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*Baseline study of the Vitogo River
and associated environment*

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PREFACE

Sixteen 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 concerted 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 fulfill 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 ten regions^{1/} and has over 120 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 (SPECC) 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.

^{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 and South Asian Seas.

^{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.

An Action Plan for the South Pacific Regional Environment Programme (SPREP) was adopted at the Conference on Human Environment in the South Pacific at Rarotonga, 8-11 March 1982, and was endorsed seven months later at the South Pacific Conference and South Pacific Forum^{3/}.

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^{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.

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EXECUTIVE SUMMARY

In 1983 the Fiji Pine Commission and British Petroleum South-West Pacific in a joint venture decided to construct a wood processing plant at Drasa, Western Viti Levu, to deal with the substantial pine wood being produced in nearby areas. The major water system in the area is the Vitogo River and it was therefore decided in 1984 to carry out a baseline study of this river and the associated environment to provide data for the assessment of the impact of the construction and operation of the processing plant. The main objective was to establish background levels for those environmental parameters which appeared to be most vulnerable to the effects of the plant operation. These included the general water quality of the river and the associated estuary, the heavy metal status of sediments and shellfish from the area and the extent of bacterial contamination of the water and shellfish (Gafrarium tumidum).

Water samples were collected at two monthly intervals from September 1984 to July 1985 from five sites for general water quality investigations. Sediment samples were collected from two sites and shellfish from one site over the same period. From September 1985 to January 1986 water samples were collected at two monthly intervals from five sites for heavy metal analysis; sediments and shellfish were collected at the same time from two sites. All samples were analyzed using standard techniques.

During the period of the study prior to the construction of the processing plant the environment in the Vitogo area was relatively free from contamination. Water quality was generally good. The values for heavy metals in both sediment and shellfish were low, often below the detection limits available, indicating a virtually pollution-free situation. Coliform contents of shellfish were all within the USEPA standards set for edible material.

This contamination-free situation may change once the processing plant becomes operational because wastes such as storm water run-off and overflows, waste oil, treated domestic sewage, burnt ash and residual wood treatment chemicals containing toxic elements such as copper, chromium and arsenic will pose problems of handling and disposal. However, with careful consideration of the proposals presented in this report the likely effects of the impact of the development on the Vitogo area environment can be kept to a minimum.

1. INTRODUCTION

Development activities in countries such as Fiji depend largely on the exploitation of natural resources which tend to be more vulnerable in tropical regions than elsewhere. Every effort must be made to preserve the natural resources for sustained development. Excessive demands on limited resources will result in significant deterioration of the ecological systems upon which life depends. Indications of such misuse usually show up as soil erosion, lack of water or its quality, deforestation, depletion of ecologically important life forms and other adverse natural phenomena. The implications of such effects on the quality of the environment should cause even more concern if the area to be developed has been relatively free of environmental problems as in the case of the Vitogo River and associated bay area in Western Viti Levu, Fiji, where a sawmill and chipmill is to be constructed to process the pine timber cultivated in the adjacent forests.

The Vitogo River enters the sea near Lautoka, the second largest city in Fiji. Until the last decade all industrial development in this area has been confined to within a few kilometres radius of the city. The area under study, which falls outside the city boundaries, has not been influenced by any major environmental changes arising from industrial development. In the surrounding hills a major pine forest plantation has been developed over the last twenty-five years. While some pine harvesting has occurred, little wood treatment has taken place; the effects of harvesting on the environment have therefore been considered to be minimal. However, the construction of the sawmill and chipmill may significantly affect water quality in the Vitogo River and associated coastal areas. The effects of the mill on the quality of the environment can be evaluated in future only on the basis of comparison with the present state of the environment.

Obviously, this necessitates the completion of a baseline study. The Institute of Natural Resources (INR), with financial support from SPREP, was able to carry out the baseline study, the objectives of the study being:

- to generate baseline data on the quality of the Vitogo River estuary and adjacent coastal bay area; and
- to assess the potential impact of the wood chipmill on the quality of the studied area and provide a proposal for mitigation of effects.

This report is a record of the findings of the baseline study. This introductory section is followed by a description of the physical characteristics of the study area. The section "Method of Investigation" records details on location of sampling sites, samples collected, regularity of sampling and analyses performed. Results and discussion of environmental quality investigations follow. Under "Potential Impact of Sawmill and Chipmill Development" the potential impact of the development on the environment and possible mitigative measures are projected. Some concluding remarks are made in the last section.

2. DESCRIPTION OF AREA

The geographical setting of the area under consideration with respect to Lautoka city is shown in Figure 1. The location of the processing complex, about 14 km north-east of Lautoka, is also indicated. Some physical characteristics of interest are outlined below.

2.1 Topography

The area is of variable terrain, from a coastal plain to gently rolling hill country a few kilometres in the interior to moderately steep dissected land along the foothills of the Mount

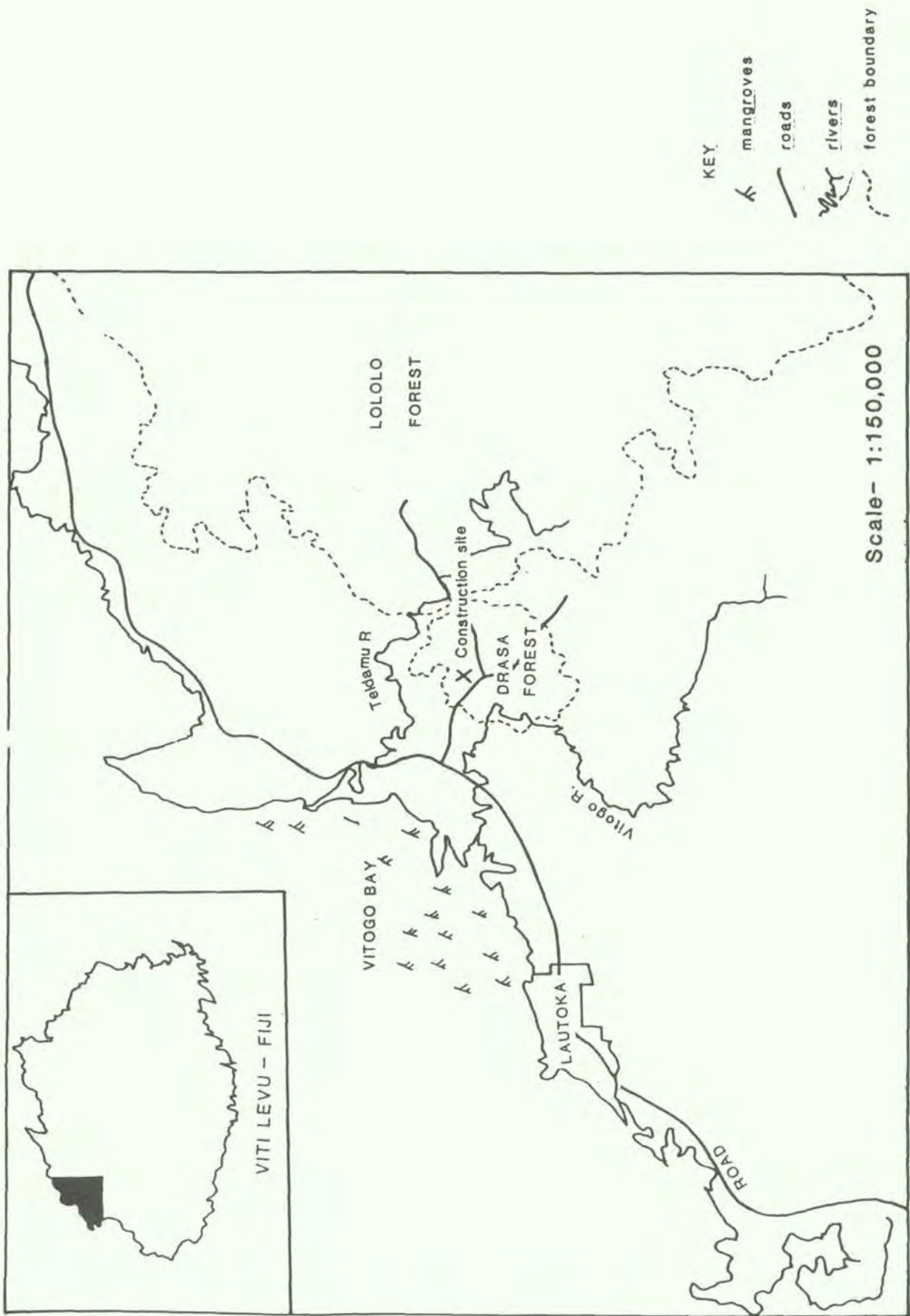


Figure 1. The study area

Evans Range. Elevation ranges from 40 m above sea level (asl) near Drasa to about 540 m asl in the vicinity of the Lololo Forest lookout. The elevation of the mill site is approximately 60 m asl. The site is on the northern side of a gently sloping ridge, falling towards the north-west, on the coastal plain. Between 1 and 4 kilometres west of the site is the coastal plain which extends to the south-west past Lautoka.

