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PREFACE

Nineteen years ago the United Nations Conference on the Human Environment (Stockholm 5-16 June 1972) adopted the Action Plan for the Human Environment, including the General principles for Assessment and Control of Marine Pollution. In the light of the results of the Stockholm Conference, the United Nations General Assembly decided to establish the United Nations Environment Programme (UNEP) to "serve as a focal point for environmental action and co-ordination within the United Nations system" [General Assembly resolution 2997 (XXVII) of 15 December 1972]. The organizations of the United Nations system were invited "to adopt the measures that may be required to undertake concerned and co-ordinated programmes with regard to international environmental problems", and the "intergovernmental and non-governmental organizations that have an interest in the field of the environment" were also invited "to lend their full support and collaboration to the United Nations with a view to achieving the largest possible degree of co-operation and co-ordination". Subsequently, the Governing Council of UNEP chose "oceans" as one of the priority areas in which it would focus efforts to fulfil its catalytic and co-ordinating role.

The Regional Seas Programme was initiated by UNEP in 1974. Since then the Governing Council of UNEP has repeatedly endorsed a regional approach to the control of marine pollution and the management of marine and coastal resources and has requested the development of regional action plans.

The Regional Seas Programme at present includes 12 regions[1] and has some 140 coastal States participating in it. It is conceived as an action-oriented programme having concern not only for the consequences but also for the causes of environmental degradation and encompassing a comprehensive approach to combating environmental problems through the management of marine and coastal areas. Each regional action plan is formulated according to the needs of the region as perceived by the Governments concerned. It is designed to link assessment of the quality of the marine environment and the causes of its deterioration with activities for the management and development of the marine and coastal environment. The action plans promote the parallel development of regional legal agreements and of action-oriented programme activities[2].

The idea for a regional South Pacific Environment Management Programme came from the South Pacific Commission (SPC) in 1974. Consultations between SPC and UNEP led, in 1975, to the suggestion of organizing a South Pacific Conference on the Human Environment. The South Pacific Bureau for Economic Co-operation (SPEC) and the Economic and Social Commission for Asia and the Pacific (ESCAP) soon joined SPC's initiative and UNEP supported the development of what became known as the South Pacific Regional Environment Programme (SPREP) as part of its Regional Seas Programme.

The Conference on the Human Environment in the South Pacific was convened in Rarotonga, from 8 to 11 March 1982. It adopted: the South Pacific Declaration on Natural Resources and Environment; the Action Plan for Managing the Natural Resources and the Environment in the South Pacific Region; and agreed on the administrative and financial arrangements needed to support the implementation of the Action Plan and on the workplan for the next phase of SPREP[3].

The legal framework of the Action Plan was developed through several meetings of legal and technical experts from the South Pacific Region. It was adopted by the plenipotentiary meeting of the High Level Conference on the Protection of the Natural Resources and Environment of the South Pacific Region convened by the Secretary-General of SPC in Noumea, New Caledonia, from 17 to 25 November 1986.

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[1] Mediterranean, Kuwait Action Plan Region, West and Central Africa, Wider Caribbean, East Asian Seas, South-East Pacific, South Pacific, Red Sea and Gulf of Aden, Eastern Africa, South Asian Seas, Black Sea and North-West Pacific.

[2] UNEP: Achievements and planned development of UNEP's Regional Seas Programme and comparable programmes sponsored by other bodies. UNEP Regional Seas Reports and Studies No. 1, UNEP, 1982.

[3] SPC/SPEC/ESCAP/UNEP: Action Plan for managing the natural resources and environment in the South Pacific Region. UNEP Regional Seas Reports and Studies No. 29, UNEP, 1983.

The legal framework adopted by the Conference consists of the following instruments[4].

- Convention for the Protection of the Natural Resources and Environment of the South Pacific Region;

- Protocol Concerning Co-operation in Combating Pollution Emergencies in the South Pacific Region;

- Protocol for the Prevention of Pollution of the South Pacific Region by Dumping.

The Convention is a comprehensive umbrella agreement for the protection, management and development of the marine and coastal environment of the South Pacific Region. It lists the sources of pollution which require control: pollution from ships, dumping, land-based sources, seabed exploration and exploitation, atmospheric discharges, storage of toxic and hazardous wastes, testing of nuclear devices, mining and coastal erosion. It also identifies environmental management issues requiring regional co-operation: specially protected areas, pollution in cases of emergency, environmental impact assessment, scientific and technical co-operation, technical assistance, and liability and compensation for damage resulting from pollution.

Considerable support to the implementation of the Action Plan is received from a number of South Pacific research and training institutions. Periodic consultative meetings of these institutions are convened to discuss the environmental problems of the region which may be mitigated or solved through the Action Plan and to identify activities which may contribute toward the goal of SPREP. The present report was commissioned by UNEP as such a contribution. The report has been prepared by Shamila Naidu, W.G.L. Aalbersberg, J.E. Brodie, V.A. Fuavao, M. Maata, Milika Naqasima, Penelope Whippy and R.J. Morrison.

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[4] Convention for the protection of the natural resources and environment of the South Pacific Region and related protocols, UNEP 1987.

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ABSTRACT

This report presents the results of studies made on five Pacific lagoons located at Suva, Fiji; Vila, Vanuatu; Tarawa, Kiribati; Tongatapu, Tonga; and Marovo, Western Province, Solomon Islands. Studies were made on water quality by physical, chemical and microbiological analyses. Analyses of shellfish and sediments were also completed for some sites.

The results indicate that the major problems in four lagoons were sewage-related. At Marovo, the limited data available indicated that the lagoon is effectively unpolluted except for isolated areas close to large villages. For the Suva, Vila and Tarawa lagoons faecal coliform counts in water and shellfish were frequenty high, indicative of potential health problems. This situation requires particular attention by local government authorities. These three lagoons plus that in Tongatapu also had relatively high nutrient (nitrate and phosphate) concentrations, sufficient to have detrimental effects on coral growth.

No analyses of pesticide residues were completed but possible pollution problems were only anticipated at Suva and Tongatapu. For trace metals, the results indicated that possible problems exist for Suva, Vila and Tongatapu. The problems were generally very localized but increasing numbers of metal-based industries are cause for concern.

There is generally a lack of monitoring activities in the countries covered by this study. If governments are to have warning of potential coastal pollution problems then some locally-based long-term monitoring is essential. This is particularly critical given the fragility of coastal ecosystems and their economic and social importance in the Pacific Islands.

1. GENERAL INTRODUCTION

Over the last twenty years the South Pacific region has seen numerous changes in the environment due to human related activities such as increased industrialization and rapid urbanization. While increased industrialization has led to the production of large volumes of waste products/water requiring subsequent disposal (usually into surrounding marine environments), the rapid urbanization has resulted in increased discharge of human wastes and domestic rubbish into surrounding aquatic environments due to inadequate waste disposal facilities. One likely consequence of such activities is the degradation or destabilization of the ecosystems to levels where it is impossible to maintain the natural resources on which most of the island communities depend.

While industrialization was initially looked on favourably as a tool for achieving higher standards of living, the increased pollution resulting from such activities has caused concern among those interested in the maintenance of good environmental standards. Industrial waste disposal can jeopardise the health of a range of organisms (including humans) and certain types of waste products may render some areas unfit for normal habitation. There is, therefore, a need to monitor pollution resulting from both industrialization and urbanization. With this in mind, the University of the South Pacific Institute of Natural Resources (USP/INR) using financial support from the South Pacific Regional Environmental Programme (SPREP) initiated a programme in 1987 to monitor in detail some chemical and biological parameters of five lagoons/harbours within countries of the South Pacific. The five areas selected for study were:

(i) Laucala Bay/Suva Harbour, Suva, Fiji
(ii) Vila Harbour and Erakor Lagoon, Vanuatu
(iii) Tarawa Lagoon, Kiribati
(iv) Fanga'uta Lagoon, Tonga
(v) Morovo Lagoon, Solomon Islands

The locations of the study sites are given in Figure 1.1.

These lagoons were selected as being representative of different environmental situations. The Laucala Bay area close to the major Suva city centre is representative of a situation where the influence of urbanization/industrialization is considerable. Vila Harbour is a situation where rapid expansion of industrialization is taking place. Tarawa Lagoon was chosen as being representative of an atoll lagoon affected by high population density but little industry, whereas Fanga'uta Lagoon is located in a low lying island of high population density, but with some industrialization occurring. Morovo Lagoon is located in an area which is virtually free of industrialization but intensification of fishing, agriculture and forestry may lead to significant changes in the lagoon environment. Thus, four of the study sites are in areas where pollution problems are expected and one is a 'clean' site.

The objectives of the study were:

(i) ***Suva*** : To gather data on the state of water quality in Suva Harbour and Laucala Bay so that appropriate action may be taken, if required, to improve or maintain quality by control of effluent discharge.

(ii) ***Vila*** : To follow-up the work of Carter (1983) in Vila Harbour and Erakor Lagoon and to monitor the current state of water quality in the harbour and in the lagoon.

(iii) ***Tarawa*** : To monitor the present water and biota quality in the southern part of Tarawa Lagoon and to assess any improvement which may have occurred since the installation of the sewarage system on South Tarawa by comparison with the data in the report of Johannes et al. (1979).

(iv) ***Fanga'uta*** : To gather data on the state of water quality in Fanga'uta Lagoon and assess any changes which may have occurred since the study of Zann et al. (1984) as a result of increased population and industrial development.

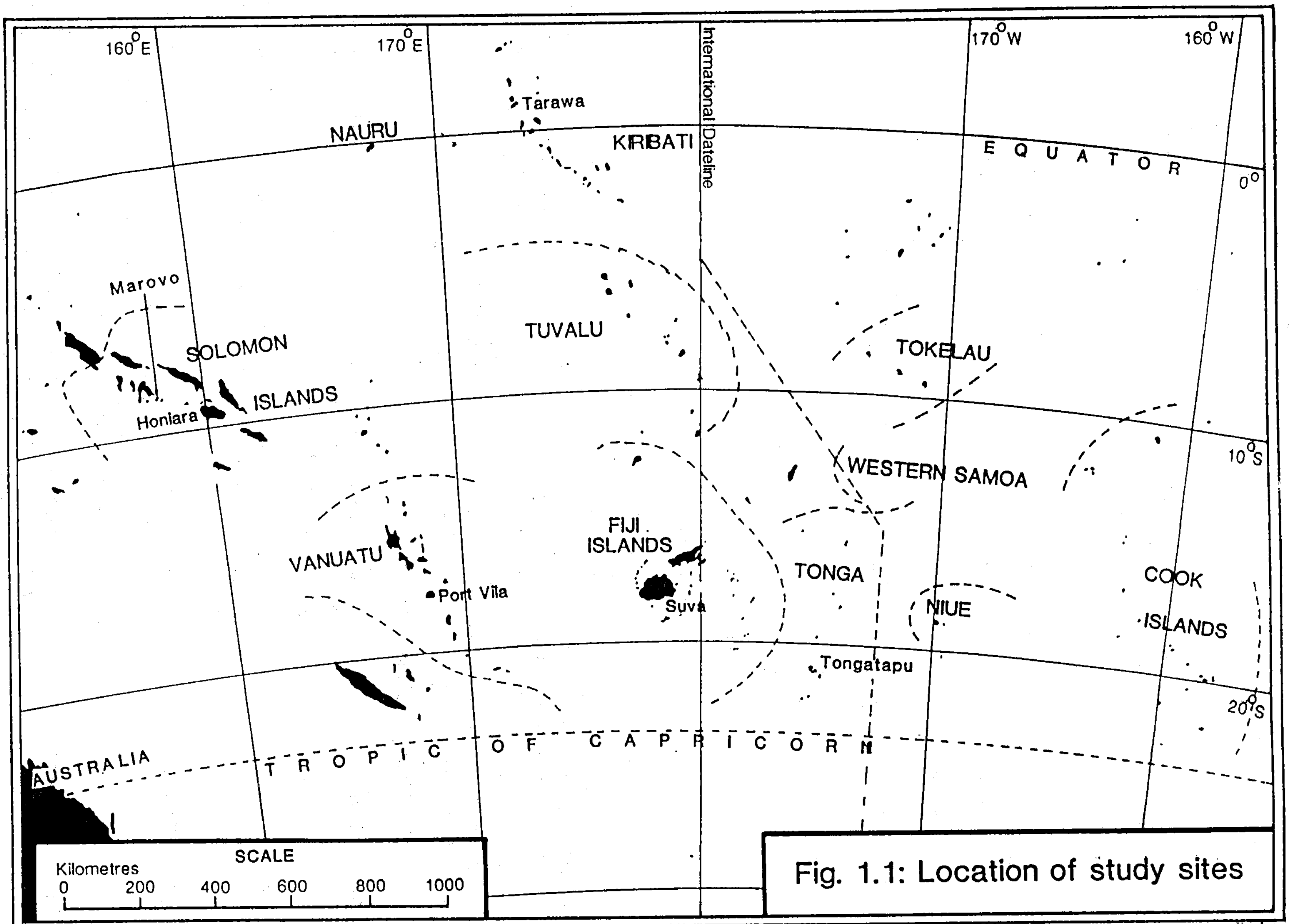

Fig. 1.1: Location of study sites

(v) ***Marovo*** : To provide baseline water quality data on an essentially unpolluted lagoon so that the impact of proposed development activities may be ascertained.

The projects were run in collaboration with

(a) Public Works Department, Fiji
(b) Environment Unit, Vanuatu
(c) USP Atoll Research and Development Unit, Kiribati and the Kiribati Ministry of Health
(d) Environment Unit, Tonga

(e) Ministry of Health and Department of Fisheries, Solomon Islands

The present report describes the findings of the chemical and biological monitoring of the five lagoons in 1987 and 1988.

2. GENERAL METHODS

2.1 SAMPLING

For general water quality assessment of an area the type of sample that is usually collected is the actual water itself. However, when water is being assessed for pollution studies it is often desirable to measure parameters that are present in extremely low concentrations and hence detection is sometimes impossible with the facilities available. Sediments and shellfish can be very good indicators of water quality because polluting agents such as trace (toxic) metals and organochlorine residues tend to concentrate in these materials and are thus easier to detect. A further advantage of studying pollution levels in shellfish is that this would give indications as to whether the shellfish meet requirements for human consumption. With these factors in mind, it was decided that water and shellfish samples would be collected for general water quality, trace metal studies and coliform status determinations.

Water samples were collected from the surface directly into clean polyethylene containers. In general, a minimum of one litre was collected. Samples for heavy metal determinations were treated with concentrated nitric acid to reduce the pH below 2. Samples for mercury analysis were further preserved by addition of potassium dichromate. Samples were transported in polystyrene boxes with ice packs. Nutrient analyses and bacteriological analyses were started on the day of collection while trace metal samples were stored in the refrigerator.

Shellfish samples were obtained by collecting 20-30 samples of the selected species at each site. If the samples could not be analysed for trace metals immediately they were frozen. An attempt was made to collect shellfish of approximately the same size at each site.

Sediment samples were usually collected by means of a grab sampler into acid washed plastic bags. The details of the sampling sites (number and reasons for selection) and the sampling programme for each study are given in the respective sections 3.2, 4.2, 5.2, 6.2, 7.2.

2.2 ANALYTICAL PROCEDURES

2.2.1 FIELD PROCEDURES

Certain water quality measurements are most conveniently made in the field. In this study, salinity, temperature, dissolved oxygen, pH and clarity were measured directly.

Salinity was measured using either a Hamon field salinity bridge or a Atago S-28 hand refractometer, previously calibrated using standard seawater solutions.

Temperature was measured using either a Hamon field temperature probe or a thermometer previously calibrated in the laboratory.

Dissolved oxygen was determined with a Yellow Springs YSI 51A dissolved oxygen meter.

pH was measured using a Jenway, Model 3070 field pH meter after calibration with standard buffer solutions.

Clarity was measured with a black-white Secchi disc, 23 cm in diameter.

Unless stated elsewhere all the above measurements were made at low tide.

2.2.2 LABORATORY ANALYSES

(a) Analyses of Water Samples

Total (Kjeldahl) nitrogen was measured by Kjeldahl digestion using sulphuric acid, potassium sulphate and selenium catalyst followed by steam distillation of the ammonia and determination by the indophenol blue colorimetric method (APHA-AWWA-WPCF, 1981). Results are reported in mg N/L.

Total phosphorus was measured by the standard molybdenum blue ascorbic acid method (APHA-AWWA-WPCF, 1981) after digestion of the water sample with perchloric acid to fumes. Results are reported in ug P/L.

Ammonia was measured using the indophenol blue colorimetric method (APHA-AWWA-WPCF, 1981). Results are reported in ug NH_3/L.

Nitrate was measured by reduction to nitrite using a cadmium column procedure and subsequent colorimetric measurement using sulphanilamide and I-naphthyl ethylene diamine dihydrochloride to produce a red azo compound (APHA-AWWA-WPCF, 1981). Results are reported in ug NO_3/L.

Nitrite was measured by the colorimetric measurement using sulphanilamide and I-naphthyl ethylene diamine dihydro-chloride to produce a red azo compound (APHA-AWWA-WPCF, 1981). Results are reported in ug NO_2/L.

Dissolved phosphate determination followed a standard molybdenum blue/ascorbic acid method (APHA-AWWA-WPCF, 1981). Results are reported in ug PO_4/L. For a number of samples inconsistencies between total phosphorus and dissolved phosphate were observed; these are being investigated further.

Reactive silica was measured by a colorimetric procedure involving formation of the reduced beta silico-molybdate complex (APHA-AWWA-WPCF, 1981). Results are reported in mg SiO_3/L.

For analyses requiring a colorimetric finish, the work in Tonga (only) was completed using a Hach-Drel/IC field kit and the procedures described in the accompanying manual.

Biological oxygen demand (BOD) was determined by sample incubation for 5 days and measurement of the resultant oxygen concentrations using the dissolved oxygen meter.

Chlorophyll a, b, c were measured by extraction of pigments into acetone and colorimetric measurements of the absorbances at 665, 645, 630 and 480 nm (APHA-AWWA-WPCF, 1981).

Trace metals in water samples were analysed by acidifying the samples to a pH of less than 2 with concentrated nitric acid. The sample for mercury analysis was further preserved by addition of potassium dichromate. Cadmium, chromium, copper and lead were measured by complexing the metals with ammonium pyrolidine dithiocarbamate (APDC) and extracting the complexed form into methyl isobutyl ketone (MIBK) followed by determination using flame atomic absorption spectrophotometry (FAAS). Mercury was determined by the cold vapour technique using a Perkin Elmer Mercury/ Hydride System (MHS-10) attached to an atomic absorption spectrophotometer.

Faecal coliforms were determined using the membrane filtration method (APHA-AWWA-WPCF, 1981). For samples analysed away from Suva this was done using a Millipore field filtration apparatus, with the samples being incubated at 44.5°C for 24 hours.

(b) Analysis of Sediment Samples

In the laboratory the sediments were oven dried in petri dishes at 80°C and stored prior to analysis in a clean hot cabinet. The dried sediments were homogenized with a mortar and pestle. In order to normalize for variations in grain-size distribution, the dried sediment samples were sieved through a plastic 63 um screen. A subsample of dried sediment was weighed into a teflon beaker and digested with concentrated nitric/hydrochloric/hydrofluoric acid mixture and metals determined using flame atomic absorption spectrophotometry except for mercury which was analyzed using the hydride generation system.

(c) Analyses of Shellfish

(i) Faecal Coliforms

The flesh from approximately twenty shellfish collected at each site was homogenised to give a composite sample. Coliforms in the sample were determined by the multiple tube technique following the UNEP method (UNEP/WHO, 1983), except in Tarawa where the method of the International Commission for Microbiological Specification in Food (ICMSF) was used (Thatcher and Clark, 1978).

(ii) Trace Metal Analyses

For trace metal analysis, the flesh of approximately 20 shellfish was homogenised to give a composite sample. A subsample was digested with concentrated nitric acid and trace metals in the digest determined using flame atomic absorption spectrophotometry except for mercury which was analysed using the mercury atom generation system.

3. LAUCALA BAY AND SUVA HARBOUR, VITI LEVU, FIJI

3.1 INTRODUCTION AND BACKGROUND

The Laucala Bay/Suva Harbour coastal zone is located in south east Viti Levu, the largest island of the Fiji group. Suva is the capital of Fiji and represents the major commercial centre in the small island territories in the South Pacific. Commercial activity in Greater Suva has increased considerably over the past 20 years and has led to large scale migration to this area from other areas. The population censuses of 1966, 1976 and 1986 have confirmed this trend as shown on Tables 3.1 and 3.2.

TABLE 3.1 : Population Census Results for the Suva Area

	Greater Suva	Suva City
1966	80,269 (17%)	54,157 (11%)
1976	117,827 (20%)	63,628 (11%)
1986	157,980 (22%)	69,665 (10%)

The figures in parentheses are the % of the total population.

TABLE 3.2 : Average Annual Population Growth Rate for the Suva Area

	Greater Suva	Suva City
1976-66	3.9%	1.6%
1986-76	3.0%	0.9%
1986-66	3.4%	1.3%

The growth rate for the Greater Suva area is more than 1.5 times the national average (2.0% for 1966-86). The majority of this increase has been in the north eastern sector of the Greater Suva area, i.e., the zone lying between Suva city and the town of Nausori.

The rapid increase in population, together with the associated increase in industrial development, port activity and waste disposal problems have led to considerable problems of management of the nearby coastal zone. Attempts have been made to develop appropriate management strategies but these have generally not been completely successful due to either underestimation of requirements or a lack of funds or timely implementation. For example a number of review of the sewerage requirements of the Greater Suva area have been produced. The latest masterplan calls for the development of a trunk mains sewerage system to cater for a population of 240,000. In this scheme all sewage in the area will be pumped to Kinoya where a major treatment plant is operating. Phased expansion of the Kinoya plant to cope with the increased load is also planned.

While the major trunk scheme is being developed, septic tanks (often old) are still in wide use as is the Raiwaqa treatment plant. However, recent data indicates that the efficiency of the Raiwaqa plant is now low (Table 3.3).

Both the Kinoya and Raiwaqa plant effluents ultimately move into Laucala Bay. The Raiwaqa effluent is discharged into the Vatuwaqa river which flows into the Bay. The Kinoya effluent is discharged directly into the Bay via an outfall pipe which runs 800 m offshore. However, a technical report prepared by Australian consultants has shown that there is a break in the outfall pipe approximately 300 m from the shore and most of the effluent is discharged at this point. Much of the effluent is carried back to the shore by current, tide and wave action. Installation of a new outfall is planned.

TABLE 3.3 : Typical Treatment Plant Characteristics Suva, Fiji (Public Works Department, Fiji, personal communication)

		Raw sweage	Plant effluent
(a)	Kinoya		
	BOD	272 mg/l	21 mg/l
	Suspended Solids	252 mg/l	27 mg/l
	Faecal Coliform		530,000 col./100 ml
(b)	Raiwaqa		
	BOD	351 mg/l	112 mg/l
	Suspended Solids	287 mg/l	74 mg/l
	Faecal Coliform		1,400,000 col./100 ml

Much of Suva is constructed on marl which does not allow city area septic tank effluents to seep away to ground. Most seepages move into the numerous creeks that discharge into Laucala Bay and Suva Harbour.

Some of the creeks represent major pollution 'hot spots' and health hazards as they are used for washing and recreational purposes.

The Suva Harbour area has located around it two major industrial zones which contain shipyards, manufacturing plants, oil storage depots, food processing industries; the effluents from these industries eventually reach the Harbour. In addition the major rubbish dump for the Suva area is also located on the shores of Suva Harbour. Leachates from this dump move directly into the Habour waters. Several attempts to relocate the dump have been initiated but a substantial amount of material has been deposited at the present site.

It can be seen from the above that there are a number of pollution problems in the Laucala Bay/Suva Harbour coastal zone. One of the aims of this activity was to determine the impact of the various pollutant sources on the local environment.

General Characteristics of Laucala Bay and Suva Harbour

The Laucala Bay/Suva Harbour area lies in the 'wet' zone of Viti Levu, i.e., there is no marked dry season. The area has a humid tropical climate; some meteorological data are summarised in Table 3.4. Suva city lies at a latitude of approximately 18° south and for most of the year the southeast trade winds prevail. However, from November to March the Fiji group is under the influence of the north east monsoon, characterised by a general drop in wind strength and an increase in occurrence of calms coupled with the sporadic incidence of the passage of intense low pressure areas.

As noted earlier much of the Suva area is located on uplifted calcareous marl, probably of lagoonal origin. There are also basaltic breccia deposits and tuffs in the area and much of the coastline consists of deposits derived from the weathered products of the marl, tuffs and breccia. Much of the coastline has been covered with mangroves, but the recent development activities have seen destruction of substantial areas of mangroves, in some cases by construction activities and in others as a consequence of overexploitation.

(a) Laucala Bay

Laucala Bay lies between Suva peninsula on the west and the Rewa river delta on the east (Figure 3.1). A series of broad coral reefs isolate and protect the bay from Pacific Ocean. The bay is connected on its west side to Suva Harbour. At high tide the reefs are submerged and a shallow layer of seawater enters the bay twice daily around high water.

TABLE 3.4 : Climatological Data for Laucala Bay, Suva, Fiji*

Description	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Average Air Temp. (%)	26.8	27.0	26.8	26.1	24.9	24.2	23.3	23.4	23.8	24.5	25.3	26.2	25.2
Relative Humidity (%)	85	85	86	85	83	83	81	81	82	82	82	83	83
Evaporation⁺ (mm)	131	131	97	92	89	65	78	96	111	110	122	142	1,264
Average Rainfall (mm)	324	315	383	385	254	172	147	140	209	220	266	272	3,087

Notes: *Source: Information Sheet No.53 (Revised), 12 April 1985, Fiji Meteorological Service

+Class A raised pan

TABLE 3.5 : Average Annual Discharge and Peak Discharge of the Rewa River

	Average Annual Discharge		Peak* Discharge	
Catchment Area (km^2)	Discharge (m^3/sec)	Specific Discharge (m^3/sec/km^2)	Discharge (m^3/sec)	Specific Discharge (m^3/sec/km^2)
2,940	160	5.4	14,900	5.1

*Peak discharge with return period of 50 years

The major source of fresh water into the bay is the Vunidawa river, a distributary of the Rewa river which discharges into the northeast portion of the bay (see data in Table 3.5). Minor sources come from the Vatuwaqa and Samabula Rivers along the western shore. Estuarine water enters from the south of Laucala Island.

At high water, Laucala Bay has a surface of 4.5×10^7 m^2 (4500 ha) and at low water an area of about 3.9×10^7 m^2 (3900 ha) (Campbell et al. 1982).

The tides in Laucala Bay are predominantly semi-diurnal with a mean range of 1.1 m. Tide height is continuously recorded on a gauge on Suva wharf and tidal predictions are published for Suva based on a harmonic analysis of the record from the gauge. The range between high and low waters is 0.9 m for neap tides and 1.3 m at spring tides.

(b) Suva Harbour

Suva Harbour lies between Suva peninsula on the east and the Suvavou village on the west (Figure 3.1). The south-eastern portion of the harbour is protected by the same series of broad coral reefs which protect Laucala Bay.

The major source of freshwater into the harbour is the Tamavua river which discharges into the north-eastern section of the harbour. Minor contributions come from the Lami river and Nabukalou creek along with seepages from stormwater pipes (about 100) and septic overflows.

The aims of this study were:

(i) To assess the state of water quality in Suva Harbour and Laucala Bay so that appropriate action may be taken, if required, to improve or maintain quality by control of effluent discharge

(ii) To compare the state of Laucala Bay with that recorded by Campbell et al. (1982).

(iii) To obtain information in water quality in some local bathing areas

(iv) to compile a shoreline rubbish survey for selected areas around Suva

3.2 WORK PROGRAMME

In March 1987 staff from INR made a preliminary visit to the study area to select sampling sites. A total of 20 sampling sites were selected, 10 in Laucala Bay and 10 in Suva Harbour (see Figure 3.2). The Laucala Bay sites were those originally used by Campbell et al. (1982) so that changes in water quality over a period of 6-7 years could be investigated. Since there has been no previous comprehensive investigation of the Suva Harbour area, results from this part of the study represent a baseline water quality data set.

