of nutrient to such as nitrate and phophorous can be as high as 12 million kgs and 3 million kgs respectively considered, the last average concentration in 1990. Community effluent is said to be responsible for most of pollutants particularly phosphorous which contain in detergent. The phenomenon of algal blooms in the gulf occurs occasionally. Its causes are being investigated whether that how much nutrients in rivers affect.

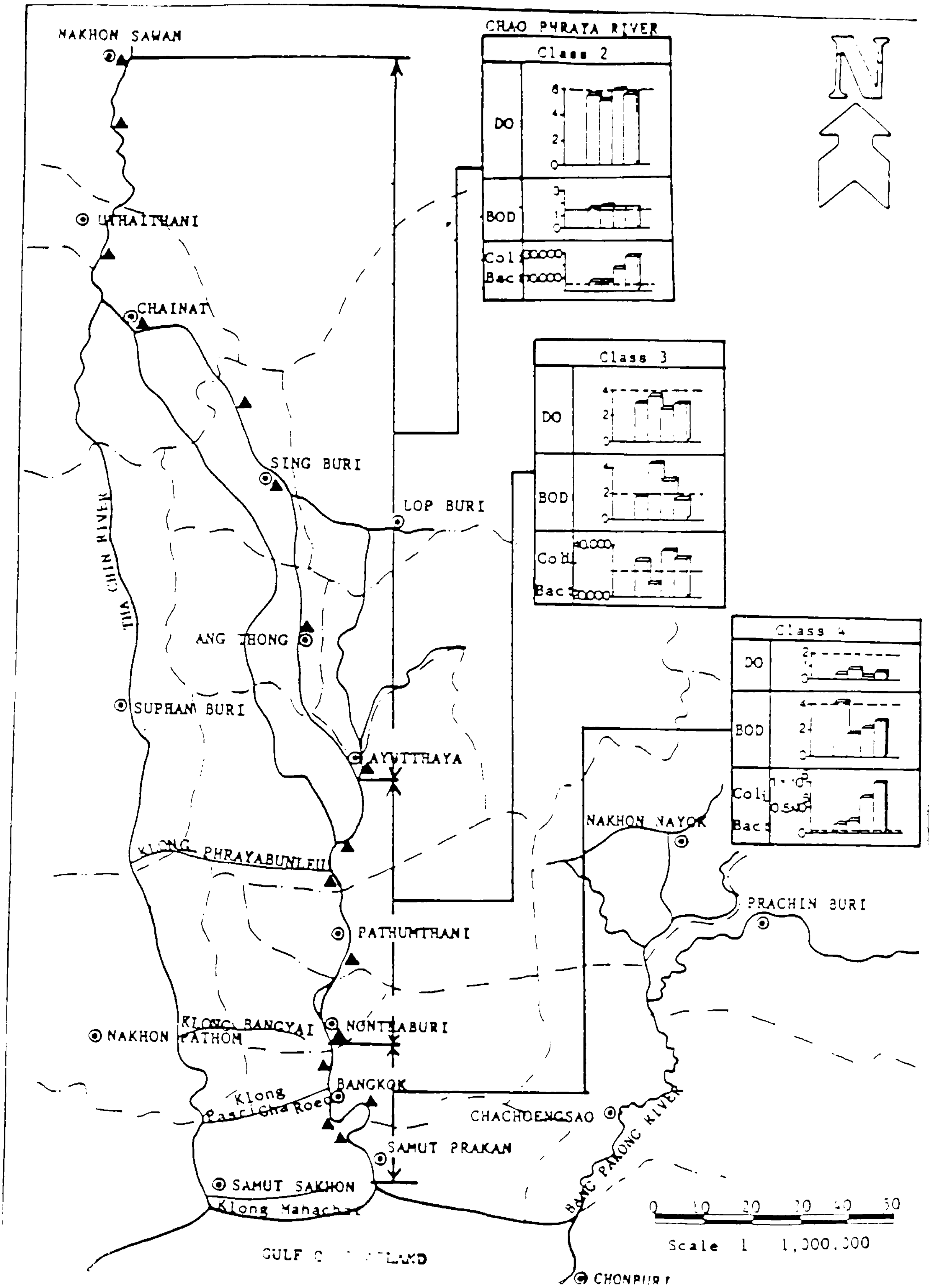
4. MEASURES IN PROTECTING THE RIVER QUALITY

The Thai Government realizes in the environmental problems and has put numbers of measures to protect and control the environment. For water pollution, measures include long and short term strategies that listed as follow:

4.1 SHORT TERM STRATEGIES

(a) The construction of community wastewater central treatment plant: The Bangkok Metropolitan Administration (BMA) has at the present projects on construction of central wastewater treatment plant which is divided into 2 phases and expected to treat about 75 percent of community wastewater before discharging into canals. The first-two projects of the first phase are the construction of Si Phraya and Rattanakosin treatment plants which are expected to be completed in 1993 and 1994 respectively.

(b) Implementation of the Building Effluent Standards: The Office of the National Environment Board has notified the Building Effluent Standards in 1989. When implemented, community activities such as hotels, offices, and restaurants will be required to treat


CHAO PHRAYA RIVER
Class 2
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Class 3
Class 4
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THA CHIN RIVER
ANG THONG
SUPHAN BURI
AYUTTHAYA
KLONG PHRAYABUNLEU
NAKHON NAYOK
PRACHIN BURI
PATHUMTHANI
NONTHABURI
KLONG BANGYAI
NAKHON PATHOM
BANGKOK
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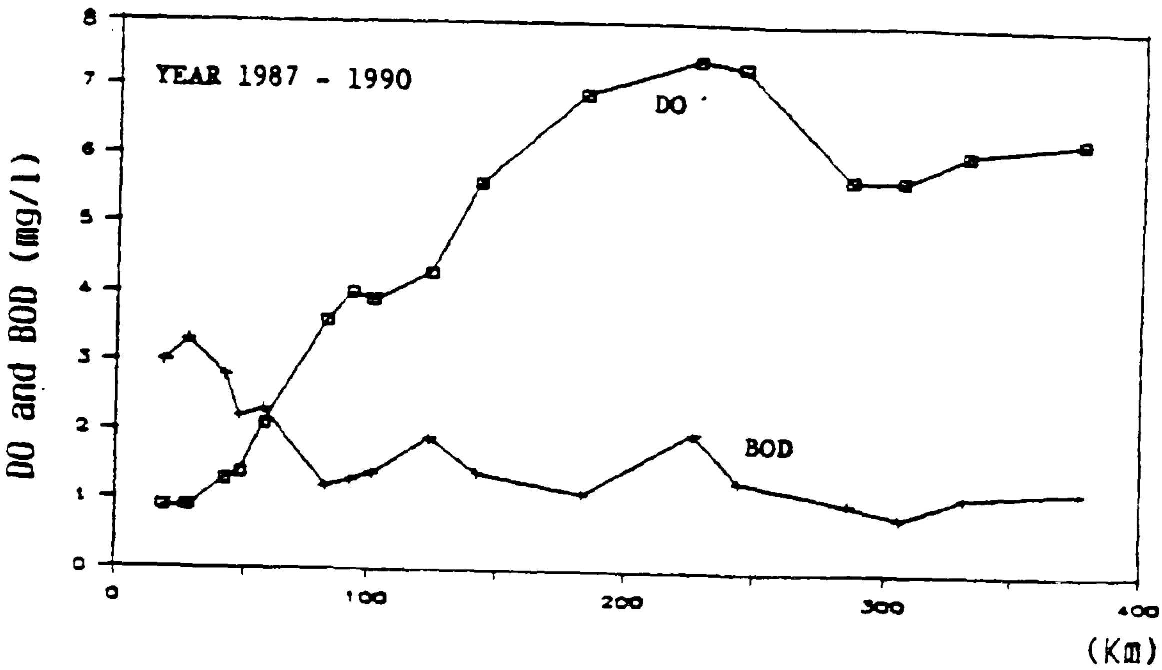