2.2 Geology

The geology of the Lautoka area is described in detail by Bartholomew (1959). The rocks underlying the higher elevation areas are mainly of volcanic origin, deriving from basaltic and andesitic volcanic activity during the Plio-Pleistocene period. The rocks include augite-olivine basalt flows, tuffs, volcanic breccias and associated sediments. The sediments of the coastal plain apparently comprise about 10 m of clayey alluvium.

2.3 Soils

The soils in this area form a complex of Oxisols, Ultisols and Inceptisols with minor areas of Entisols, Alfisols and Mollisols (Twyford and Wright, 1965; Leslie *et al.*, 1985).

Oxisols: these are typical soils of the highly weathered and highly degraded dry zone areas of Fiji. They have been formed in materials that have been intensively weathered chemically and frequently have oxidic mineralogy. They generally have red colours, deep profiles, high porosity, weak structures and are erosion prone. They tend to be moderately acidic (pH 5-6) and low in Ca, Mg, K and P.

Ultisols (usually Oxyc subgroup): have better structures than Oxisols with clay accumulation in subsoil horizons. The mineralogy tends to be kaolinitic and oxidic. They generally have red or red-brown colours, are moderately to strongly acidic (pH 4.5-6) and are formed from weathering products of basalts and andesites. In a few areas soils having similar morphological features but having high base status (Alfisols) have been identified.

In some highly degraded areas erosion has removed most of the soil profile leaving a thin surface layer on top of *in situ* weathered rock. These soils frequently are strongly acidic (pH 4-5) and are classified as Entisols or Inceptisols.

There are limited areas of shallow, dark, soils found particularly on steeper slopes and formed from uplifted sediments. They are strongly structured due to the presence of montmorillonites which stabilize soil aggregates. These shallow dark soils (known locally as nigrescents) have a high pH (pH 6-7.3) and are relatively rich in phosphate, bases and organic matter. These soils are classified as Inceptisols or Mollisols.

2.4 Climate

The island of Viti Levu is divided climatically into two zones, the north-west (project area) region having a marked dry season from May to November and the south-east region having a humid climate with a more evenly distributed rainfall. Surface wind directions and speed in the region exhibit a marked diurnal variation (Sharma, 1982). During the day, westerly to north-westerly wind flow (sea breeze) usually prevails while south-westerlies usually predominate at night. South-easterlies tend to be augmented by a downhill wind drift from the east, i.e. a night-time land breeze. The average annual temperature of the area under study is 26 °C and the average annual rainfall is 2.5 m at Lololo which is the closest monitoring station to the study area [Fiji Meteorological Service information supplied to Cawthron Technical Group (1984)].

2.5 Vegetation

Most of the steeper slopes of the region are under pine (*Pinus caribaea* var. *hondurensis*) cultivation as shown in Figure 1. The pines were established on badly degraded "talasiga" grasslands. Talasiga vegetation, consisting of the introduced mission grass (*Pennisetum polystachyon*), Karuka fern (*Pteridium esculentum*), Qato or bracken fern (*Dicranopteris linearis*) and Nokonoko (*Casuarina equisetifolia*), can still be found in places. Remnants of indigenous hardwood forest occur within the pine plantations. The native reed (*Miscanthus floridulus*) and the guava (*Psidium guajava*) are common in such areas. The flat coastal area and the rolling countryside have been utilized for intensive sugarcane cultivation. The lower reaches of the Vitogo River and the Vitogo Bay have rich stands of mangroves.

2.6 Water resources

The major rivers draining the catchments of the study area are the Vitogo and the Teidamu. The catchment areas of these two rivers are marked in Figure 2. The Vitogo River is of particular interest in this study because water requirements of the mill are to be met by drawing water (position marked in Figure 2) at a rate of 0.015 m³/sec from this source. The catchment area of the Vitogo River extends well into the foothills of Mount Evans Range. The major tributaries are Vilakolewasautoko Creek, Savubasaga Creek and the headwaters of the river itself. The Teidamu River is also of interest because it drains the area around the mill. These two rivers constitute a major proportion of the fresh water input into Vitogo Bay. Other fresh water inputs to Vitogo Bay are shown in Figure 3.

3. METHOD OF INVESTIGATION

The Institute of Natural Resources was involved in studies of the general quality of the water at the proposed intake site even before this comprehensive baseline study was initiated. The data obtained from that study is given in Table 1. As part of the present study a preliminary tour of the project area was made in July 1984 to determine accessibility to potential sampling sites, availability of appropriate sample types that would indicate water quality and the precautionary measures that would need to be taken for sample preservation. Details of the location of the sampling sites, dates of sampling, types of samples collected and the analyses performed are outlined in this section.

3.1 Sample collection

The type of sample that is usually collected in investigations into water quality is the actual water itself. However, when looking at water quality from the point of view of pollution one often needs to measure parameters that, in water, are present in extremely low concentrations, such that detection is sometimes impossible with the facilities available. The higher concentrations that occur in bioaccumulating organisms and sediments with which the water in question is in contact can be used as a partial solution to this problem. Sediments and shellfish can be very appropriate indicators of water quality because polluting agents such as heavy metals tend to concentrate in such samples and are therefore more easily detectable. Besides, studies on heavy metals in shellfish are useful in themselves because they indicate the quality of shellfish which are usually heavily harvested for human consumption. With these considerations in mind it was decided that water, sediment and shellfish samples would be collected from various sites within the study area (Figure 4) for general water quality, heavy metal and coliform status determination. The most common species of shellfish found in the area was *Gafrarium tumidum*, a food source for the local villagers. Water was sampled bimonthly at five sites (marked 1 to 5 in Figure 4) along the Vitogo River from September 1984 to July 1985 for general water quality