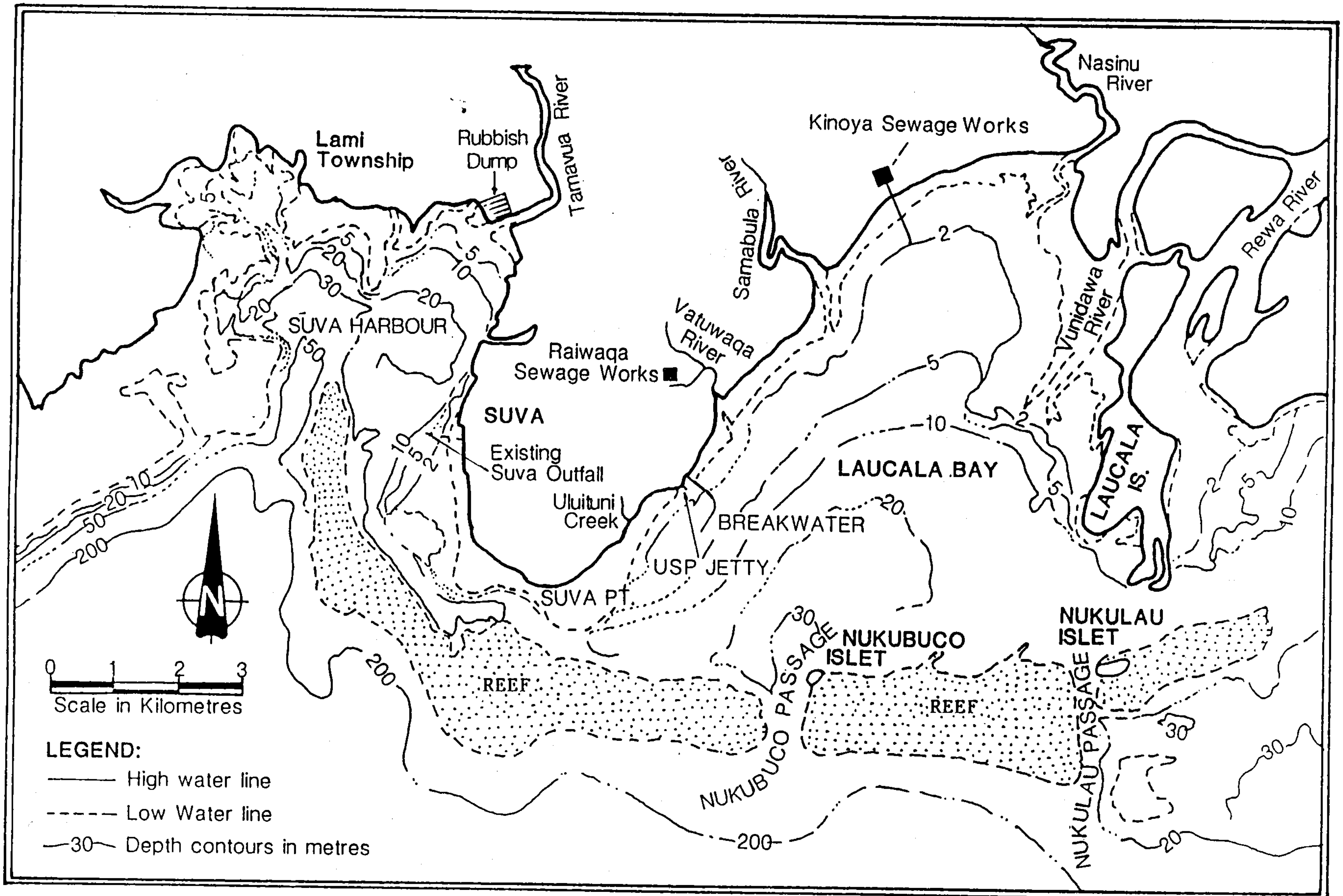

FIG. 3.1 : LAUCALA BAY/SUVA HARBOUR AREA

SUVA HARBOUR/LAUCALA BAY

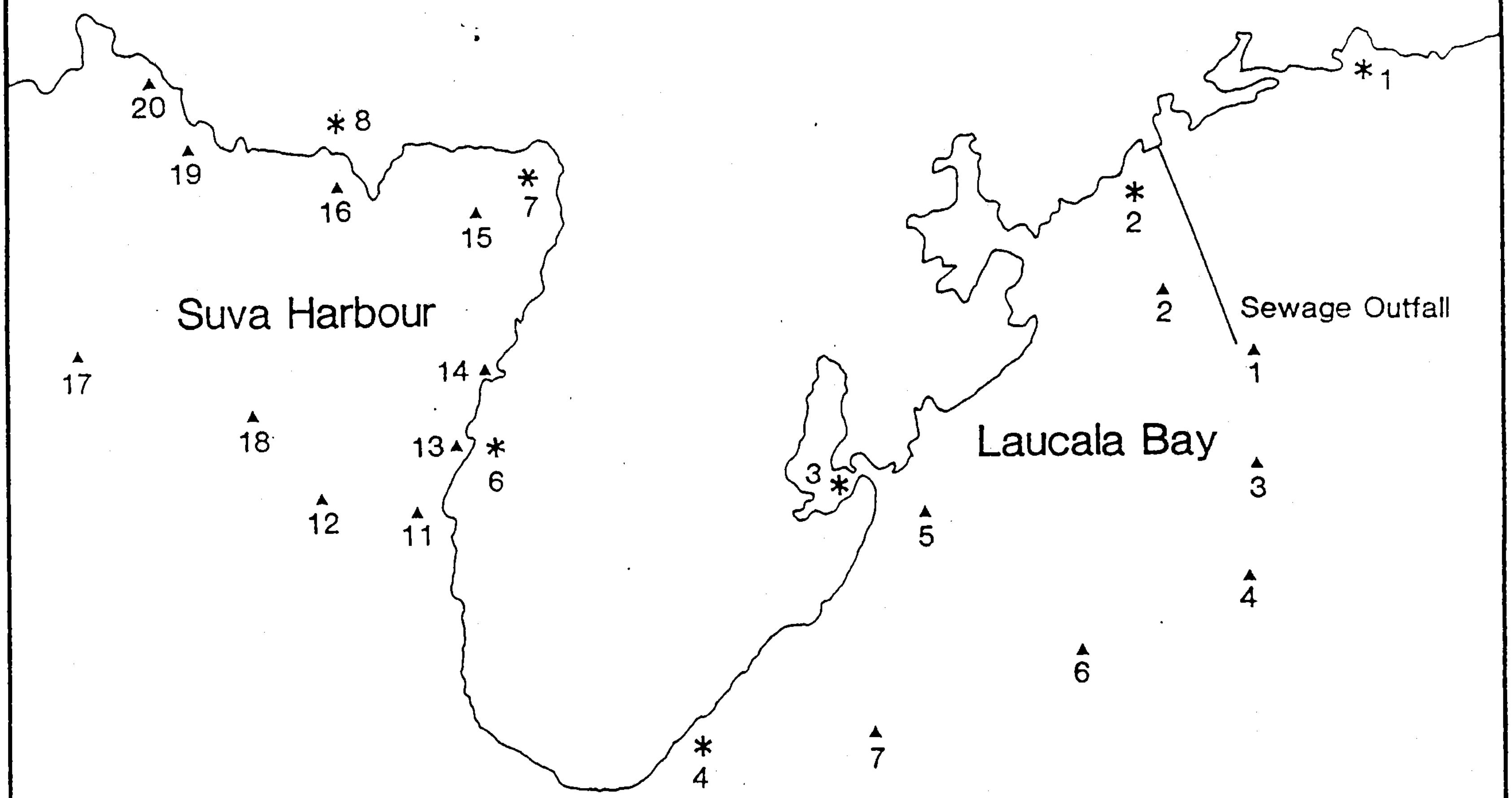

Figure 3.2: Locations of Sampling Sites around Suva

KEY: Water Sampling ——— ▲
Shellfish ——— *

Because shellfish tend to concentrate toxic metals and organic (organochlorine) residues a further 8 shellfish collecting sites were selected for these investigations. The most common shellfish species found in the study area was Crassostrea mordax (mangrove oyster) and it was decided to sample these every two months. These oysters are not consumed locally in large amounts so they were commonly available and no difficulty was encountered in collecting oysters of similar size. To assess the state of the swimming beaches a further 8 sites were chosen for monitoring of faecal coliforms. Two sites were also selected for a shoreline rubbish survey. Table 3.6 gives location and description of the water sampling sites, while Table 3.7 gives details of the shellfish sampling sites.

3.3 RESULTS AND DISCUSSION

All general water quality analytical data are attached as annexes to this section.

Salinity and Temperature Profiles

Figures 3.3-3.9 show the variation in temperature and salinity with depth during the sampling period (no graphs are given for sites 10, 11, 13, 15, 16 and 20 as they were very shallow). Temperature variations within the water column at all sites were usually less than 0.5°C and seldom exceeded 1°C. Also there was very little change from station to station on any particular day. No thermocline formation was noticed during the period of investigation.

The salinity of the surface water in the bay and the harbour varied from 7 parts per thousand (ppt) to 35 ppt. The results showed substantial change in salinity from station to station on any day. Not surprisingly lower salinities were frequently observed at entrances to river mouths and areas which receive discharges from industries and hotels. In general during drier periods (July-October) there was very little fresh water present in the bay and the harbour. The only areas which showed slight stratification during this period were sites 9 (at Nukulau) and 19 (at Mosquito Island).

During the wet season, December-April, both the bay and the harbour showed strong stratification. All the sites in the bay had large amounts of fresh water and from Figures 3.3 to 3.9 it is apparent that some sites had up to 3 metres of fresh water.

TABLE 3.6 : Location and Description of the Water Sampling Sites

Site No.	Location and Description
1	Vicinity of Kinoya sewage treatment plant outfall, Laucala Bay; represents point source pollution
2	About 50 m west of site 1, Laucala Bay; represents a zone of backwashing of the outfall products and also leachates from factories in the Laucala Beach Estate industrial division
3, 4 7, 8 10	In Laucala Bay but located away from the main land mass; hence are not directly influenced land mass; hence are not directly influenced by any major human activity
5	In Laucala Bay about 200 m away from the mouth of a sewage polluted river which also receives effluents from industries in the Vatuwaqa industrial division
9	At a jetty off Nukulau Island in Laucala Bay; a popular tourist resort
11	In Suva Harbour about 25 m from the coast opposite a big hotel; receives a lot of water via many stormwater pipes
12	In Suva Harbour away from mainland, not directly receiving effluents of any sort

TABLE 3.6 (cont'd)

13	At the mouth of Nabukalou Creek in Suva Harbour; receives a lot of sewage effluent from a faulty sewerage junction box, seepages from septic tanks and water from stormwater pipes
14	At the mouth of Walu Bay creek in Suva Harbour; receives effluent from an edible oil refinery plant and seepages from villages along the creek
15	At the mouth of the Tamavua river and adjacent to the municipal rubbish dump, in Suva Harbour
16	At the mouth of Wailada river in Suva Harbour; receives various industrial and sewage effluents
17 & 18	In Suva Harbour away from main land masses and hence any pollution point sources
19	Suva Harbour area close to a jetty off Mosquito Island, a popular recreational area where a lot of boating activity occurs
20	Slightly enclosed area in Suva Harbour, opposite the cement factory

TABLE 3.7 : Location and Sources of Pollution for Shellfish Sampling Sites

Site No.	Location	Description - source and pollution
1	North of Kinoya village	Septic seepages from villages
2	Kinoya village, south of treatment plant outfall	Municipal sewage outfall effluent. Industrial effluent
3	Vatuwaqa River mouth	Direct recipient of municipal sewage. Industrial effluent
4	Adventure playground, Nasese	Septic seepages, stormwater outlets, excretions of excretions of lower animals
5	Bridge near China Club	Septic seepages, stormwater runoff, domestic outlets and excretions of lower animals
6	Nabukalou Creek	Poorly treated municipal effluent, sanitary wastes from creekside residences and stormwater runoff
7	Tamavua River mouth	Industrial effluent, municipal rubbish dump leachate, septic seepages and excretions of lower animals
8	Wailada River mouth	Poorly treated municipal and industrial effluent, stormwater runoff and excretions of lower animals

Chemical and Microbiological Characteristics

The results for chemical and microbiological analyses are discussed under the following headings:

(i) Nutrient concentrations
(ii) Clarity

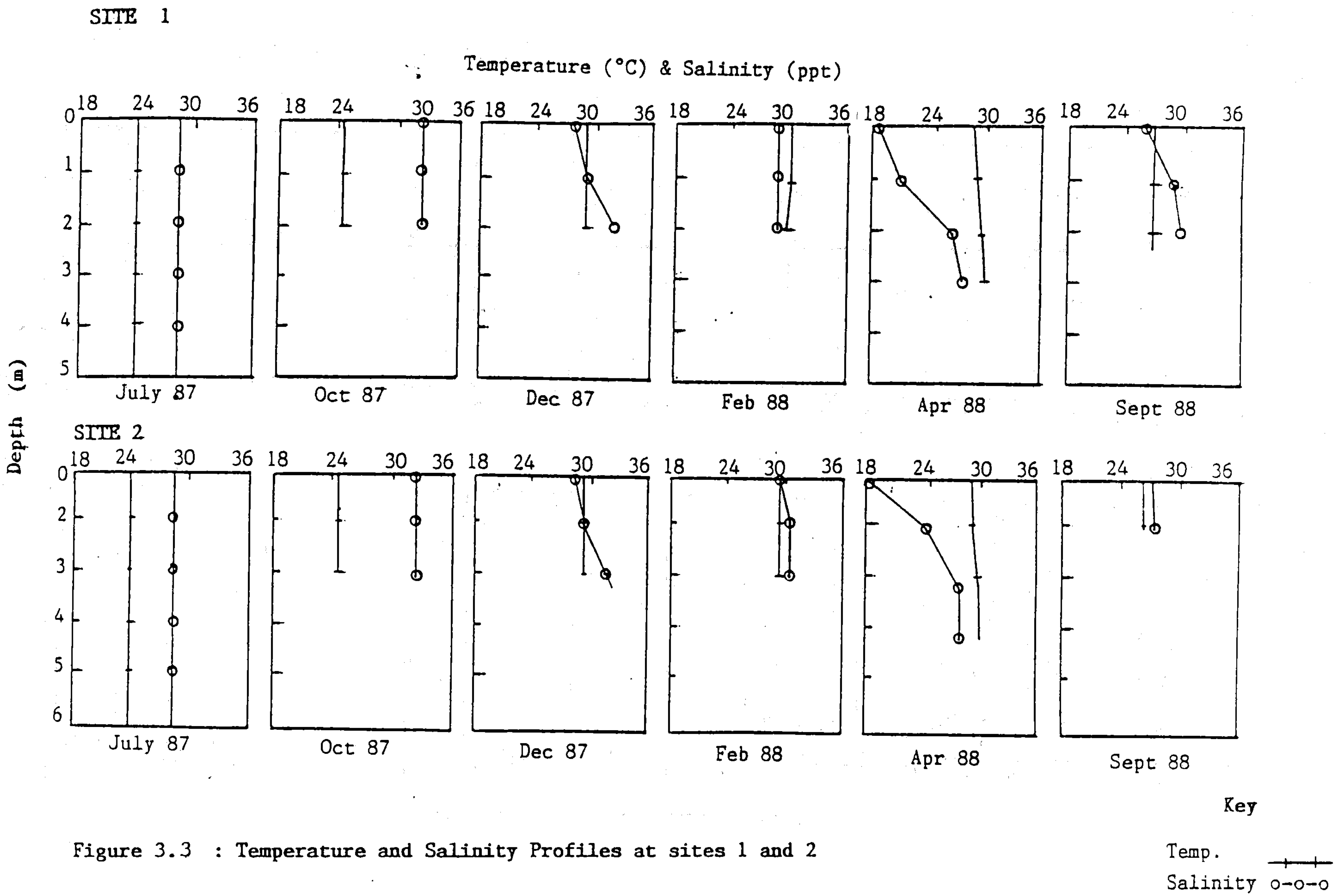

Figure 3.3 : Temperature and Salinity Profiles at sites 1 and 2

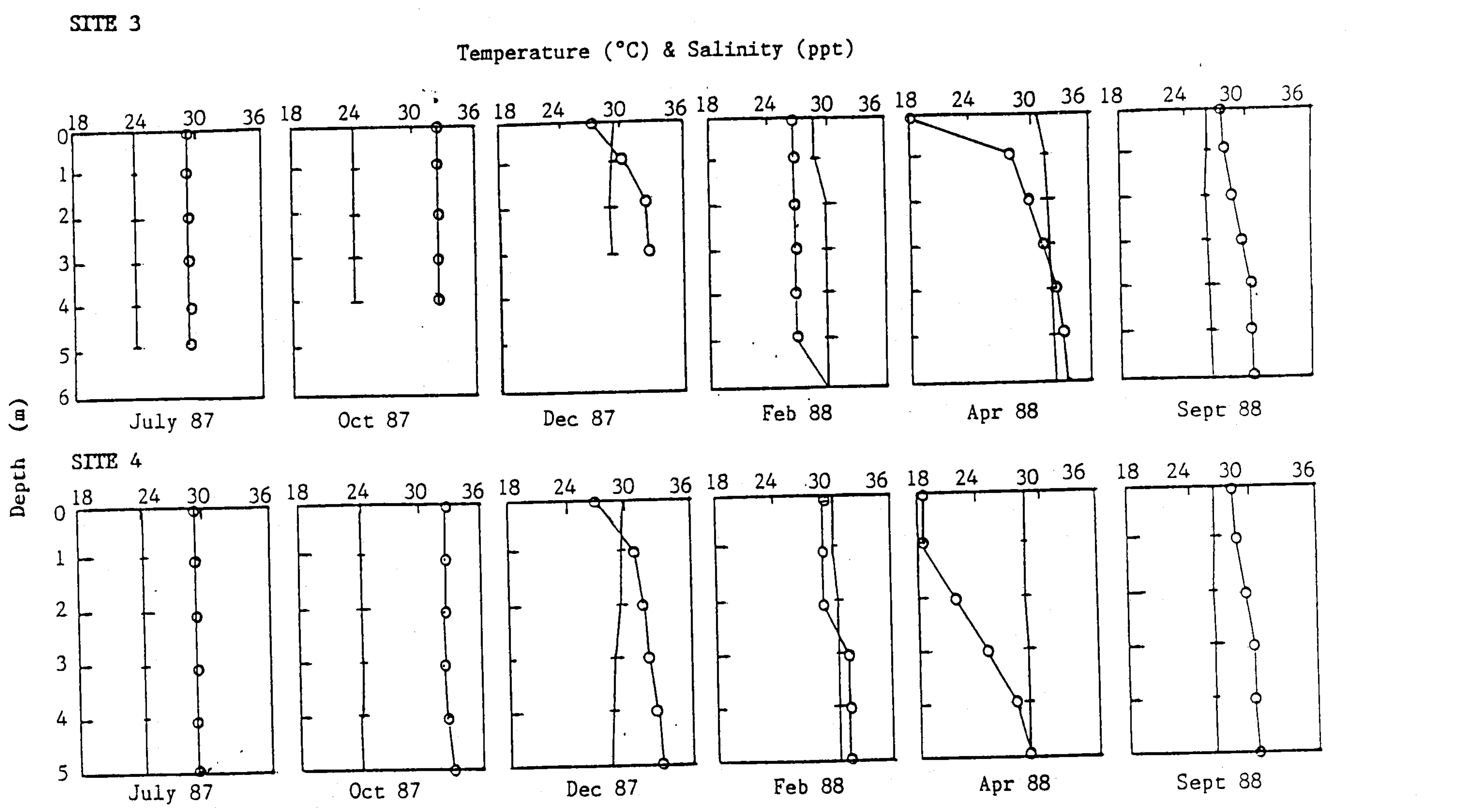

Figure 3.4 : Temperature and Salinity Profiles at Sites 3 and 4

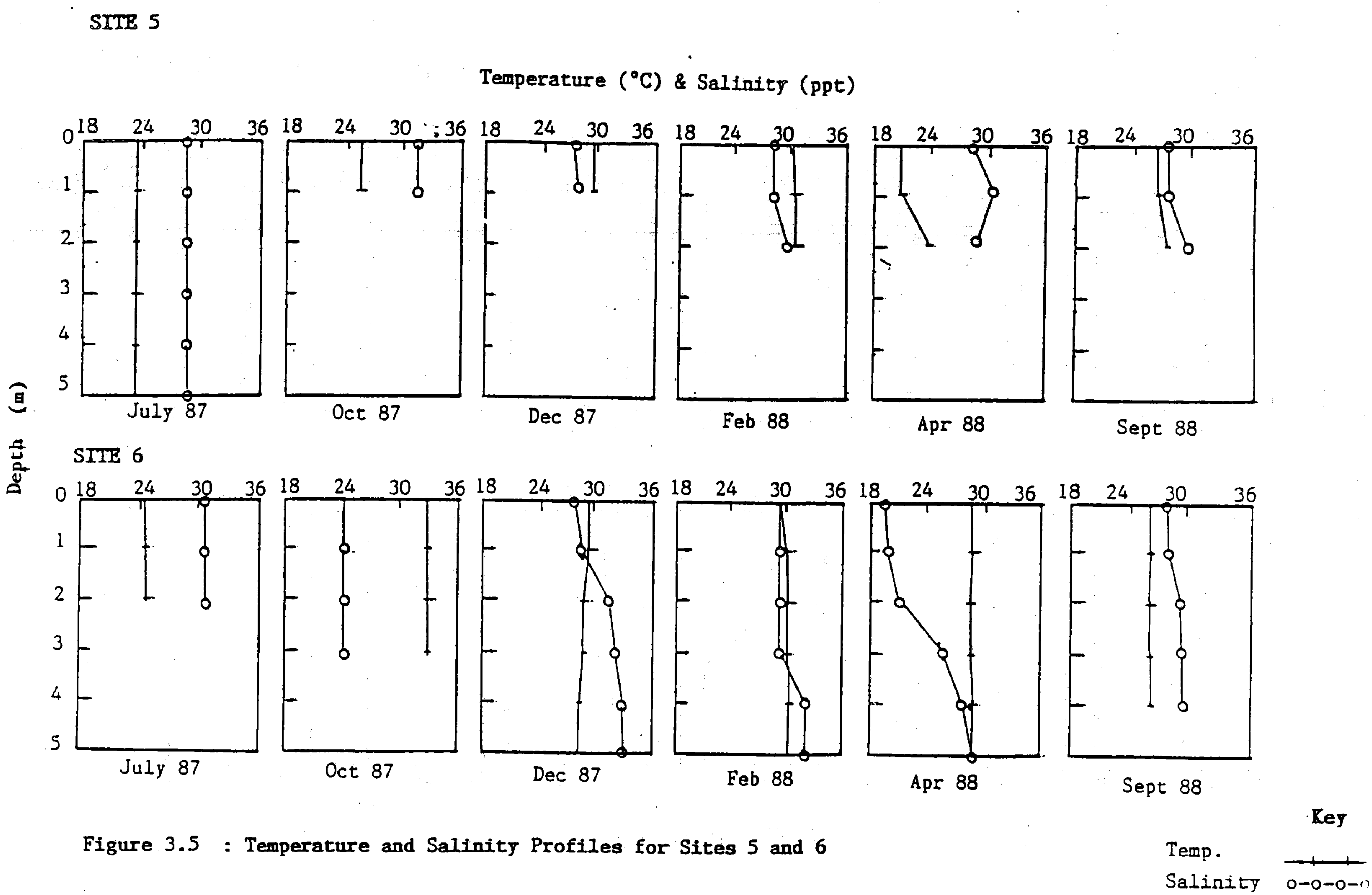

Figure 3.5 : Temperature and Salinity Profiles for Sites 5 and 6

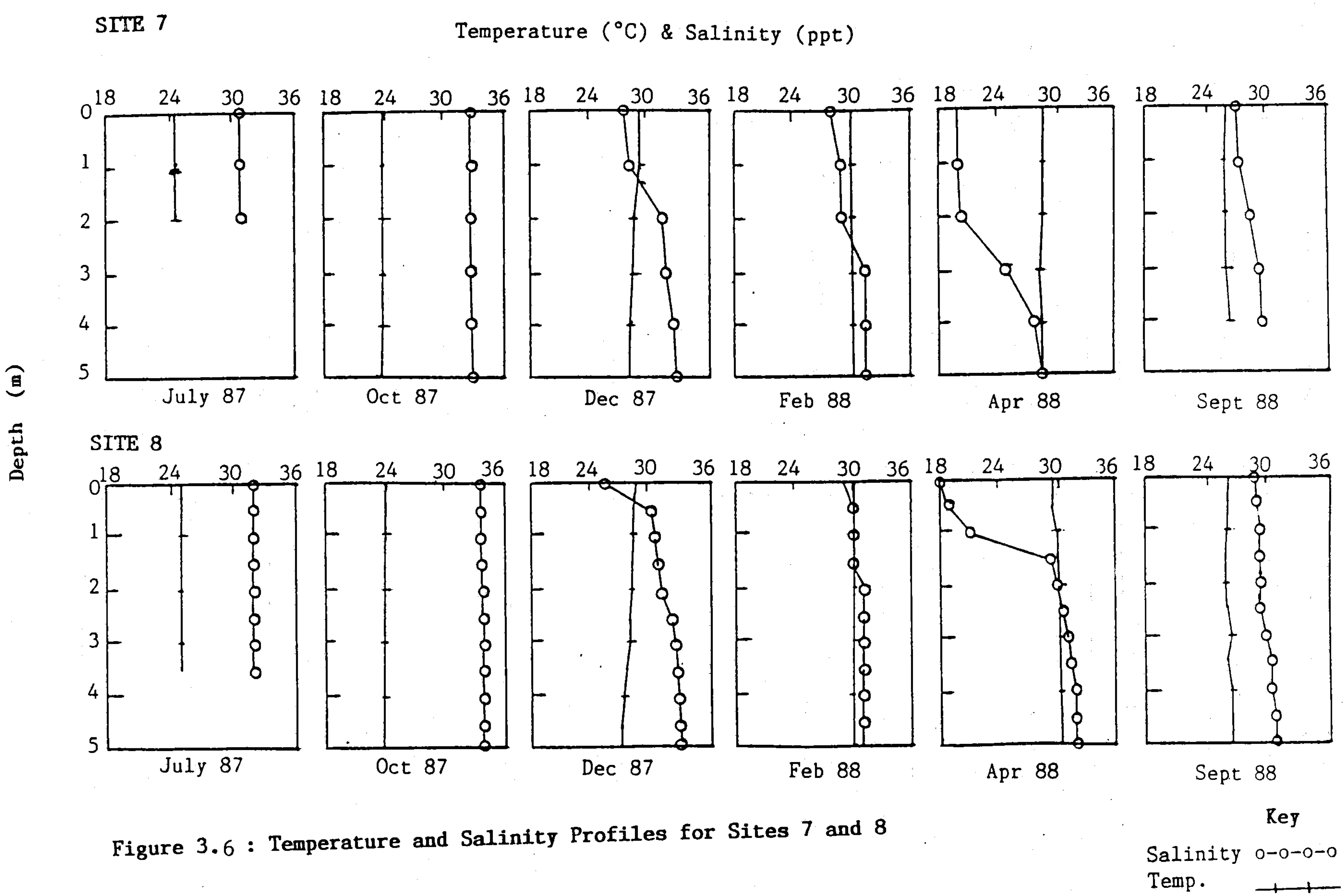

Figure 3.6 : Temperature and Salinity Profiles for Sites 7 and 8

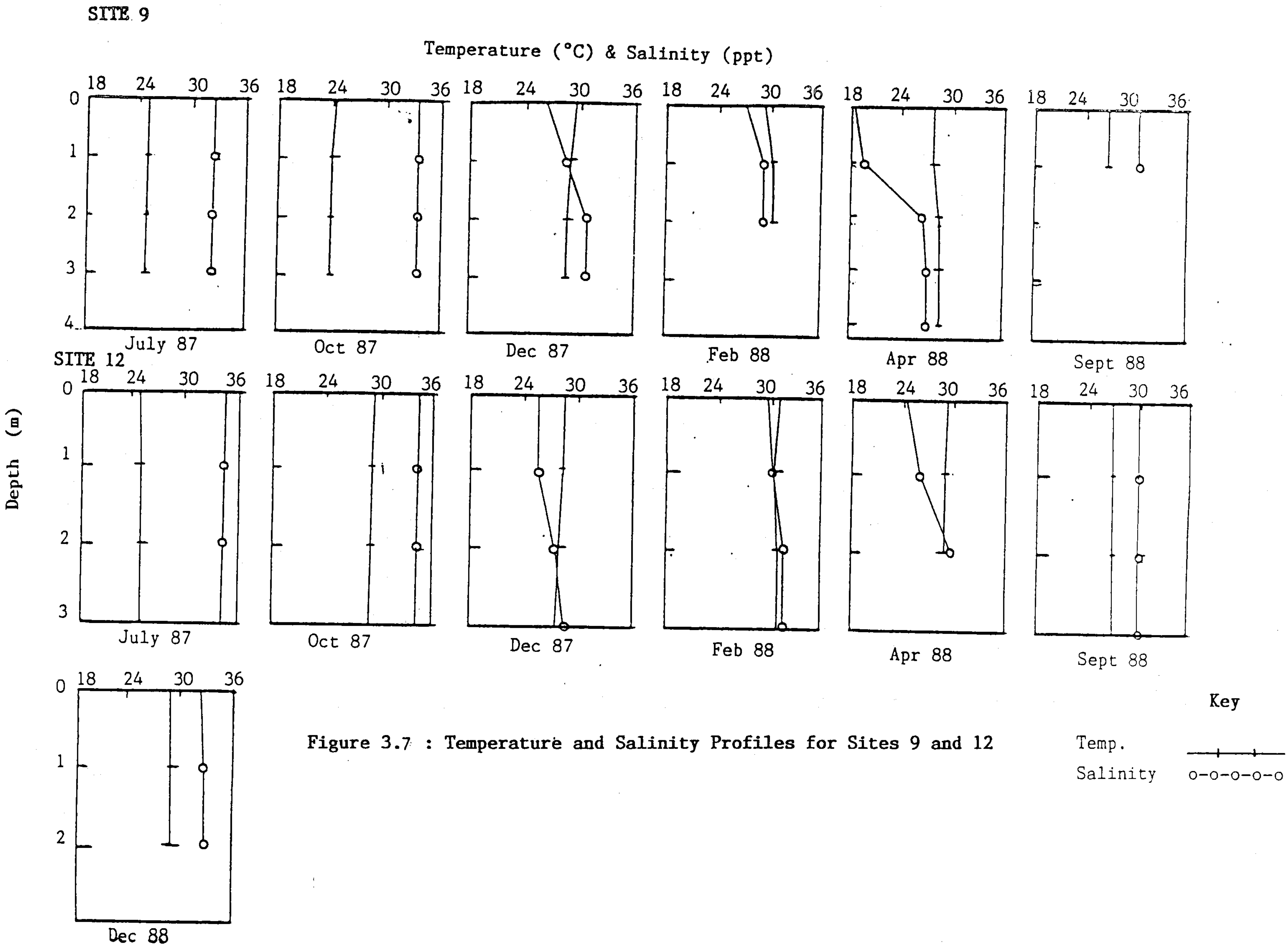

Figure 3.7 : Temperature and Salinity Profiles for Sites 9 and 12

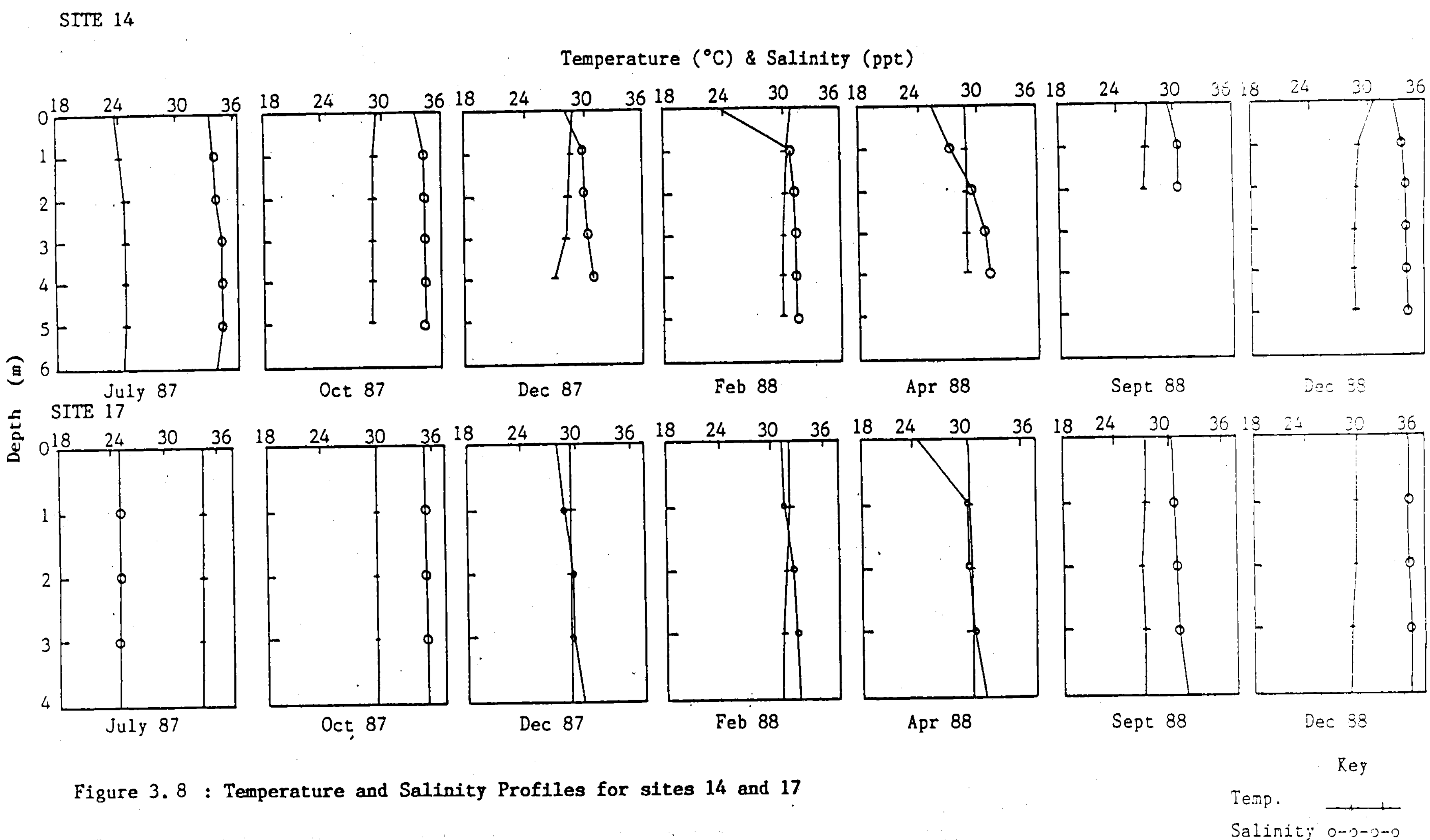

Figure 3. 8 : Temperature and Salinity Profiles for sites 14 and 17

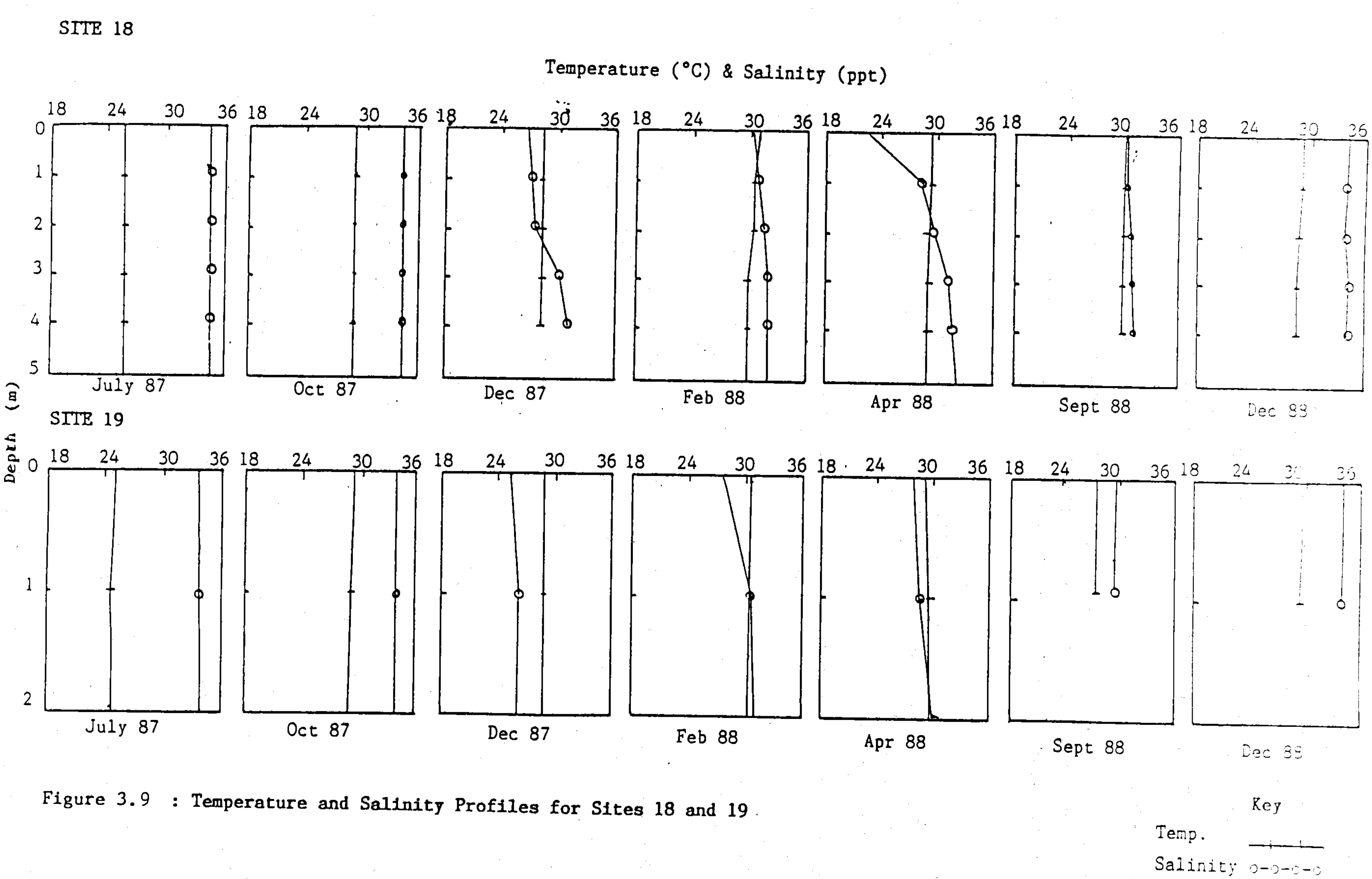

Figure 3.9 : **Temperature and Salinity Profiles for Sites 18 and 19**

(iii) Trace metal studies
(iv) Faecal coliforms
(v) State of swimming beaches
(vi) Shoreline rubbish survey at Suva Point and Lami beaches
(vii) Other observations

(i) Nutrient levels in Laucala Bay and Suva Harbour

The full chemical data is included as annexes at the end of this section.

(a) Total Nitrogen

The major inputs of dissolved organic nitrogen into Laucala Bay are the effluents from the Kinoya and the Raiwaqa sewage treatment plants, inputs from rivers (Vunidawa, Nasinu, Vatuwaqa and Samabula) and also industrial effluents. In Suva Harbour, inputs are mainly from industrial discharges and river inputs (Lami and Tamavua).

Total nitrogen content ranged from 0.04-6.8 mg/L (Table 3.8), the highest values being found at sites 1, 13, 14, 15 and 16. These results are not surprising since these sites were either in the vicinity of the major treatment plant outfall (site 1) or are polluted by sewage discharges (site 13 and 16) or receive leachates from the municipal rubbish dump (15). Site 14 receives effluent from a vegetable oil refinery and septic seepages from nearby villages (Table 3.6).

Statistical analysis of the data using an F test showed no significant difference between the average total nitrogen concentration (N_T) at sites 1 to 10; hence these results were used to calculate an average of 1.8 mg/L for Laucala Bay. This result is lower than the average value of 3.3 mg/L obtained in 1982 (Campbell et al.). The decrease in N_T cannot be assumed to reflect an improvement of water quality as lower N_T could also mean greater utilization by phytoplankton. This higher productivity would be reflected by decreasing clarity as seen in Table 3.12.

The average N_T content for Suva Harbour was 2.4 mg/L. This value is somewhat higher than that for Laucala Bay. Table 3.8 shows that in Laucala Bay, apart from site 1 which has point source pollution, only Nukulau has high levels of N_T whereas in Suva Harbour at least 4 areas have significant levels of nitrogen in the water (sites 13, 14, 15 and 16). The data on these sites are indicative of the occurrence of point source pollution.

(b) Nitrate, Nitrite and Ammonia

The relative concentrations of the inorganic forms of nitrogen are dependent on the oxygen content of the water. In open waters like Laucala Bay and Suva Harbour where there is effective mixing of water due to tides, winds and currents, the water is generally saturated with oxygen. The levels of nitrite and ammonia were generally very low as seen in the annexes (except when samples were kept for more than 12 hours prior to analysis - December 1987 monitoring) and thus are ineffective as indicators of pollution.

The nitrate levels in the study area ranged from <10 ug/L to >5000 ug/L (Table 3.9). The highest values were again found at sites 1 and 13 followed by sites 14 and 16. Sites 1, 13 and 16 are all direct recipients of sewage while site 14 receives sewage as seepages from villages nearby and also industrial effluents. Sites 7, 8 and 10 which are well away from the shore and thus from major human activity show the lowest values for nitrate. The nitrate content of open ocean water is usually between 30-300 ug/L and the values for sites 7, 8 and 10 also fall within this range.

The maximum level of dissolved inorganic nitrogen (nitrate + nitrite + ammonia) considered desirable for coral reef survival has up until recently been of the order of 1 umol N/L (Crossland, 1983; Bell and Greenfield, 1987) but more on recent studies (Brodie et al., 1989; Blake and Johnson, 1988) on Australian near-shore fringing reefs in good condition have found levels of 1.5-2 umol N/L (equivalent to 90-120 ug NO_3/L). Based on this data the values shown in Table 3.9 appear acceptable for all the offshore sites (3, 4, 6, 7, 12, 17, 18) and many of the inshore sites (2, 5, 8, 9, 10, 11, 12, 15, 17, 18, 19, 20). The stations showing consistently elevated nitrate levels (1, 13, 14, 16) are associated with sewage and industrial waste discharge

TABLE 3.8 : Total Nitrogen Concentrations (mg/L) in Laucala Bay and Suva Harbour

Date/Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
July 87	2.0	0.9	1.8	1.4	1.3	1.4	2.5	2.1	1.0	1.4	1.4	1.9	1.8	1.3	1.2	2.2	2.1	2.1	2.2	1.7
Oct. 87	1.7	1.1	0.6	0.6	0.7	1.6	1.0	1.0	2.6	2.2	2.1	2.3	4.0	4.8	5.1	4.1	2.7	5.4	3.7	2.9
Dec. 87	6.7	5.9	2.9	2.5	2.8	3.0	6.7	2.8	4.9	4.7	4.3	4.2	3.8	5.5	5.4	3.2	4.3	5.0	4.1	4.5
Feb. 88	0.2	<0.1	0.3	0.2	0.1	0.3	0.1	<0.1	0.1	0.1	2.7	1.1	4.0	2.1	0.2	1.3	0.2	3.0	0.4	0.8
Apr. 88	1.4	0.4	0.6	0.5	0.6	0.5	0.5	0.6	0.8	0.8	0.6	0.7	1.0	0.7	0.6	0.8	0.6	0.5	0.8	1.0
Sept 88	2.3	1.4	0.9	1.4	1.4	1.1	0.7	0.8	2.6	1.4	8.1	0.5	0.8	0.8	0.6	0.6	0.5	0.5	0.8	0.8
Dec. 88	1.2	3.9	5.0	5.8	2.6	4.3	4.2	2.2	4.8	2.5	1.2	3.9	5.0	5.8	2.6	4.3	4.2	2.2	4.8	2.5
Site Average	2.2	1.9	1.7	1.7	1.3	1.7	2.2	1.3	2.4	1.9	2.9	2.1	2.9	3.0	2.2	2.3	2.1	2.7	2.4	2.0

TABLE 3.9 : Nitrate Concentrations (µg/L) in Laucala Bay and Suva Harbour

Date/Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
July 87	37	12	31	31	62	12	12	12	25	31	43	28	1550	28	62	167	28	28	93	28
Oct. 87	1971	99	<6	17	112	42	32	99	<6	17	57	20	570	426	73	79	20	20	37	73
Dec. 87	5704	25	33	42	33	15	7	7	7	33	272	744	890	7	88	1339	<6	7	349	134
Feb. 88	1265	32	15	87	<6	<6	15	62	15	<6	62	87	2802	570	126	235	39	86	54	87
Apr. 88	2356	545	57	25	42	198	72	99	176	131	17	131	843	719	267	273	372	17	49	131
Sept 88	1686	52	44	52	62	106	44	52	52	52	25	63	905	63	429	109	53	44	53	72
Dec. 88	22	322	230	144	59	30	59	44	44	30	62	62	359	77	47	62	47	315	62	47
Site Average	1863	155	59	57	54	58	39	44	23	43	70	162	1131	270	156	323	81	74	100	82

but dispersion and dilution of this material reduces dissolved nitrogen concentrations to acceptable levels near the main reef.

(c) Total Phosphorus/Dissolved Phosphate

The total phosphorus concentration in Laucala Bay continued to be low as found in 1982 by Campbell et al. (1982). Values for Suva Harbour were also low. The total phosphorus concentrations ranged from 6 ug/L to 305 ug/L. All sites where point source pollution has been identified showed higher levels of phosphorus (e.g., 1 and 13). In fact the average value for site 1 is almost 16 times higher than the lowest average value obtained, while the average value for site 13 is almost 10 times as high. Sites 14, 15 and 16 around Suva Harbour also show considerable levels of total phosphorus (Table 3.10).

Since the total phosphorus content of uncontaminated surface waters is between 10-50 ug/L (Wetzel, 1975), it may be concluded that most of the sites were quite polluted.

The dissolved phosphorus levels followed a similar pattern to those for total phosphorus, i.e., site 1 had the highest levels followed by site 13. Sites 14 and 16 also showed elevated levels of dissolved phosphorus. The average dissolved phosphorus content at site 1 was almost 13 times the lowest average value while for site 13 it was about 6 times as high (Table 3.11). From the data for average total phosphorus values in Table 3.11 and it is apparent that apart from site 1, Laucala Bay had quite low levels of total phosphorus and this was also reflected in the concentrations of dissolved phosphorus.

Dissolved phosphate levels considered 'normal' for coral reef waters have generally been in the range 10-30 ug/L (Crossland, 1983; Bell and Greenfield, 1987) but, again, more recent studies on near-shore and fringing reefs have often found higher levels (Blake and Johnson, 1988) - up to about 70 ug/L. Most of the results for Laucala Bay and Suva Harbour are higher than can be considered desirable for the maintenance of coral growth on the Suva reef. Corals grown in high phosphate conditions have a very low skeletal density (Rasmussen, 1987) and hence are weak and break very easily. Excess phosphate also increases benthic algal growth at the expense of coral cover and causes increased phytoplankton growth leading to higher water column turbidity (Smith et al., 1981; Tomascik and Sander, 1985).

The average total nitrogen to average total phosphorus ratio (N_T:P_T) for Laucala Bay was 102 and for Suva Harbour waters the ratio was 68. The higher ratio in Laucala Bay tended to confirm that phosphorus was still the limiting factor for algal growth; this is consistent with the findings of Campbell et al. (1982). In Suva Harbour, however, the total phosphorus concentrations were slightly higher.

Examination of the NO_3/PO_4 ratio shows a distinctly different picture. In Laucala Bay the ratio of NO_3 to PO_4 was 1.2. (Values at site 1 were not included in the calculation because they were significantly different from values at other sites) while in Suva Harbour the ratio was slightly higher (4). If primary productivity is controlled by nitrate and phosphate concentrations rather than N_T and P_T, then both Laucala Bay and Suva Harbour may no longer be phosphorus limiting.

While there may be debate on whether phosphorus is still the limiting factor for primary productivity in these waters or not, the sewage effluent at site 1 is contributing most of the phosphorus addition to Laucala Bay. If the point source pollution at site 1 can be controlled/eliminated or diverted beyond the reefs then the quality of bay waters will improve significantly. Suva Harbour has at least 4 areas which are of concern and because of these the nutrient levels in the harbour are higher in Laucala Bay.

(ii) Clarity

Clarity measurements for the entire monitoring period are shown in Table 3.12. In general the clarity ranged from about 0.5 m to 5 m.

Clarity of water in Laucala Bay was largely affected by the clay and fine silt discharged by the Rewa and Vunidawa rivers. The clarity in Laucala Bay was lowest in April 1988 after heavy rainfall during the week prior to sampling. In Suva Harbour sites 13 and 20 consistently had the lowest clarity. Since correlation between clarity and chlorophyll at site 13 was not evident from the data, it is difficult to identify the cause of lower clarity at this site. However, from the discussion above, site 13 has been identified as one of the problem

TABLE 3.10 : Total Phosphorus Concentrations (µg/L) in Laucala Bay and Suva Harbour

Date/Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
July 87	50	30	40	30	80	14	30	40	14	24	20	14	100	64	30	70	14	20	14	14
Oct. 87	360	36	31	18	45	18	28	18	28	18	18	18	158	18	18	22	18	18	18	18
Dec. 87	218	17	17	22	35	17	12	12	9	17	22	<6	196	35	17	<6	<6	<6	<6	12
Feb. 88	72	13	14	10	6	10	14	14	25	14	10	10	151	44	10	10	10	10	10	10
Apr. 88	134	18	27	9	<6	<6	9	9	<6	<6	<6	45	76	62	<6	<6	<6	<6	<6	<6
Sept 88	305	10	10	10	15	10	10	10	20	10	20	20	91	176	51	72	25	20	30	20
Dec. 88	259	9	<6	13	9	9	<6	<6	18	<6	<6	<6	152	53	129	31	<6	<6	18	40
Site Average	200	19	21	16	28	12	15	15	17	13	14	17	132	65	37	31	12	12	15	17

TABLE 3.11 : Dissolved Phosphate Concentrations (μg/L) in Laucala Bay and Suva Harbour

Date/Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
July 87	186	186	263	186	560	263	263	186	186	263	93	93	1123	262	260	373	93	262	93	93
Oct. 87	5853	563	710	300	563	413	300	300	300	300	300	300	1125	863	412	563	300	300	300	413
Dec. 87	673	153	153	137	122	92	137	174	92	107	92	92	704	183	153	144	92	92	122	128
Feb. 87	254	61	46	46	36	61	67	46	125	76	46	86	468	147	85	92	62	33	38	33
Apr. 88	416	150	235	107	30	30	64	82	30	40	82	165	352	202	30	30	55	30	55	55
Sept 88	832	64	39	52	64	40	52	52	64	64	30	30	153	661	46	138	30	30	30	46
Dec. 88	700	30	30	30	30	30	30	40	30	30	30	30	428	122	113	88	101	36	30	49
Site Average	1273	172	211	122	200	133	130	125	118	125	96	113	622	348	157	204	108	112	95	117

TABLE 3.12 : Clarity Data (Secchi Disc-m) for Laucala Bay and Suva Harbour

Date/Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Jul 87	1.0	1.0	1.0	3.0	0.5	4.0	>2	4.0	4.0	1.5	>0.75	>3	0.5	1.75	>0.5	>0.5	3.7	5.0	2.0	2.0
Oct 87	0.75	1.0	1.75	2.5	0.75	2.0	2.0	3.0	>3	0.5	>0.75	>3.5	0.75	1.5	>0.5	>0.5	3.0	5.0	2.0	1.5
Dec 87	1.75	1.75	1.75	2.0	>1.75	2.25	2.0	3.0	>2	1.25	>0.75	2.0	0.5	1.0	>0.5	>0.5	2.0	2.0	1.5	0.75
Feb 88	1.5	1.5	2.5	2.5	>2	2.5	2.0	2.5	1.5	1.0	>1	>3	>0.75	1.0	0.75	0.75	2.0	3.0	2.0	0.5
Apr 88	1.0	0.75	0.5	1.5	1.0	1.0	1.5	1.0	1.0	1.0	>0.75	>2	>0.75	1.25	0.5	0.5	4.0	1.5	1.25	0.5
Sep 88	1.0	1.0	1.5	2.0	1.5	3.0	1.0	2.5	>1	1.0	>0.5	>1.5	>0.25	1.0	0.5	0.5	3.0	3.0	1.5	0.5
Dec 88	-	-	-	-	-	-	-	-	-	-	1.0	>1.0	0.5	0.5	-	-	1.5	1.5	1.5	0.5
Site Average	1.2	1.2	1.5	2.3	1.3	2.4	1.9	2.7	2.1	1.0	>0.8	2.3	>0.8	1.1	>0.5	>0.5	2.7	3.0	1.7	0.9

areas in the harbour. Site 20 receives effluent from the cement factory and the lower clarity here could be attributed to fine dust particles in the discharged water. In addition dredging operations were in progress around this area throughout the monitoring period. A correlation between clarity and dissolved silica at site 20, however, showed no significant relationship.

In general, the clarity of Laucala Bay water has decreased considerably since 1982 when the average secchi disc reading then was 3.1 while the present study gave an average value of only 1.7. This decline in clarity may be associated with increased phytoplankton growth as discussed above.

(iii) Trace Metal Studies

Water samples were collected on seven occasion from 5 sites (numbers 5, 13, 14, 15 and 16 in Table 3.6) where likely trace metal pollution problems were suspected. Results of the analyses of these samples are given in Table 3.13. These data show that most of the values were below the locally attainable detection limits. For mercury, lead and chromium only a few values were above the detection limits and the reliability of these results was low as the absorbances were just above the blank value. For copper, most values were above the detection limit and ranged from <2-39 ug/L with an average of 11 ug/L. This is well above the values normally quoted for copper in seawater. However, given that the samples were taken from the mouths of small rivers draining industrial areas around Suva within a coastal area having restricted circulation and known high geological copper levels, the copper concentrations were not unexpected.

For cadmium approximately one third of the values were above the detection limit. The sites where these detectable values were obtained are all located close to industrial zones where battery factories, electroplating and other metal finishing businesses operate. Given the high detection limit and the low reliability of the results it is difficult to draw definite conclusions but some (spasmodic) discharge of cadmium into the marine environment may have occurred.

Shellfish samples for trace metal analysis were also collected at the sites used for the faecal coliforms in shellfish study (Table 3.7). At some sites on some visits only limited numbers of shellfish could be found; the results should be considered in this light. Results of the analyses are given in Table 3.14. These results indicate that trace metal concentrations were generally low with mercury contents <0.1 mg/kg and cadmium contents, <0.25 mg/kg. Chromium contents, with two exceptions, were less than 1 mg/kg, the two exceptions being for Nabukalou Creek which is known locally to be severely polluted. The lead concentrations ranged from less than 0.5 mg/kg (detection limit) up to 5.5 mg/kg, with two of the highest values again being found for samples from Nabukalou Creek. Other significantly high values were found in samples taken from sites (4 and 5) close to major roads where lead from petrol is a possible source. Copper concentrations ranged from 15-84 mg/kg but with no particular pattern. These values were considerably higher than those found for Fanga'uta Lagoon (Section 6.3), but a similar range (4-79 mg/kg) was found in Vila (Section 4.3). The higher values in Suva and Vila may be related to locally higher copper contents in the environment (as indicated by the water data above) due to the use of copper based antifouling paints or a high natural level associated with local volcanic rocks or both.

Using the locally derived ratio of wet weight/dry weight (4:1) for oysters, calculated average values for the trace metals in oysters on a dry weight basis were Cd 0.4, Cr 1.6, Cu 152, Pb 5.3, Hg 0.1 mg/kg. Comparison of these values with those quoted by Bryan (in Johnson (1976)) of Cd 10, Cr 1.5, Cu 100, Pb 3, Hg 0.4 mg/kg tend to indicate that no particular contamination problems were occurring.

(iv) Faecal Coliform Study

Filter feeding shellfish have the ability to accumulate toxic chemicals and pathogenic organisms in their tissues in concentrations greater than the levels found in the surrounding water. Hence they are often used as indicators of the presence of human sewerage and thus of human pathogenic organisms such as Vibrio cholera, Shigella, Salmonella and Hepatitis A virus. In the present study, mangrove oysters were chosen as the test organism because they are readily available and easily collected throughout the study area. Also they are eaten both raw and cooked, though not as commonly as other species. The 8 sites selected for the present study all have some source of domestic and industrial pollution, but the extent of pollution is different (Table 3.7). The site north of Kinoya village (site 1) is probably the cleanest because it is furthest from industrial activity and is only influenced by domestic pollution. Because faecal coliforms are sposmatic, only

TABLE 3.13 : Trace Metal Concentrations (µg/L) at Selected Sites in Laucala Bay and Suva Harbour

	Cd	Cr	Cu	Pb	Hg
Site 5					
Jul 87	<5	<5	8	<10	<1
Oct 87	5.0	7	9	<10	<1
Dec 87	15.6	<5	24	12	<1
Feb 88	21.0	<5	19	<10	<1
Apr 88	9.4	6	5	<10	<1
Sep 88	<5	<5	39	<10	<1
Dec 88	5.0	<5	<2	<10	<1
Site 13					
Jul 87	<5	<5	10	<10	<1
Oct 87	<5	<5	19	<10	2.5
Dec 87	10.5	<5	12	<10	2.0
Feb 88	21.0	<5	19	11	3.1
Apr 88	10.5	11	4	<10	2.9
Sep 88	<5	<5	6	<10	2.0
Dec 88	<5	<5	5	<10	2.0
Site 14					
Jul 87	<5	<5	5	<10	<1
Oct 87	<5	<5	19	<10	8.8
Dec 87	22.6	<5	20	<10	2.0
Feb 88	21.0	<5	15	<10	5.8
Apr 88	10.7	7	<2	<10	1.0
Sep 88	<5	<5	<2	<10	<1
Dec 88	<5	<5	4	<10	<1
Site 15					
Jul 87	<5	<5	5	<10	<1
Oct 87	<5	<5	21	<10	8.8
Dec 87	24.8	<5	37	12	2.0
Feb 88	<5	8	4	<10	2.0
Apr 88	12.0	8	<2	<10	2.6
Sep 88	<5	<5	13	<10	<1
Dec 88	<5	<5	2	<10	2.0
Site 16					
Jul 87	<5	<5	8	19	<1
Oct 87	<5	<5	22	<10	2.0
Dec 87	<5	<5	4	<10	2.0
Feb 88	<5	<5	6	<10	1.3
Apr 88	<5	8	<2	<10	<1
Sep 88	<5	<5	8	<10	<1
Dec 88	<5	<5	8	<10	<1

TABLE 3.14 : Trace Metal Concentrations in Crassostrea Mordax (Mangrove Oyster - mg/kg fresh weight)

Date	Site No*	Cd	Cr	Cu	Pb	Hg
Jul 87	1	<0.10	<0.10	31.2	<0.5	<0.001
Oct 87		0.16	0.26	53.0	2.83	n.d.
Nov 87		0.12	0.25	26.8	<0.5	0.010
Feb 88		0.14	0.29	20.3	<0.5	n.d.
Jul 87	2	<0.10	<0.10	23.4	<0.5	0.004
Oct 87		0.14	0.23	62.7	3.31	n.d.
Nov 87		<0.10	0.10	15.3	<0.5	0.008
Feb 88		0.22	0.35	35.0	<0.5	n.d.
Jul 87	3	<0.10	<0.10	16.3	<0.5	0.005
Oct 87		0.10	0.64	27.2	1.43	n.d.
Nov 87		0.12	<0.10	19.4	0.50	0.009
Feb 88		0.13	0.23	20.7	<0.5	n.d.
Jul 87	4	<0.10	<0.10	16.9	<0.5	0.011
Oct 87		0.19	0.92	46.7	2.46	n.d.
Nov 87		0.10	0.28	36.4	2.38	0.013
Feb 88		0.25	0.23	23.8	<0.5	n.d.
Jul 87	5	<0.10	0.98	20.9	0.60	0.026
Oct 87		0.11	0.24	65.9	4.00	n.d.
Nov 87		0.12	0.31	61.6	2.10	0.032
Feb 88		<0.10	0.58	69.3	2.40	0.018
Jul 87	6	<0.10	1.38	22.5	<0.5	0.025
Oct 87		0.15	<0.10	26.1	3.50	n.d.
Nov 87		0.15	0.35	32.4	<0.5	0.061
Feb 88		0.18	1.75	50.8	5.48	0.022
Jul 87	7	<0.10	<0.10	22.5	<0.5	0.041
Oct 87		0.16	<0.10	84.6	0.63	n.d.
Nov 87		<0.10	0.27	68.4	1.81	0.032
Feb 88		0.13	0.58	161.3	3.05	0.025
Jul 87	8	<0.10	<0.10	22.5	<0.5	0.017
Oct 87		<0.10	<0.10	37.5	<0.5	n.d.
Nov 87		<0.10	0.21	44.2	<0.5	0.044
Feb 88		<0.10	1.52	55.7	1.63	0.040

n.d. = not determined

* see Table 3.7

the oysters were collected. Faecal coliform concentrations are strongly influenced by die-off so the intergrating ability of shellfish can assist monitoring average levels in the environment. Sufficient numbers of benthic shellfish could not be found to provide an effective study.

Faecal coliform levels in oysters ranged from 0.7 most probable number (MPN) to 24,000 MPN per gram of fresh weight (Table 3.15). There was considerable variation in results from station to station as well as within the stations. A number of factors could be responsible for the analytical data obtained. Of these, the most probable reasons in this study were climatic conditions, e.g., rainfall, tides, and the variations in population and size of the shellfish collected.

To eliminate variations in results due to tidal effects all samples were collected at low tide. To eliminate variations due to differences in density of oysters and size, ten oysters of similar size were taken during all samplings. It is extremely difficult to determine what rainfall parameter to use in correlation studies, but casual examination of data in this study and earlier work shows that coliform levels in water and shellfish increased following periods of heavy rain.

It is also apparent from these results that oysters/ shellfish present in Laucala Bay and Suva Harbour should be treated as potentially hazardous because only 5% of the results in Table 3.15 fall within recognized safety limits. The US Microbiological National Shellfish Sanitation Programme (1964) states that the International Safety Standard for faecal coliforms in edible shellfish is 2.3 MPN per gram of fresh weight. In the Mediterranean, sale of shellfish having >10 FC/g flesh was prohibited in interim criteria proposed as part of the MED POL programme while for shellfish having 3-10 FC/g temporary prohibition of sale was recommended (UNEP/WHO, 1986). Continued consumption of shellfish with high coliform contents may result in bacterial and viral diseases such as typhoid and paratyphoid infections caused by Salmonella as well as amoebic dysentery, type A hepatitis and poliomyelitis.

(v) State of Some Popular Swimming Beaches

To assess the state of some popular swimming beaches around Suva, a total of 8 sites were selected for study. Water was collected at low tide approximately every two months and tested for faecal coliforms using the membrane filtration technique (UNEP/WHO, 1983a). The results (Table 3.16) showed faecal coliform levels ranging from nil to 46,300 colonies per 100 mL. Only Nabukalou Creek and Lami water consistently showed high counts. Since the World Health Organisation (WHO) criteria for marine bathing waters is less than 350 faecal coliforms in 100 mL of water (WHO, 1983) it is apparent that most of the sites under investigation are acceptable for recreational facilities (the exceptions being the Lami River and Nabukalou Creek).

The potential sources of infectious agents reaching these recreational sites include untreated or poorly treated municipal and industrial effluents, sanitary wastes from seaside residences, storm water runoff and excretions of lower animals. The health hazard potential from infectious disease associated with each of these sources is different. The untreated human faecal waste presents the greatest hazard to human health and both the Lami and Nabukalou Creek sites receive such wastes.