Fig. 6 The variation mean DO and BOD along the Chaophraya River during 1980 - 1990 (4 years).

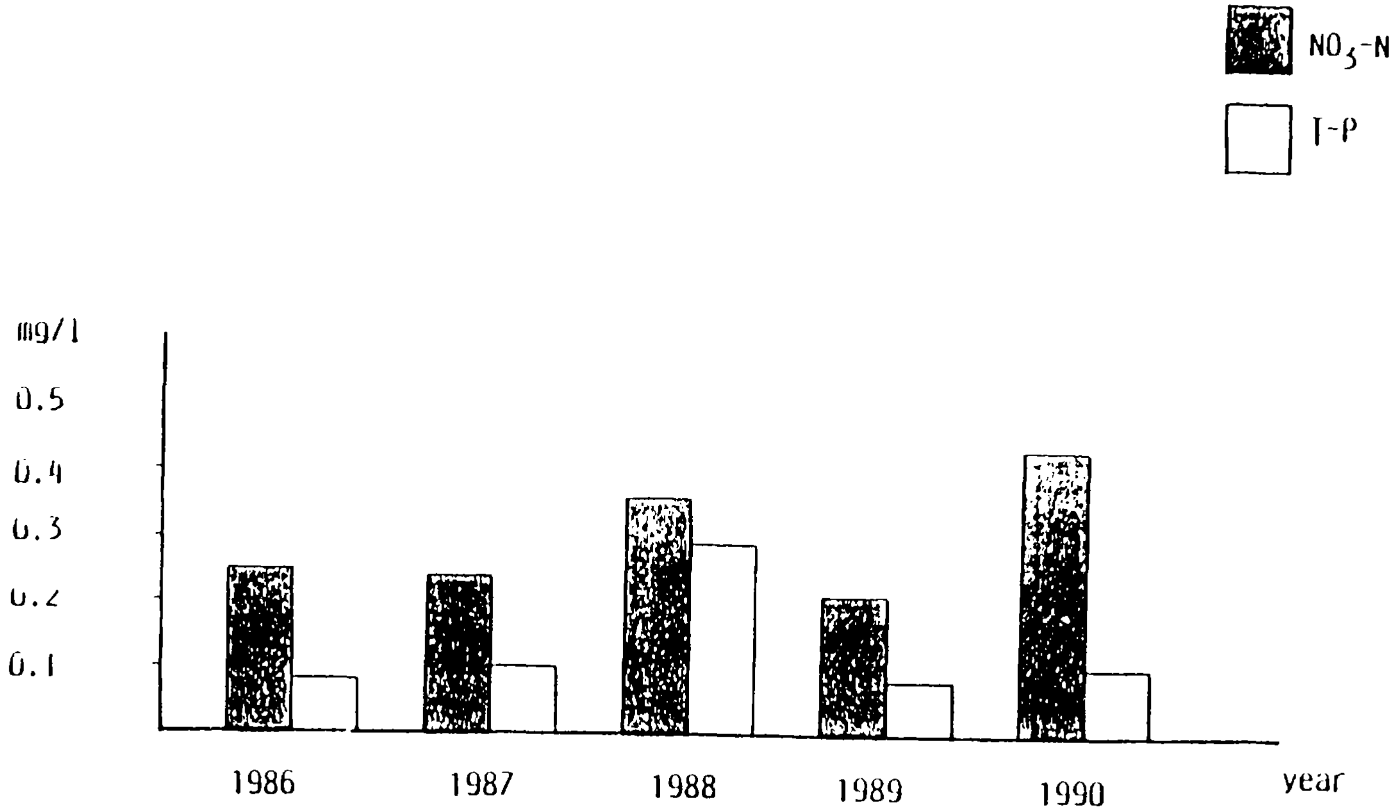

Fig. 7 Nitrate-Nitrogen and Total Phosphorus in The Chao Phraya during the last 5 years (1986-1990)