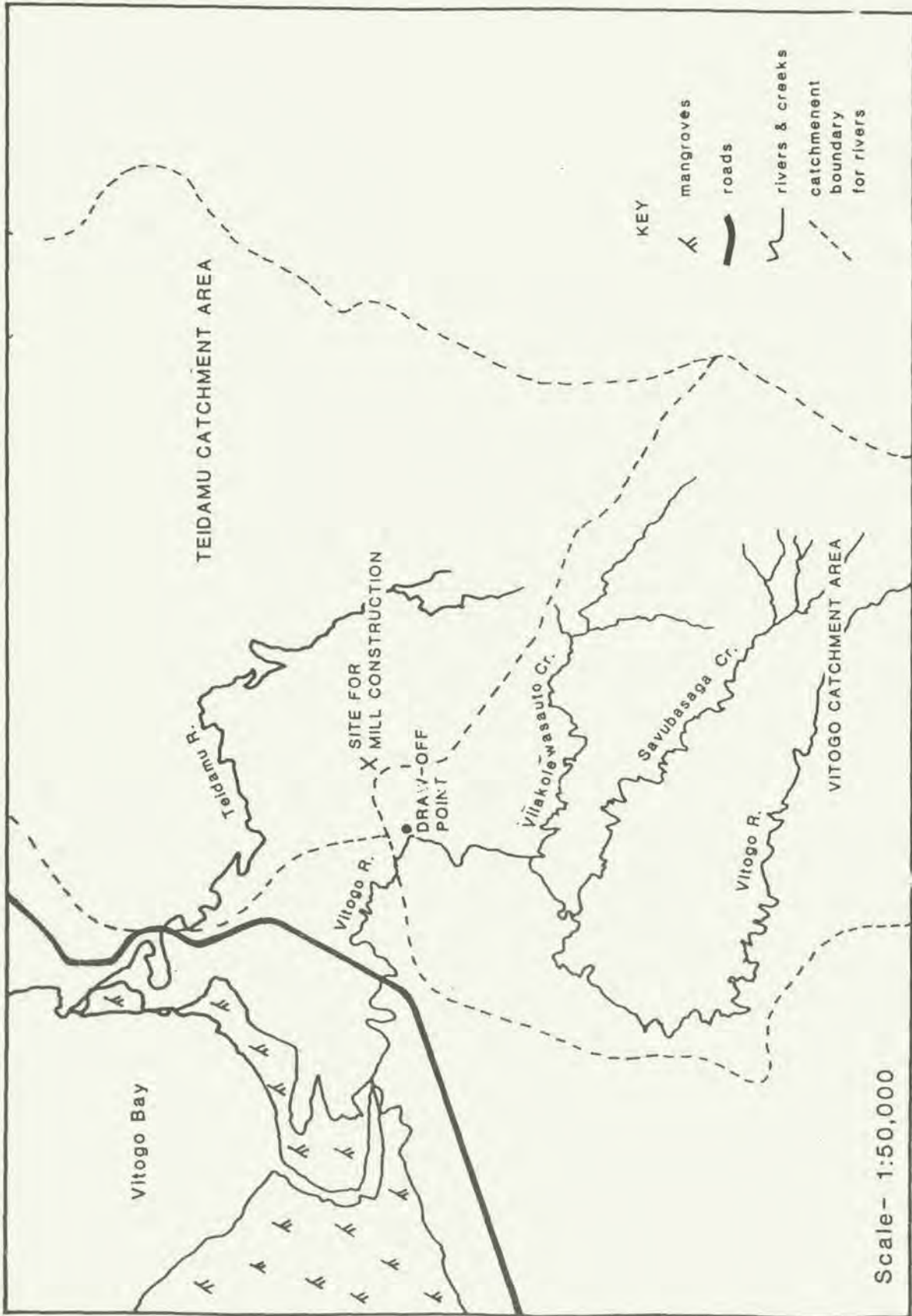


Figure 2. Vitogo and Teidamu catchment areas

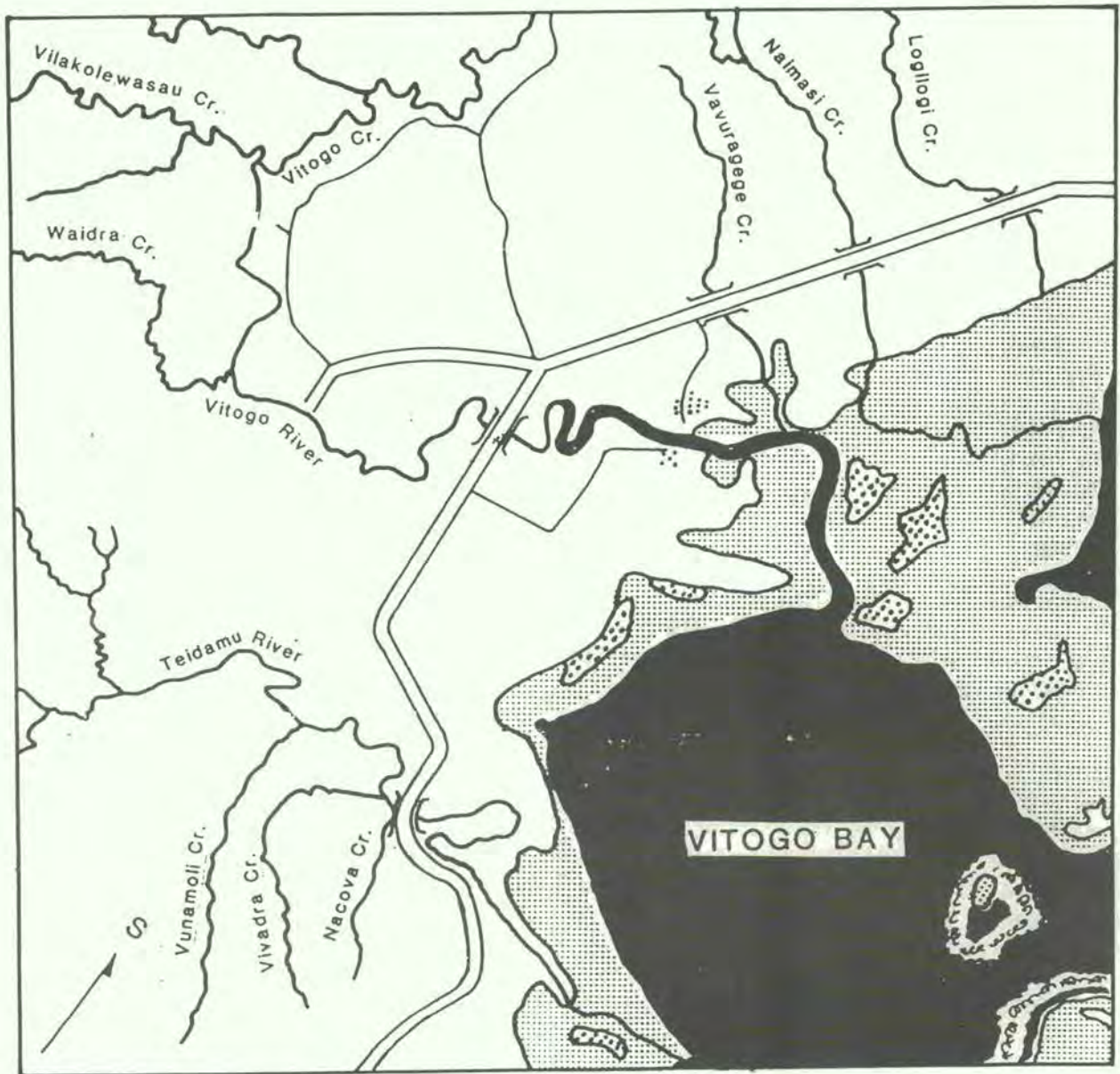


Figure 3. Freshwater inputs into Vitogo Bay

Table 1. General water quality results for water draw-off point on the Vitogo River*

Measurement	1983						1984	
	Feb.	Jul.	Aug.	Oct.	Nov.	Dec.	Mar.	Apr.
pH	6.95	9.20	7.71	9.00	7.00	7.20	6.30	7.10
Turbidity	170	14	30	6	18	32	10	6
Colour	35	25	45	5	15	45	25	15
Alkalinity (mg CaCO ₃ /l)	26	53	37	52	33	23	8	34
Total Fe (mg/l)	<0.2	0.84	0.77	0.22	0.73	2.0	0.32	0.37
Dissolved Fe (mg/l)	<0.2	0.15	0.07	0.5	0.23	0.50	0.14	0.09
Total Mn (mg/l)	<0.1	0.60	0.50	<0.1	<0.1	0.10	<0.1	<0.1
Dissolved Mn (mg/l)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Cl (mg/l)	7.2	12.0	8.0	6.1	6.2	6.0	5.8	6.2
SO ₄ (mg/l)	19.5	6.8	3.5	4.0	1.4	1.2	11.0	3.0
Total dissolved solids (mg/l)	80	120	140	70	55	58	46	80
Suspended solids (mg/l)	107	1.6	3.3	3.2	20	26	2.5	0.4
Ca (mg/l)	5.0	13.9	12.0	9.1	5.6	6.0	1.5	1.5
Mg (mg/l)	1.8	3.5	3.4	4.1	4.3	2.4	0.9	0.9
Na (mg/l)	10.8	8.7	7.1	5.0	4.9	3.3	3.8	3.8
K (mg/l)	0.86	0.80	1.0	2.0	1.8	1.2	0.70	0.70

* Water samples were received from the joint venture company such that more than 24 hours elapsed between collection and the initiation of analyses. No special preservation techniques were employed. Hence pH, turbidity, suspended solids, dissolved Fe and Mn data have low confidence limits.

determination. During the same period 5 sediment samples were taken from site 5 (Vitogo River bed), 8 from site 6 (Vitogo shellfish bed), and 3 from site 9 (Teidamu shellfish bed). Water samples were collected from September 1985 to January 1986 for heavy metal analyses only, from sites 1 to 3 along the Vitogo River and sites 7 and 8 along the Teidamu River. Shellfish were collected from sites 6 and 9 from May 1985 to January 1986 for coliform and heavy metal analyses. A summary of this information is given in Table 2.

3.2 Analytical procedures

The samples collected were brought back to the Institute of Natural Resources Analytical Services Laboratory where all analyses were carried out. Analytical procedures are outlined.

Analyses of water samples

Conductivity was measured on a conductivity meter standardized against a standard salt solution.

pH was measured with a glass electrode standardized against buffers of pH 4, 7 and 9.

Salinity was measured using a salinity meter standardized against a salinity standard.