Routine examination of recreational waters for faecal coliforms has limitations as a monitoring tool since the discharges and hence a number of enteric pathogens are sporadic. Regular monitoring programmes, however, are designed to overcome some of these difficulties. If a particular site gives elevated levels in most samples it is clear that there is sewage contamination and problems exist. In the South Pacific water coliform numbers will be influenced by the salinity and levels of ultraviolet radiation, especially at low tide. As with faecal coliforms in shellfish data discussed above, faecal coliforms in recreational waters increased following heavy rain, indicating that bacterial contamination was probably a consequence of movement in increased runoff.

Despite these limitations the results showed that both Nabukalou Creek and Lami river should be monitored further and if possible closed for bathing until appropriate corrective measures have been taken.

(vi) Shoreline Rubbish Survey at Suva Point and Lami Beaches

A shoreline rubbish survey was conducted over an 8 month period at two of the popular beaches around Suva to find the types of rubbish present. A 5 m cord was attached to a 1 m^2 quadrat and the quadrat

TABLE 3.15: Faecal Coliforms in Crassostrea Mordax (Mangrove Oyster) - FC(MPN)/g Fresh Weight

Date	North Kinoya Village	Kinoya Village South of Outfall	Vatuwaqa River Mouth	Adventure Playground, Nasese	Bridge - China Club	Nabukalou Creek	Tamavua River Mouth	Wailada River Mouth
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
1/6/87	79	3500	33	0.7	n.d.	n.d.	n.d.	n.d.
8/6/87	n.d.	220	170	33	110	n.d.	49	920
16/6/87	460	1100	130	33	n.d.	n.d.	n.d.	n.d.
22/6/87	7.9	330	130	35	n.d.	n.d.	n.d.	n.d.
29/6/87	17	280	790	130	n.d.	n.d.	n.d.	n.d.
6/7/87	7.9	35	94	7.9	n.d.	n.d.	n.d.	n.d.
13/7/87	17	2400	79	33	n.d.	n.d.	n.d.	n.d.
5/10/87	24	540	18	170	n.d.	n.d.	n.d.	n.d.
26/10/87	n.d.	n.d.	n.d.	n.d.	110	540	117	92
23/11/87	3.3	350	92	54	n.d.	n.d.	n.d.	n.d.
7/12/87	n.d.	n.d.	n.d.	n.d.	4.6	110	4.9	35
29/2/88	2400	9300	24000	2400	n.d.	n.d.	n.d.	n.d.
14/3/88	n.d.	n.d.	n.d.	n.d.	2400	460	460	2400
12/4/88	460	460	2100	930	n.d.	n.d.	n.d.	n.d.
26/4/88	n.d.	n.d.	n.d.	n.d.	2400	2400	11000	930
13/6/88	110	43	75	1099	n.d.	n.d.	n.d.	n.d.
27/6/89	n.d.	n.d.	n.d.	n.d.	110	2398	46	46
23/8/88	40	90	350	35	n.d.	n.d.	n.d.	n.d.
7/9/88	n.d.	n.d.	n.d.	n.d.	220	540	92	920
11/10/88	4.9	4.0	34.5	91.8	n.d.	n.d.	n.d.	n.d.
24/10/88	n.d.	n.d.	n.d.	n.d.	34.5	17.2	91.8	54.2
7/12/88	13	0.7	92	1.7	n.d.	n.d.	n.d.	n.d.
19/12/88	n.d.	n.d.	n.d.	n.d.	33	1.4	1.7	17

TABLE 3.16 : Faecal Coliforms in Water at Swimming Beaches Around Suva

SITE	Faecal Coliforms/100 mL									
	13.5.87	23.7.87	23.9.87	3.11.87	28.1.88	17.3.88	12.5.88	27.7.88	7.9.88	6.12.88
NUKULAU IS.	70	50	10	2	4	198	n.d.	Nil	Nil	Nil
SUVA POINT	740	7,700	100	Nil	200	42	1,380	1,570	190	56
LAUCALA BAY (Near Childrens Park)	30	70	350	100	510	20	43	30	3	18
NASESE Opposite Police Training College	850	90	100	Nil	43	52	530	80	16	Nil
LAMI Opposite Lami Town Council	3,200	9,000	6,000	500	15,000	276	46,300	250	355	300
MOSQUITO IS.	80	760	10	120	180	27	n.d.	10	10	7
DEUBA - CORAL COAST	53	210	1	2	400	27	200	60	4	Nil
PACIFIC HARBOUR International Resort	n.d.	90	Nil	2	2	20	44	2,660	4	329
NAITONITONI BEACH	n.d.	320	200	20	37	45	300	4	29	Nil
NABUKULAU CREEK	n.d.	n.d.	7.500	36,000	15,900	17,000	n.d.	3,600	3,600	1,400

placed randomly in a zig-zag manner on the shore to cover the whole beach. The amount of rubbish deposited by man in each quadrat was estimated as a percentage of the area enclosed within the quadrat. Rubbish present was then categorised as percent plastic bag; percent other plastic; percent metal; percent cloth/clothing; and percent rubber/tyre. The results are presented in the Table 3.17.

The Suva Point shore is a popular recreational area, a non-commercial shellfish harvesting site and also a dumping site for various types of rubbish. Results of the shoreline rubbish survey (Table 3.17) indicated that about 35% of the area was covered by rubbish at any time. The major form of rubbish at the beach was plastic bags (50%). Other categories of rubbish were roughly equally abundant with the exception of metals which were less common.

Lami beach is just opposite a major industrial area and is used as a dumping site for all types of rubbish by the nearby industries. It is not used as a swimming beach although shellfish are often harvested. Analysis of the data showed that about 39% of the shore was covered by rubbish. The different categories of rubbish were again somewhat evenly distributed, with the metals being least abundant and plastic bags the most abundant.

Plastic bags represented the major source of rubbish at the two sites studied. This survey was terminated because the local authority has now employed youths to clean up the shores.

(vii) Other Measurements

(a) Oil and grease

Oil and grease were measured only at site 14 because this area receives considerable amounts of effluent from a vegetable oil refinery. Table A3.14 (see Annex) shows that values ranged from 24 mg/L to 62 mg/L with a mean of 47 mg/L. Visible signs of oil and grease were often seen as white flecks in the water around this area. The visible signs were scattered over a wide area. A preliminary investigation of the composition of effluents from the oil refinery showed the effluents to have the following characteristics:

Suspended solids mg/L	=	2250
Oil/grease mg/L	=	3418
BOD_5 mg/L	=	3000
COD mg/L	=	1804
pH	=	8.40

Although it appears that the oil and grease were diluted about 70 times in nearshore waters, continuous discharge of such concentrated effluents will have a marked effect on the water quality and on the local marine life.

TABLE 3.17 : Analysis of Shoreline Rubbish Survey

Date	Suva Point					
	%Area rubbish	%Plastic bag	% Other plastic	% Metal clothing	%Cloth tyre	%Rubber
11.8.87	15.7	65.3	10.8	13.4	10.8	0
14.10.87	31.4	40.1	31.4	4.8	13.8	10.2
17.12.87	33.5	64.4	1.3	8.5	4.0	21.9
17.2.88	58.5	39.5	15.6	1.8	11.5	31.8
AVERAGE	34.5	52.3	14.8	7.1	10.0	16.0

TABLE 3.17 (cont'd)

Date	Lami shore					
	%Area rubbish	%Plastic bag	%Other plastic	%Metal clothing	%Cloth tyre	%Rubber
11.8.87	20.1	38.5	4.5	5.9	45.2	5.9
14.10.87	35.5	35.2	21.1	4.5	21.1	18.4
17.12.87	46.0	31.2	7.9	25.6	11.0	24.8
17.2.88	52.6	22.2	35.7	5.1	14.2	22.9
AVERAGE	38.6	31.9	17.3	10.3	22.9	18.0

% Area rubbish = $\frac{\text{area by rubbish}}{\text{Total area}} \times 100$

% Area plastic etc. = $\frac{\text{area plastic bag}}{\text{Total area covered by rubbish}} \times 100$

(b) Oil Slick Counts

On each sampling trip a lookout for oil slicks was kept. No slicks were observed in Laucala Bay. However, in Suva Harbour, in the area round sites 14 and 18, oil slicks were often seen. These slicks were probably a consequence of the very large number of boats using these areas.

3.4 CONCLUSIONS AND RECOMMENDATIONS

The results of this study indicate that the general water quality status of Laucala Bay and Suva Harbour is cause for concern.

The faecal coliform counts in water show the frequent occurrence of unacceptably high values at several sites, although other sites usually gave values within the WHO limits for recreational waters. The lack of consistently low values at most sites indicated that sewage pollution was relatively widespread. This was confirmed by the values obtained for faecal coliforms in oysters which indicated that most samples (95%) exceeded recognized international safety standards. There is considerable potential for disease outbreak and spread if action is not taken urgently to reduce the untreated sewage input to coastal waters around Suva.

Trace metal studies showed a less serious situation but the fact that cadmium was detected in water samples at several sites indicated some industrial pollution. With the recent push to expand the local industrial base, greater controls on effluents and spillages must be exerted to prevent toxic metals from entering and being accumulated in the food chain. Relatively high copper contents found in water and shellfish require further investigation to determine whether the cause is natural (geological) or due to pollution.

The most serious cause for concern is the high nutrient status of the waters around Suva. Nitrate and phosphate values are generally high and occasionally very high. Apart from the probable impact on coral growth and reef development, the levels of these nutrients are such that the potential for serious problems such as algal blooms now exists. Unless urgent action is taken to reduce nutrient inputs (particularly phosphate) to Suva's coastal waters it is only a matter of time before a bloom occurs with the consequent devastating effect on local fishing.

The obvious source of nutrient input is treated, partially treated and untreated sewage reaching the coastal water. It is recommended that immediate action be taken to speed up the completion of the Greater Suva trunk sewer system. In addition, action should be taken at the Kinoya treatment plant to reduce the nitrate and phosphate content of the effluent. Analysis of available data should be made to determine the

nitrate and phosphate inputs to the Suva coastal zone and if sufficient data is unavailable, the necessary steps to generate such data should be intiated forthwith.

One difficulty that may be encountered is that part of the problem is under the jurisdiction of the Suva City Council while another part is under the Public Works Department of the Fiji Government. It is recommended that appropriate officers of both agencies meet to quickly develop a concerted action plan to address the problems discussed above.

ANNEX TO SECTION 3

TABULATED ANALYTICAL DATA
FOR LAUCALA BAY AND SUVA HARBOUR

TABLE A3.1 : Analytical Data for Laucala Bay/Suva Harbour Samples

Site 1

Date	Clarity (m) Secchi Disc	Total N mg/L	NH_3 µg/L	NO_2 µg/L	NO_3 µg/L	Total P µg/L	PO_4 µg/L	SiO_3 mg/L	Chlorophyll mg/m^3 a	b	c	Oil/ Grease mg/L	Oil Slick Count
Jul 87	1.0	2.0	<20	16	37	50	186	3.0	28.8	49.3	121.3	-	0
Oct 87	0.75	1.7	2600	94	1971	360	5853	2.8	6.0	6.7	9.5	-	0
Dec 87	1.75	6.7	6100	90	5704	218	673	2.7	0.1	0.4	0.9	-	0
Feb 88	1.5	0.2	52	44	1265	72	254	1.4	-	-	-	-	0
Apr 88	1.0	1.4	140	107	2356	134	416	4.1	1.8	6.8	31.9	-	0
Sep 88	1.0	2.3	1960	100	1686	305	832	4.0	4.6	5.8	30.5	-	0
Dec 88	no data	1.2	1460	<10	22	259	700	2.1	2.3	2.4	22.0	-	0

TABLE A3.2 : Analytical Data for Laucala Bay/Suva Harbour Samples

Site 2

Date	Clarity (m) Secchi Disc	Total N mg/L	NH_3 µg/L	NO_2 µg/L	NO_3 µg/L	Total P µg/L	PO_4 µg/L	SiO_3 mg/L	Chlorophyll mg/m^3 a	b	c	Oil/ Grease mg/L	Oil Slick Count
Jul 87	1.0	0.9	25	<10	12	30	186	3.4	2.6	0.7	10.3	-	0
Oct 87	1.0	1.1	<20	<10	99	36	563	1.3	3.6	0	55.2	-	0
Dec 87	1.75	5.9	1250	<10	24	17	153	2.2	0	0	0	-	0
Feb 88	1.5	<0.1	<20	<10	32	13	61	0.8	2.3	1.5	35.6	-	0
Apr 88	0.75	0.4	40	34	545	18	150	3.8	0	0	0	-	0
Sep 88	1.0	1.4	26	30	52	10	64	2.4	1.7	5.8	44.0	-	0
Dec 88	no data	3.9	34	<10	322	9	30	1.7	3.1	6.5	31.2	-	0

TABLE A3.3 : Analytical Data for Laucala Bay/Suva Harbour Samples

Site 3

Date	Clarity (m) Secchi Disc	Total N mg/L	NH_3 µg/L	NO_2 µg/L	NO_3 µg/L	Total P µg/L	PO_4 µg/L	SiO_3 mg/L	Chlorophyll mg/m^3 a	b	c	Oil/ Grease mg/L	Oil Slick Count
Jul 87	1.0	1.8	30	<10	31	40	263	1.5	24.3	32.0	97.5	-	0
Oct 87	1.75	0.6	<20	<10	<6	31	710	1.0	8.2	0	14.3	-	0
Dec 87	1.75	2.9	1250	<10	33	17	153	2.5	0	0	0	-	0
Feb 88	2.5	0.3	<20	<10	15	14	46	2.1	0	0	0	-	0
Apr 88	0.5	0.6	68	26	57	27	235	6.1	0	0	0	-	0
Sep 88	1.5	0.9	26	20	44	10	39	2.7	1.7	6.7	31.9	-	0
Dec 88	no data	5.0	24	<10	230	<6	30	3.2	3.4	14.4	50.3	-	0

TABLE A3.4 : Analytical Data for Laucala Bay/Suva Harbour Samples

Site 4

Date	Clarity (m) Secchi Disc	Total N mg/L	NH_3 µg/L	NO_2 µg/L	NO_3 µg/L	Total P µg/L	PO_4 µg/L	SiO_3 mg/L	Chlorophyll mg/m^3 a	b	c	Oil/ Grease mg/L	Oil Slick Count
Jul 87	3.0	1.4	<20	16	31	30	186	1.9	5.7	7.0	41.5	-	0
Oct 87	2.5	0.6	<20	<10	17	18	300	0.8	0	0	20.3	-	0
Dec 87	2.0	2.5	2100	<10	42	22	137	2.7	0.1	2.9	9.2	-	0
Feb 88	2.5	0.2	<20	<10	87	10	46	1.2	0	0	0	-	0
Apr 88	1.5	0.5	<20	17	25	9	107	5.2	5.0	17.5	136.3	-	0
Sep 88	2.0	1.4	<20	10	52	10	52	2.3	3.9	9.2	56.2	-	0
Dec 88	no data	5.8	27	<10	144	13	30	1.8	0	4.3	9.9	-	0

TABLE A3.5: Analytical Data for Laucala Bay/Suva Harbour Samples

Site 5

Date	Clarity (m) Secchi Disc	Total N mg/L	NH_3 µg/L	NO_2 µg/L	NO_3 µg/L	Total P µg/L	PO_4 µg/L	SiO_3 mg/L	Chlorophyll mg/m^3 a	b	c	Oil/ Grease mg/L	Oil Slick Count
Jul 87	0.5	1.3	142	48	62	80	560	1.7	7.2	8.3	13.7	-	0
Oct 87	0.75	0.7	<20	<10	112	45	563	0.4	7.7	3.5	10.6	-	0
Dec 87	>1.75	2.8	2000	<10	33	35	122	2.1	0.3	0.4	7.2	-	0
Feb 88	>2.0	0.1	<20	<10	<6	6	36	1.0	0	0	0	-	0
Apr 88	1.0	0.6	<20	13	42	<6	30	4.5	2.3	3.3	8.5	-	0
Sep 88	1.5	1.4	<20	15	62	15	64	2.7	0.6	15.4	51.6	-	0
Dec 88	no data	2.6	30	<10	59	9	30	1.9	8.6	16.8	57.3	-	0

TABLE A3.6 : Analytical Data for Laucala Bay/Suva Harbour Samples

Site 6

Date	Clarity (m) Secchi Disc	Total N mg/L	NH_3 µg/L	NO_2 µg/L	NO_3 µg/L	Total P µg/L	PO_4 µg/L	SiO_3 mg/L	Chlorophyll mg/m^3 a	b	c	Oil/ Grease mg/L	Oil Slick Count
Jul 87	4.0	1.4	<20	<10	12	14	263	1.1	0	0	13.6	-	0
Oct 87	2.0	1.6	<20	<10	42	18	413	0.8	7.4	4.8	29.1	-	0
Dec 87	2.3	3.0	60	<10	15	17	92	2.3	0	0	0	-	0
Feb 88	2.5	0.3	<20	<10	<6	10	61	1.3	2.3	3.3	8.5	-	0
Apr 88	1.0	0.5	<20	17	198	<6	30	4.7	2.3	1.5	35.6	-	0
Sep 88	3.0	1.1	<20	15	106	10	40	2.2	1.7	5.8	44.0	-	0
Dec 88	no data	4.3	27	<10	30	9	30	1.8	0	0	0	-	0

TABLE A3.7 : Analytical Data for Laucala Bay/Suva Harbour Samples

Site 7

Date	Clarity (m) Secchi Disc	Total N mg/L	NH_3 µg/L	NO_2 µg/L	NO_3 µg/L	Total P µg/L	PO_4 µg/L	SiO_3 mg/L	Chlorophyll mg/m^3 a	b	c	Oil/ Grease mg/L	Oil Slick Count
Jul 87	>2.0	2.5	<20	<10	12	30	263	0.9	0	0	0	-	0
Oct 87	2.0	1.0	<20	<10	32	28	300	0.8	11.4	0	0	-	0
Dec 87	2.0	6.7	228	<10	7	12	137	2.3	0.6	0.1	10.3	-	0
Feb 88	2.0	0.1	<20	<10	15	14	67	1.1	18.2	24.9	94.9	-	0
Apr 88	1.5	0.5	<20	17	72	9	64	5.1	1.0	12.8	53.4	-	0
Sep 88	1.0	0.7	<20	20	44	10	52	2.7	1.1	11.1	41.7	-	0
Dec 88	no data	4.2	24	<10	59	<6	30	1.8	6.2	10.7	89.5	-	0

TABLE A3.8 : Analytical Data for Laucala Bay/Suva Harbour Samples

Site 8

Date	Clarity (m) Secchi Disc	Total N mg/L	NH_3 µg/L	NO_2 µg/L	NO_3 µg/L	Total P µg/L	PO_4 µg/L	SiO_3 mg/L	Chlorophyll mg/m^3 a	b	c	Oil/ Grease mg/L	Oil Slick Count
Jul 87	4.0	2.1	<20	<10	12	40	186	0.2	5.7	0	17.6	-	0
Oct 87	3.0	1.0	<20	<10	99	18	300	0.2	0	0	0	-	0
Dec 87	3.0	2.8	32	<10	7	12	174	3.0	0.5	2.2	8.3	-	0
Feb 88	2.5	<0.1	<20	<10	62	14	46	2.6	2.3	3.3	8.5	-	0
Apr 88	1.0	0.6	<20	21	99	9	82	7.3	2.8	16.0	100.7	-	0
Sep 88	2.5	0.8	<20	10	52	10	52	1.7	5.6	15.0	99.3	-	0
Dec 88	no data	2.2	36	<10	44	<6	40	2.9	4.0	10.1	40.3	-	0

TABLE A3.9 : Analytical Data for Laucala Bay/Suva Harbour Samples

Site 9

Date	Clarity (m) Secchi Disc	Total N mg/L	NH_3 µg/L	NO_2 µg/L	NO_3 µg/L	Total P µg/L	PO_4 µg/L	SiO_3 mg/L	Chlorophyll mg/m^3 a	b	c	Oil/ Grease mg/L	Oil Slick Count
Jul 87	4.0	1.0	<20	16	25	14	186	0.1	0	0	0	-	0
Oct 87	>3.0	2.6	<20	<10	<6	28	300	0.2	0	10.5	0	-	0
Dec 87	>2.0	4.9	30	<10	7	9	92	2.6	0	0	0	-	0
Feb 88	1.5	0.1	<20	<10	15	25	125	2.6	7.9	18.6	107.8	-	0
Apr 88	1.0	0.8	<20	26	176	<6	30	6.6	8.3	18.5	69.0	-	0
Sep 88	>1.0	2.6	30	30	52	20	64	0.9	7.9	19.3	94.2	-	0
Dec 88	no data	4.8	30	<10	44	18	30	2.5	2.3	3.4	8.5	-	0

TABLE A3.10: Analytical Data for Laucala Bay/Suva Harbour Samples

Site 10

Date	Clarity (m) Secchi Disc	Total N mg/L	NH_3 µg/L	NO_2 µg/L	NO_3 µg/L	Total P µg/L	PO_4 µg/L	SiO_3 mg/L	Chlorophyll mg/m^3 a	b	c	Oil/ Grease mg/L	Oil Slick Count
Jul 87	>1.5	1.4	<20	16	31	24	263	0.1	6.0	6.2	16.3	-	0
Oct 87	>0.5	2.2	<20	<10	17	18	300	0.4	11.4	0	0	-	0
Dec 87	>1.25	4.7	<20	<10	33	17	107	2.9	0	0	0	-	0
Feb 88	>1.0	0.1	<20	<10	<6	14	76	2.4	3.7	11.8	52.1	-	0
Apr 88	>1.0	0.8	<20	21	131	<6	40	7.7	5.1	19.4	109.2	-	0
Sep 88	>1.0	1.4	36	30	52	10	64	1.5	3.3	9.8	118.0	-	0
Dec 88	no data	2.5	28	<10	30	<6	30	3.8	2.3	3.9	22.0	-	0

TABLE A3.11 : Analytical Data for Laucala Bay/Suva Harbour Samples

Site 11

Date	Clarity (m) Secchi Disc	Total N mg/L	NH_3 µg/L	NO_2 µg/L	NO_3 µg/L	Total P µg/L	PO_4 µg/L	SiO_3 mg/L	Chlorophyll mg/m^3 a	b	c	Oil/ Grease mg/L	Oil Slick Count
Jul 87	>0.75	1.4	<20	<10	43	20	93	0.6	0	0	0	-	0
Oct 87	>0.75	2.1	<20	<10	57	18	300	0.4	0	0	0	-	0
Dec 87	>0.75	4.3	570	<10	272	22	92	0.9	0.3	0	4.8	-	0
Feb 88	>1.0	2.7	<20	10	62	10	46	1.1	5.4	9.6	39.6	-	0
Apr 88	>0.75	0.6	<20	<10	17	<6	82	3.2	0	0	0	-	0
Sep 88	>0.5	8.1	38	20	25	20	30	0.6	2.7	11.0	26.7	-	0
Dec 88	>1.0	1.2	31	13	62	<6	30	0.9	7.3	29.5	149.5	-	0

TABLE A3.12: Analytical Data for Laucala Bay/Suva Harbour Samples

Site 12

Date	Clarity (m) Secchi Disc	Total N mg/L	NH_3 µg/L	NO_2 µg/L	NO_3 µg/L	Total P µg/L	PO_4 µg/L	SiO_3 mg/L	Chlorophyll mg/m^3 a	b	c	Oil/ Grease mg/L	Oil Slick Count
Jul 87	>3.0	1.9	<20	<10	28	14	93	0.2	0	0	0	-	0
Oct 87	>3.5	2.3	<20	<10	20	18	300	0.2	0	0	0	-	0
Dec 87	>2.0	4.2	44	<10	744	<6	92	2.4	0	0	0	-	0
Feb 88	>3.0	1.1	<20	<10	87	10	86	1.0	7.7	12.9	48.1	-	0
Apr 88	>2.0	0.7	<20	21	131	45	165	3.2	0	0	0	-	0
Sep 88	>1.5	0.5	30	20	63	20	30	0.9	4.5	11.0	36.4	-	0
Dec 88	>1.0	3.9	66	<10	62	<6	30	1.6	4.5	3.9	44.1	-	0

TABLE A3.13: Analytical Data for Laucala Bay/Suva Harbour Samples

Site 13

Date	Clarity (m) Secchi Disc	Total N mg/L	NH_3 µg/L	NO_2 µg/L	NO_3 µg/L	Total P µg/L	PO_4 µg/L	SiO_3 mg/L	Chlorophyll mg/m^3 a	b	c	Oil/ Grease mg/L	Oil Slick Count
Jul 87	0.75	1.8	24	62	1550	100	1123	2.8	0	0	0	-	0
Oct 87	0.75	4.0	70	60	570	158	1125	2.2	1.4	0	12.9	-	0
Dec 88	0.5	3.8	156	120	890	196	704	5.7	0	0	0	-	0
Feb 88	>0.75	4.0	186	60	2802	151	468	13.2	8.0	10.3	50.0	-	0
Apr 88	>0.75	1.0	90	47	843	76	352	4.8	6.2	29.5	164.5	-	0
Sep 88	>0.25	0.8	68	62	905	91	153	1.8	3.9	8.2	67.4	-	0
Dec	0.5	5.0	78	35	359	152	428	1.9	12.0	49.5	168.9	-	0

TABLE A3.14: Analytical Data for Laucala Bay/Suva Harbour Samples

Site 14

Date	Clarity (m) Secchi Disc	Total N mg/L	NH_3 µg/L	NO_2 µg/L	NO_3 µg/L	Total P µg/L	PO_4 µg/L	SiO_3 mg/L	Chlorophyll mg/m^3 a	b	c	Oil/ Grease mg/L	Oil Slick Count
Jul 87	1.75	1.3	<20	<10	28	64	262	0.9	0	0	0	43.0	0
Oct 87	1.5	4.8	<20	<10	426	18	863	0.7	12.3	0	3.6	39.0	0
Dec 87	1.0	5.5	30	<10	7	35	183	1.3	0	0	0	24.0	0
Feb 88	1.0	2.1	170	40	570	44	147	3.7	8.0	10.3	50.0	62.0	0
Apr 88	1.25	0.7	30	21	719	62	202	4.7	2.3	3.3	8.5	56.0	0
Sep 88	1.0	0.8	254	134	63	176	661	1.8	6.6	40.3	283.6	49.0	0
Dec	0.5	5.8	31	18	77	53	122	1.3	9.7	27.9	99.0	60.0	0

TABLE A3.15: Analytical Data for Laucala Bay/Suva Harbour Samples

Site 15

Date	Clarity (m) Secchi Disc	Total N mg/L	NH_3 µg/L	NO_2 µg/L	NO_3 µg/L	Total P µg/L	PO_4 µg/L	SiO_3 mg/L	Chlorophyll mg/m^3 a	b	c	Oil/ Grease mg/L	Oil Slick Count
Jul 87	no data	1.2	<20	<10	62	30	260	0.8	0	0	0	-	0
Oct 87	0.3	5.1	20	<10	73	18	412	1.0	18.5	0	0	-	0
Dec 87	no data	5.4	88	<10	88	17	153	0.4	0	0	0	-	0
Feb 88	0.75	0.2	34	18	126	10	85	17.0	6.2	12.7	62.3	-	0
Apr 88	0.5	0.60	34	17	267	<6	30	11.0	14.8	29.3	119.7	-	0
Sep 88	0.5	0.6	94	41	429	51	46	4.7	32.5	60.4	84.7	-	0
Dec 88	no data	2.6	40	42	47	129	113	2.5	4.3	8.4	28.7	-	0

TABLE A3.16: Analytical Data for Laucala Bay/Suva Harbour Samples

Site 16

Date	Clarity (m) Secchi Disc	Total N mg/L	NH_3 µg/L	NO_2 µg/L	NO_3 µg/L	Total P µg/L	PO_4 µg/L	SiO_3 mg/L	Chlorophyll mg/m^3 a	b	c	Oil/ Grease mg/L	Oil Slick Count
Jul 87	no data	2.2	30	22	167	70	373	6.8	0	0	0	-	0
Oct 87	no data	4.1	<20	<10	79	22	563	1.7	2.3	3.8	1.7	-	0
Dec 87	no data	3.2	78	<10	1339	<6	144	12.3	1.2	0.1	3.4	-	0
Feb 88	0.75	1.3	32	10	235	10	92	15.6	5.4	9.6	39.7	-	0
Apr 88	0.5	0.8	34	17	273	<6	30	12.8	2.3	1.5	35.6	-	0
Sep 88	0.5	0.6	192	56	109	72	138	9.7	8.0	21.1	67.0	-	0
Dec 88	no data	4.3	34	18	62	31	88	4.8	6.8	9.1	39.0	-	0

TABLE A3.17: Analytical Data for Laucala Bay/Suva Harbour Samples

Site 17

Date	Clarity (m) Secchi Disc	Total N mg/L	NH_3 µg/L	NO_2 µg/L	NO_3 µg/L	Total P µg/L	PO_4 µg/L	SiO_3 mg/L	Chlorophyll mg/m^3 a	b	c	Oil/ Grease mg/L	Oil Slick Count
Jul 87	3.7	2.1	<20	<10	28	14	93	0.2	0	0	0	-	0
Oct 87	3.0	2.7	<20	<10	20	18	300	0.2	0	0	0	-	0
Dec 87	2.0	4.3	26	<10	<6	<6	92	1.8	0.3	0	0	-	0
Feb 88	2.0	0.2	22	14	39	10	62	0.9	5.4	9.2	46.4	-	0
Apr 88	4.0	0.6	26	13	372	<6	55	3.0	2.3	3.3	8.5	-	0
Sep 88	3.0	0.5	48	30	53	25	30	1.1	6.2	13.4	48.8	-	0
Dec 88	1.5	4.2	31	18	47	<6	101	0.5	6.3	12.5	62.4	-	0

TABLE A3.18: Analytical Data for Laucala Bay/Suva Harbour Samples

Site 18

Date	Clarity (m) Secchi Disc	Total N mg/L	NH_3 µg/L	NO_2 µg/L	NO_3 µg/L	Total P µg/L	PO_4 µg/L	SiO_3 mg/L	Chlorophyll mg/m^3 a	b	c	Oil/ Grease mg/L	Oil Slick Count
Jul 87	5.0	2.1	30	<10	28	20	262	0.1	0	0	0	-	0
Oct 87	5.0	5.4	<20	<10	20	18	300	<0.1	0	0	0	-	0
Dec 87	2.0	5.0	32	<10	7	<6	92	2.0	0.2	0.8	1.8	-	0
Feb 88	3.0	3.0	<20	18	86	10	33	0.6	0	0	0	-	0
Apr 88	1.5	0.5	22	<10	17	<6	30	3.2	0	0	0	-	0
Sep 88	3.0	0.5	54	52	44	20	30	0.7	1.7	6.7	31.9	-	0
Dec 88	1.5	2.2	72	13	315	<6	36	0.6	5.4	9.6	39.7	-	0

TABLE A3.19: Analytical Data for Laucala Bay/Suva Harbour Samples

Site 19

Date	Clarity (m) Secchi Disc	Total N mg/L	NH_3 µg/L	NO_2 µg/L	NO_3 µg/L	Total P µg/L	PO_4 µg/L	SiO_3 mg/L	Chlorophyll mg/m^3 a	b	c	Oil/ Grease mg/L	Oil Slick Count
Jul 87	2.0	2.2	25	<10	93	14	93	0.8	0	0	0	-	0
Oct 87	2.0	3.7	<20	<10	37	18	300	0.2	0	2.6	0	-	0
Dec 87	1.5	4.1	33	<10	349	<6	122	2.0	0	0	0	-	0
Feb 88	2.0	0.4	<20	14	54	10	38	1.1	2.9	8.9	29.3	-	0
Apr 88	1.25	0.8	<20	30	49	<6	55	5.1	0	0	0	-	0
Sep 88	1.5	0.8	74	36	53	30	30	0.9	18.8	41.2	132.9	-	0
Dec 88	1.5	4.8	130	<10	62	18	30	0.5	2.8	8.4	36.1	-	0

TABLE A3.20: Analytical Data for Laucala Bay/Suva Harbour Samples

Site 20

Date	Clarity (m) Secchi Disc	Total N mg/L	NH_3 µg/L	NO_2 µg/L	NO_3 µg/L	Total P µg/L	PO_4 µg/L	SiO_3 mg/L	Chlorophyll mg/m^3 a	b	c	Oil/ Grease mg/L	Oil Slick Count
Jul 87	2.0	1.7	25	<10	28	14	93	0.9	0	0	0	-	0
Oct 87	1.5	2.9	<20	<10	73	18	413	0.9	2.8	0	25.7	-	0
Dec 87	0.75	4.5	35	<10	134	12	128	5.8	0.7	0.7	0.2	-	0
Feb 88	0.5	0.8	32	18	87	10	33	12.8	4.6	6.2	11.4	-	0
Apr 88	0.5	1.0	26	43	131	<6	55	10.1	6.2	29.7	99.9	-	0
Sep 88	0.5	0.8	96	52	72	20	46	0.6	13.7	19.1	64.4	-	0
Dec 88	0.5	2.5	38	18	47	40	49	4.8	5.4	9.6	135.0	-	0

4. PORT VILA HARBOUR AND ERAKOR LAGOON, EFATE, VANUATU

4.1 INTRODUCTION AND BACKGROUND

Vanuatu is an archipelago of about 70 islands with a total land area of about 12,190 km^2. The four main islands are Espiritu Santo, Malekula, Erromango and Efate and these make up about 66 percent of the total land area. Port Vila, Efate, is the capital with a population (estimated in 1987) of 21,000. It is an area of rapidly expanding population and industrial development and the impact of these activities on the surrounding aquatic environment has not been thoroughly assessed. The Environment Unit of the Vanuatu Government is concerned about pollution of this coastal environment and could take either the legislative or other necessary means to control water quality. This study was to provide background data on water quality in the coastal area around Vila and help the Vanuatu Environment Unit establish a locally-based monitoring programme by training staff in sampling procedures and basic laboratory techniques. The study was also aimed at being a follow-up to the work of Carter (1983) who carried out a basic oceanographic study of the area, but without any detailed analyses.