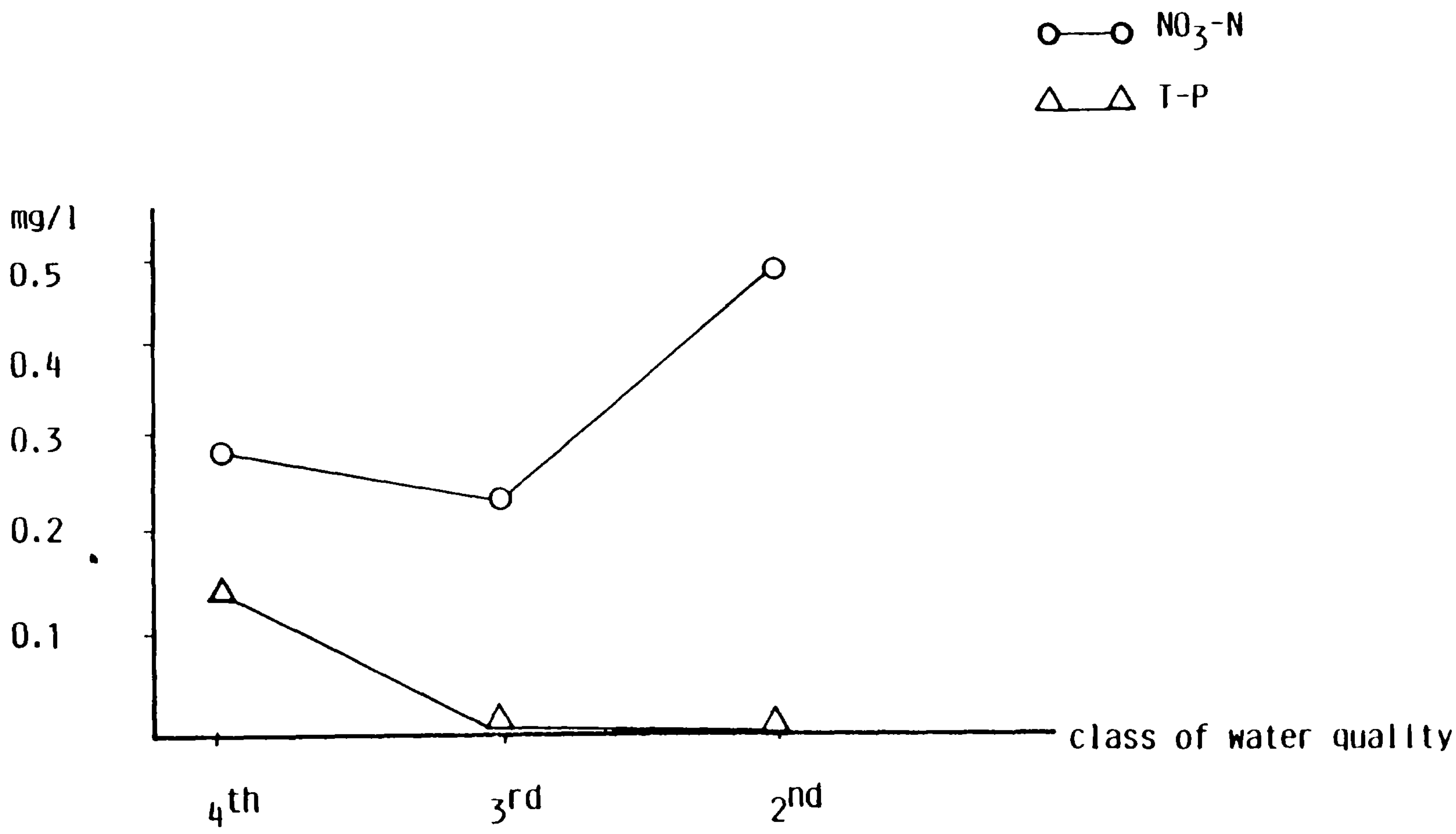

Fig. 8 Nitrate-Nitrogen and Total phosphorus in The Chao Phraya River in 1990

Table : Climatic data for the period 1961-1990 (29 years)

Station : NAKHON SAWAN

Latitude : 15 48 N Elevation of station above MSL : 34 Meters

Longitude : 100 10 E Hight of barometer above MSL : 35 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Mean temp. (°C)	25.4	28.3	30.4	31.8	30.3	29.5	28.9	28.4	27.9	27.7	26.4	24.
Wind (Knots)												
-Mean wind speed	2.7	4.4	5.9	5.8	4.5	4.6	4.1	3.6	2.3	2.1	2.2	2.
-Prevailing wind	E	S	S	S	S	S	S	S	S	NE,E	E	N,E
Mean evaporation (mm)	148.7	177.2	233.9	253.3	212.3	184.0	174.6	156.5	132.6	132.6	130.7	136.
Rainfall (mm)												
-Mean	9.8	14.9	30.0	60.9	138.7	117.1	134.1	194.9	231.6	144.4	35.3	7.3

Station : Bangkok Metropolis

Latitude : 13 44 N Elevation of station above MSL : 2 Meters

Longitude : 100 34 E Hight of barometer above MSL : 20 Meters

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Mean temp. (°C)	25.9	27.4	28.7	29.7	29.2	28.7	28.3	28.1	27.8	27.6	26.9	25.
Wind (Knots)												
-Mean wind speed	2.5	3.9	4.8	4.4	3.6	3.8	3.6	3.6	2.4	2.0	2.2	2.4
-Prevailing wind	E	S	S	S	S	SW	SW	SW	SW	NE	NE	NE
Mean evaporation (mm)	138.0	141.3	183.4	190.1	172.5	152.2	150.6	151.4	132.1	126.6	126.1	134.
Rainfall (mm)												
-Mean	9.1	29.9	28.6	64.7	220.4	149.3	154.5	196.7	334.2	241.6	48.1	9.7

their effluent comply to the standard.

(c) Industrial Relocation: The Plan is underway to relocate industrial plants, particularly these with high potential in pollution, within the BMA into other site where impacts from pollution can be properly and effectively managed.

4.2 LONG TERM STRATEGIES

In the long run, measures which are proposed in protecting the country's environment include:

(a) The establishing of Water Board Authority.

(b) The reuse of treated wastewater.

(c) The land use control according to environmental susceptibility.

(d) The long term planning in land acquirement for wastewater treatment and refuse disposal.

(e) The introduction of mass transportation system which is environmental and energy efficient.

REVIEW OF PERAK RIVER

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Department of Fisheries
Ministry of Agriculture, Malaysia

INTRODUCTION

Perak River, the second longest in Peninsular Malaysia, is approximately 427 km long and flows in the southwesterly direction into the Straits of Malacca (Fig. 1). It has 140 tributaries including the Kangsar River, Parit River and Kinta River. It should be noted that Kinta River is flowing through Kinta Valley which is considered to be one of the richest tin mining areas of the world.

The Perak River has a total discharge value of 186 cubic metres/sec. and an average annual suspended load of 0.9×10^6 metric tonnes.

The river and its tributaries traverse almost the whole state of Perak. It has for its watershed the Chenderoh Lake and dam area and the entire Kinta Valley. The river is being used for various human activities. Since early settlement along the river ensured the growth of towns, the river and its distributaries inevitably meander through them thus unavoidably becoming a part of the sewage and waste disposal system for the urban population with reference to the existing housing areas and industrial zones, not forgetting the potential impact from new housing and industrial developments.

Away from the towns, the river passes through vast areas of padi, rubber, oil palm, cocoa and coconut cultivation facilitating their irrigation and drainage. Here the usage of fertilizers and pesticides may further compound the adverse effects upon the river. Furthermore the use of its water for tin mining in the Kinta Valley (one of the richest mining grounds) which ultimately drains into the river complicates matters further. Additionally there have been cases, where reinforced embarkments containing mining pools have given way, flooding the vicinity and carrying sand to the rivers.

The construction of highways and new bridges has been noted to add to the woes of the river, in that deforestation increases flooding and worsens soil erosion. Bridges have contributed to the formation of islets (e.g. Sultan Iskandar Bridge, Sultan Azlan Shah Bridge) in the river.

RELIEF

The river begins its journey from the Bintang Range, being fed by numerous tributaries descending from various mounts averaging between 3,000 ft. and 5,000 ft. above sea level. Almost one third of the river at its hinterland traverses higher ground until it reaches Kuala Kangsar. Tasik Chenderoh, a reservoir on the Perak River with a surface area of 2,500 ha. is situated about 190 km from the river mouth. It is the first in a series of reservoirs constructed on Perak River for flood control and hydro-electric power generation. The river then meanders through lowland fed by tributaries flowing through mining areas and industrial sites e.g. S. Kinta. At the lower end, another tributary, the Bidor River which receives discharge from an extensive rice cultivation project joins the Perak River. From this point downwards till the river mouth at Bagan Datoh the river is deep enough to enable oil tankers to steam upstream and anchor at the Teluk Intan for unloading.