Turbidity was measured in a nephelometer against suspended silica standards and is expressed as nephelometric turbidity units (NTU).

Alkalinity was measured by titrating an aliquot of the sample with standard HCl to the phenolphthalein end point for carbonate alkalinity and the mixed bromocresol green-methyl red end point for bicarbonate alkalinity (APHA-AWWA-WPCF, 1981).

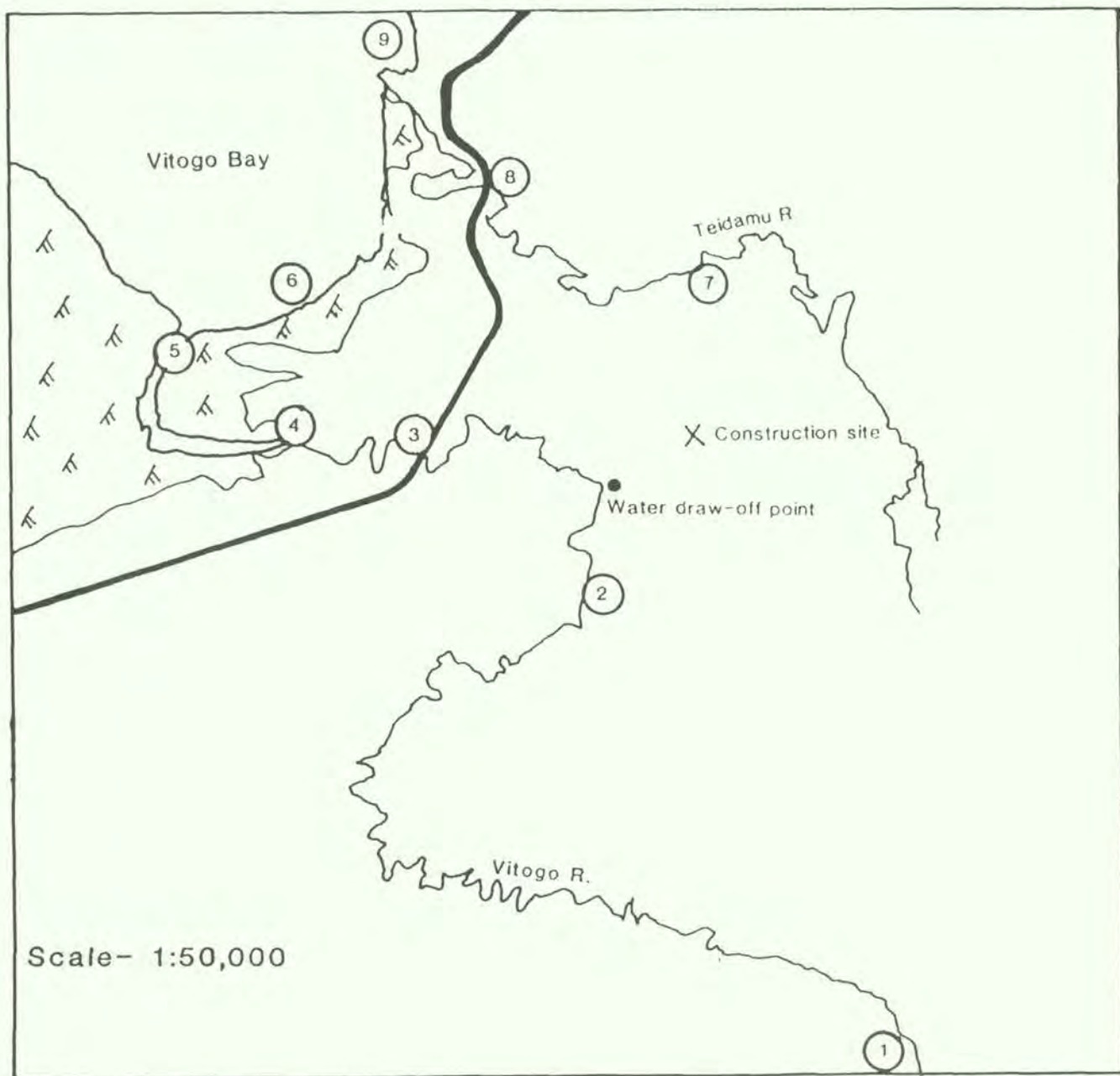


Figure 4. Sampling sites

Table 2. Summary of information on sampling and analysis

Bimonthly sampling	Sample types collected	Collection sites	Analysis performed
July 1984	(Preliminary tour - no sampling)		
September 1984 through July 1985	Water	1 to 5	General water quality - conductivity, pH, turbidity, salinity, alkalinity, Ca, Mg, Na, K, Fe, Mn, Cl, SiO ₂ , SO ₄ , NO ₃ , NH ₃ , TN, TP, PO ₄ , faecal and total coliforms*
September 1985 through January 1986	Water	1, 2, 3, 7, 8	Heavy metals (As, Cd, Cr, Cu, Fe, Hg, Mn, Pb, Se, Zn)
November 1984 through January 1986	Sediment	5, 6, 9	Heavy metals
May 1985 through January 1986	Shellfish	6, 9	Heavy metals, coliforms

* Coliforms only on September 1984 through March 1985 samples.

Calcium, magnesium, sodium and potassium were measured after suitable dilution by flame atomic absorption spectrophotometry (FAAS).

Chloride was measured using a chloride ion selective electrode.

Sulphate was measured using a turbidimetric barium sulphate method.

Silica (dissolved) was measured by a colorimetric procedure by formation of the reduced beta silicomolybdate complex.

Dissolved iron and manganese were measured after filtration of a sample which had been acidified immediately upon collection. The filtration, through a 0.47 µm membrane, was completed under vacuum and iron and manganese determined by FAAS on the filtrate.

Total iron and manganese were determined on another aliquot of the acidified sample. An aliquot of 3 cm³ of concentrated perchloric acid was added to 100 cm³ of the sample and the mixture heated and evaporated until fumes of perchloric acid were evolved. The digest was diluted to 100 cm³ and iron and manganese determined by FAAS.

Total Kjeldahl nitrogen was measured by Kjeldahl digestion using sulphuric acid, potassium sulphate and a selenium catalyst followed by steam distillation of the ammonia and determination by the indophenol blue colorimetric method (see ammonia method following).

Total phosphorus was measured by the orthophosphate method after digestion of the water sample with perchloric acid to fumes.

Ammonia was measured using the indophenol blue colorimetric method (APHA-AWWA-WPCF, 1981).

Nitrate was measured by the cadmium reduction column procedure and subsequent colorimetric measurement using sulphanilamide and 1-naphthylethylenediamine dihydrochloride to produce a red-azo compound (APHA-AWWA-WPCF, 1981).

Samples for heavy metal analysis were acidified upon sampling to a pH of less than 2 with nitric acid. The mercury sample was further preserved with addition of potassium dichromate. Cadmium, chromium, copper, lead and zinc were measured by complexing the metals with ammonium pyrrolidine dithiocarbamate (APDC), extracting the complexed form into an organic solvent (MIBK) and determined using FAAS. Arsenic and selenium were determined by the hydride generation technique and mercury by the cold vapour technique using a Perkin Elmer Mercury/Hydride System (MHS-10) linked to an atomic absorption spectrophotometer.

Faecal and total coliforms were determined using the membrane filtration method (APHA-AWWA-WPCF, 1981).

Analysis of sediments

Sediment samples were air dried and aggregates broken down to <2 mm in diameter. For total heavy metal content, a 0.5 g sample was digested completely with a mixture of perchloric, hydrofluoric and hydrochloric acids and made up to volume with deionized water. For weak acid extractable heavy metals, a 0.5 g sample was left to stand overnight with a 25% solution of acetic acid, centrifuged and the supernatant used for determination. Heavy metals such as cadmium, chromium, copper, iron, manganese, lead and zinc were measured using flame and graphite furnace atomic absorption spectrophotometry. Arsenic, selenium and mercury were determined as for water samples (see above).

Analysis of shellfish

The flesh from approximately twenty shellfish from each site was homogenized to give a composite sample. A subsample was digested with nitric acid and heavy metals in the digest determined by the techniques described above. Coliform counts in the sample were determined by the multiple tube technique. Moisture content of the sample was measured by determining moisture lost on drying a subsample at 105 °C to a constant weight.