GENERAL CHARACTERISTICS OF THE STUDY AREA

Efate lies approximately at the centre of the Vanuatu group at 17°45'S, 168°22'E. The island consists of marine rock formations : eruptive volcanic rocks, uplifted coral reef limestone and sedimentary derivatives. There are few areas of truly terrestial rock formations.

Average monthly temperatures at sea level range from almost 27°C in February to 23°C in July. Port Vila has an average annual rainfall of 2300 mm, distributed as shown in Table 4.1. Port Vila lies on the leeward side of Efate where a short dry season is typical of the Vanuatu group.

TABLE 4.1 : Average Monthly Rainfall (in mm), Port Vila, Vanuatu (Meteorological Office, Port Vila, pers. comm.)

J	F	M	A	M	J	J	A	S	O	N	D	Total
318	240	356	242	161	155	119	111	122	96	175	205	2300

General Characteristics of Vila Harbour, Ekasuvat Lagoon and Emten Lagoon

Vila Harbour

Vila Harbour lies between Port Vila city on the east and Malapoa on the north (Figure 4.1). The harbour has four distinct areas: (i) the north (Fatumaru Bay) of approximately 84 ha; (ii) Vila Bay with 190 ha; (iii) Paray Bay with 68 ha and (iv) Pontoon Bay with 143 ha, giving a total estimated area of 483 ha at Chart Datum (Carter, 1983). Reefs isolate each of the bays in the central and south end of the harbour. The harbour entrance is also well protected by a series of coral reefs. The depth of the water inside the entrance is 48 m while in Paray Bay the maximum depth is 51 m. The only sources of fresh water additions to the harbour are small springs at Fatumaru Bay, from storm water pipes along the coast and from groundwater seepages. There are no significant additions of fresh water from streams or rivers flowing into the harbour.

The main wharf in Vila Bay is located on the southern end and the city centre is to the north east of it. Practically all the houses, offices and the hotels along the water front have septic tanks. During the April 1987 monitoring period most of the hotels were not operating because of damage caused in February 1987 by hurricane Uma. The hotel Iririki on Iririki Island has a sewage treatment plant where solid wastes are settled out in an oxidation pond before the effluent drains into the harbour.

Erakor Lagoon

Erakor Lagoon is made up of Ekasuvat and Emten lagoons (Figure 4.1). At 0.2m Chart Datum, MLLW, the surface area of Ekasuvat lagoon is 178 ha while Emten lagoon has an area of about 219 ha

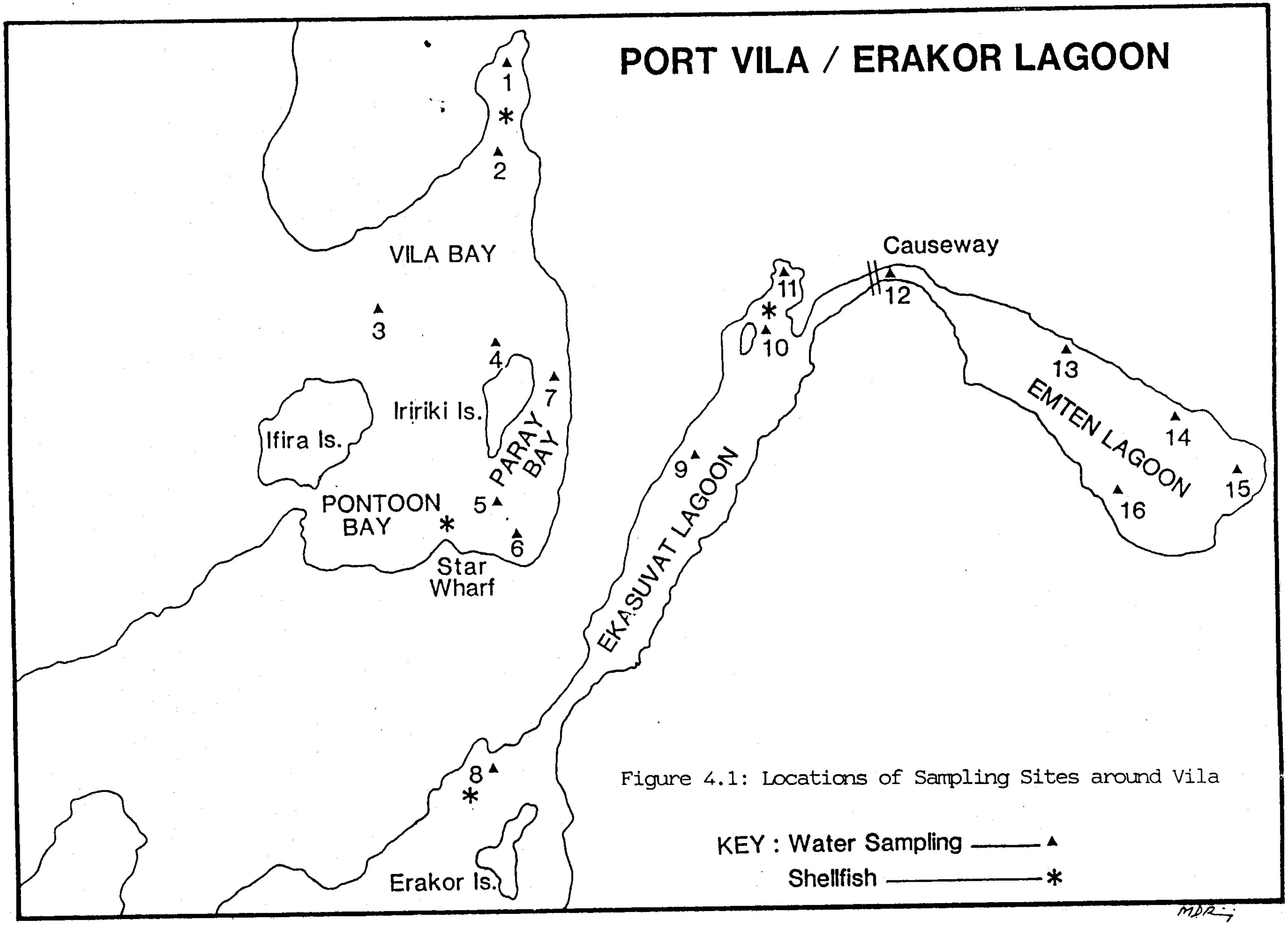

Figure 4.1: Locations of Sampling Sites around Vila

(Carter 1983). The maximum depth at 0.2m chart datum, MLLW for Ekasuvat lagoon is 10.7 m and Emten lagoon is 6.4 m. There are no large riverine fresh water inputs into the lagoons.

The western shores of Ekasuvat lagoon are well developed with houses and hotels. The eastern shores are still undeveloped. At the northern end of the Ekasuvat lagoon an artifical island has been created and the Inter-continental Hotel is located around here. The Le Lagon hotel is at the southern end of the lagoon and Erakor Hotel is on Erakor Island.

The two lagoons are separated by a causeway at the narrowest point. The causeways has restricted tidal water flow between Emtem and Ekasuvat lagoons increasing water residence times, particularly in Emtem Lagoon. Less development has occurred along Emten lagoon. Along with a few houses, the Hypocampe Restaurant is at the southeastern side and a horse riding school, Hippique, on the southern end. The Intercontinental Hotel and the Vila base hospital have sewage treatment facilities. In the Intercontinental Hotel treatment plant, solid wastes are first settled in an oxidation pond before the effluent drains into a pond from which the water is allowed to seep into the ground. The effluent from the hospital treatment plant is chlorinated before it is drained into the lagoon.

4.2 WORK PROGRAMME

In April 1987 a team from INR travelled to Vanuatu with necessary field equipment to start the project in collaboration with the Vanuatu Environment Unit. The April 1987 analyses were carried out by the INR team and the other 7 sets were completed by personnel from the Agriculture Laboratory, Vanuatu using the methods and advice from INR.

Site Selection

A total of 16 sites were selected for general water quality assessment and four sites for trace metal studies in shellfish.

Site 1 is located in the northern end of Port Vila harbour (Fatumaru Bay). This area receives considerable septic wastes as seepages and local villages use the water and the nearby springs for bathing and washing. Site 2 is situated by a shallow raised reef/sandbar that restricts water movement between Site 1 and the main part of Port Vila harbour. Site 3 is the deepest site in this study. It is perhaps the cleanest site since it is furthest from the coast and hence least influenced by human activities. Site 4 is on the northwest coast of Iririki Island and north of the hotel Iririki sewage treatment plant while site 5 is between Iririki Island and the mainland. Site 6 is offshore from the Fisheries Department and site 7 is to the south of the landing jetty on Iririki Island. Sites 4 and 7 cover an area which is likely to be affected by discharges from hotel sewage plants.

The sites in the lagoon represent areas affected by different activities. For example site 8 is at the mouth of the Ekasuvat lagoon, immediately north of the Erakor Island jetty and is most influenced by ocean waters. Site 9 is midway along the western shore of Ekasuvat lagoon near the hospital outfall. Site 10 is along the shoreline to the north of the small artificial island belonging to the Intercontinental Hotel. This area is likely to be affected by the hotel discharges. Site 11 is an artificial inlet to the northern end of the Ekasuvat lagoon. This site has very poor circulation and receives a lot of septic seepages from the residential area around it.

Site 12 is on the northern bank of the Erakor causeway/bridge. Water circulation between the two lagoons at this site is through a series of culverts. Site 13 is on the northern shore of Emten lagoon while site 14, also on the northern shore of Emten lagoon, is just beside a house called the "Le Weekender". Site 15 is on the eastern shore of Emten lagoon. Site 16 is in the southeastern part of Emten lagoon and this area receives significant seepage from a nearby club called Hippique, where there is a horse riding school and cattle farm. Sites 13, 14, 15 and 16 represent lagoon waters of very long residence time.

4.3 RESULTS AND DISCUSSION

The results obtained are summarised in Tables 4.2 to 4.17.

TABLE 4.2 - Analytical Data for Vanuatu Water Samples

SITE : 1

Date	Depth (m)	Temperature (°C)	Salinity (ppt)	Clarity (m) Secchi Disc	Dissolved Oxygen (mg/L)	NH_3 (μg/L)	NO_2 (μg/L)	NO_3 (μg/L)	Total P (μg/L)	PO_4 Dissolved (μg/L)	Faecal Coliforms No/100 mL	Oil Slicks Count
April 87	0	30.3	15.0	-	6.6	<10	<10	58	-	36	130	0
July 87	0	-	-	-	-	12	-	-	-	38	-	-
Sept 87	0	-	-	-	-	<10	<10	-	28	134	-	
Nov 87	0	-	-	-	-	55	14	-	28	73	-	
Jan 88	0	-	-	-	-	18	12	-	-	76	-	
May 88	0	-	-	-	-	15	18	-	6	24	-	
Aug 88	0	-	-	-	-	-	22		76	122	-	
Nov 88	0	-	-	-	-	75	25.	1910	28	171	-	

TABLE 4.3 - Analytical Data for Vanuatu Water Samples

SITE : 2

Date	Depth (m)	Temperature (°C)	Salinity (ppt)	Clarity (m) Secchi Disc	Dissolved Oxygen (mg/L)	NH_3 (μg/L)	NO_2 (μg/L)	NO_3 (μg/L)	Total P (μg/L)	PO_4 Dissolved (μg/L)	Faecal Coliforms No/100 mL	Oil Slicks Count
April 87	0	31.9	33.2	-	6.6	12	<10	93	-	24	18	0
July 87	0	-	-	-	-	13	-	-	-	22	-	
Sept 87	0	-	-	-	-	44	<10	-	32	61	-	
Nov 87	0	-	-	-	-	70	<10	-	14	18	-	
Jan 88	0	-	-	-	-	<10	<10	-	-	76	-	
May 88	0	-	-	-	-	<10	<10	-	<6	<18	-	
Aug 88	0	-	-	-	-	-	<10	-	6	<18	-	
Nov 88	0	-	-	-	-	<10	<10	40	<6	<18		

TABLE 4.4 - Analytical Data for Vanuatu Water Samples

SITE : 3

Date	Depth (m)	Temperature (°C)	Salinity (ppt)	Clarity (m) Secchi Disc	Dissolved Oxygen (mg/L)	NH_3 (µg/L)	NO_2 (µg/L)	NO_3 (µg/L)	Total P (µg/L)	PO_4 Dissolved (µg/L)	Faecal Coliforms No/100 mL	Oil Slicks Count
April 87	0	31.0	33.2	11 m	6.8	20	<10	37	-	49	1	0
	1	30.9	33.2		6.8							
	2	30.9	33.2		6.8							
	3	30.9	33.2		6.8							
	4	30.9	33.2		6.7							
	5	30.9	33.2		6.7							
	10	30.6	33.2		6.4							
	15	30.6	33.2		6.4							
	18	30.5	33.1		6.4							
July 87	0	-	-	-	-	20	<10	-	-	49	-	-
Sept 87	0	-	-	-	-	51	<10	-	32	36	-	-
Nov 87	0	-	-	-	-	47	<10	-	12	24	-	-
Jan 88	0	-	-	-	-	<10	<10	-	-	55	-	-
May 88	0	-	-	-	-	<10	<10	-	<6	<18	-	-
Aug 88	0	-	-	-	-	-	<10	-	6	<18	-	-
Nov 88	0	-	-	-	-	<10	<10	10	<6	<18		

TABLE 4.5 - Analytical Data for Vanuatu Water Samples

SITE : 4

Date	Depth (m)	Temperature (°C)	Salinity (ppt)	Clarity (m) Secchi Disc	Dissolved Oxygen (mg/L)	NH_3 (μg/L)	NO_2 (μg/L)	NO_3 (μg/L)	Total P (μg/L)	PO_4 Dissolved (μg/L)	Faecal Coliforms No/100 mL	Oil Slicks Count
April 87	0	31.3	33.4	8 m	6.6	<10	<10	49	-	49	0	0
	1	31.0	33.4		6.6							
	2	31.0	33.4		6.6							
	3	30.7	33.4		6.6							
	4	30.7	33.4		6.4							
	5	30.7	33.3		6.4							
	6	30.6	33.3		6.4							
	7	30.6	33.3		6.4							
	8	30.6	33.3		6.4							
	9	30.6	33.3		6.4							
July 87	0	-	-	-	-	<10	-	-	-	48		
Sept. 87	0	-	-	-	-	44	<10	-	26	49		
Nov. 87	0	-	-	-	-	<10	<10	-	14	18		
Jan. 88	0	-	-	-	-	20	<10	-	-	73		
May 88	0	-	-	-	-	40	<10	-	<6	24		
Aug. 88	0	-	-	-	-	-	<10	-	6	<18		
Nov. 88	0	-	-	-	-	16	<10	30	<6	<18		

TABLE 4.6 - Analytical Data for Vanuatu Water Samples

SITE : 5

Date	Depth (m)	Temperature (°C)	Salinity (ppt)	Clarity (m) Secchi Disc	Dissolved Oxygen (mg/L)	NH_3 (µg/L)	NO_2 (µg/L)	NO_3 (µg/L)	Total P (µg/L)	PO_4 Dissolved (µg/L)	Faecal Coliforms No/100 mL	Oil Slicks Count
April 87	0	31.1	33.3	11 m	6.4	<10	15	111	-	61	0	0
	1	31.1	33.3		6.2							
	2	31.1	33.3		6.2							
	3	31.1	33.3		6.2							
	5	31.1	33.3		6.2							
	10	31.1	33.3		6.2							
	15	31.1	33.3		5.2							
	18	30.5	33.0		5.2							
July 87	0	-	-	-	-	<10	-	-	-	60	-	-
Sept 87	0	-	-	-	-	51	<10	-	32	24	-	-
Nov 87	0	-	-	-	-	50	<10	-	10	<18	-	-
Jan 88	0	-	-	-	-	25	<10	-	-	30	-	-
May 88	0	-	-	-	-	<10	12	-	<6	<18	-	-
Aug 88	0	-	-	-	-	-	<10	-	8	<18	-	-
Nov 88	0	-	-	-	-	<10	<10	10	<6	<18	-	-

TABLE 4.7 - Analytical Data for Vanuatu Water Samples

SITE : 6

Date	Depth (m)	Temperature (°C)	Salinity (ppt)	Clarity (m) Secchi Disc	Dissolved Oxygen (mg/L)	NH_3 (μg/L)	NO_2 (μg/L)	NO_3 (μg/L)	Total P (μg/L)	PO_4 Dissolved (μg/L)	Faecal Coliforms No/100 mL	Oil Slicks Count
April 87	0	31.5	33.3	6 m	6.0	46	11	248	-	49	5	0
	1	31.5	33.3		6.0							
	2	31.5	33.3		6.0							
	3	31.5	33.3		6.0							
	5	31.5	33.3		6.0							
	10	31.5	33.3		6.0							
	15	31.5	33.3		5.0							
	18	30.7	33.4		4.6							
July 87	0	-	-	-	-	44	-	-	-	49	-	-
Sept 87	0	-	-	-	-	62	<10	-	32	49	-	-
Nov 87	0	-	-	-	-	45	<10	-	12	<18	-	-
Jan 88	0	-	-	-	-	17	<10	-	-	73	-	-
May 88	0	-	-	-	-	15	13	-	<6	<18	-	-
Aug 88	0	-	-	-	-	-	<10	-	6	<18	-	-
Nov 88	0	-	-	-	-	<10	<10	10	<6	<18	-	-

TABLE 4.8 - Analytical Data for Vanuatu Water Samples

SITE : 7

Date	Depth (m)	Temperature (°C)	Salinity (ppt)	Clarity (m) Secchi Disc	Dissolved Oxygen (mg/L)	NH_3 (µg/L)	NO_2 (µg/L)	NO_3 (µg/L)	Total P (µg/L)	PO_4 Dissolved (µg/L)	Faecal Coliforms No/100 mL	Oil Slicks Count
April 87	0	31.6	33.3	7 m	6.3	<10	<10	62	-	36	1	0
	1	31.6	33.3		6.3							
	2	31.6	33.3		6.3							
	5	31.6	33.3		6.3							
	10	31.6	33.3		6.0							
	15	31.6	33.3		5.5							
	19	30.8	33.3		5.2							
July 87	0	-	-	-	-	<10	<10	-	-	36	-	-
Sept 87	0	-	-	-	-	72	<10	-	26	122	-	-
Nov 87	0	-	-	-	-	35	<10	-	26	18	-	-
Jan 88	0	-	-	-	-	<10	<10	-	-	134	-	-
May 88						20	13		<6	<18	-	-
Aug 88	0	-	-	-	-	-	<10		<6	<18	-	-
Nov						20	<10	20	<6	<18	-	-

TABLE 4.9 - Analytical Data for Vanuatu Water Samples

SITE : 8

Date	Depth (m)	Temperature (°C)	Salinity (ppt)	Clarity (m) Secchi Disc	Dissolved Oxygen (mg/L)	NH_3 (μg/L)	NO_2 (μg/L)	NO_3 (μg/L)	Total P (μg/L)	PO_4 Dissolved (μg/L)	Faecal Coliforms No/100 mL	Oil Slicks Count
April 87	0	31.2	31.3	-	6.4	15	<10	80	-	49	25	0
July 87	0	-	-	-	-	16	<10	-	-	86	-	-
Sept 87	0	-	-	-	-	72	<10	-	38	49		
Nov 87	0	-	-	-	-	28	<10	-	15	<18		
Jan 88	0	-	-	-	-	18	<10	-	-	49		
May 88						13.	16		<6	<18		
Aug 88							<10	210	8	<18		
Nov 88						56.	<10	90	10	36		

TABLE 4.10- Analytical Data for Vanuatu Water Samples

SITE : 9

Date	Depth (m)	Temperature (°C)	Salinity (ppt)	Clarity (m) Secchi Disc	Dissolved Oxygen (mg/L)	NH_3 (μg/L)	NO_2 (μg/L)	NO_3 (μg/L)	Total P (μg/L)	PO_4 Dissolved (μg/L)	Faecal Coliforms No/100 mL	Oil Slicks Count
April 87	0	32.4	28.1		6.6	19	14	961	-	85	16	0
July 87						20	<10	-	-	38		
Sept 87						87	<10	-	34	122		
Nov 87						39	10	-	12	18		
Jan 88						33	<10	-	-	153.		
May 88						23	19		<6	<18		
Aug 88						-	29	3840	12	<18		
Nov 88						95	54	3530	10	36		

TABLE 4.11- Analytical Data for Vanuatu Water Samples

SITE : 10

Date	Depth (m)	Temperature (°C)	Salinity (ppt)	Clarity (m) Secchi Disc	Dissolved Oxygen (mg/L)	NH_3 (µg/L)	NO_2 (µg/L)	NO_3 (µg/L)	Total P (µg/L)	PO_4 Dissolved (µg/L)	Faecal Coliforms No/100 mL	Oil Slicks Count
April 87	0	31.6	25.5	-	6.4	14	<10	1085	-	36	28	0
July 87	0	-	-			13	<10	-	-	222	-	
Sept 87	0	-	-			102	10	-	28	73		
Nov 87	0	-	-			40	10.	-	20	85		
Jan 88	0	-	-			48	10	-	-	55		
May 88						25	10		<6	<18		
Aug 88						-	<10	1530	24	36		
Nov 88						33	<10	940	27	24		

TABLE 4.12 - Analytical Data for Vanuatu Water Samples

SITE : 11

Date	Depth (m)	Temperature (°C)	Salinity (ppt)	Clarity (m) Secchi Disc	Dissolved Oxygen (mg/L)	NH_3 (µg/L)	NO_2 (µg/L)	NO_3 (µg/L)	Total P (µg/L)	PO_4 Dissolved (µg/L)	Faecal Coliforms No/100 mL	Oil Slicks Count
April 87	0	31.7	15.0		6.3	46	<10	1302	-	220	46	0
July 87						43	<10	-	-	86		
Sept 87						143	12	-	40	110		
Nov 87						21	<10	-	26	85		
Jan 88						68	<10	-	-	122		
May 88						23	12		18	73		
Aug 88							<10	1510	26	36		
Nov 88						25	<10	1240	28	134		

TABLE 4.13 - Analytical Data for Vanuatu Water Samples

SITE : 12

Date	Depth (m)	Temperature (°C)	Salinity (ppt)	Clarity (m) Secchi Disc	Dissolved Oxygen (mg/L)	NH_3 (µg/L)	NO_2 (µg/L)	NO_3 (µg/L)	Total P (µg/L)	PO_4 Dissolved (µg/L)	Faecal Coliforms No/100 mL	Oil Slicks Count
April 87	0	33.0	32.0		7.2	39	<10	254	-	85	14	0
July 87	0	-	-			37	<10	-	-	97		
Sept 87	0	-	-			117	<10	-	38	73		
Nov 87	0	-	-			14	<10	-	10	18		
Jan 88	0	-	-			40	<10	-	-	116		
May 88						60	21		10	61		
Aug 88						-	10	120	12	49		
Nov 88						53	10	60	11	49		

TABLE 4.14 - Analytical Data for Vanuatu Water Samples

SITE : 13

Date	Depth (m)	Temperature (°C)	Salinity (ppt)	Clarity (m) Secchi Disc	Dissolved Oxygen (mg/L)	NH_3 (µg/L)	NO_2 (µg/L)	NO_3 (µg/L)	Total P (µg/L)	PO_4 Dissolved (µg/L)	Faecal Coliforms No/100 mL	Oil Slicks Count
April 87	0	33.5	26.4		6.1	34	<10	186	-	98	0	0
July 87						36	<10	-	-	75		
Sept. 87						102	<10	-	34	85		
Nov. 87						14	23	-	12	49		
Jan. 88						18	14	-	-	98		
May 88						105	21		6	36		
Aug. 88							14	170	20	36		
Nov. 88						64	12	40	14	49		

TABLE 4.15- Analytical Data for Vanuatu Water Samples

SITE : 14

Date	Depth (m)	Temperature (°C)	Salinity (ppt)	Clarity (m) Secchi Disc	Dissolved Oxygen (mg/L)	NH_3 (µg/L)	NO_2 (µg/L)	NO_3 (µg/L)	Total P (µg/L)	PO_4 Dissolved (µg/L)	Faecal Coliforms No/100 mL	Oil Slicks Count
April 87	0	32.0	22.6		6.2	39	<10	458	-	73	68	0
July 87						37	<10	-	-	74		
Sept. 87						102	<10	-	37	73		
Nov. 87						20	<10	-	14	36		
Jan. 88						33	12	-	-	79		
May 88						25	20	-	10	36		
Aug. 88						-	14	220	14	36		
Nov. 88						107	13	170	14	36		

TABLE 4.16 - Analytical Data for Vanuatu Water Samples

SITE : 15

Date	Depth (m)	Temperature (°C)	Salinity (ppt)	Clarity (m) Secchi Disc	Dissolved Oxygen (mg/L)	NH_3 (µg/L)	NO_2 (µg/L)	NO_3 (µg/L)	Total P (µg/L)	PO_4 Dissolved (µg/L)	Faecal Coliforms No/100 mL	Oil Slicks Count
April 87	0	32.4	21.4		6.3	21	<10	99	-	73	36	0
July 87						20	<10	-	-	72		
Sept. 87						77	<10	-	40	73		
Nov. 87						45	16	-	15	61		
Jan. 88						138	<10	-	-	73		
May 88						68	16		14	49		
Aug. 88							12	170	16	49		
Nov. 88						75	<10	30	10	85		

TABLE 4.17 – Analytical Data for Vanuatu Water Samples

SITE : 16

Date	Depth (m)	Temperature (°C)	Salinity (ppt)	Clarity (m) Secchi Disc	Dissolved Oxygen (mg/L)	NH_3 (µg/L)	NO_2 (µg/L)	NO_3 (µg/L)	Total P (µg/L)	PO_4 Dissolved (µg/L)	Faecal Coliforms No/100 mL	Oil Slicks Count
April 87	0	33.8	25.1		6.1	18	<10	49	-	61	152	0
July 87						19	<10	-	-	60		
Sept. 87						62	<10	-	34	73		
Nov. 87						45	11.0	-	-	134		
Jan. 88						40	<10	-	-	183		
May 88						62	10		14	49		
Aug. 88						-	17	220	16	49		
Nov. 88						53	10	30	14	49		

Salinity

Vertical profiles of salinity were made at sites 3 to 7 in the harbour. At sites 1, 2 and 8-16 only surface water salinities were measured (Tables 4.2-4.17). It is apparent from the results that there was no salinity stratification at sites 3 to 7 in the harbour in April 1987. The overall values ranged from as low as 15 ppt to as high as 33.8 ppt. The lower values were associated with sites 9 to 16 in the lagoon and site 1 in the harbour.

Low salinities in coastal and lagoon waters can be caused by a number of factors among which are inputs from rivers and springs, effluents from selected industries and seepages from ground water and septic systems. At site 1 and sites 9 to 16 sources of fresh water could only be attributed to ground water and septic seepages and there was only a small contribution from springs at sites 1 and 16 in particular.

In general the salinity pattern obtained for the harbour water is consistent with the findings of Yuen (1980) and Carter (1983). The surface salinities of harbour waters are also consistent with those obtained in a similar study of Suva harbour (Section 3.3).

Faecal Coliform Survey

Faecal coliform levels were only monitored during the April 1987 analyses. In general the results are well within the World Health Organisation (WHO) standards for marine bathing waters which require less than 350 faecal coliforms per 100 mL (WHO, 1983). The highest readings in the present study were at sites 1 (130) and 16 (152). These results are not surprising since Yuen (1980) also recorded rather high faecal coliform levels at these sites. Faecal pollution in these two areas may be attributed to septic seepages and seepages from the horse riding premises (site 16 only). Rather low faecal counts recorded at the majority of the sites may be related to the time of sampling which was completed approximately 3 months after cyclone Uma had devastated Efate and hotels like the Rossi which normally discharged septic waste directly into the harbour were not operating. Correlation studies between salinities and faecal coliform levels show a reasonably ($p < 0.01$) strong inverse relationship suggesting a decrease in faecal counts with increase in salinity. Thus higher counts in less saline areas support the above suggestion that septic seepages were the probable sources of faecal coliforms and freshwater into sites 1, 11, 14, 15 and 16.