GEOLOGY

From the Bintang Range, where the river starts, the surrounding terrain and bedrock constitutes acid intrusives evidently from early volcanic activity. As it reaches the lowlands i.e. near the Kuala Kangsar town it flows through carbonacous material e.g. phyllite, shale, slate and sandstone. The major tributary, Kinta River flows between prominent formations of limestone hills. At the river mouth where it merges with the sea, estuarine clay and silt make up the river bed.

The soil type varies accordingly i.e. in the lowland the Perak River flows over arenaceous type material while the Kinta River flows through limestone areas. At the estuary the soil is made up of almost total alluvium.

VEGETATION COVER

There is very little natural vegetation cover except for the areas drained by tributaries in the hills. There are forest reserves before the Chenderoh Dam. In the lower reaches, the river flows through cultivated land, plantations and mining areas.

LAND USE

Referring to Fig. 2, there are 3 main areas of land use namely:

(i) Mining
(ii) Agriculture
(iii) Forest Reserve

The main river i.e. Perak River traverses agricultural land while the Kinta River drains mining areas especially tin-mining operations. Frining both these areas are forest reserves. Mounts and hills which are also starting points for numerous tributaries. The Manik River and Bidor River irrigate an extensive rice cultivation plain.

(i) **Mining**

The Kinta River, one of the major tributaries of the Perak River serves as the conveyance means for whatever tailings that result from monitor pump and klongs (tin mining operations). Areas that have been mined for tin, appear bare and white, with the earth stripped of all organic matter and soil resulting in loose sand. During sudden heavy downpours, the sand gets mobilized and is carried to the main river or tributary draining the area. This is in addition to whatever was washed away during the mining operations. The scale of operation is massive, hills have been excavated and washed away by monitor pumps. Besides tin, other metals mined include aluminium, copper, berylium and zinc, but they are carried out on a much smaller scale.

(ii) **Agriculture**

Figure 3 and 4 show areas where rubber and palm oil processing factories are concentrated. These activities are important sources of effluent discharge. The discharge is rich in organic material with subsequent reductions in BOD valves in the receiving water bodies. The oil plam factories are concentrated in one particular district i.e. at the confluence of Bidor and Perak River. The rubber factories on the other hand are more evenly distributed over the entire Perak River watershed. Amount of effluent discharged varies according to the scale of operation. A small palm oil processing mill can discharge up to 10 tonne/hr while a large plant can go up to 60 tonne/hr. during operation.

Rice cultivation areas are located along the Perak River all the way up to the hill slopes. The biggest acreage under rice cultivation is the Sg. Marnik region (flat plain) which is irrigated by a tributary of Perak River i.e. the Manik River. Rice cultivation entails heavy use of fertilizer and pesticide both of which get flushed down rivers during heavy rainfall.

Livestock Rearing

Piggery farms are significant contributors of nutrient rich water to the tributaries draining from the farms. Fig. 5 shows the location of pig farms in relation to the Perak River. There are very few farms along the mean river itself but its tributaries serve as important avenues of waste removal.

Waste from pig farms have been reported to clog up streams rendering them black and murky scum pools.

Industrial Areas

The Perak itself does not flow through many industrial areas except for one near Kuala Kangsar but the Kinta River and its distributaries flowing through the capital city of Ipoh receive waste water from Tasek and Jelapang Industrial Areas (Fig. 6).

Human Activities

Owing to the proximity of human settlement along the river, it is conveniently used as a disposal means for sewage and wastewater. As mentioned earlier the Kinta River receives more wastewater as it flows near major towns and industrial areas. Thus it is to be expected that Perak River be comparitively cleaner than Kinta River especially before the confluence of the tributary with the main river. Even so there were times when rural populace were advised not to use Perak River water for human consumption during cholera epidemic.

Kinta river water pollution study was done at the request of Perak Regional Office by the Division of Environment. Final results of the river water quality samplings are still pending. However preliminary results indicate that sewage is a major contributor to pollution in Kinta River.

Nutrient Flux Studies

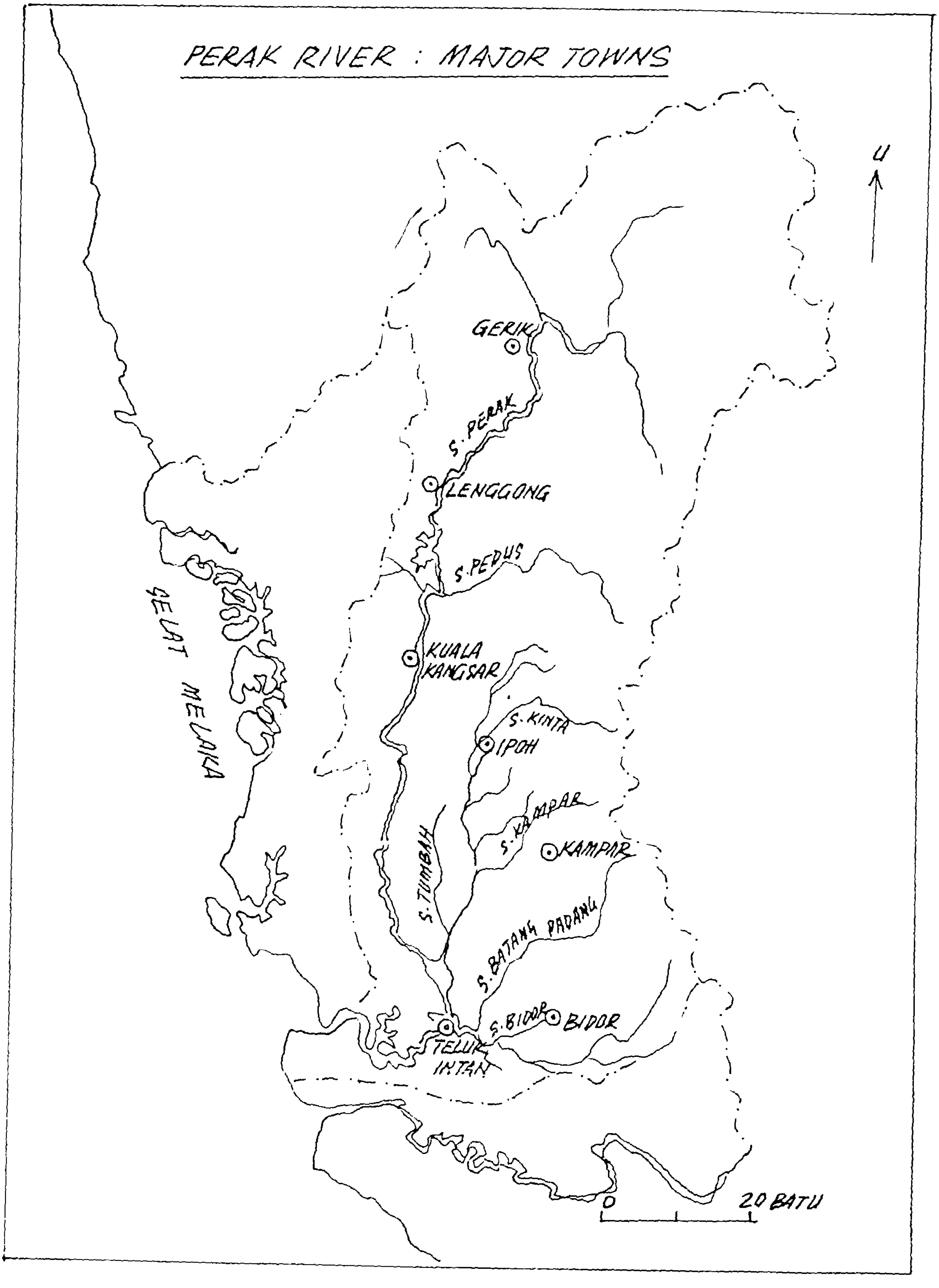
The Division of Environment which monitors the water quality of rivers has data on nitrates and phosphates for Perak River from the year 1985. Sampling was carried out on an average of four times annually. There are altogether 28 sampling stations on the River and its tributaries. Figures A to D show graphical representations of nitrate and phosphate values for 6 stations i.e. on the main River from Sg. Dulang at the estuary to Lenggeng upriver.