4. RESULTS AND DISCUSSION

4.1 General water quality

The results of the analyses carried out on the samples collected from the Vitogo River for indication of general water quality are given in Tables 3 to 8. Some characteristics of the river drawn from visual observations made during sampling trips, interpretation of data assembled over the duration of the project and from discussions with other interested parties (e.g. hydrologists) are outlined below.

Vitogo River flow

The Hydrology Section of the Ministry of Works has carried out occasional discharge measurements since 1969, and more regularly since August 1977. Fortunately, the flow measurements have been taken at a site which coincides with one of the water sampling sites of this study (site 2 in Figure 4) and is some 1.5 km upstream from the proposed intake site for the mill water supply. The analyses are based on spot gauging and extrapolated on the basis of rainfall patterns. The data is given in Table 9. A point worth noting is that such flow rates are not representative of the entire river. Visual observations indicate great variability in flow rate in different sections of the river.

Table 3. Results of samples collected on 12-13 September 1984

Measurement	Site				
	1	2	3	4	5
Conductivity (mS/cm)	0.184	0.102	20.8	29.6	42.3
pH	7.60	8.60	7.55	7.63	7.88
Turbidity	5.4	8.0	11.0	8.4	10.4
Salinity (ppt)	0	0	16.2	23.2	34.6
Alkalinity (mg CaCO ₃ /l)	52.3	50.3	77.7	91.4	108
Ca (mg/l)	10.8	8.7	-	-	-
Total Fe (mg/l)	0.2	0.4	0.6	0.5	0.6
Dissolved Fe (mg/l)	<0.2	<0.2	<0.2	<0.2	<0.2
Total Mn (mg/l)	<0.1	<0.1	<0.1	<0.1	<0.1
Dissolved Mn (mg/l)	<0.1	<0.1	<0.1	<0.1	<0.1
Cl (mg/l)	1.8	2.1	-	-	-
SiO ₂ (mg/l)	48.2	53.5	28.9	21.4	4.8
SO ₄ (mg/l)	2.2	3.5	-	-	-
Mg (mg/l)	1.9	2.5	-	-	-
Na (mg/l)	5.8	7.5	-	-	-
K (mg/l)	1.2	1.6	-	-	-
NO ₃ (mg/l)	0.21	0.06	0.05	0.04	0.04
NH ₃ (µg/l)	45	<20	37	33	<20
TN (mg/l)	2.20	1.68	1.91	2.30	2.61
TP (µg/l)	152	244	116	150	212
PO ₄ (µg/l)	466	748	356	460	650

Table 4. Results of samples collected on 6-7 November 1984

Measurement	Site				
	1	2	3	4	5
Conductivity (mS/cm)	0.083	0.089	25.9	28.3	40.1
pH	8.05	9.10	7.62	7.64	7.73
Turbidity	5	18	10	8	9
Salinity (ppt)	0	0	20	22.1	32.5
Alkalinity (mg CaCO ₃ /l)	40.4	42.9	85.1	88.1	106.6
Ca (mg/l)	9.2	8.1	-	-	-
Total Fe (mg/l)	<0.2	0.5	<0.2	0.5	0.5
Dissolved Fe (mg/l)	<0.2	0.3	<0.2	<0.2	<0.2
Total Mn (mg/l)	<0.1	<0.1	<0.1	0.2	0.2
Dissolved Mn (mg/l)	<0.1	<0.1	<0.1	<0.1	<0.1
Cl (mg/l)	0.4	0.5	-	-	-
SiO ₂ (mg/l)	30.8	43.0	20.0	17.1	8.0
SO ₄ (mg/l)	<1	5	-	-	-
Mg (mg/l)	0.25	0.29	-	-	-
Na (mg/l)	6.3	6.6	-	-	-
K (mg/l)	1.3	1.8	-	-	-
NO ₃ (mg/l)	0.31	0.02	0.04	0.01	0.22
NH ₃ (µg/l)	5	7	18	8	6
TN (mg/l)	0.31	4.39	3.40	0.93	0.31
TP (µg/l)	173	226	144	280	312
PO ₄ (µg/l)	502	793	446	858	956

Table 5. Results of samples collected on 14-15 January 1985

Measurement	Site				
	1	2	3	4	5
Conductivity (mS/cm)	0.059	0.087	12.77	41.90	47.20
pH	6.7	8.7	7.2	7.5	7.9
Turbidity	6	20	10	8	8
Salinity (ppt)	0	0	9.0	31.1	38.0
Alkalinity (mg CaCO ₃ /l)	28.2	42.7	59.9	113.3	115.1
Ca (mg/l)	5.1	7.6	-	-	-
Total Fe (mg/l)	0.6	0.7	0.4	0.5	0.4
Dissolved Fe (mg/l)	<0.2	0.4	<0.2	0.2	0.3
Total Mn (mg/l)	<0.1	<0.1	<0.1	<0.1	<0.1
Dissolved Mn (mg/l)	<0.1	<0.1	<0.1	<0.1	<0.1
Cl (mg/l)	0.8	3.1	-	-	-
SiO ₂ (mg/l)	23	37.0	28.0	4.8	2.1
SO ₄ (mg/l)	<1	<1	-	-	-
Mg (mg/l)	1.2	2.4	-	-	-
Na (mg/l)	3.6	5.0	-	-	-
K (mg/l)	0.73	1.2	-	-	-
NO ₃ (mg/l)	0.5	0.24	0.03	<0.01	0.01
NH ₃ (µg/l)	45	25	32	32	32
TN (mg/l)	8.3	8.3	11.1	5.8	9.2
TP (µg/l)	30	120	30	30	20
PO ₄ (µg/l)	92	25	61	92	31

Table 6. Results of samples collected on 27-28 March 1985

Measurement	Site				
	1	2	3	4	5
Conductivity (mS/cm)	0.059	0.071	0.074	1.140	12.11
pH	5.9	5.8	6.5	6.9	6.8
Turbidity	1	12	24	48	10
Salinity (ppt)	0	0	0	0.8	9.1
Alkalinity (mg CaCO ₃ /l)	23.4	27.0	25.6	25.2	48.4
Ca (mg/l)	5.6	5.8	4.8	10	-
Total Fe (mg/l)	<0.2	1.2	1.2	1.8	0.4
Dissolved Fe (mg/l)	<0.2	1.0	1.2	1.5	<0.2
Total Mn (mg/l)	<0.1	<0.1	<0.1	<0.1	<0.1
Dissolved Mn (mg/l)	<0.1	<0.1	<0.1	<0.1	<0.1
Cl (mg/l)	4.8	5.2	-	-	-
SiO ₂ (mg/l)	28	23	18	17	16
SO ₄ (mg/l)	<1	<1	-	-	-
Mg (mg/l)	1.2	1.9	1.8	26.0	-
Na (mg/l)	2.1	2.1	2.4	59	-
K (mg/l)	0.77	0.99	0.98	7.4	-
NO ₃ (mg/l)	0.11	0.19	0.42	0.52	0.06
NH ₃ (µg/l)	10	42	46	103	42
TN (mg/l)	4.2	3.1	2.9	3.0	2.2
TP (µg/l)	320	85.2	65.2	130	85.2
PO ₄ (µg/l)	102	139	184	215	92

Table 7. Results of samples collected on 28-29 May 1985

Measurement	Site				
	1	2	3	4	5
Conductivity (mS/cm)	0.083	0.096	7.48	27.0	37.9
pH	7.0	7.5	6.6	6.7	7.1
Turbidity	1	10	20	20	10
Salinity (ppt)	0	0	5.7	21.1	30.7
Alkalinity (mg CaCO ₃ /l)	39	50	58	83	100
Ca (mg/l)	8.7	9.6	61	-	-
Total Fe (mg/l)	<0.2	0.2	0.3	<0.2	0.2
Dissolved Fe (mg/l)	<0.2	<0.2	<0.2	<0.2	<0.2
Total Mn (mg/l)	<0.1	<0.1	<0.1	<0.1	<0.1
Dissolved Mn (mg/l)	<0.1	<0.1	<0.1	<0.1	<0.1
Cl (mg/l)	3.4	1.9	-	-	-
SiO ₂ (mg/l)	29	41	34	18	9
SO ₄ (mg/l)	3	7	425	1640	3000
Mg (mg/l)	0.8	1.1	-	-	-
Na (mg/l)	6.6	6.8	-	-	-
K (mg/l)	1.0	1.3	-	-	-
NO ₃ (mg/l)	0.12	0.31	<0.01	0.25	9.3
NH ₃ (µg/l)	62	48	68	140	108
TN (mg/l)	7.5	3.8	2.9	3.2	2.0
TP (µg/l)	450	250	200	165	15
PO ₄ (µg/l)	98	196	196	25	25