Dissolved Oxygen

The harbour and lagoon surface waters were generally saturated with oxygen. Bottom waters in the Harbour in April 1987 had near saturation levels of oxygen down to depths of almost 20 m.

Nutrient Levels

The Agricultural Laboratory at Tagabe continued the monitoring of several nutrients after April 1987. These include nitrate, nitrite, ammonia and dissolved phosphate. Other parameters could not be monitored regularly either because of lack of required equipment or chemicals. The dissolved phosphate and nitrate content of coastal waters often gives a good indication of areas heavily contaminated by sewage. The dissolved phosphate values ranged from 18.4 ug/L to 222.3 ug/L. In general, the sites in the lagoon showed higher phosphate values than sites in the harbour. Only sites 11, 13, 14, 15 and 16 in the lagoon consistently showed high levels of phosphate, probably as a result of limited circulation and long residence times. As discussed earlier these sites are recipients of sewage discharges either directly (from treatment plants-11) or indirectly (via seepages - 11, 13, 14, 15 and 16). Correlation coefficient analysis between rainfall for the month and dissolved phosphate for all the sites, however, showed no significant relationship.

Nitrate analyses were carried out only three times and the values ranged from 10 ug/L to 3840 ug/L. Once again the sites in the lagoon (particularly 9, 11, 12 and 13) showed higher levels. The higher levels of nitrate in the lagoon could again be explained by septic seepages but no significant correlation was found between either faecal coliforms and nitrate or salinity and nitrate to substantiate this conclusion. Because of the differences in the method of analysis employed by Carter (1983) and those used in the present study no direct comparison can be made of the results. The trends obtained in the present study are, however, consistent with those obtained by Carter (1983).

If the nitrate and dissolved phosphate concentrations found at sites 9, 11, 12, 13, 14, 15 and 16 are compared to some contaminated sites from Suva Harbour/Laucala Bay (sites 1, 13, 14, 15, and 16) it can be said that the state of the water in Erakor Lagoon is not much better than the quality of water in selected areas from Suva Harbour and Laucala Bay. The Suva Harbour/Laucala Bay water unlike Erakor lagoon water has a short residence time and thus is flushed out effectively.

Other nutrients measured in the study were ammonia, nitrite and occasionally total phosphorus. Nitrite concentrations were generally low as expected in surface waters that are well oxygenated. The total phosphorus, however, was quite high and exceeded the value of 18.8 ug/L often taken as the upper limit for uncontaminated open waters (Wetzel, 1975).

The phosphate and nitrate levels found in the lagoons and particularly the ammonia levels show water quality in both lagoons to be far beyond that normal for coral reef growth (Bell and Greenfield, 1988). 'Normal' ammonia levels found on coral reefs range up to 20 ug/L but values of the order of 30-150 ug/L as found in this study especially combined with nitrate levels of 60-360 ug/L on a consistent basis, suggest the lagoons are strongly eutrophic for tropical coastal waters. Anecdotal evidence suggests the lagoons were cleaner in the past and supported a diverse 'coral reef' type environment but this is not the case at present. During the April, 1987 sampling trip localized red tides were noted near the Intercontinental Hotel and with the nurtrient levels found in the lagoons these must be common.

Clarity

Clarity was measured once for sites 3 to 7 in the harbour. The transparency decreases from 11 m in Vila Bay (sites 3 and 5) to 8 m in site 4, 7 m in Paray Bay (site 7) and 6 m in Pontoon Bay (site 6). The results obtained in this study were once again consistent with the findings of Carter (1983) except at Pontoon Bay (site 6) where considerable reduction in transparency has occurred since 1983. Since there are no rivers or streams introducing silt, clay and other inorganic suspended solids to reduce transparency, plankton is probably the main suspended solid in the water. These may have bloomed from the inputs of nutrients in the Harbour. Correlation studies between clarity and nutrients (PO_4 and NO_3) did not show any significant relationship.

Oil Slicks

During April 1987 visual checks were made for oil slicks both in the harbour and the lagoon. No signs of any oil spills were observed.

Survey of Marine Organisms

During the April 1987 activity it was obsered that some sites had numerous holothurians and starfish. A detailed survey by Chambers et al. (pers. comm.) showed that no significant correlation existed between holothurians and starfish numbers and nutrients like nitrate and dissolved phosphate.

Trace Metal Content of Edible Shellfish

Trace metal contents of edible shellfish (Anadara sp.) and rock oysters (Crassostrea sp.) are given in Table 4.18. The contents in shellfish from Erakor lagoon and Vila Harbour were generally low for all the metals analysed except copper which was slightly higher in oysters collected near the Star Wharf. This was probably due to release of copper from copper-based antifouling paints used on the ships berthing at the Star Wharf.

The levels of trace metals in the shellfish were generally lower than the values found in similar studies in Suva Harbour/Laucala Bay (Section 3.3) but were comparable to levels found in Fanga'uta Lagoon, Tonga (Section 6.3). Comparison of trace metal levels with those in other marine specimens (J.E. Brodie, pers. comm.; Bryan (in Johnston (1976); other sections of this report) leads to the conclusion that, at the time of the study, trace metal levels in shellfish were not a major cause for concern in Vila Harbour/Erakor Lagoon waters.

TABLE 4.18 : Trace Metal Concentrations in Vanuatu Shellfish (mg/kg wet weight)

Date	Location	Species	Hg	Cu	Cr	Cd	Pb
April 87	Mouth of Erakor Lagoon	Anadara sp.	0.02	4.2	0.33	0.78	0.60
April 87	Star Wharf	Rock oysters	0.02	32.6	0.20	0.31	0.72
April 87	Intercontinental Hotel	Rock oysters	0.01	13.9	0.13	0.20	0.91
April 87	Malapoa Bay	Anadara sp.	0.04	3.2	0.20	0.15	<0.50
June 87	Star Wharf	Rock oysters	0.02	79.1	<0.10	<0.10	0.90
June 87	Intercontinental Hotel	Rock oysters	0.01	15.9	<0.10	<0.10	0.94

4.4 CONCLUSIONS AND RECOMMENDATIONS

Based on the analytical results presented in Tables 4.2 to 4.17 it can be concluded that quality of water in the harbour was generally better than that in the lagoon. Nutrient levels in the lagoon were high and comparable to levels found in some polluted areas of Suva Harbour/Laucala Bay (Section 3.3). The situation is more critical in Erakor Lagoon because of the longer residence time of water compared to those studied in Fiji. Compared to other tropical coastal waters much of the lagoon area is already eutrophic. This means that eutrophication will be a major problem in the lagoon if nutrient inputs into the lagoon are not controlled. Treatment plants at the hotels and the hospital are reducing the BOD of the effluents but they are not removing the nutrients. Thus it is important to connect the hospital to a sewer system so that waste can be diverted from the lagoon. If nutrients from the hospital and the hotels continue to enter the lagoon, eutrophication will ultimately lead to fish kills, odour problems and general reduction in the suitability of the water for recreational purposes. The causeway across the lagoons is restricting the flow of water between the two lagoons and as suggested by the study of Carter (1983), an adequate channel is required, if major problems are to be avoided.

The population of Vila is increasing rapidly and so is the extent of industrial development. Many new industries are also being set up; thus it is very important that an adequate sewerage system be installed as soon as possible. Feasibility studies have already been carried out and two sites have been selected as possible outfall areas. The urgent priority must now be construction of the system.

During the construction and post construction, monitoring of the quality of waters in the harbour and lagoon must continue so that the impact of the sewerage system can be quickly assessed.

5. TARAWA LAGOON, KIRIBATI

5.1 INTRODUCTION AND BACKGROUND

Tarawa, a typical (low) atoll, consists of a string of narrow islands derived from coral reef limestone along the southern and north-eastern perimeters. The western end of the atoll is made up of a series of reefs which form a boundary between the lagoon and the ocean.

The islands along the southern part of Tarawa are very heavily populated because most educational and employment opportunities are available on islands like Bairiki, Bonriki and Betio. Because of the high population density, great pressure is placed on the limited groundwater resources of the atoll. An outbreak of cholera in 1977 and the work of Johannes et al. (1979) highlighted the fact that groundwater, nearshore water and the edible shellfish in the lagoon are contaminated with bacteria. Sewerage treatment systems were subsequently constructed at Betio, Bairiki and Bikenibeu under an Australian aid programme in 1983 to improve the level of sanitation and to try and avoid a reoccurrence of the 1977 epidemic. The aims of the study were to monitor the present water and biota quality in the southern part of Tarawa Lagoon and to assess any improvement which may have occurred since the installation of the sewage system on South Tarawa by comparison with the data in the report of Johannes et al. (1979).

Climate

Tarawa lies close to the equator, within the equatorial low pressure belt. There is little seasonal change in atmospheric pressure. The prevailing winds are easterly, but the direction varies slightly during the year. From October to April the prevailing wind direction is NE and ENE, while from April to October there is a shift to E and SE winds. There is little variation in wind direction during the day (Sachet, 1957).

Incomplete meteorological data was collected up to the beginning of the Second World War, but good records have been maintained since 1946. Sachet (1957) in a review of the data from 1905-55 found that Tarawa had an average rainfall of 1640 mm with a minimum of 390 mm (1950) and a maximum of 3300 mm (in 1940). Rainfall over the period 1946-1978 averaged 1945 mm, with January being the wettest month on average (325 mm) and October the driest (95 mm) (Table 5.1).

TABLE 5.1 : Average Monthly Rainfall (in mm), Tarawa, 1946-78 (Meteorological Office, Tarawa, personal communication)

J	F	M	A	M	J	J	A	S	O	N	D	Total
325	222	222	170	127	120	150	106	103	95	115	190	1945

The data in Table 5.1 show that on average there is a marked drier season from May to November. However, this data does not reflect the considerable variability in the rainfall pattern at Tarawa. As mentioned earlier the variations can occur by almost a factor of ten; although this is the extreme, annual rainfall of less than 1000 mm or greater than 3000 mm is not uncommon. There is no orographic influence.

The average temperature is 28 ± 1°C (Table 5.2) throughout the year with a daily maximum of about 32°C and minimum of 25°C. The relative humidity is usually high (> 50%) and the number of sunshine hours varies from about 125 per month to about 300 per month, being inversely related to the rainfall. On average sunshine hours/month are higher in the drier period from May to November.

TABLE 5.2 : Average Monthly Temperature (°C), Tarawa, 1946-78 (Meteorological Office, Tarawa, personal communication)

J	F	M	A	M	J	J	A	S	O	N	D
27.7	27.7	27.6	27.7	28.0	27.9	27.6	27.9	28.0	28.0	27.9	27.9

5.2 WORK PROGRAMME

In July 1987 a team from INR travelled to Kiribati with necessary field equipment and this report presents findings of the July 1987 studies. Lack of funds has prevented a follow-up visit.

To assess the present state of the lagoon and the biota, 16 sites were selected in the lagoon and 4 sites on the ocean side (Figure 5.1). The sampling sites were primarily those used by Johannes et al. (1979) so that findings could be compared. Table 5.3 gives the description of the sites. A further 3 sites were selected for analysis of faecal coliforms in the commonly eaten shellfish Anadara maculosa ('te bun') (Table 5.6).

Five sampling trips were made (28 July, 30 July, 1 August, 5 August, 6 August). Due to transportation difficulties, water from all sites was not collected on each trip. The 28 July collection was made from a boat and a portable temperature/dissolved oxygen meter used to take readings. Collections at a depth of about 0.5 m were made about 100 m from shore when the water depth was about 1 m. All other collections were made from shore at a distance of about 10-20 m. Low tide collection, especially on 5 August, could not be made at a depth of 0.5 m due to the shallowness of the water.

Sterilised plastic bottles or polythene bags were used to collect the water samples which were stored in a dark, cool container and refrigerated within four hours. Collections were generally made in the morning between 9.00 and noon.

TABLE 5.3 : Description of Tarawa Water Collection Sites

1.	Eita, opposite main village, just west of church
2.	Bikenibeu village between St. Mary's church and Maneaba
3.	Bikenibeu village in front of sewage project maintenance yard
4.	Bikenibeu opposite Air Tungaru office
5.	Bikenibeu opposite Bahai Church headquarters (past Otintai Hotel)
6.	Eita, west end of fish pool outlet
7.	Ambo, outside fisheries (W. end)
8.	Banraeaba, across from Maneaba
9.	Antebuka, Tarawa Motors
10.	Teaoraereke, near slipway for Bishop's boat
11.	E. Bairiki, end of Anderson Causeway
12.	Bairiki Harbour
13.	Channel in middle of Betio causeway
14.	Betio marine training school
15.	Bikenibeu, road to Hospital
S1.	Sewerage outlet, Tungaru Central Hospital
S2.	Sewerage outlet, Bairiki
S3.	Sewerage outlet, Betio
S4.	Betio village, ocean side

Key

1-15 : lagoon sites

S1-S4 : ocean sites

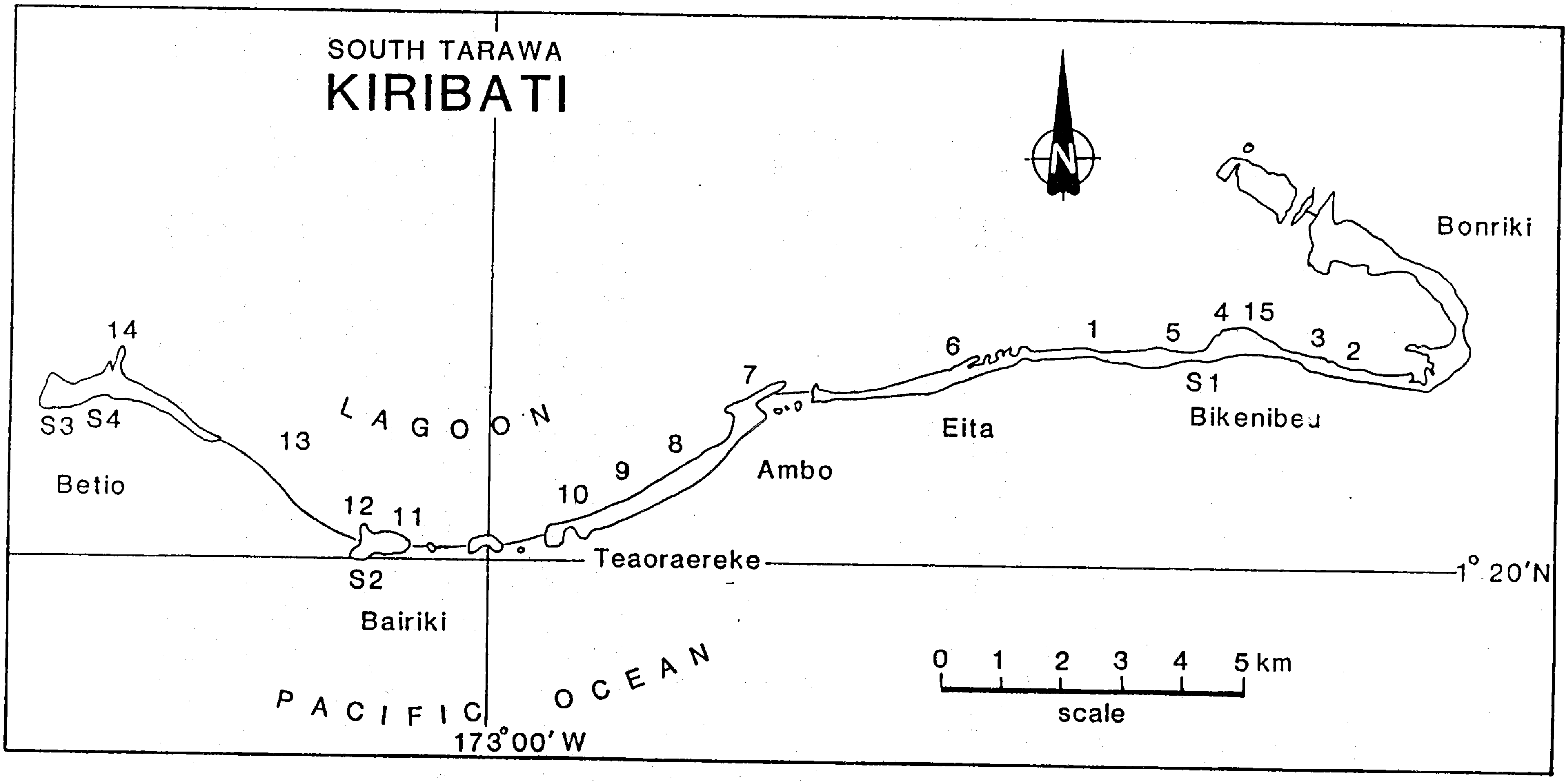

Figure 5.1: Locations of Sampling Sites in Tarawa

5.3 RESULTS AND DISCUSSION

Bacterial Water Quality

Faecal Coliforms in Water

The presence of pathogenic enteric bacteria, viruses and protozoans in the aquatic environment is normally assessed using the presence of non-disease transmitting indicator organisms such as faecal coliforms and faecal streptococci. Their presence in the water indicates faecal pollution and the numbers often indicate the relative risk of transmission of water-bourne diseases that often accompany them. During this study faecal coliform levels in the lagoon water were tested and these ranged from 0 to 29,000 counts per 100 mL (Table 5.4). These results indicate that faecal coliforms continue to be high where the human population is highest, i.e., near Bikenibeu (sites 2, 3, 4, 5 and 15) and Betio (sites 14 and S4). Johannes et al. (1979) had found similar trends in faecal coliform levels. For comparison, results for identical sites which continue to be heavily contaminated are pooled together in Table 5.5.

From the data in Table 5.5 it is apparent that while there has been some improvement in the quality of water in the lagoon at sites 3 and 4, sites 2 and 5 continue to be very heavily contaminated. In fact, the quality of water at sites 2 and 5 has deteriorated somewhat. The fact that highest counts for faecal coliforms were obtained on the outgoing tide suggests that the source of pollution is land based. Sites S2 and S4 on the ocean side have improved in quality considerably suggesting that effluents from outfalls at Betio and Bikenibeu quickly disperse in the ocean and do not cause serious inner reef pollution. In general, sites 7, 11, 12 and 13 were least contaminated. There seems to have been a dramatic improvement, in fact, in the water quality in Bairiki harbour (site 12).

The fact that faecal coliform levels are lower with incoming tides showed that contamination generally decreased with tidal flushings. Based on the US Environmental Protection Agency (USEPA, 1974, 1976) criteria for classifying recreational and bathing waters only sites 7, 11 and 13 are acceptable for natural bathing and recreational facilities.

Shellfish Analysis Results

Because shellfish are filter feeders they have the ability to concentrate pathogenic organisms present in the aquatic environment. Hence they are often used as indicators of the presence of human sewerage and thus of human pathogenic organisms such as Vibrio cholera, Shigella spp., Salmonella spp., and Hepatitis A virus. The levels of faecal coliforms in the edible shellfish Anadara maculosa ('te bun') from the sites studied are given in Table 5.6.

The US microbiological standards for shellfish flesh developed by the National Shellfish Sanitation Programme (1964) require that faecal coliform counts determined by the most probable number (MPN) method should be less than 2.3 MPN per gram of flesh for safe consumption. On the basis of this criterion, shellfish collected from Eita and Teaoraereke are highly contaminated. In the vicinity of the Otintai Hotel, faecal coliform levels were lower, ranging from 2.3 to <5 MPN per gram of flesh. It is interesting that on the basis of water quality data, the inshore water in this area was more polluted than the other two sites.

In the collection of 6 August an attempt was made to determine the effect of distance from shore on shellfish contamination. This was not entirely possible as the 'te bun' are collected in a fairly narrow band of sand. In both cases, however, the 'te bun' collected farther from the shore were more contaminated than those collected closer in which is contrary to what one might expect based on the presumed source of the pollution. In fact Johannes et al. (1979) attributed the greater contamination of Asaphis pectinatum ('te koikoi') and Gafrarium violascens ('te koumara') to the fact that they were generally collected closer to shore.

TABLE 5.4 - Faecal Coliform (FC/100 ml) in Lagoon and Ocean Water - Tarawa, Kiribati

		30.7.87	1.8.87	5.8.87
Site	1	125 H/OG	200 H	61 L/IC
	2	7,700 H	2,900 H/OG	0 L
	3	1,000 H	2,000 H/OG	100 L
	4	200 H/OG	2,400 H/OG	0 L
	5	2,700 H/OG	29,000 H/OG	10 L/IC
	6	200 H/OG	100 H/OG	145 L/IC
	7	0 OG	45 H/OG	-
	8	12 OG	1,000 H/OG	21 L/IC
	9	174 OG	1,400 H/OG	56 L/IC
	10	100 OG	300 H/OG	800 L/IC
	11	OG	-	-
	12	24 OG	78 OG	132 IC
	13	-	-	0 IC
	14	190 L/OG	108 OG	600 IC
	15	62 H/OG	1,600 IC/H	239 L
	S1	1,000 OG	79 H	0 IC
	S2	0 L/OG	7 L/OG	9 H/OG
	S3	246 L/OG	5 OG	24 IC
	S4	73 L/OG	300 OG	167 IC

Tides OG = outgoing
IC = incoming
H = high
L = low

TABLE 5.5 : Comparison of Faecal Coliform Levels for Some Selected Sites

Johannes *et al.* 1979					This study				
Site No	OG	IC	H	L	Site No	OG	IC	H	L
2-L	290 60	nd	420	nd	2	2900	nd	7700	
3-L	600 370 15,400	nd	620	nd	3	2000	100	1000	nd
4-L	8,600	nd	nd	nd	4	200	0	nd	nd
5-L	1,300 120 15,000	22	nd	nd	5	nd	10	2,700 29,000	nd
15-L A B C	 8,400 1,700 70	nd	TNTC	nd	12	24 78	nd	132	nd
S2-0	8,200	nd	nd	nd	S1	1000	0	79	nd
S4-0	nd	TNTC	nd	nd	S3	5	24	nd	246

Key

X-L	:	Sites in lagoon (Johannes et al., 1979)
X-O	:	Sites in ocean (Johannes et al., 1979)
OG	:	Outgoing or receding tide
IC	:	Incoming or rising tide
H	:	High tide
L	:	Low tide
TNTC	:	Too numerous to count
nd	:	Not determined

The flesh of these shellfish were also analysed for contamination by trace metals. It was assumed that with no major heavy industry in Tarawa levels of trace metals would be low, reflecting the natural presence of these metals in the surrounding ocean water. The results are summarised in Table 5.7 along with analyses of a NIES Certified Reference Material, Mussel No.6, conducted at the same time.

TABLE 5.6 : Faecal Coliform Levels in Anadora maculosa ('te bun') - Fresh Weight Basis

Site	Date	Location	F.C./g
FC1	31.7.87	Otintai Hotel, 200 m from shore, low tide	2.3
	6.8.87	Otintai hotel, 200 m from shore, low tide	3.2
	6.8.87	Otintai hotel, >200 m from shore, low tide	4.9
FC2	31.7.87	Eita, 200 m from shore, low tide	70
FC3	31.7.87	Teaoraereke, 200 m from shore, low tide	22
	6.8.87	Teaoraereke, 200 m from shore, low tide	9.4
	6.8.87	Teaoraereke, >200 m from shore, low tide	35

TABLE 5.7 : Trace Metal Concentrations in Anadara maculosa ('te bun') from Tarawa

Location	Hg ug/kg	Cu ug/kg	Cr ug/kg	Cd ug/kg	Pb ug/kg
Teaoraereke	5.6	2.1	1.1	0.7	0.2
Bikenibeu	5.5	18.0	2.7	1.2	0.2
Eita	<0.1	1.0	0.4	1.0	0.5
NIES Reference Material Certified Values	50	4.9 ±0.3	0.63 ±0.07	0.82 ±0.03	0.91 ±0.04
INR Results	60	5.1	0.75	0.81	0.96

The results were quite low, as expected. The level of cadmium was higher than usually found in shellfish in such unpolluted water. No obvious explanation for the elevated levels of cadmium was forthcoming.

Faecal Coliform Levels in Selected Wells, 'Babai' Pits and Tank Samples

Faecal coliforms and faecal streptococci levels were also measured in a number of wells, pits ('babai') and tank waters at selected sites to determine the extent of pollution. The details of the pits examined and the results obtained are presented in Table 5.8.

The Geldreich faecal coliform to faecal streptococcus (FC/FS) ratio is used to determine whether bacterial contamination is due to human or other warm-blooded animals (Geldreich 1976). A FC/FS ratio of 4.0 or greater indicates human contamination while a ratio of <0.7 indicates probable contamination of waters by warm-blooded animals. The FC/FS ratios (column 6, Table 5.8) indicate contamination predominantly from warm-blooded animals except at two sites where the ground water is perhaps contaminated by human sewerage. The data, therefore, indicates that the wells sampled in the present study were probably not adequately covered and hence got contaminated by faeces of birds and animals like cats. The high population levels in some wells should be of great concern to local health authorities.

Nutrient Analysis Results

A number of parameters have been used as indicators of pollution in the aquatic environment. The choice of parameters, however, appears to depend on the source of pollution under investigation. For instance, the most important parameters used to determine contamination by human sewerage are dissolved phosphate, ammonia and nitrate levels. Another important indicator of water pollution is the level of dissolved oxygen. In a highly nutrient rich and poorly mixed environment oxygen may be severely depleted especially near the bottom of the system. In the present study nitrate, ammonia and phosphate levels were measured. The results are presented in Tables 5.9 and 5.10 respectively.

The results in Table 5.9 show considerable variation in nitrate levels amongst the sites studied. Site 15 appears to be most heavily polluted with respect to nitrate with the concentration exceeding 4000 ug/L.

This sample may not be representative as an additional collection at site 15 gave a nitrate level of 205 ug/L. Other high nitrate readings were recorded at sites 1, 4 and S4, all of which had high coliform levels. In general these nitrate levels are much higher than those reported by Johannes et al. (1979). Although data at individual stations were not included in that report, lagoon samples over the reef ranged from 10 to 42 ug/L nitrate. The nitrate concentration at the lagoon entrance on an incoming tide was 187 ug/L and based on this and other data Johannes et al. concluded that, "despite the large quantity of nitrogen in human waste being released into the south lagoon, the benthic biota is removing both this nitrogen and some additional nitrogen brought in with incoming ocean water".

Many of the nitrate readings in the lagoon were higher than that of incoming ocean water and suggest that the conditions of 1979 may no longer be true. This is supported by the fact that nitrate levels were generally lower for the 28 July collection which was made further offshore. High nitrate levels are certainly a danger signal as high nutrient levels can lead to algal blooms followed by oxygen depletion and associated problems.

TABLE 5.8 : Faecal Coliform and Faecal Streptococci Levels in Selected Wells, Pits and Tank Samples

Location	Source	FC/ 100 mL	FS/ 100 mL	FC/FS	Possible Pollution Source
Betio, Temakin, Karaitis house	Well	10	23,000	<0.01	Animal
Betio, Temakin Karaitis house	Pit	170	19,000	0.01	Animal

TABLE 5.8 (cont'd)

Location	Source	FC/ 100 mL	FS/ 100 mL	FC/FS	Possible Pollution Source
Betio, Tokis house	Well	20	180	0.11	Animal
Betio, near Water Reserve	Well	10	1,040	0.01	Animal
Betio, near Water Reserve	Pit	40	13,000	<0.01	Animal
Betio, Tokis house	Pit	1,800	5,400	0.33	Animal
Teaoraereke, Koura	Well	600	290	2.1	Uncertain
Teaoraereke, Koura	Pit	170	1,200	0.14	Animal
Banraeaba, Tekoba	Well	90	10	9.0	Human
Banraeaba, Tekoba	Pit	440	56,000	0.01	Animal
Eita, Bire	Pit	1,400	3,700	0.38	Animal
Eita, Bire	Well	2,400	710	3.38	Uncertain
Bikenibeu, Temaribo	Pit	37,000	68,000	0.54	Animal
Bikenibeu, Temaribo	Well	25,000	4,600	5.43	Human
Bikenibeu, Nawerewere	Pit	1,000	10,700	0.09	Animal
Bikenibeu, Nawerewere	Well	800	104,000	0.01	Animal

TABLE 5.9 : Nitrate Levels in South Tarawa Lagoon (ug/L)

Site	28.7.87	Tide	1.8.87	Tide	5.8.87	Tide
1	nd		nd	H	310	L/IC
2	9	OG	180	H/OG	118	L
3	14	OG	37	H/OG	310	L
4	9	OG	112	H/OG	998	L
5	66	OG	nd		68	L/IC
6	14	OG	53	H/OG	143	L/IC
7	0	OG	8	H/OG	nd	L/IC
8	24	OG	nd	H/OG	136	L/IC
9	0	OG	198	H/OG	nd	
10	0	OG	nd		384	L/IC
11	nd		nd		nd	
12	nd		12	OG	31	IC
13	124	L	nd		0	IC
14	29	L	74	OG	217	IC
15	nd		nd		4836	L
S1	nd		nd		198	IC
S2	nd		279	L/OG	50	H/OG
S3	nd		71	OG	nd	
S4	339	L	nd		856	IC

TABLE 5.10 : Dissolved Phosphate Levels in South Tarawa Lagoon (ug/L)

Site	28.7.87	Tide	1.8.87	Tide	5.8.87	Tide
1	9	OG	nd		45	L/IC
2	10	OG	34	H/OG	28	L
3	38	OG	21	H/OG	23	L
4	86	OG	53	H/OG	25	L
5	0	OG	nd		23	L
6	0	OG	118	H/OG	37	L/IC
7	8	OG	23	H/OG	nd	
8	4	OG	nd	H/OG	47	L/IC
9	6	OG	49	H/OG	nd	
10	22	OG	nd		28	L/IC
11	9	OG	nd		nd	
12	13	OG	50	OG	28	IC
13	3	L	nd		53	IC
14	17	L	53	OG	23	IC
15	nd		nd		57	L
S1	nd		nd		26	IC
S2	nd		41	L/OG	25	H/OG
S3	nd		20	OG	nd	
S4	36	L	nd		15	IC

Phosphate levels ranged from 0-118 ug/L and generally did not show any correlation with nitrate or faecal coliform levels in the water. Again most levels were higher than those found by Johannes et al. (3-16 ug/L) and some even higher than the dissolved phosphate of incoming ocean water (35 ug/L). Such increased nutrient levels may warn of a potential danger to the lagoon.

Other Water Chemistry Measurements

Salinity in the lagoon sites ranged from 35.2-36.0 parts per thousand. Dissolved oxygen readings ranged from 8.8 mg/L to 10.8 mg/L indicating oxygen saturation at all sites. Water temperatures were in the range 27°-28°C. Several samples that were tested for nitrate were also tested for nitrites and in all cases the dissolved nitrite level was less than 5% of the value of dissolved nitrate. The biological oxygen demand was quite low for the sites tested (2, 4, 5, 15), ranging from 4.2-6.8 mg/L.