The Figs. A to D show nitrate and phosphate values against time. The phosphate levels are very low, at times not detectable. It is noted that the values increase during mid-year. Referring to rainfall patterns as indicated in Figs. B and E there is a corresponding decrease in rainfall during the period.

Fig. G which has measurements for station (1) at the estuary shows that there were elevated levels during the year 1988, 1989 and 1990.

Conclusion

There are several factors affecting the nutrient fluxes in the Perak River, one of them being rainfall. Certain tributaries are carying a heavier load and the measurements taken after confluence points show elevated levels. There is a need to gather detail background information on development patters over time to correlate the fluctuations in the graphs presented earlier. Frequency of samples should ideally be at least once a month.


PERAK RIVER : MAJOR TOWNS
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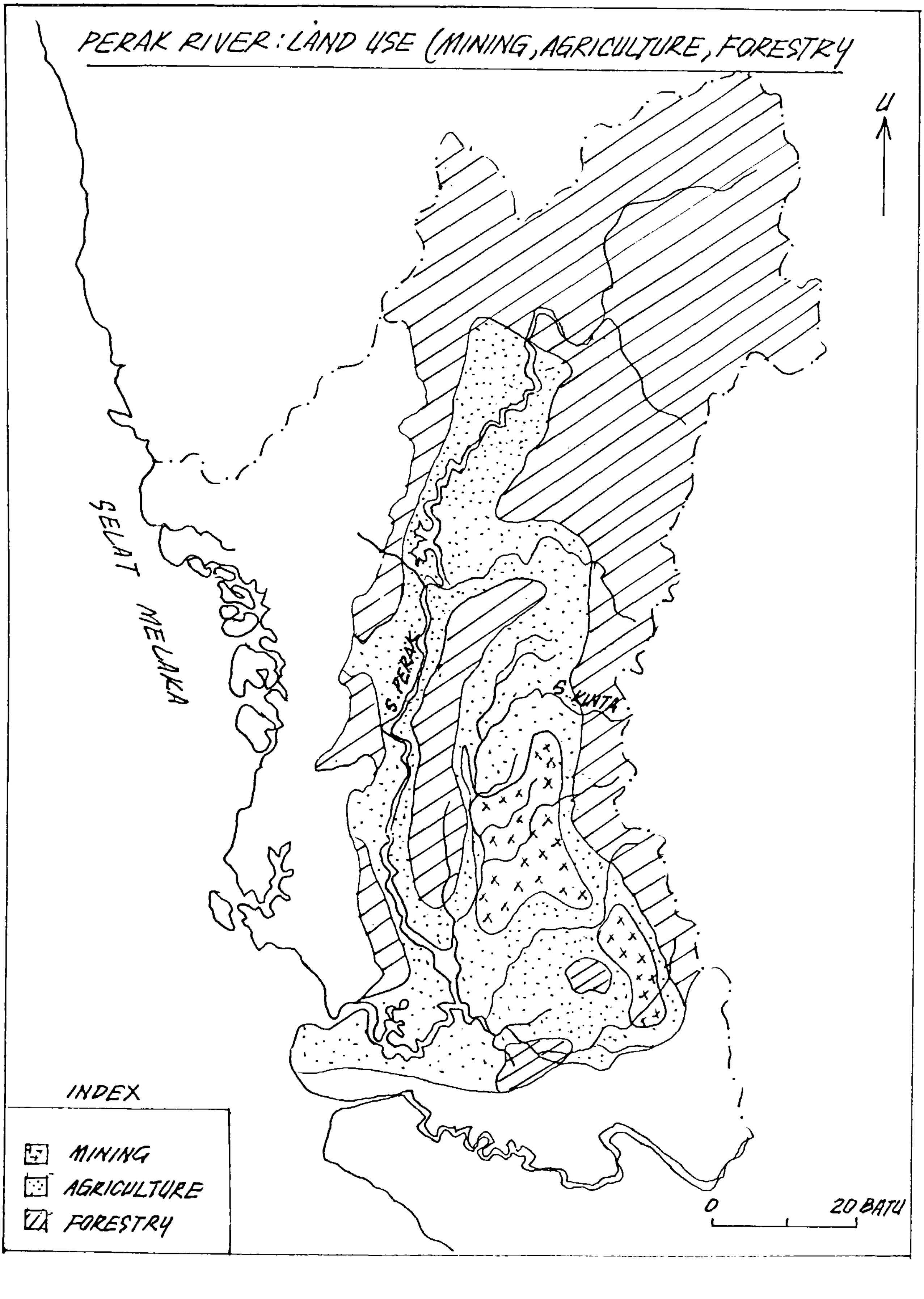
PERAK RIVER: LAND USE (MINING, AGRICULTURE, FORESTRY
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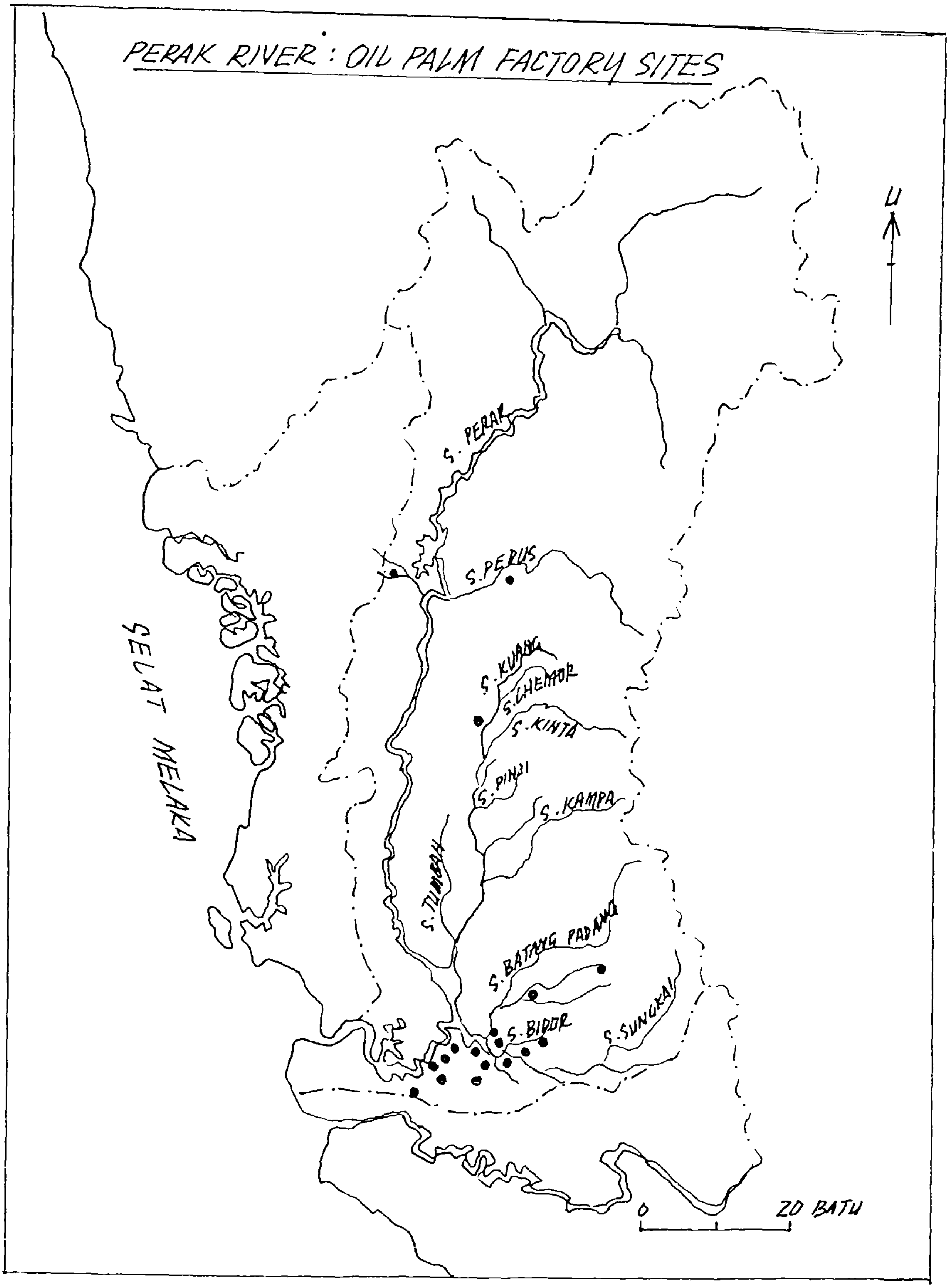
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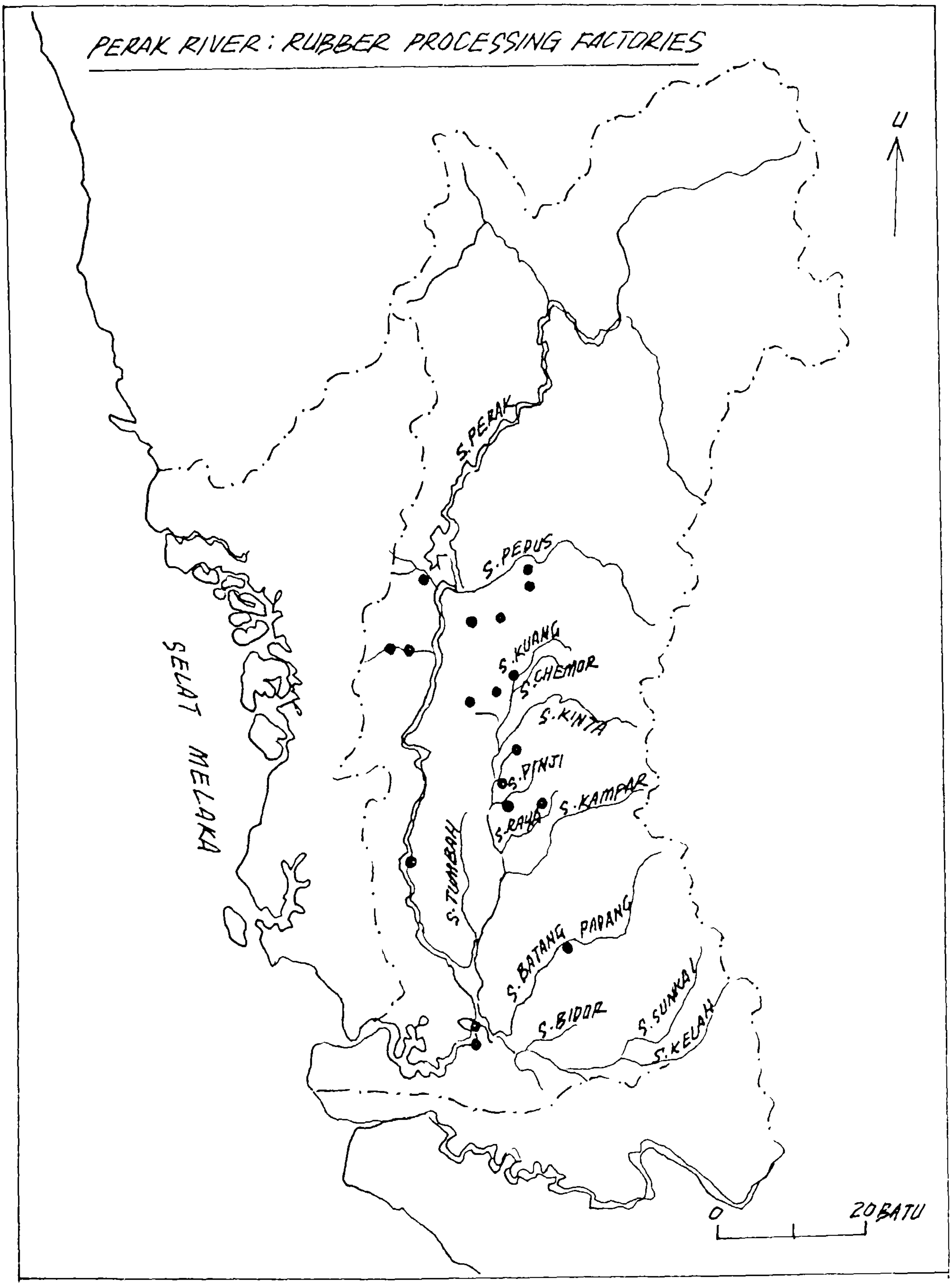
PERAK RIVER: RUBBER PROCESSING FACTORIES
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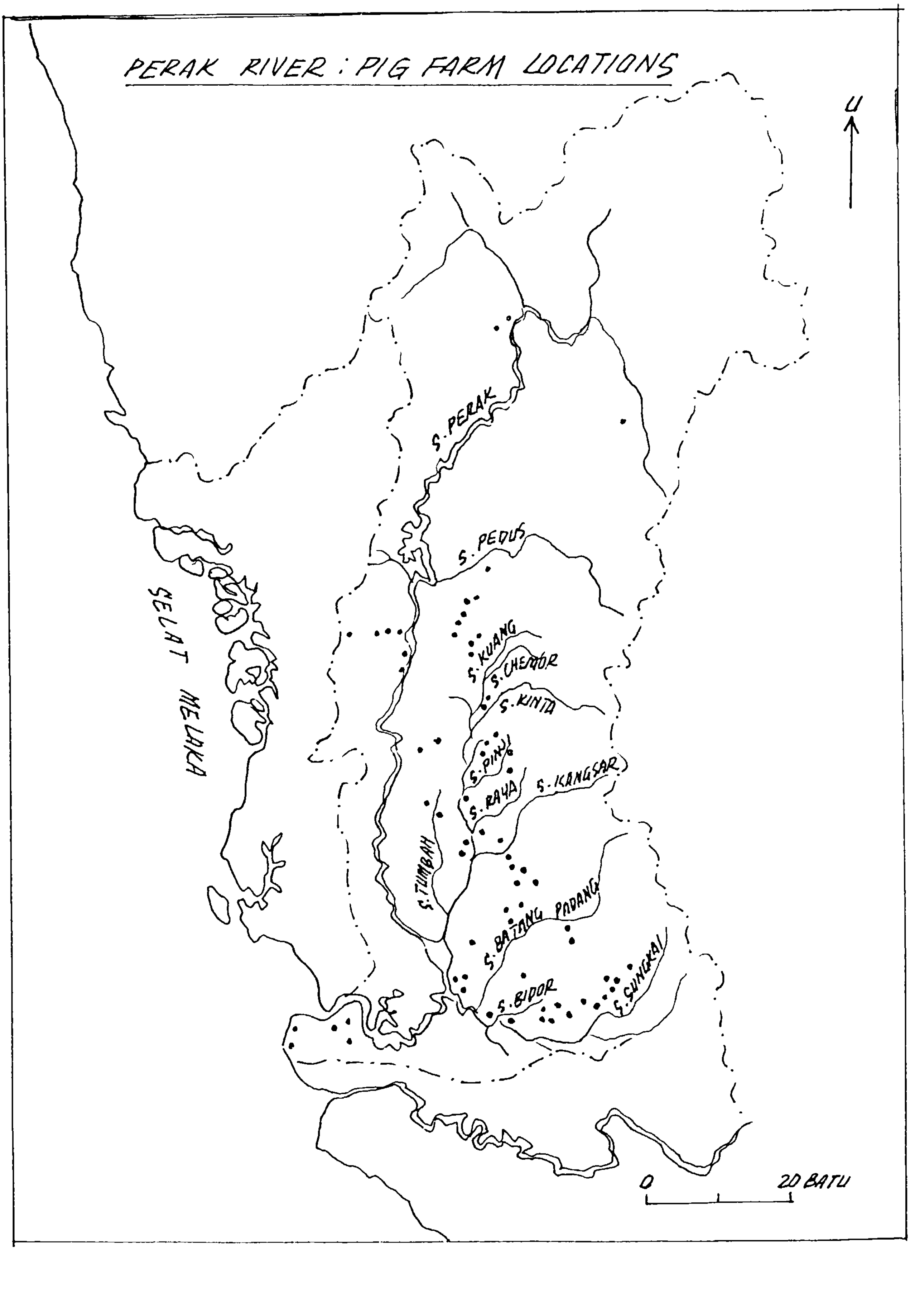
PERAK RIVER : PIG FARM LOCATIONS
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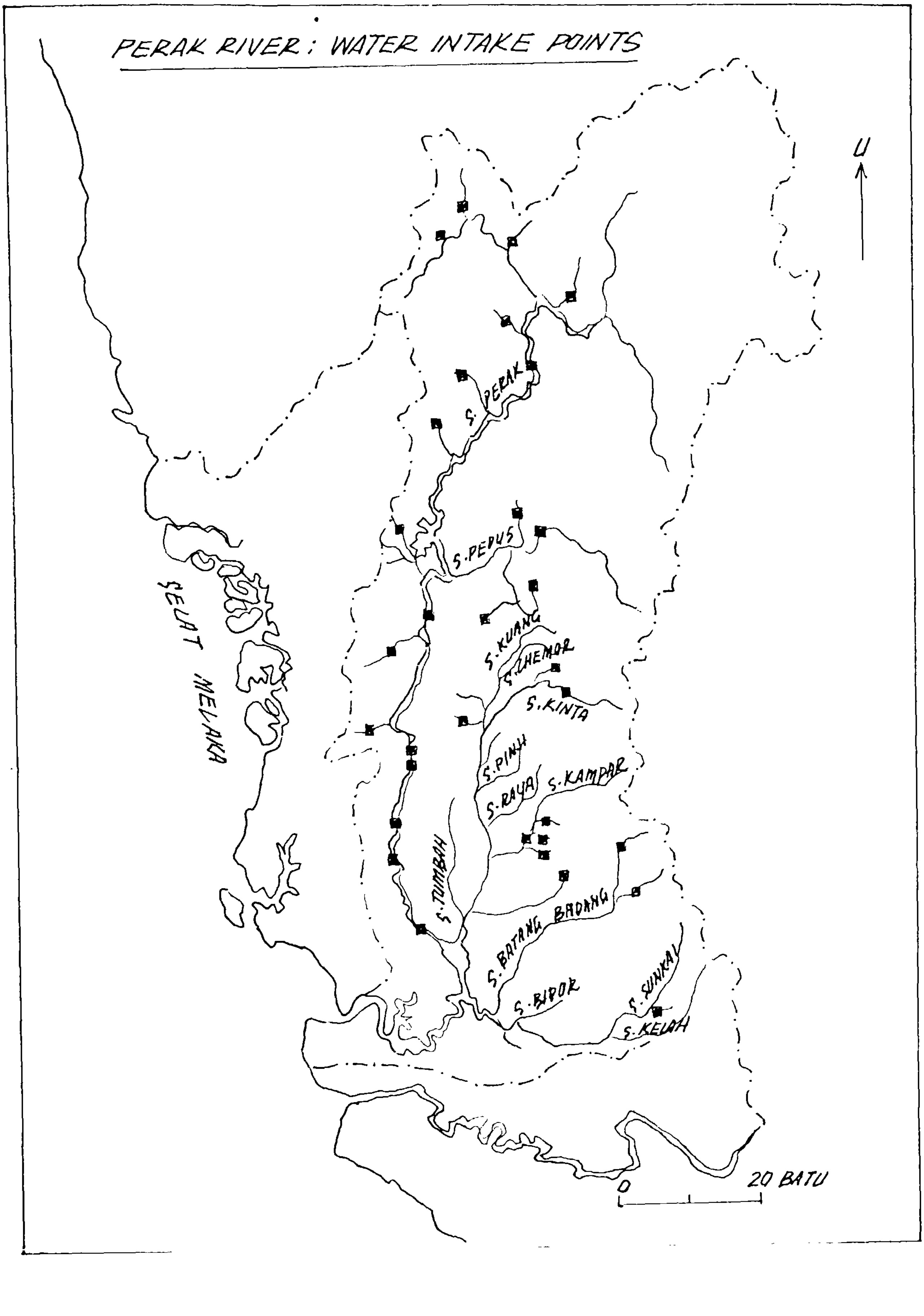
PERAK RIVER: WATER INTAKE POINTS
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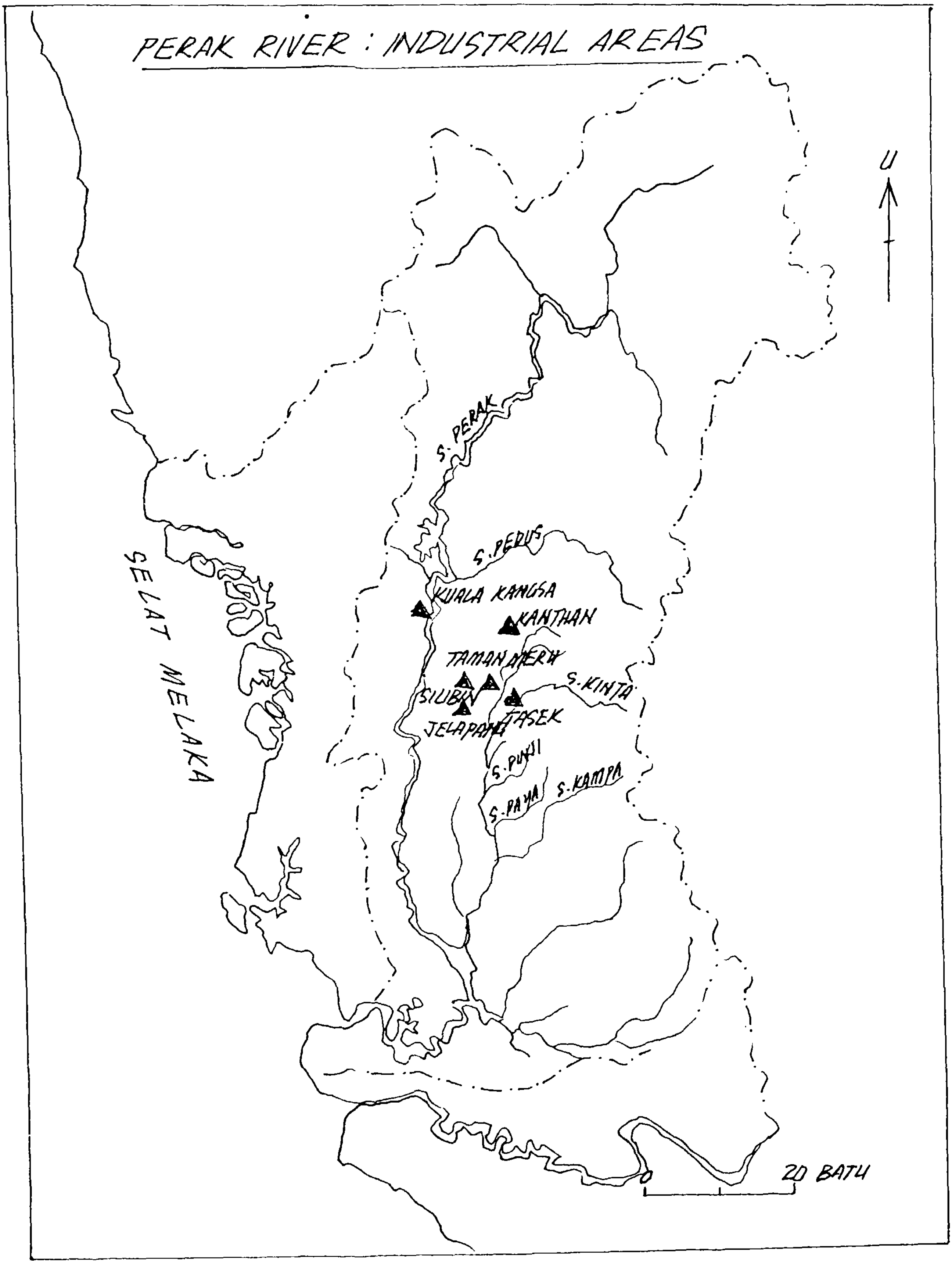
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No.	Title	Languages