Table 8. Results of samples collected on 29-30 July 1985

Measurement	Site				
	1	2	3	4	5
Conductivity (mS/cm)	0.069	0.099	17.4	25.7	49.9
pH	7.7	6.9	7.2	7.3	7.6
Turbidity	2	2	7	4	10
Salinity (ppt)	0	0	13.3	20.1	41.1
Alkalinity (mg CaCO ₃ /l)	-	-	-	-	-
Ca (mg/l)	16.8	18.2	-	-	-
Total Fe (mg/l)	<0.2	0.4	0.7	0.6	0.8
Dissolved Fe (mg/l)	<0.2	0.3	0.5	0.4	0.2
Total Mn (mg/l)	0.1	0.1	0.3	0.1	0.2
Dissolved Mn (mg/l)	<0.1	0.1	0.2	0.1	0.1
Cl (mg/l)	3.4	3.2	4920	2600	-
SiO ₂ (mg/l)	20	35	24	20	5.4
SO ₄ (mg/l)	5	3	3740	-	-
Mg (mg/l)	3.8	4.6	-	-	-
Na (mg/l)	3.1	4.8	-	-	-
K (mg/l)	4.0	1.4	-	-	-
NO ₃ (mg/l)	0.50	0.31	0.11	0.07	3.1
NH ₃ (µg/l)	100	26	28	34	32
TN (mg/l)	3.6	2.1	3.1	2.3	2.5
TP (µg/l)	70	85	70	45	25
PO ₄ (µg/l)	92	153	92	61	61

Table 9. Flow data for the Vitogo River*

	Flow estimate (m ³ /sec)
Mean annual minimum	0.23
5-year minimum	0.17
30-year minimum	0.11
Average low flow (1983 drought period)	0.18
Average annual peak flow	120

* Data from Hydrology Section of Ministry of Works.

Salinity and turbidity

It is obvious from the salinity measurements recorded in Tables 3 to 8 that the salt wedge is located between sites 2 and 3 in Figure 4. More detailed measurements made by Stonefish Co. Ltd. (1983) have shown that the salt wedge does not reach the proposed intake site for the mill water. The data given in Table 1 demonstrates the absence of any tidal effect at this site. In appearance, the river water above the influence of salinity (especially at site 1) is generally clearer than the greenish-brown coloured water in the lower reaches of the river stirred up by tidal movement and wind. It would appear from the data obtained that prior to March 1985 there was a build-up of turbidity at site 2. This was due to severe infestation of the site with water weeds which restricted river flow and clearing of turbidity. The two cyclones in March 1985 accompanied by torrential amounts of rainfall dislodged this accumulation from site 2 and carried it further downstream. The effect of this and increased silt loading due to high levels of rainfall can be seen in subsequent turbidity measurements. The river in appearance has virtually no silt load during the predominantly dry conditions that prevail through most of the year.

Chemical composition

The water carried in rivers consists of contributions from several sources. One of these is the subsurface water and groundwater which re-enters the surface river water and the other is the direct surface run-off fraction which enters the drainage system during and soon after precipitation periods. In the case of the Vitogo River the contribution from the sea water to a certain point needs also to be considered. The relative inputs from each of these sources and the concentration of dissolved species in each determine the chemical composition of the water at the different sites along the Vitogo River. The water of site 1, which is totally removed from any possible salt water influence and has its composition affected by surface and subsurface contributions only, is taken for discussion. The composition of each of these waters is looked at before their affect on the river water is considered. The surface run-off would normally have only a short contact with soil and vegetation, and hence the composition of species dissolved in it would not change dramatically from that in rainwater. There is a lack of data on rainfall composition for the area under study. Subsurface waters on the other hand tend to contain more dissolved material because of their more intimate and longer contact with organic material, soil and rock particles. Often there is a direct relationship between the composition of subsurface water and its host rock. For the Vitogo area which has a substratum of volcanic origin (see Geology Section), subsurface water characteristic of basaltic and andesitic host rocks would be expected. Once again there is a shortage of chemical composition data on subsurface waters in the area under study. Data reported by Garrels and MacKenzie (1968) for the spring waters of Sierra Nevada, considered as being characteristic of igneous rock areas, is used in this study for discussion purposes. The similarity in the Garrels and MacKenzie data and the data from the Vitogo River (Table 10) should be noted.

Table 10. Chemical composition data for site 1 on the Vitogo River and the spring waters of Sierra Nevada (Garrels and MacKenzie, 1968)

Measurement	Vitogo River						Sierra Nevada water
	Sept. 84	Nov. 84	Jan. 85	Mar. 85	May 85	July 85	
pH	7.6	8.1	6.7	5.9	7.0	7.7	6.8
Ca (mg/l)	10.8	9.2	5.1	5.6	8.7	16.8	10.4
Cl (mg/l)	1.8	0.4	0.8	4.8	3.4	3.4	1.06
SiO ₂ (mg/l)	48.2	30.8	23.0	28	29	20	24.6
SO ₄ (mg/l)	2.2	<1	<1	<1	3	5	2.38
Mg (mg/l)	1.9	0.25	1.2	1.2	0.8	3.8	1.70
Na (mg/l)	5.8	6.3	3.6	2.1	6.6	3.1	5.95
K (mg/l)	1.2	1.3	0.73	0.77	1.0	4.0	1.57
NO ₃ (mg/l)	0.21	0.31	0.50	0.11	0.12	0.50	0.28
CaCO ₃ (mg/l)	52.3	40.4	28.2	23.4	39.0	-	54.6

As already pointed out the composition of the water in rivers is dependent upon relative contributions from surface and subsurface sources. During periods of low rainfall, the direct run-off is small and the river water is predominantly of subsurface origin which has reached solid-solution equilibrium. In this instance the solute concentration in the river is relatively independent of river flow. On the other hand, if direct run-off is larger than the flow that has penetrated into the subsurface, then the solute concentrations in the subsurface water are diluted by the direct run-off. Thus the solute concentrations in the river water would be inversely related to flow. Superimposed are the influences of pollution and waste disposal which in the case of Vitogo are considered to be insignificant. Fertilizer run-off from agricultural land may affect composition of river water downstream. Table 10 gives the concentration of certain dissolved species at site 1 at different times of the year and illustrates quite clearly the effect discussed. A dilution and hence a decrease in the concentration of most parameters under consideration is noted during the rainy months (November to May). In the lower reaches of the river the effect of sea water on the composition of the river water becomes increasingly obvious as evidenced by massive increases in conductivity, salinity and ionic composition.

4.2 Status of heavy metals in the study area

Although at suitable concentrations some heavy metals are essential for enzymic activity, they also form an important group of enzyme inhibitors when natural concentrations are exceeded. Metals such as Ag, Hg, Cd, Cu and Pb are particularly toxic and usually inhibit enzymes by forming mercaptides with sulphhydryl groups which are responsible for catalytic activity. Consequently, most heavy metals, whether essential or not, are potentially toxic to living organisms and their status in the environment needs to be carefully monitored.

Heavy metals in waters

The concentration of heavy metals (As, Cd, Cr, Cu, Hg, Pb, Se, Zn) in the Vitogo River and the adjacent Teidamu River were found to be less than their respective detection limits for the period of this study. Table 11 gives the results obtained together with the average concentration of these metals in river and ocean waters.

Table 11. Heavy metal content in the Vitogo and Teidamu Rivers from September 1985 to January 1986 and average river and ocean values given by Riley and Chester (1971)

Constituent	Vitogo and Teidamu (ug/l)	Average values (ug/l)	
		River water	Ocean water
As	<1	1	2.3
Cd	<2	0.03	0.05
Cr	<10	1	0.6
Cu	<2	5	3
Hg	<1	0.07	0.05
Pb	<20	3.0	0.03
Se	<1	0.2	0.45
Zn	<1	10	5

For some of the heavy metals (Cd, Cr, Hg, Pb and Se) it was not possible with the resources available to detect precisely near the average concentrations found in unpolluted waters. However, perhaps more important than the measurement of the actual quality is the distinction between the different physico-chemical forms that may be present because different physico-chemical forms usually participate in different ways in the biogeochemical cycles and heavy metals generally tend to be more toxic in ionized forms than in complexed forms. The US National Academy of Sciences (1973) set guidelines for hazardous levels of inorganic forms of heavy metals in coastal waters. With the exception of Hg, which could not be detected at the level reported by NAS, the hazardous levels for As, Cd, Cr, Cu, Pb, and Zn are considerably higher than those obtained in this study. This finding is not unexpected since the Vitogo and Teidamu Rivers are virtually pollution-free as far as heavy metal contamination is concerned.