Ammonia levels were measured along with nitrate and phosphate for the water samples collected. The plot of standard ammonia solution concentration against absorbance was not linear in the region 0-20 ug/L and indeed blanks showed varying readings, indicating ammonia contamination of the distilled water used to make the solutions. Because of this the only conclusions that could be reached was that samples collected all showed ammonia levels below what was considered a reliable detection level of 40 ug/L.

5.4 CONCLUSIONS AND RECOMMENDATIONS

The results of this study indicate that the quality of the southern part of the Tarawa lagoon has not shown improvement since the 1977 cholera outbreak and by some measurements has declined. A number of sites, especially near densely populated areas, show high levels of water pollution from human waste. 'Te bun' collected from all sites also showed serious contamination, whereas in 1979 at least some of the 'te bun' collected near less populated areas were found to be free of faecal coliforms. The nutrient levels in the water over the sand reef in the lagoon are also significantly higher than those found in 1979. Some of the wells tested also showed serious contamination from both animal and human sources. The combination of contaminated well water and 'te bun' that led to the cholera outbreak in 1977 are still present in South Tarawa.

There is a paradoxical situation that the high dissolved oxygen levels and low biological oxygen demand indicate the Tarawa lagoon is still not seriously affected by this pollution. Because of the flushing by fresh oceanic water the pollution that presents a hazard to human health has not as yet adversely affected the living resources in the lagoon itself. The increasing nutrient levels indicate, however, that problems may lie ahead in this area also.

It had been hoped that the introduction of the Tarawa Sewerage Project would increase the quality of both lagoon water and ground water by piping human waste to the edge of the ocean reef instead of having it deposited on beaches or in pit latrines. In fact, a 1985 study team commissioned by the Australian Department of Housing and Construction, which supervised construction of the sewerage system, reported that "the sewerage system has substantially improved the quality of near-shore waters" but offered little data to support this claim (Bellair et al. 1985).

The Tarawa Sewerage Scheme provided toilet blocks which serviced a majority of the South Tarawa population. A salt water flush system has been used to discharge the sewage into the ocean at the edge of the reef. This may have improved ground water quality by replacing cesspits but data is not available on this.

The traditional waste disposal method in Kiribati is on the beach below the high water mark. During this investigation this practice still seems to be widely followed, especially by children. Adults also, especially at night, may find it more convenient to use the beach. The toilet blocks, especially in the warm climate, often emit a foul odour which, along with the sitting bowl design, may discourage use. People suffering from endemic diarrhoea which is prevalent in South Tarawa may not be able to reach the toilet blocks.

In addition to these factors the fact that the population of South Tarawa continues to rise rapidly means that areas are being settled that are not serviced by the sewerage scheme. This may explain why lagoon water in central Bikenibeu (sites 3 and 4), where toilets are present, showed improved water quality compared with 1979 whereas fringe areas (sites 2 and 5) that have been more recently populated showed higher levels. Overall the evidence would tend to indicate that due to population growth and toilet block disuse, the extent of faecal lagoon pollution has not changed much since 1979. Presumably it would have been much worse without the introduction of the Tarawa Sewerage Scheme.

The situation is clearly a difficult one. One urgent need is to monitor the quality of well water that is used for drinking. Although a microbiological testing laboratory was established in Betio as part of the Tarawa

Water Supply Project, the extent of its use is unclear. A WHO project which was to study lagoon and ocean water quality and train local personnel stopped after the initial visit of a consultant toward the end of 1986. It is critical that a regular groundwater monitoring programme be established, that training which is provided be put to good use, and that facilities and equipment for water quality monitoring are maintained in working order. In this way advice can be given to people about the severity of water contamination. Regular monitoring of lagoon water and shellfish quality is also highly recommended.

The improvement of lagoon water quality would appear to be very difficult given the continued population increase in South Tarawa. It does not seem likely that education about the dangers of lagoon defication will change long-entrenched habits in the near future. Cultural change is never easy but it certainly seems that the issues involved need to be discussed at both the national and local level so that the dangers can be realised. This limited study shows continued serious pollution of the lagoon and its shellfish as well as increasing nutrient levels. All of these should be cause for considerable concern to those responsible for health standards in Tarawa.

6. FANGA'UTA LAGOON, TONGATAPU, TONGA

6.1 INTRODUCTION AND BACKGROUND

Fanga'uta Lagoon is a shallow, almost enclosed lagoon located on the northern coastline of Tongatapu (Figure 6.1). The lagoon is composed of two branches, the Western and the South-eastern. The western branch is referred to as the Nuku'alofa branch and is made up of a wide channel called "Folaha Sector" (Sector II in Figure 6.1) and a broad basin surrounding Kanatea Island called the Pe'a Sector (Sector I). The south-eastern branch, known as the Mu'a, is also made up of two sectors. These are the Vaini and the Mu'a sectors (Sector III). The dimensions of each sector are given in Table 6.1.

TABLE 6.1 : Fanga'uta Lagoon Dimensions and Residence Time

	Area 10^6 m^2	Volume 10^6 m^3	Mean depth (m)	Maximum depth (m)	Residence time (days)
Nuku'alofa Branch					
Pe'a	8.8	6.8	0.8	2.5	19
Folaha	4.9	7.3	1.5	3.2	7
Total	13.7	14.1	1.1	3.2	
Mu'a Branch					
Vaini	3.8	4.5	1.6	2.8	9
Mu'a	9.7	19.4	2.0	6.0	12
Total	13.5	23.9	1.8	6.0	
TOTAL	27.2	38.0	1.4	6.0	Entire lagoon 23 days

The two branches of Fanga'uta lagoon are separated from each other and from the ocean by a complex of reefs and channels with distinct passes. One pass consists of a deep channel and a wider,

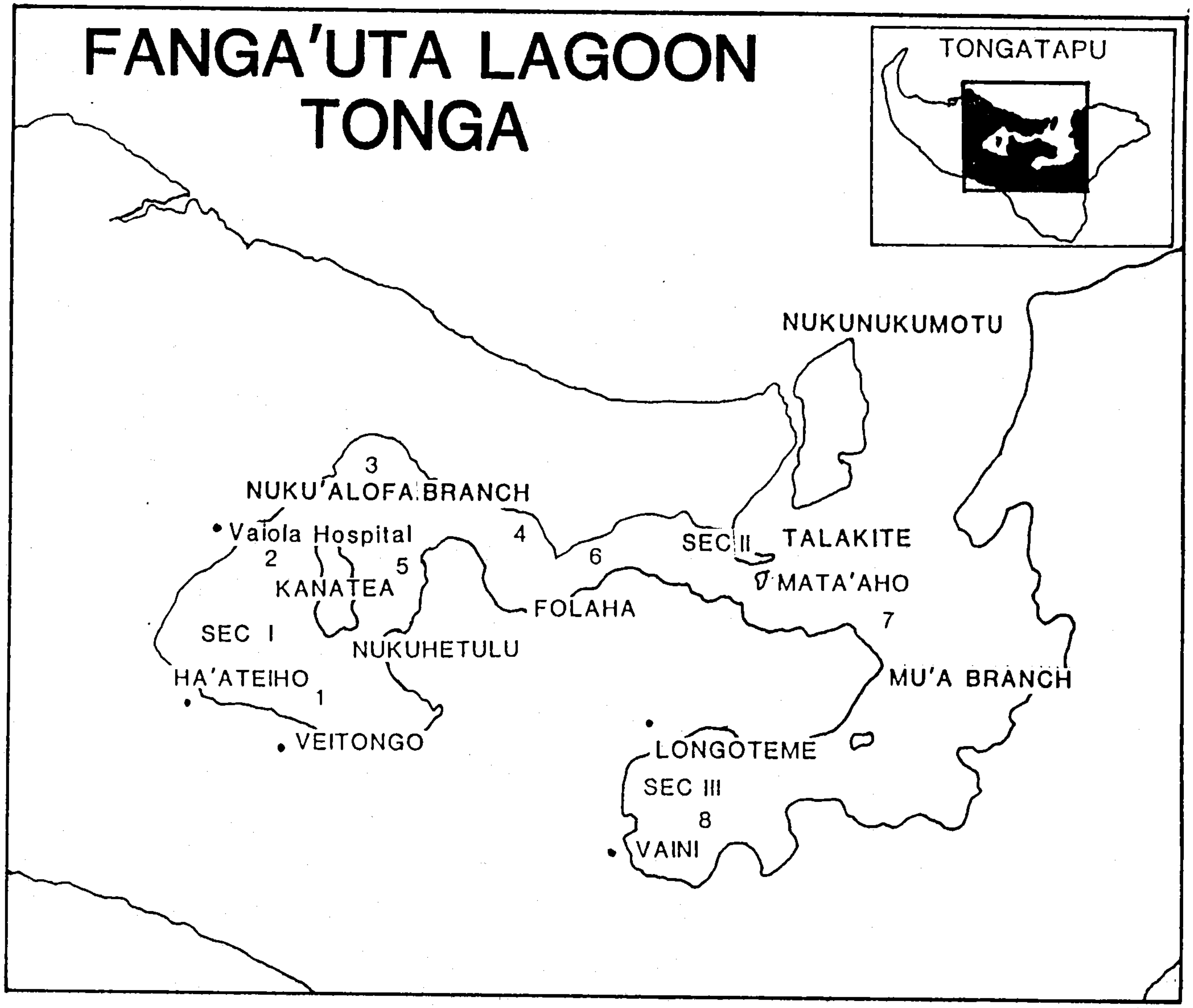

Figure 6.1: Locations of Sampling Sites in Tongatapu

shallower one extends through a broad reef flat. The other pass has few channels and is further restricted by Talakite and Mata'aho islands.

The lagoon encompasses an area of 27 km^2 with a mean depth of 1.4 m and a maximum of 6 m, excluding the entrance channel. A substantial difference in tidal cycles both in height and time of tidal range between the ocean and the lagoon has been observed with the lagoon tide lagging 3-4 hours behind the ocean (Zann et al., 1984). This is attributed to the geometry of the reef flats and channels which constrain the tidal circulation in the lagoon. In spite of the geometry restriction it was concluded that the circulation in Fanga'uta lagoon is driven predominantly by tides. Pe'a sector circulation is perhaps restricted by Kanatea island and this sector has the longest residence time of 19 days while the Folaha sector with the lowest residence time of 7 days is fairly well mixed with ocean water. The Pe'a sector is fairly large and shallow while the Mu'a sector is the deepest and also well mixed with the ocean.

Tongatapu is a reef coral platform (probably an atoll) that has been covered with several metres of andesitic volcanic ash. This ash (from two major events at 20,000 years and 5,000 years b.p.) was transported by wind from the active volcanoes to the west. The ash has weathered to produce fertile soils which have sustained a relatively large population for several centuries. Most of the original forest cover has been removed and the island is now dominated by coconut plantations and food gardens.

The climate in Tongatapu is humid tropical with average monthly temperatures varying from 22-27°C in the warmer months (November-April) to 18-24°C in the cooler season. The rainfall pattern is summarised in Table 6.2.

TABLE 6.2 : Average Monthly Rainfall (in mm) for Tongatapu

J	F	M	A	M	J	J	D	S	O	N	D	Total
234	199	319	190	95	76	97	91	107	108	119	166	1801

Fanga'uta lagoon has been known for centuries to support a large mullet fishery and prolific edible mussels which have served the needs of the inhabitants of Nuku'alofa and other villages in the northern part of Tongatapu. In recent years, however, the populations of mullet and edible mussels have declined at an alarming rate to the present stage where it is now a cumbersome task to fish for mullet in the lagoon. Furthermore, edible mussels have not only declined in numbers but have disappeared from some locations (e.g., sites 1 and 5) of the lagoon which were known to be colonies for them. This decline has perhaps resulted from the recent urbanization involving movement from Vava'u and Ha'apai to Nuku'alofa. This has put pressure on the lagoon resources through overfishing, dredging for building aggregate, increased land reclamation and mangrove encroachment, and at least some indiscriminant discharges of domestic and industrial wastes into the lagoon.

Dredging of the lagoon affects the tidal height and the normal circulation of the lagoon. Land reclamation has resulted in the destruction and abuse of the mangrove areas, the sanctuary and breeding ground for marine organisms. Almost all of the mangroves in the Pe'a sector (between sites 1-6) have been destroyed by dredging and land reclamation. In spite of this, the decline in the resources of the lagoon had been blamed on overfishing and this resulted in the closure of the lagoon to commercial fishing between 1975-1981. The contribution of mangrove encroachment to the current state of the lagoon resources cannot be overemphasised. The Environmental Section of the Ministry of Land, Survey and Natural Resources has implemented some measures to remedy the problems but it is clear that additional remedial action is required to rectify the damage, some of which is probably unrecoverable as it has been accummulating for years in which the lagoon and the mangroves were abused and squandered.

In addition to private residences, several industries and public and government projects have been erected alongside the lagoon including the Marine School complex, the Electric Power Board station, Joe Kahana hotel, a Ministry of Education Development Centre, a new multi-million cultural centre complex, Vaiola Hospital, a golf course and the newly estalished Lavengamalie High School. The Electric Power Board is using water from the lagoon for cooling purposes. Discharges into the lagoon also arise from the Marine

School complex, Joe Kahana hotel, the development centre, the cultural centre and the high school. Vaiola Hospital has been discharging its wastes into the lagoon for years. Dredging and clearing portions of mangrove were carried out to make way for the recently completed cultural centre complex. Lavengamalie High School was constructed on a reclaimed area of lagoon mangroves and it is difficult to know how there can be sufficient proper drainage to cater for a school of its size. Small industrial structures are located short distances from the mangroves and the lagoon. The effects of their discharges on the quality of water in the lagoon remains unknown. The environment impact of some (if not all) of these projects is not known.

A major portion of the lagoon front is a residential area. This is especially true along the front of Nuku'alofa branch. A general lack of enforcement of the Housing Codes has resulted in situations where houses have been built without proper drainage and waste disposal systems. Wastes are washed into the lagoon particularly at high tide. In other cases, the septic tanks have been built on improper land filled areas and thus are resting on the top of the water table. Consequently, wastes find their way into the lagoon. During the sampling visits it was noticed that, at high tide, some toilet outlets were immersed in water from the lagoon.

The aims of this project were:

(1) To assess the levels of nutrients and other chemical parameters in the water of the lagoon

(2) To assess the concentrations of some trace heavy metals in the shellfish to form a basis for a monitoring programme for the lagoon

(3) To use the information above as baseline data to facilitate a surveillance programme for the lagoon thereby monitoring the pollutant inputs and the effects of land reclamation and the discharges of wastes and effluents from industries and public projects constructed near the lagoon.

6.2 WORK PROGRAMME

In April 1987 a team from INR travelled to Tongatapu to initiate the project in collaboration with the Environmental Section of the Tonga Ministry of Lands, Survey and Natural Resources. The team returned in April 1988 to monitor the chemical parameters and hence to assess the state of the water in the lagoon after a year. During the period April 1987-June 1988 staff of the Environmental Section sent shellfish samples (and occasional data on water quality assessment of the lagoon) to INR for analysis of trace metal contents. Staff of the Environmental Section were trained in sampling techniques and on-site measurements of physical and chemical parameters of water during the two visits to Tonga.

The Central Health Laboratory (CHL) of the Tonga Ministry of Health has the only facility in the Kingdom capable of carrying out accurate microbiological assessment (coliform and total bacteria counts) of water. Attempts to secure CHL assistance in carrying out coliform analyses of water samples from the lagoon proved unsuccessful. Thus this report does not contain data on this important facet of water quality assessment of the lagoon.

A total of eight sites were selected for general water quality assessment and three shellfish collection sites for trace metal studies (the three shellfish collection sites were actually the three sectors of the lagoon identified earlier). Of the eight sites selected for water quality assessment, four were in Sector I, three in Sector II and one in Sector III. The four sites identified in Sector I were selected to permit study of any variations within the sector. Sectors I and III represent two main areas of the lagoon with Sector II connecting the two.

Site 1 is located facing the area where there used to be a motel and is now occupied by the newly established Lavengamalie High School. Soil erosion is evident as a result of mangrove destruction. Site 2 is in the vicinity of the new culture complex and the discharge outlet from Vaiola Hospital. There is a large residential area between sites 2 and 4. Site 3 is facing the area of residential houses without proper sanitation facilities, while the location of site 4 is in the vicinity of the Joe Kahana hotel, a popular resort in Tonga. Site 5 was selected as a control site, and is located in a virtually undisturbed area. It is facing a thick mangrove swamp on both the Kanatea and Folaha sides, and there is little evidence of human activities in this area. Site 6 is by the cooling water discharges from the Electric Power Board and is less than two hundred metres from the Marine School Complex's wharf. Site 7 is by Mata'aho island facing the reef that separates Pe'a and Folaha Sectors from Mu'a branch and the open ocean while site 8 is in Sector III, a popular location for the local fishermen.

6.3 RESULTS AND DISCUSSION

The nutrient content of any lagoon can affect the numbers and diversity of species, the biomass content and hence the general state of the marine environment. Nutrients can enter a lagoon via septic and groundwater seepages, sewage and industrial effluents, run-off and ocean water. At Fanga'uta a major source of lagoon nutrients is rich groundwater discharges. Table 6.3 gives the analytical results for the lagoon water during the study. The trace metal contents of shellfish are given in Table 6.4.

The pH of the water in the lagoon was within the accepted range of 6-9 (Wetzel 1975). The salinity was highest for sites which were most exposed and hence well mixed with the ocean water (sites are 4, 5, 6 and 7). Site 2 near the vicinity of the hospital sewage outfall showed the greatest range for salinity and had the highest level of freshwater. The surface waters at all the sites were highly saturated with oxygen. The nitrate levels at all the sites in the lagoon were very high. In fact, they were much higher than values found in the other four lagoons studied. These values could be the actual level of nitrate in the lagoon or they may represent an artifact produced by use of the Hach Drel kits procedure, instruments and reagents which were used throughout these on-site measurements. Results of a very recent survey of nitrate levels in the lagoon using the cadmium reduction column procedure (shown in Table 6.5) have confirmed that the values in Table 6.3 represented an artifact of Hach Drel kit procedures used. Inputs of nitrate at site 2 from the hospital sewage outfall did not appear to be making significant contributions. The data obtained using the Hach Drel kits indicated that phosphate rather than nitrate was the limiting nutrient in the lagoon. However, the data in Table 6.5 do not confirm this. The level of phosphate in the lagoon could have been higher had local farmers been obliged to use substantial quantities of phosphate containing fertilizer. Fortunately the fertile soils of Tongatapu have not required this. The future use of phosphate fertilizers may have a significant influence on the lagoon and needs to be closely monitored.

Considering the nature of shellfish (which tend to accumulate trace metals and other pollutants) and the discharges into the lagoon of wastes from the hospital, houses and industries that have been going on for decades, it is somewhat surprising that the levels of trace metals in the edible shellfish are very low. The low levels of mercury are particularly noted since marine samples from Tonga have been found to contain high levels of mercury attributed at times to local undersea volcanic activity and associated high (natural) levels of mercury in seawater. There is no immediate explanation for the sudden increase in copper concentration from the samples collected from the three sections in 1987 to those collected in early 1988. Further study is required to investigate if this change is seasonal or due to other factors.

6.4 CONCLUSIONS AND RECOMMENDATIONS

In general the water chemistry data suggests that no major change in the nutrient distribution pattern has occurred since 1984. Thus the lagoon continues to be fairly free from effects of human activities as found by Zann et al. 1984. The data collected in late 1988 indicated that levels of nitrate and phosphate are relatively high. A consequence of lagoon being relatively nutrient rich is that some parts of both the Vaini and Pe'a sectors are covered with seagrass.

It is recommended that the water quality assessment of Fanga'uta lagoon be continued. Basic chemical data on quality of water in the lagoon have been gathered which indicate that the lagoon has not been substantially affected to date by the pressure being imposed by human activities, and is highly nutritious. It should be borne in mind, however, that some of the major public projects and industries by the lagoon have just been completed and their effects on the lagoon ecosystem will not be fully known for several years. Furthermore, the Tongan government proposes to place an energy generator in the vicinity of site 7. This is located by the main channel that connects the lagoon to the open ocean. Dredging of a channel to the newly completed Marine School has also been suggested. These two major projects may have major effects on the hydrology, nutrient cycles and quality of water in the lagoon.

Mangrove encroachment has created a visible problem of soil erosion in some sections of Pe'a Sector. Remedial action needs to be considered and implemented.

It is also essential to collect microbiological data including faecal coliform and total bacteria counts on samples from the lagoon in order to accurately assess the biological quality of water in the lagoon.

TABLE 6.3 : Analytical results for Fanga'uta Lagoon water samples

Site	Date	pH	Temp. °C	DO mg/L	Salinity ppt	NO_3 mg/L	NO_2 mg/L	NH_3 mg/L	PO_4 g/L	Clar (m)
1	14.4.87	8.0	28	nd	28	6.6	nd	1.1	0.55	>2.5
1	16.4.88	7.6	28	9.0	30	8.8	0.08	1.7	0.60	>2.5
1	28.5.88	nd	-	-	-	-	-	-	-	
2	14.4.87	7.6	28	nd	28	4.8	nd	1.1	0.20	>1.5
2	16.4.88	7.6	28	8.0	30	8.8	0.08	>3	0.60	>1.0
2	28.5.88	7.8	27	7.0	27	5.3	0.05	nd	0.24	>1.0
3	14.4.87	8.0	28	-	29	6.6	-	1.0	0.80	>3.2
3	16.4.88	8.5	29	7.9	30	6.6	0.06	1.8	<2.0	>3.2
3	28.5.88	7.9	27	7.2	28	4.4	0.03	-	0.24	<3.2
4	14.4.87	7.7	28	-	30	6.6	-	1.1	0.20	>3.2
4	16.4.88	7.5	29	9.1	31	12.8	0.06	1.8	<2.0	>3.2
4	28.5.88	8.0	26	7.2	31	4.4	0.03	-	0.24	>3.2
5	14.4.88	8.0	28	-	26	4.8	-	1.1	0.55	>1.5
5	16.4.88	7.5	29	8.0	34	8.8	0.07	1.7	0.30	>1.5
5	28.5.88	-	-	-	-	-	-	-	2.0	<1.5
6	14.4.87	7.8	28	-	31	6.2	-	1.0	0.18	>2.8
6	16.4.88	7.9	27	8.0	32	2.0	0.02	1.1	2.0	>2.8
6	28.4.88	7.7	27	7.4	33	5.3	-	-	3.3	>2.8
7	14.4.87	7.8	28	-	31	6.2	-	1.0	0.18	>6.0
7	16.4.88	8.0	27	9.0	34	7.5	0.07	1.5	0.50	>6.0
7	28.5.88	-	-	-	-	-	-	-	-	-
8	14.4.87	7.8	28	-	32	5.7	-	1.1	1.2	>6.0
8	16.4.88	6.0	26	7.0	35	7.5	0.03	1.6	>2	>6.0
8	28.5.88	7.8	27	7.0	32	0.03	-	-	0.62	>6.0

TABLE 6.4 : Analytical data for <u>Gafrarium</u> <u>Tumidum</u> from Fanga'uta Lagoon (on Fresh Weight Basis)

Site	Date	Hg mg/kg	Cu mg/kg	Cr mg/kg	Cd mg/kg	Pb mg/kg
1	Apr 1987	0.037	4.80	0.16	<0.05	<0.50
1	Jul 1987	0.043	2.53	<0.05	<0.05	<0.50
1	Sep 1987	0.068	2.20	0.17	0.13	<0.50
1	Dec 1987	0.055	3.45	0.17	0.13	<0.50
1	Feb 1988	0.022	7.15	0.23	0.07	<0.50
2	Apr 1987	0.024	1.76	0.10	<0.05	<0.50
2	Jul 1987	0.081	0.68	0.17	0.22	<0.50
2	Sep 1987	0.090	0.60	0.52	<0.05	<0.50
2	Dec 1987	0.063	1.07	<0.05	0.06	<0.50
2	Feb 1988	0.022	7.85	0.23	0.07	<0.50
3	Apr 1987	0.025	0.24	0.10	<0.05	<0.50
3	Jul 1987	0.081	1.92	0.35	<0.05	<0.50
3	Sep 1987	0.047	1.38	0.10	<0.05	<0.50
3	Dec 1987	0.191	2.17	0.68	0.19	<0.50
3	Feb 1988	0.034	5.37	0.10	0.07	<0.50

TABLE 6.5 : Nutrient Analyses[+] for Fanga'uta Lagoon Water Samples

Site	Date	$NO_3^{\cdot}$ ug/L	NO_2 ug/L	NH^3 ug/L	PO_4 ug/L
1	27/12/88-17/2/89	221	<10	<10	243
2	"	114	<10	<10	96
3	"	65	<10	<10	138
4	"	83	<10	<10	147
6	"	112	<10	<10	219

[+]These are an average of 6-12 analyses.
[·]Nitrate determination using cadmium reduction column technique

7. MAROVO LAGOON, WESTERN PROVINCE, SOLOMON ISLANDS

7.1 INTRODUCTION AND BACKGROUND

Marovo Lagoon encompasses the coasts of three large volcanic islands in the Western Province of the Solomon Islands : New Georgia to the north, Vangunu and Gatokae to the south (see Figure 7.1). It covers an extensive area totalling some 700 sq. km. (Stoddart, 1969) and one of the most striking features of the lagoon is the host of small islands that are scattered throughout its length. There is also a great number of patch and fringing reefs, the outer boundary of the lagoon being, of course, the barrier reef.

The width of the lagoon varies on going from north to south. It has been estimated that distances from the mainland to the barrier reef in the narrow northern New Georgia portion seldom exceed 2.5 km, whereas in the widest portion of the lagoon, off northern and eastern Vangunu, distances to the barrier reef can be as much as 8 km. There is also a great variation in water depth, from less than 10 m in the northern section to depths of more than 25 m in the main lagoon (Hviding, 1988).

The New Georgia group is made up of young andesitic volcanoes and their derivatives. New Georgia is the largest island in the group and consists of several volcanic centres. There are extensive reef - lagoon complexes surrounding the island. Vangunu, the other large island in the group comprises a young, high volcanic centre in the south and an older, less distinct centre in the north-east (Stanton and Bell, 1969).

A striking feature of the larger islands is that land use is concentrated around the coast and there is virtually no cultivation inland. Vegetation on the large islands is mainly tropical rainforest. Along the coasts of these larger islands and on the smaller islands, there are large areas of mangroves, sago palm and coconut trees. The rainforest is still largely intact with scattered patches cleared for gardening purposes, but some logging activity has commenced in New Georgia. Small areas of mangrove have also been cleared as the wood is used for construction of homes and for firewood. These cleared patches, however, constitute a relatively small area.

There are several rivers that run through the larger volcanic islands and it is at the mouths of these rivers that the largest and thickest stands of mangrove are found, mainly of the genera Rhizophora and Bruguiera.

The lagoon is host to a great diversity of species and its ecological complexity merits further study.

Climate

The climate in Marovo for the most part is hot, with south-easterly trade winds prevailing during the period April-October and the NW monsoons occurring during the November-March period.

The New Georgia group receives a substantial amount of rainfall annually as summarised in Table 7.1.

Temperatures show a high degree of uniformity and the variation of mean monthly screen temperature is about 1°C between the extreme monthly means of about 25°C and 27°C. There is only a slight seasonal variation. Temperatures on clear days range from about 22°C in the early morning to about 29°C in the middle of day.

TABLE 7.1 : Average Monthly Rainfall (in mm) for Munda, New Georgia (Ash et al., 1974)

J	F	M	A	M	J	J	A	S	O	N	D	Total
450	302	409	275	272	254	410	292	263	253	233	276	3689

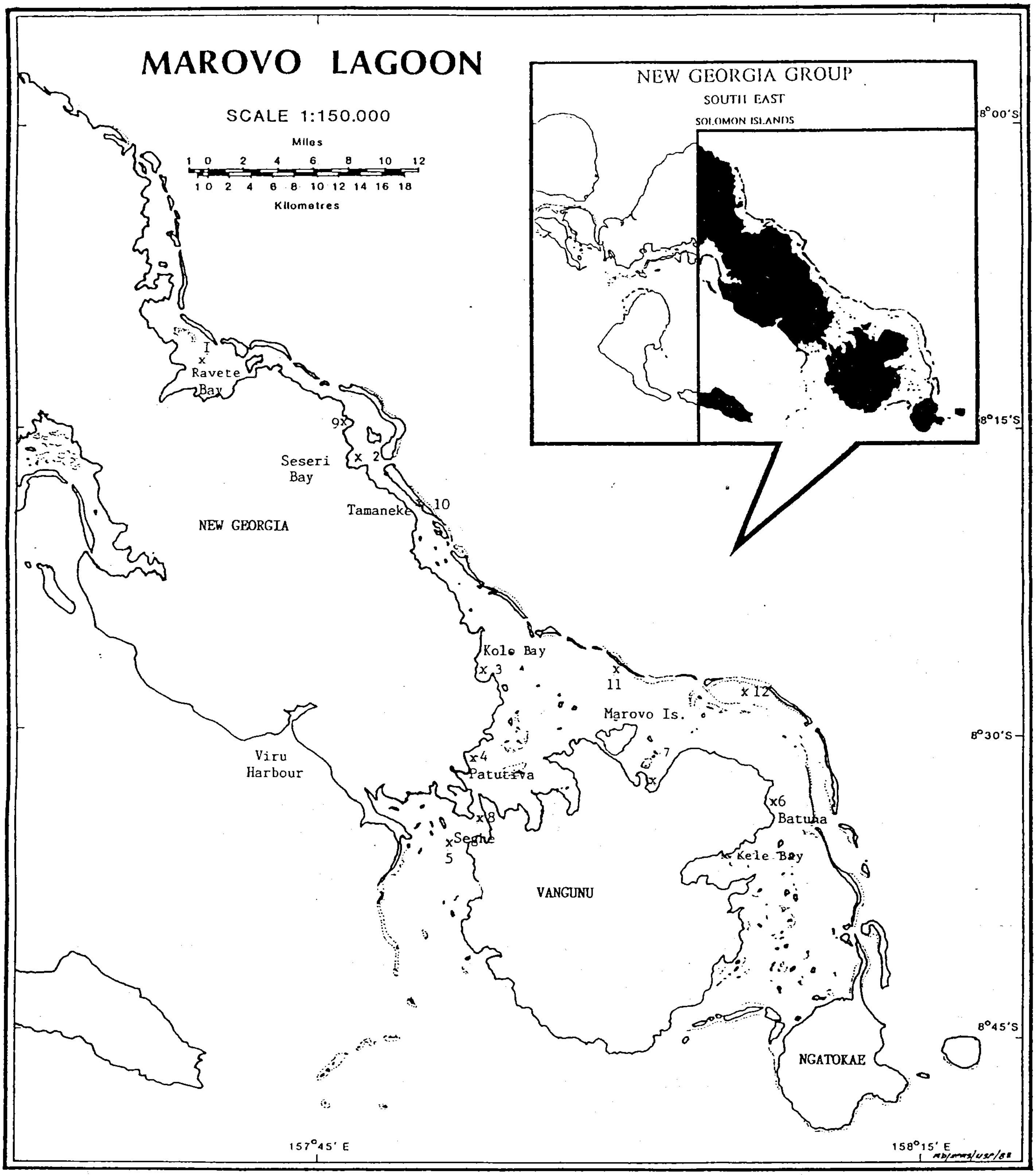

Figure 7.1: Locations of Sampling Sites in Marovo Lagoon

7.2 WORK PROGRAMME

A team from INR spent one week working in the lagoon during November 1988, and were based at the Fisheries Training Centre in Seghe. A total of twelve sites were selected, ranging from Ravete Bay in the north to Batuna in the south. Various factors were taken into consideration when selecting the sites; proximity to human settlements, areas of freshwater run-off and areas where mineral prospecting and logging operations are being actively carried out (see Table 7.2).