69	IOC-SCAR Workshop on Sea-Level Measurements in the Antarctica, Leningrad, USSR 28-31 May 1990	E
69 Suppl	IOC-SCAR Workshop on Sea-Level Measurements in the Antarctica, Leningrad USSR. 28-31 May 1990	E
70	IOC-SAREC-UNEP-FAO-IAEA-WHO Workshop on Regional Aspects of Marine Pollution Mauritius, 29 October - 9 November 1990	E
71	IOC-FAO Workshop on the Identification of Penaeid Prawn Larvae and Postlarvae Cleveland, Australia, 23-28 September 1990	E
72	IOC/WESTPAC Scientific Steering Group Meeting on Co-operative study of the Continental shelf Circulation in the Western Pacific, Kuala Lumpur, Malaysia, 9-11 October 1990	E
73	Expert Consultation for the IOC Programme on Coastal Ocean Advanced Science and Technology Study Liege, Belgium, 11-13 May 1989	E
74	IOC-UNEP Review Meeting on Oceanographic Processes of Transport and Distribution of Pollutants in the Sea Zagreb, Yugoslavia, 15-18 May 1989	E
75	IOC-SCOR Workshop on Global Ocean Ecosystem Dynamics Solomons, Maryland, USA 29 April - 2 May 1991	E
76	IOC/WESTPAC Scientific Symposium on Marine Science and Management of Marine Areas of the Western Pacific Penang, Malaysia, 2-6 December 1991	E
77	IOC/SAREC-KMFRI Regional Workshop on Causes and Consequences of Sea-Level Changes on the Western Indian Ocean Coasts and Islands, Mombasa, Kenya, 24-28 June 1991	E
78	IOC-CEC-ICES-WMO-ICSU Ocean Climate Data Workshop Greenbelt, Maryland, USA. 18-21 February 1992	E
79	IOC/WESTPAC Workshop on River Inputs of Nutrients to the Marine Environment in the WESTPAC Region. Penang, Malaysia, 26-29 November 1991	E
80	IOC/SCOR Workshop on Programme Development for Harmful Algal Blooms Newport, Rhode Island, USA. 2-3 November 1991	E