Heavy metals in sediments

The concentration of heavy metals in sediments depends on natural and manmade processes including pollutant discharges, the geochemical environment, water discharges and water and sediment characteristics. Although heavy metals are transported from their source to the sediments both in solution and suspended matter, a high proportion is usually transported bound to suspended matter. The process of sedimentation is rapid in estuaries because as a river enters an estuary, its rate of flow is reduced and suspended sediments are deposited. Also changes in salinity and pH as freshwater mixes with sea water cause precipitation of metals and flocculation of colloidal clay particles. Heavy metals are removed from solution by co-precipitation or absorption.

Heavy metals in sediments may be differentiated into two categories according to their source: lithogenic and anthropogenic, or more simply, geochemical and manmade, respectively. The anthropogenic fraction which indicates the extent of pollution may be obtained by determining natural background levels and subtracting from existing values. Several methods may be utilized for establishing background levels:

- (a) average shale composition as a global standard;
- (b) fossil lake and river sediments as a standard for the effects of natural factors and mechanisms as well as regional influences;
- (c) recent deposits in relatively unpolluted areas; and
- (d) short, dated sedimentary cores which provide a historical record of the events that have occurred in the watershed of a particular river.

In the sediments under consideration in this study the anthropogenic fraction is considered to be negligible since the area is relatively unpolluted. The results reported in Table 12 provide an estimate of the natural background levels from November 1984 to January 1986. The heavy metal contents of the sediments are dominated by iron and manganese and to a lesser extent by copper and zinc. There does not appear to be any significant pattern in the results obtained over the sampling period. Comparison of data obtained with data available from other sources gives relatively good agreement, particularly for cadmium, chromium, mercury, lead and zinc (Table 13). However, the mineralogical and sedimentological composition of sediments should be an important consideration in comparison studies. Natural sediments are mixtures of sands, clays and organic constituents and since each component has its own particular physico-chemical characteristics, the interaction and concentration of heavy metals in natural sediments depend upon the composition of the sediments. This consideration may explain the elevated levels of copper, iron and manganese in the Vitogo and Teidamu sediments.

Discussion of the distribution of heavy metals in the different components of sediments raises the question on the various forms in which the heavy metals are present and their bioavailability. Heavy metals may be present in mineral crystal lattices, as precipitates or absorbed and adsorbed onto various organic and inorganic substrates. The fraction in crystal lattices of minerals is not bioavailable. For determination of those fractions relevant for geochemical and biological processes various leaching procedures may be utilized. In this study the weak (acetic) acid extractable fraction was determined. This procedure measures the bioavailable fraction thought to be associated with carbonates, hydrous iron and manganese oxides and organic molecules. Results are reported in Table 14 which show that up to 50% (Cr and Mn) of the total metal content can be present in potentially bioavailable forms.

Table 12. Total heavy metal content of sediment samples under study from November 1984 to January 1986 (mg/kg except for Fe which is expressed in %)

Site	Date of Sampling	As	Cd	Cr	Cu	Fe	Hg	Mn	Pb	Se	Zn
5 Vitogo River bed	Nov.84	8.4	1.7	35	130	9.3	<0.2	640	10	<0.2	85
	Jan.85	2.1	1.5	72	96	13	<0.2	1500	8.4	<0.2	140
	Mar.85	1.4	1.5	88	99	15	<0.2	1400	10	<0.2	150
	May 85	1.9	1.6	38	140	9.5	<0.2	870	9.3	<0.2	54
	Jul.85	3.7	1.2	42	150	9.0	<0.2	570	7.8	<0.2	78
6 Vitogo shellfish area	Nov.84	4.2	1.7	73	96	15	<0.2	1500	9.7	<0.2	150
	Jan.85	14	2.1	96	97	17	<0.2	1900	8.6	<0.2	190
	Mar.85	9.3	1.5	36	110	11	<0.2	930	9.3	<0.2	120
	May 85	2.2	1.1	100	100	19	<0.2	2200	6.8	<0.2	220
	Jul.85	7.8	1.7	79	110	16	<0.2	1600	8.8	<0.2	160
	Sep.85	2.9	2.2	77	92	16	<0.2	1800	7.2	<0.2	160
	Nov.85	10	2.1	91	91	16	<0.2	1600	7.1	<0.2	150
Jan.86	8.9	1.3	79	82	13	<0.2	1000	7.4	<0.2	110	
9 Teidamu shellfish area	Sep.85	1.8	1.7	95	78	11	<0.2	1300	7.5	<0.2	100
	Nov.85	12	2.9	69	59	8.4	<0.2	940	8.6	<0.2	88
	Jan.86	13	2.5	51	73	7.3	<0.2	700	9.0	<0.2	60

Table 13. Comparison with other sources of heavy metal content of sediments in the Vitogo area (mg/kg except for Fe which is expressed as %)

	VITOGO		TEIDAMU	PURARI ^a	Recent ^b
	Site 5 River bed	Site 6 Shellfish area	Site 9 shellfish area	River sediment	unpolluted aquatic sediments
As	1.4-8.4	2.2-14	1.8-13		
Cd	1.2-1.7	1.1-2.2	1.7-2.9	<0.1	0.10-1.50
Cr	35-88	36-100	51-95		20-190
Cu	96-150	82-110	59-78	44	20-90
Fe	9.0-15	11-19	7.3-11		1.2-6.7
Hg	<0.2	<0.2	<0.2	0.09	0.15-1.50
Mn	570-1500	930-2200	700-1300	639	100-1800
Pb	7.8-10	6.8-9.7	7.5-9.0	11	10-100
Se	<0.2	<0.2	<0.2		
Zn	54-150	110-220	60-100	85	50-250

a) Petr (1980)

b) Forstner and Wittmann (1979)

Table 14. Weak acid extractable fraction of heavy metals of sediments in Vitogo area
(a) (mg/kg for all metals except Fe which is expressed as %)
(b) (% of total heavy metal content that is weak acid extractable)

Site	Date of Sampling	As		Cd		Cr		Cu		Fe		Mn		Pb		Zn	
		(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
5 Vitogo River bed	Nov.84	<0.1	<1	<0.2	<7	18	50	13	10	0.31	3	250	39	<2	<20	13	15
	Jan.85	<0.1	<1	<0.2	<7	14	19	18	19	0.22	2	260	17	<2	<20	7.5	5
	Mar.85	<0.1	<1	<0.2	<7	26	30	13	13	0.33	2	390	28	<2	<20	8.9	6
	May.85	<0.1	<1	<0.2	<7	11	29	42	30	0.52	5	380	44	<2	<20	9.5	18
	Jul.85	<0.1	<1	<0.2	<7	14	33	40	27	0.20	2	140	25	<2	<20	12	15
6 Vitogo shell- fish area	Nov.84	<0.1	<1	<0.2	<7	30	41	14	15	0.30	2	450	30	<2	<20	8.1	5
	Jan.85	<0.1	<1	<0.2	<7	25	26	14	14	0.27	2	370	19	<2	<20	7.7	4
	Mar.85	<0.1	<1	<0.2	<7	11	31	17	16	0.32	3	280	30	<2	<20	8.9	7
	May.85	<0.1	<1	<0.2	<7	10	10	15	15	0.28	1	440	20	<2	<20	9.8	5
	Jul.85	<0.1	<1	<0.2	<7	24	30	18	16	0.33	2	490	31	<2	<20	9.5	6
	Sep.85	<0.1	<1	<0.2	<7	23	30	14	15	0.35	2	490	27	<2	<20	7.9	5
	Nov.85	<0.1	<1	<0.2	<7	28	31	7	8	0.25	2	480	30	<2	<20	8.1	5
Jan.86	<0.1	<1	<0.2	<7	25	32	10	12	0.33	3	460	46	<2	<20	9.0	8	
9 Teidamu shell- fish area	Sep.85	<0.1	<1	<0.2	<7	21	22	13	17	0.38	3	660	51	<2	<20	13	13
	Nov.85	<0.1	<1	<0.2	<7	18	26	16	27	0.41	5	370	39	<2	<20	9.4	11
	Jan.86	<0.1	<1	<0.2	<7	20	39	16	22	0.45	6	470	67	<2	<20	9.6	14

Heavy metals in shellfish

The total heavy metal content of the shellfish samples from May 1985 to January 1986 is given in Table 15. Data for other bivalve samples obtained by various other workers is included with the Vitogo data in Table 16 for comparison.