Clarity, dissolved oxygen, salinity, temperature and pH were measured on site. As the lagoon is large and the local transport available was a fibreglass canoe powered by a 12 hp outboard motor, travelling to the sites required about 6 hours per day. At each site water samples were collected at the surface and at a depth of 10 m (where appropriate) for laboratory analysis. Due to the non-arrival (by ship) of concentrated acids, only ammonia analyses could be completed at Seghe. Arrangements were therefore made for the airfreighting of samples to Honiara where the analyses for nitrate, phosphate and faecal coliforms were completed by team members. In this way samples from sites 4, 5 and 8 (the most accessible to Seghe) were analysed. The results of the analyses are given in Tables 7.3, 7.4 and 7.5.

TABLE 7.2 : Location of Study/Sampling Sites on Marovo Lagoon

No.	Name	Map position	Description	Reason for choice
1	Ravete Bay	157° 43.7' E 8° 10.6' S	At a point formed by a line drawn from Loloma Passage to Vilo Point and another at right angle to this from Malavari Island.	As a 'control' since there was no ongoing activities. Considered relatively unpolluted.
2	Seseri Bay	157° 47.5' E 8° 17.7' S	About 300 m away from mouth of Piongo Lavata River.	Mouth of a large river with a large sediment load during heavy rainfall.
3	Kolo Bay	157° 56.6' E 8° 27.3' S	Directly opposite mouth of smaller river rather than Kolo River and about 60 m away.	Mineral prospecting has begun in surrounding hills thus baseline data of physical parameters needed now to monitor potential impact of mining (and later the actual impact)
4	North Patutiva	157° 56' E 8° 32.4' S	Right in the centre about mid-way between Chuchulu and Patutiva villages.	Considered to be a true-lagoonal site far from rivers and villages and relatively unpolluted.
5	South Seghe	157° 54.8' E 8° 38.1' S	Mid-way between Noki Is. (2nd small island near Vangunu) and Moluana Is. (to the N.E.)	Considered relatively unpolluted. Sites 4 and 5 were also recommended by Graham Baines as he felt that there was inadequate mixing because of the narrow Njae Passage

TABLE 7.2 (cont'd)

				joining the two sites. These sites were also thought to be relatively far from human waste sources.
6	Batuna	158° 03.4' E 8° 34.3' S	On northern side of Batuna, directly opposite school on west and shop on the south.	To monitor any impact of the existing small saw mill plant.
7	Kasere Bay (Ring dove)	158° 02.3' E 8° 34.3' S	Directly opposite the middle river and about 100 m out in the estuary.	To monitor impact of mining operation proposed in the hills between this bay and Kele Bay.
8	Njae Passage	157° 56.5' E 8° 35' S	About mid-way between the jetty at Patutiva village on the east and the Fisheries Centre on the west.	Very close to human settlement and to provide comparison with data from sites 4 and 5 especially with regards to faecal coliform content.
9	Kaolo	157° 46.9' E 8° 14.7' S	In a stream inland about mid-way at Mbarumbaruku Point.	For future monitoring of an Anadara population
10	Tamaneke	157° 52.1' E 8° 21.0' S	Mid-way between Tamaneke and Ngurengure River and opposite the end of the bay on Kotukuriana Island.	To see the effect of mixing in this narrowest part of lagoon with numerous streams in the adjacent mainland.
11	Karikana Is.	157° 59.9' E 8° 26.7' S	About 150 m from Karikana Is. along a line almost perpendicular from this island to Levichi Is.	To see the effect of a fringing land mass on mixing of water.
12	North Lolou	158° 09' E 8° 27.6' S	About 300 m from the barrier reef along a line joining Lolou and Tambaka Islands. Almost opposite Cheke village on Vangunu Island.	To see the effect of barrier reef on mixing of water in comparison with that of Site 11.

One of the main purposes of this activity was to initiate a baseline study of the Marovo lagoon. It was, therefore, considered worthwhile establishing permanent reef transects for future monitoring. One such site was a patch reef in Kolo Bay, the reason being that it is subjected to sediment-laden water in times of heavy rainfall. A quick survey revealed numerous colonies of Porites and Montipora species. The coral diversity was, as expected, rather limited. The water clarity at this particular site did not exceed 1.5 m, an indication of the sediment content of the water.

Patch reefs around site 5 displayed a greater diversity of species. A fringing reef adjacent to Karuhahe Island was surveyed and the species diversity was markedly greater than the reef in Kolo Bay. This was expected since there was no freshwater runoff nearby and water clarity was at least ten times greater than at the former site. Corals belonging to the genera Porites, Montipora, Fungia, Favites, Galaxea and Acropora were in abundance along with the other reef-associated invertebrates such as holothurians, sea stars and urchins, in addition to the large numbers of reef fish. The Karuhahe reef could serve as a 'control' site.

There was a number of patch reefs scattered throughout the length of the lagoon and several of these would appear worthy of future monitoring to provide biological indicators of lagoon quality.

7.3 RESULTS AND DISCUSSION

Physical parameters such as salinity, temperature and water clarity assess the changes that may take place in well-defined environmental characteristics, as a result of the addition of potential pollutants. On the other hand, chemical parameters such as pH, dissolved oxygen and nutrients may be used to assess the impact of potential pollutants (Olson & Burgess, 1967).

As expected the water clarity in the Marovo lagoon was seen to be lowest in estuarine areas due to sediment input via rivers (see Table 7.3).

TABLE 7.3 : Physical Parameters for Selected Sites in Marovo Lagoon (14-18 November, 1988)

Site	Temperature (°C)		Salinity (ppt)		Water clarity
	0 m	10 m	0 m	10 m	(m)
1	26.0	25.0	32	36 (5m)	5
2	25.0	24.7	24	36	10.5
3	25.3	24.8 (4m)	34	-	1.5
4	24.0	23.8	35	36	9
5	24.7	24.5	37	37	12
6	24.4	24.4	34	36	10.5
7	25.5	25.0	37	37	4.5
8	24.6	24.3	35	36	12
9	26.3	-	22	-	-
10	25.4	20.4	26	36	4
11	24.8	24.5	34	35	8
12	26.0	25.0	34	36	9

The salinity was found to be slightly higher at10 m depth than at the surface, except for two sites (5 and 7) where values were the same. Sites 2 and 10 showed the largest differences of 12 and 10 ppt respectively between the surface and at 10 m depth. This may be explained in terms of mixing of water in this part of the lagoon. These results tend to indicate that there is inadequate mixing of freshwater from the numerous streams on the adjacent mainland of New Georgia with seawater coming in from the ocean and thus the denser salt water is at the bottom while the fresher water floats on top. Those sites (5 and 7) with equal salinity at the surface and at 10 m depth may very well be experiencing thorough mixing. These salinity trends are generally confirmed by the conductivity data (Table 7.4).

Dissolved oxygen (DO) concentration is one of the most important chemical analyses in determining water quality. It can be a reflection of organic loading, nutrient input and biological activity (Ruivo, 1972). Oxygen content was higher in surface samples than in those from 10 m depth (see Table 7.4). This is expected as there is a greater chance of equilibrium with atmospheric oxygen for surface waters. Sites 1, 2 and 12 had relatively higher DO values at the surface, compared with the rest of the sites. This is expected for unpolluted areas as there is little organic material introduced. Site 9 which had the lowest DO reading of 4.6 mg/L is in a stream inland with a dense mangrove area on either side of the stream. Dissolved oxygen would tend to be low as it is being utilised by the plants and in the decomposition of plant litter.

The primary source of nitrates and phosphates are rivers which transport run-off from the land into the marine environment. Unfortunately those sites situated near river mouths, namely sites 2, 3 and 7, were not analysed for nitrate and phosphate content due to their relative inaccessibility from Seghe. For those sites from which samples were analysed, site 8 exhibited the highest phosphate concentration (see Table 7.4). This is almost certainly due to wastes from the village nearby. The nitrate results have not been tabulated due to blatant discrepancies in the results. For some unknown reason, the 'blank' solutions gave higher readings than the actual samples. The distilled water was suspected to have been contaminated since it was essentially rain water which was collected in a holding tank located on the roof of the Chemistry laboratory at King George VI School in Honiara. There also appeared to be inconsistencies in the values for ammonia (see Table 7.4). One would expect high values of ammonia in estuarine areas where organic matter is being actively broken down by the bacteria that abound in such places (Zottoli, 1973). Sites 2, 3 and 7 which could be described as estuarine areas do not show any consistent trend. Sites 2 and 7 had high NH_3 concentration but a relatively low NH_3 concentration was recorded at site 3.

TABLE 7.4 : Chemical Parameters for Selected Site in Marovo Lagoon

Site	pH	Dissolved Oxygen (mg/L) 0 m	Dissolved Oxygen (mg/L) 10 m	Conductivity (mS) 0 m	Conductivity (mS) 10 m	NH_3 (ug/L) 0 m	NH_3 (ug/L) 10 m	PO_4^{3-} (ug/L) 0 m
1	7.80	9.8	7.4	11757	13270 (5m)	5	77	n.d
2	8.10	8.8	8.1	9610	13411	90	11	n.d.
3	8.15	6.7	5.9 (4m)	6480	7520 (4m)	21	21 (4m)	n.d.
4	8.05	6.3	6.2	7480	7620	13	28	15
5	8.00	7.0	6.2	7520	7600	8	28	15
6	7.40	6.3	5.9	7560	7840	45	32	n.d.
7	7.30	6.3	3.6	6140	7780	52	77	n.d.
8	7.50	5.9	5.5	7560	7720	69	54	90
9	8.10	4.6	-	5140	-	13	-	n.d.
10	7.65	5.7	5.5	6020	7860	10	n.d.	n.d.
11	8.22	6.1	5.8	8420	8520	n.d.	n.d.	n.d.
12	8.18	9.2	6.2	8220	8240	n.d.	n.d	n.d.

Site 8 also showed a high NH_3 concentration although it is not considered estuarine. This could be due to human waste disposal from the nearby villages. Ammonia concentrations in unpolluted sea and ocean waters usually do not exceed 50 ug/L; however, this may vary with season and location. The concentration may be as high as 300 ug/L in sewage polluted coastal waters (Goldberg, 1972). Figures for 5 of the 10 sites for which data was obtained indicate a relatively unpolluted state.

Coliform numbers were ascertained for only three sites for reasons already stated (see Table 7.5). Sites 4 and 5 are situated at either end of the passage running through Seghe, well away from any human settlement. Coliform numbers were thus expected to be negligible.

Site 8 on the other hand, is in the middle of the passage and is located between the village of Patutiva and the Fisheries Training Centre. It was observed that in most of the villages, small huts were constructed on the water's edge to serve as toilets. It was therefore reasonable to expect faecal coliform numbers to be considerably greater in waters close to the villages and the result for site 8 confirmed this.

TABLE 7.5 : Coliform Results for Three Sites in Marovo Lagoon

Site	Faecal Coliforms/100 mL Water
4	0
5	0
8	150

Sediment samples were collected (grab samples) at each site and analysed for cadmium, chromium, copper and lead. The samples were not sieved before analysis. The results are summarised in Table 7.6 which also includes data for NBS Estuarine Sediment Reference Sample Number SRM 1646 and some literature data.

TABLE 7.6 Trace Metal Analyses of Marovo Lagoon Sediment Samples (mg/kg dry weight)

Site	Cu	Cr	Cd	Pb
1	8.4	8.1	1.7	53.1
2	81.2	75.0	1.0	37.5
3	49.4	78.7	0.8	34.3
4	11.2	61.2	1.6	53.1
5	16.5	29.3	1.1	56.2
6	6.2	1.1	2.6	79.5
7	163.7	18.7	0.8	18.7
8	29.4	86.2	1.1	53.1
9	10.6	8.1	1.7	66.5
10	48.4	20.6	1.1	43.7
11	7.5	16.2	2.0	65.5
12	9.4	15.0	2.2	75.0
NBS Ref Sample*	16.9	70	0.37	34
No SRM 1646	(18±3)	(76±3)	(0.36±0.07)	(28.2±1.8)
Soils (mean value)+	25.8	84	0.62	29.2
Sediments (range)#	10-700	10-200	0.2-2.0	10-200

*( ) = Reference value
+ Data from Ure and Berrow (1982)
# Data from Johnston (1976)

The data in Table 7.6 show that the sediment samples collected at Marovo generally contained low amounts of trace metals. The exception was the sample from site 7 which gave a copper value considerably above all the other samples. This may be related to the copper/gold ore deposit in the area, which was being explored at the time of the study. Other relatively high copper values (sites 2, 3, 10) correspond to areas where major riverine sediment deposition occurs. Several cadmium values were above the range normally found for marine sediments, but only marginally so. There was a wide range of chromium contents (1.1-86.2 mg/kg) but no pattern could be discerned. There was no pattern relating lead contents to site characteristics, but an inverse relationship between lead and copper contents was observed;

$$Pb = -0.323\ Cu + 64.9 \quad (r = 0.85)$$

7.4 CONCLUSIONS AND RECOMMENDATIONS

The reconnaissance survey has highlighted the severe logistics problems of carrying out water quality work at an isolated Pacific island location like Marovo. The lack of any local laboratory facilities, reliable transport of incoming materials, reliance on relatively slow canoe transport make it difficult to carry out the same programme of work as at the other study areas. The size of the lagoon itself means that routine sampling is not easily completed.

Despite the difficulties, some initial monitoring of the water quality in Marovo lagoon has been completed. Twelve monitoring sites that represent the range of coastal environments found in the lagoon have been selected for continuing study.

No firm conclusions can be drawn from the results of one visit, particularly when the data obtained is limited, but the initial results indicate that, as expected, Marovo lagoon is relatively unpolluted except for locations close to villages having significant populations. In order to confirm these indications it is recommended that another sampling/analysis visit be made to Marovo as soon as possible. In the long-term, it is recommended that a regular monitoring programme be established at Marovo.

The reasons for this are as follows:

(a) Certain Marovo sites are free from pollution and are likely to remain so for the foreseeable future. Data obtained could therefore be used to monitor long-term changes in the marine environment in this part of the Pacific.

(b) The impact of increasing population (in certain areas) on the surrounding environment can be monitored to ensure that pollution does not occur to the extent where it impacts on local health standards, i.e., monitoring will indicate when action has to be taken to reduce pollutant levels.

(c) The impact of changes in land use locally (e.g., logging, intensification of agriculture, mining) can be more effectively predicted if a good baseline statement on the quality of the lagoon is available.

Two possible systems for carrying out future monitoring are available:

(a) Scientists travel to Marovo, establish the sampling programme and return to Honiara to carry out the analyses, with the samples being air-freighted daily from Seghe to Honiara. The analyses could be carried out at King George VI High School, or the Solomon Islands College of Higher Education or at the Laboratories of the Ministry of Natural Resources (Geological Survey Fisheries) and Ministry of Agriculture and Lands (Dodo Creek Research Station).

(b) That facilities at Marovo be upgraded so that all the elementary analyses (nutrients, coliforms, etc.) can be carried out on site, with samples for trace metals or pesticides only, being sent away.

The latter is recommended as being the more appropriate long-term procedure. In order to achieve the establishment of a locally-based monitoring programme at Marovo a number of requirements will have to be met.

(i) The Fisheries Training Centre could be turned into a permanent base for the Marovo monitoring programme. It is ideally located near the centre of the lagoon and at present has sufficient space that is not being utilized.

(ii) Some simple equipment is required including a dissolved oxygen meter, a refractometer for salinity measurements and a robust colorimeter for nutrient (N and P) analyses, a field kit for microbiological assessment of water and shellfish. Also some basic laboratory glassware and sampling facilities (e.g., bottles, anchor rope).

(iii) Some training of locally based people in sampling and analysis techniques.

(iv) Sufficient fuel to ensure that the local generator can be run for adequate times when electricity is required for analyses (perhaps 15 days per year).

(v) A collection of maps, marine charts, tide tables, etc.

If funds cannot be made available for upgrading the facilities at Marovo then future monitoring exercises should involve a minimum of three researchers. Several days could be spent at Marovo carrying out the on-site analyses and arranging for samples to be collected and dispatched to Honiara for laboratory analyses. The arrangements for a continuing locally-controlled monitoring programme should be established as soon as possible.

8. GENERAL CONCLUSIONS

From the previous sections it is obvious that the amount of work done and data available for the different sites vary enormously. The main reason for this is that the project was not completed as originaly scheduled. The project planning was carried out in 1986 with only 4 lagoons included. Early in 1987, following requests from the Tonga Government through SPREP, the Fanga'uta Lagoon study was added. In the original plan 2 visits to Vila, Tarawa and Marovo were scheduled with local staff being trained to carry out local monitoring between the visits. In fact, only Fanga'uta received two visits.

The main reason for this was financial. The project was originally planned for 2 years and funding projected over the 2 years. Funds were received for 1987 but unfortunately (and due to no fault on the part of the authors) only partial funding was received for 1988, and this near the end of the year. For the Fiji study work continued partly using funds obtained by staff of the Institute of Natural Resources, but it was not possible to obtain sufficient funding for a second visit to Vila, Tarawa and Marovo.

Following the initial visit to Vila, some local monitoring was continued. In Tarawa the person trained to carry on the work left for further studies in Australia. In Tongatapu a similar situation occurred but the Environment Unit attempted to continue monitoring. At Marovo the lack of any local infrastructure made it virtually impossible to establish a locally-based monitoring programme without a massive injection of resources.

Examination of the data clearly shows that in four lagoons the major pollution problems are associated with sewage disposal. At Marovo no major population centre is present within the study area and as a consequence sewage disposal problems on a large scale do not occur. No investigations of pesticide residues were completed, but knowledge of pesticide use in the areas concerned indicated that a potential problem could only occur in two areas (Suva and Tongatapu) as pesticide use in the other areas was minimal. For Laucala Bay there is a potential problem due to extensive spraying of rice crops on the plains of the Rewa River about 10 km upstream. In Tongatapu pesticide use is quite widespread and there is concern locally about movement of residues into groundwater and hence into coastal waters. For trace metals, potential problems associated with industrial development exist for Suva, Vila and Tongatapu. Results from other investigations (INR, unpublished results) indicated that a few very localized problems do occur, but the discharge of metal residues is not yet at a scale to cause major problems. However, this situation could change quickly with a rapid increase in the numbers of metal-based industries.

Drawing valid conclusions from the data on sewage-related pollutants is complicated by the fact that data is very limited (in terms of number of samplings) for some sites. However, some general points can be made.

There is considerable variation in the faecal coliform counts between sites and also for different samples from the same site. This is not entirely surprising given the nature of the variables controlling such values, e.g., time of sampling, climate, tide, etc. The number of high values, both in water and in shellfish, should be of concern to health authorities in Suva, Port Vila and Tarawa. This is particularly important as at each location population increases are occurring at a time when planned improvements to sewage treatment/disposal facilties have not been completed. The potential obviously exists for major disease outbreaks in addition to the prevailing likelihood of recurring diarrhoea, dysentry and hepatitis. There is an urgent need to address the microbiological pollution problems observed in some of the lagoons studied in this project.

Examination of the data for nutrient concentrations (summarised in Table 8.1) also indicates cause for concern. Recent investigations have shown that increased nutrient concentrations can have a detrimental effect on coral reefs. Kinsey and Davies (1979) have shown that phosphate concentrations as low as 60 ug/L can cause significant reductions in calcification rate. Smith et al. (1981) concluded that phosphate concentrations of 20-50 ug/L and nitrate concentrations of about 50 ug/L could cause significant algal growth problems. Increased nutrient concentrations can also promote the growth of phytoplankton.

TABLE 8.1 : Nitrate and Phosphate Values for Pacific Lagoons (ug/L)

SITE		NO_3	PO_4
Laucala Bay	av.	240	255
	SD	542	147
	Range	<10-5700	30-5700
Suva Harbour	av.	245	175
	SD	306	156
	Range	<10-2800	30-1004
Vila	av.	453	52
	SD	822	43
	Range	10-3840	18-222
Tarawa	av.	279	30
	SD	789	23
	Range	0-4836	0-118
Tongatapu	av.	119	118
	SD	54	54
	Range	65-221	96-243
Marovo	av.	n.d.	39
	SD	n.d.	33
	Range	n.d.	15-90
Lizard Is[1]			
windward	av.	43	23
	SD	30	8.7
	Range	7-150	11-52
leeward	av.	31	19
	SD	19	5.9
	Range	4-82	11-45
Whitsunday Is[2]	av.	13	22
	SD	9	3
	Range	n.d.	n.d.

[1]AIMS (1983)
[2]Furnas et al. (1988)

The phytoplankton compete with symbiotic zooxanthellae for nutrients and light, thus interfering with coral growth; this is in addition to the direct problems of increased sedimentation associated with enhanced phytoplankton production. Benthic algae directly compete with corals for space.

The data in Table 8.1 show that concentrations of nitrate and phosphate are in excess of those considered likely to cause reef growth problems for Suva, Vila, Tarawa and Tonga. For Suva and Tarawa this is also of immediate concern because in these two locations the reefs have considerable economic, social and physical importance. Damage to the complex reef ecological balance would have profound effects on Tarawa where much of the local subsistence food supply and baitfish supply for commercial fishing is dependent on a productive reef system. The study of Smith et al. (1981) indicated that elevated phosphate levels tended to cause more damage than elevated nitrate levels. This would indicate a need for particular attention to the control of phosphate levels. It is obvious that further work in this area is required.

A disappointing feature of this project has been the inability of local government authorities to commit the resources necessary to establish significant on-site monitoring programmes. The value of time-series data cannot be overemphasized. If local authorities are to take serious action to control the quality of coastal waters then the regular production of data using local recurrent resources is essential so that changes can be detected and action taken before the problems become so severe that either they cannot be resolved or the costs are prohibative. This is particularly important for the fragile coastal environments on which so many people depend for their livelihood and source of food.

The results obtained may be used to estimate the conditions likely to prevail in a wide range of Pacific lagoons. The Suva results, associated with a coastal city bounded by a lagoon with limited circulation, give an indication of the problems that may be found in cities like Port Moresby, Noumea and Papeete. Nuku'alofa and Vila, being smaller, are likely to be representative of medium size centres with limited industrial development like Apia, Koror or Lautoka. Tarawa is representative of highly populated atolls; if the sewage problems are excluded, most atolls should be free of major pollution problems (e.g. trace metals, pesticides). Marovo, typical of many sparsely populated coastal areas of high islands (e.g. Solomon Islands, Vanuatu, Fiji, Papua New Guinea, Western Samoa, American Samoa), shows little evidence of pollution except close to large villages. Marovo, however, like many similar coastal areas may not remain pristine as logging and mining activities could lead to considerable deterioration. Utilization of the data herein and a knowledge of the local environment will facilitate preparation of lagoon management strategies and recommendations for governments/administrations responsible for environmental management in a significant number of regional countries.

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10. REFERENCES

AIMS. 1983. Physical, chemical and biological properties of water over coral reefs at Lizard Island, Great Barrier Reef. Australian Institute of Marine Science, Data Report, Reef Studies Series, AIMS-RS-83-1, Townsville.

APHA-AWWA-WPCF. 1981. Standard Methods for the Examination of Water and Wastewater. Amer. Pub. Health Assoc., 15th Ed., 1134 p.

Ash, P.G., Wall, J.R.D., Hansell, J.R.F. 1974. Rainfall data for the British Solomon Islands Protectorate to the end of 1973. Suppl. Rep. No. 12, Land Resources Division, O.D.M., London, 453 p.

Bellair, J.T., Chidgey, S.S., Mathews, R. and Wallis, I.G. 1985. Tarawa Project Outfall Reconnaisance Survey. Report by Connsulting Environmental Engineers (Australia) prepared for the Department of Housing and Construction, Canberra, 45 p.

Bell, P.R. and Greenfield, P.F. 1988. Monitoring treatment and management of nutrients in wastewater discharges to the Great Barrier Reef Marine Park. In : Baldwin, C.L. (Editor) Nutrients in the Great Barrier Reef Region, GBRMPA Workshop Series No.10, pp.115-126.

Blake, S.G. and Johnson, D.P. 1988. Preliminary report on water quality, current patterns and sediment composition around Hamilton and Hayman Islands, the Whitsundays. Report to the Great Barrier Reef Marine Park Authority (GBRMPA), Department of Geology, James Cook University, Townsville.

Brodie, J.E., Mapstone, B.D. and Mitchell, R.L. 1989. Magnetic Quay water quality and sediment baseline study. Report to GBRMPA by the Australian Centre for Tropical Freshwater Research, James Cook University, Townsville.

Campbell, L.E., Cock, P.R. and Corris, R.A. 1982. Kinoya Sewage Treatment Plant. Report on Receiving Water Study. Department of Transport and Construction and Caldwell Connell Engineers, Canberra, 91 p.

Carter, R. 1983. Baseline Studies of Port Vila and Erakor Lagoon, Vanuatu. Cruise Report No.82, CCOP/SOPAC, Suva, 20p.

Crossland, C.J. 1983. Dissolved nutrients in coral reef waters. In : D.J. Barnes (Editor) Perspectives on Coral Reefs, AIMS Publication No. 200, Townsville, pp. 56-68.

Furnas, M., Mitchell, A.W., Wellington, J. and Brady, B. 1988. Dissolved and particulate nutrients in waters of the Whitsunday Island Group. Report prepared for the Great Barrier Reef Marine Park Authority, Townsville.

Geldreich, E.E. 1976. Fecal coliform and fecal streptococcus density ratios in waste discharge and receiving waters. CRC Critical Reviews of Environmental Contaminants, 6, 349-69.

Goldberg, E.D. 1972. A Guide to Marine Pollution. Gordon and Breach Science Publishers, New York, 168 p.

Hviding, E. 1988. Marine Tenure and Resource Development in Marovo Lagoon, Solomon Islands. FFA (South Pacific Forum Fisheries Agency) Report No. 88/35, Honiara.

Johannes, R.E. 1975. Pollution and degradation of coral reef communities. In : E.J.F. Wood and R.E. Johannes (Editors) Tropical Marine Pollution. Elsevier Scientific Publishing Co., Amsterdam, 192p.

Johannes, R.E., Kimmerer, W., Kinzie, R., Shiroma, E. and Walsh, T. 1979. The Impact of Human Activities on Tarawa Lagoon. South Pacific Commission, Noumea, 83p.

Johnston, R. (Editor) 1976. Marine Pollution. Academic Press, London, 729 p.

Kinsey, D.W. and Davies, P.J. 1979. Effects of elevated nitrogen and phosphorus on coral reef growth. Limnol. Oceanogr., 25, 939-940.

National Shellfish Sanitation Programme. 1964. Proceedings Fifth National Shellfish Sanitation Workshop, United States Department of Health, Education and Welfare, Washington, D.C.

Olson, T.A. and Burgess, F.J. 1967. Pollution and Marine Ecology, Interscience Publishers, New York.

Rasmussen, C. 1988. Effects of nutrients carried by mainland run-off on reefs in the Cairns area : A research plan and preliminary results. In: Baldwin, C.L. (Editor) Nutrients in the Great Barrier Reef Region, GBRMPA Workshop Series No.10, pp.66-91.

Ruivo, M. 1972. Marine Pollution and Sea Life, Fishing News (Books) Ltd, 624 p.

Sachet, M.H. 1957. Climate and meteorology of the Gilbert Islands. Atoll Res. Bull., 60, 4p + appendices.

Smith, S.V., Kimmerer, W.J., Laws, E.A., Brock, R.E. and Walsh, T.W. 1981. Kaneohe Bay sewage diversion experiment: perspectives on ecosystem responses to nutritional parturbation. Pac. Sci., 35, 279-395.

Stanton, R.L. and Bell, J.D. 1969. Volcanic and associated rocks of the New Georgia Group, British Solomon Islands Protectorate. Overseas Geology and Mineral Resources, 10, 113-145.

Stoddart, D.R. 1969. Geomorphology - the Marovo elevated barrier reef, New Georgia. Phil. Trans. Roy. Soc., B255, 383-402.

Thatcher, F.S. and Clark, D.S. 1978. Microorganisms in Food : Their Significance and Methods of Enumeration, Second Ed. ICMSF Publication, University of Toronto Press.

Thomascik, T. and Sander, F. 1985. Effects of eutrophication on reef building corals : Growth rate of the reef building coral Montastrea annularis. Mar. Biol., 87, 143-55.

UNEP/WHO. 1983. Determination of Faecal Coliforms in Bivalves by Multiple Test Tube Method. Reference Methods for Marine Pollution Studies No. 5, Rev. 1, UNEP, 15p.

UNEP/WHO, 1983 a. Determination of faecal coliforms in sea-water by the membrane filtration culture method. Reference Methods for Marine Pollution Studies No.3, Rev. 1, UNEP, 23 p.

UNEP/WHO, 1986. Assessment of the state of microbial pollution of shellfish and shellfish-growing waters in the Mediterranean Sea and proposed measures. Report of Fourth Meeting of the Working Group for Scientific and Technical Cooperation for MED POL, Athens 16-20 June 1986, 28 p.

Ure, A.M. and Berrow, M.L. 1982. The elemental constituents of soils. Environmental Chemistry, Volume 2, Royal Society of Chemistry, London, pp. 94-204.

USEPA. 1974. Current practices in water microbiology. United States Environmental Protection Agency National Technical Information Service, Springfield, Virginia, 340 p.

USEPA. 1976. Quality Criteria for Water. United States Environmental Protection Agency, Washington, D.C., 501 p.

Wetzel, R.G. 1975. Limnology. Saunders College Publishing, Philadelphia, 743p.

WHO. 1983. Compendium of Environmental Guidelines and Standards for Industrial Discharges. WHO, Geneva.

Yuen, T.L. 1980. Baseline Studies of port Vila and Erakor Lagoon, Vanuatu. Cruise Report No.82, CCOP/SOPAC, Suva, 31p.

Zann, L.P., Kimmerer, W.J. and Brock, R.E. 1984. The Ecology of Fanga'uta Lagoon, Tongatapu, Tonga. Sea Grant Cooperative Report No. UNIHI-SEAGRANT-CR-84-04, University of Hawaii, Honolulu, 100 p.

Zottoli, R. 1973. Introduction to Marine Environments. C.V. Mosby Company, Great Britain, 125 p.