Table 15. Heavy metals in shellfish in the Vitogo area from May 1985 to January 1986 (mg/kg wet weight)

		As	Cd	Cr	Cu	Fe	Hg	Mn	Pb	Se	Zn
Vitogo	May 85	0.50	0.21	0.51	2.7	570	0.04	22	0.18	0.44	8.7
	Jul.85	0.68	0.08	0.39	2.6	1400	0.03	18	0.13	0.15	8.0
	Sep.85	0.58	0.08	0.59	3.0	670	0.03	11	0.17	0.44	10
	Nov.85	0.58	0.05	0.34	2.4	610	0.03	9.0	0.12	0.15	7.3
	Jan.86	0.55	0.03	0.39	1.7	890	0.01	11	0.12	0.15	6.0
Teidamu	Sep.85	1.6	0.16	0.78	2.5	790	0.04	15	0.15	0.29	9.0
	Nov.85	1.6	0.05	0.27	2.0	420	0.03	6.0	0.09	0.28	7.3
	Jan.86	1.6	0.04	0.50	1.5	560	0.02	5.6	0.14	0.33	8.5

Table 16. Heavy metals in shellfish (mg/kg)

	<u>Gafrarium tumidum</u>		<u>Mytilus edulis</u>		<u>Chama</u>	<u>Anadara</u>		
	VITOGO		TEIDAMU		<u>iostoma</u>	<u>granosa</u>		
	Wet wt.	Dry wt.*	Wet wt.	Dry wt.*	(Baseline data)	PHILIPPINES ^d		
					AUSTR ^c	Wet wt.		
					Dry wt.*			
As	0.50-0.68	2.5-3.4	1.6	8.0				
Cd	0.03-.21	.15-1.1	.04-.16	0.20-0.30	0.3-1.6	1.5-8.8	6.2-38.9	1-5
Cr	.34-.59	1.7-3.0	.27-.78	1.4-3.9				16-18
Cu	1.7-3.0	8.5-15	1.5-2.5	7.5-13	1.7-18	3.3-12.3	3.5-6.8	8-13
Fe	570-1400	2900-7000	420-790	2100-4000	8.3-49	2.5-601		560-1020
Hg	.01-.04	.05-.20	.02-.04	.10-.20	.2-.5		.006-.083	
Mn	9.0-22	45-110	5.6-15	28-75		4.2-33.3		11-19
Pb	.12-.18	.60-.90	.09-.15	.45-.75	0.1-2.0	0.6-38.9	<0.35-<1.01	7-18
Se	.15-.44	.75-2.2	.28-.33	1.4-1.7				
Zn	6.0-10	30-50	7.3-9.0	37-45	3.8-26	77-466	41.8-319	72-104

* Dry wt. = wet wt. x 5 (average of 80% moisture in samples)

a) Nielsen and Nathan (1975)

b) Fabris et al (1978)

c) Burdon-Jones and Denton (1984)

d) Hungspreugs (1985)

For comparison purposes the data for Anadara granosa from the Philippines would appear to be most appropriate because this shellfish, like the Gafrarium tumidum, lives buried in the sediments as distinct from, for example, Mytilus edulis which is anchored on top of sedimentary deposits. The primary source of heavy metals for Gafrarium tumidum and Anadara granosa would therefore appear to be the water just above the sediments in which they are present. Their siphons are projected through the sediment into the open water as they filter feed and this water is in much closer contact with the sediment than in the case of mussels and oysters.

The level of heavy metals in the Gafrarium tumidum is considerably lower, except for Fe and Mn, than the levels in the other species included in Table 16. It should be noted however that some of the species used for comparison arise out of moderately polluted areas, e.g. the Mytilus edulis from Port Phillip Bay in Australia and the Anadara granosa from the Philippines. Iron and manganese are two exceptions to the trend noted above.

Elevated levels of these metals in the Gafrarium tumidum could be the result of the high iron and manganese status of the water and sediments in the study area (see Tables 3 to 8 and "Heavy Metals in Sediments" section).

4.3 Coliform contamination

In coastal waters with sewage discharges there is usually a good correlation between the degree of pollution demonstrated by animal and plant indicators and by microorganisms of faecal origin. The faecal and total coliform counts in the water samples from the Vitogo River are given in Table 17.

Table 17. Coliform levels in the Vitogo River (organisms/100 cm³)

Vitogo River samples	Faecal coliforms			Total coliforms		
	Sept. 1984	Nov. 1984	Mar. 1985	Sept. 1984	Nov. 1984	Mar. 1985
Site 1	0	0	100	0	800	400
Site 2	0	100	0	0	110	60
Site 3	0	70	0	160	210	40
Site 4	0	200	0	0	200	100
Site 5	13	10	30	50	10	70

The maximum counts obtained for faecal and total coliforms over the monitoring period were 200 and 800 organisms/100 cm³, respectively. Faecal coliform organisms may be considered indicators of recent faecal pollution by warm blooded animals. In general faecal coliform bacteria do not cause human disease (although some strains of E. coli are implicated in gastroenteritis) but are indicators of the possible presence of human sewage and thus human pathogenic organisms which are excreted in faeces, e.g. Vibrio cholera, Shigella sps, Salmonella and Hepatitis A virus. Since the survival time of faecal coliforms once outside the gut and present in water bodies and in shellfish is different than for the pathogenic bacteria and viruses, they are somewhat uncertain indicators but no better indicator has yet been developed. Wolf (1972) reports that the USDI Committee on Water Quality Criteria recommends the average count of faecal coliforms not to exceed 2000 organisms/100 cm³. For waters for recreational purposes other than primary contact (swimming, etc.), an average of 1000/100 cm³ is recommended and 200/100 cm³ is the guideline considered for primary contact purposes. The faecal coliform counts in the Vitogo River are well within the above limits.

The total coliform group includes a great variety of bacteria such as faecal coliforms, Enterobacter, Citrobacter and Klebsiella, all having in common the property of being gram-negative and able to ferment lactose at 35-37 °C with acid and gas production. Several of the strains in the group are widespread in nature and do not necessarily originate in faecal material. Therefore they are of little value as indicators of faecal pollution. However as indicators of certain types of industrial wastes with a high content of polycarbohydrates, e.g. in sewage discharges from timber and paper mills, coliform bacteria counts may be useful.

The shellfish samples from the Vitogo area were analyzed for total coliform counts and a maximum value of 24 organisms per 100 g was obtained. This is very low when compared to the levels (of the order of 35,000 faecal organisms per 100 g) found in commonly eaten freshwater and marine bivalves (INR, unpublished data) in other parts of Fiji. Standards for shellfish meat in the US are less than 230 faecal coliforms per 100 g (USEPA, 1976).

5. POTENTIAL IMPACT OF SAWMILL AND CHIPMILL DEVELOPMENT

5.1 Project description

The project proposal comprises the harvesting of the forest, transportation of the logs to the industrial site at Drasa, the construction and operation of processing plant and equipment on the site to produce sawn timber, woodchips, posts and poles, and the transport of product to domestic markets and to the Lautoka port area for export.

The construction site of the mill in the area under study is shown in Figure 1. Included on the mill site will be a log debarking and sorting plant, a chipping plant, a sawmill, steamheated drying kilns, a timber preservation plant, a planer mill and a boiler to generate steam for processing and on site power generation. An outline of the industrial process is shown in Figure 5.

5.2 Impact assessment

Water abstraction from the Vitogo River

The water requirements of the mill are to be met by drawing water from the Vitogo River. The rate at which the water is to be abstracted is 0.015 m³/sec. The flow reductions which could be expected in the Vitogo River as a result of this draw-off are shown below.

	Flow estimate (m ³ /sec)	Post-abstraction flow (m ³ /sec)	Flow Reduction (%)
Mean annual minimum	0.230	0.215	6.5
5-year minimum	0.170	0.155	8.8
30-year minimum	0.110	0.095	13.6
Average low flow	0.181	0.166	8.3

Under normal annual low-flow conditions the abstraction represents approximately 6.5% of the natural flow and under extreme drought conditions (1 in 30 years) it would represent approximately 13.6% of the natural flow. Although this may not appear to be a significant proportion, the abstraction of any quantity of water would have some effect on the river environment. However,

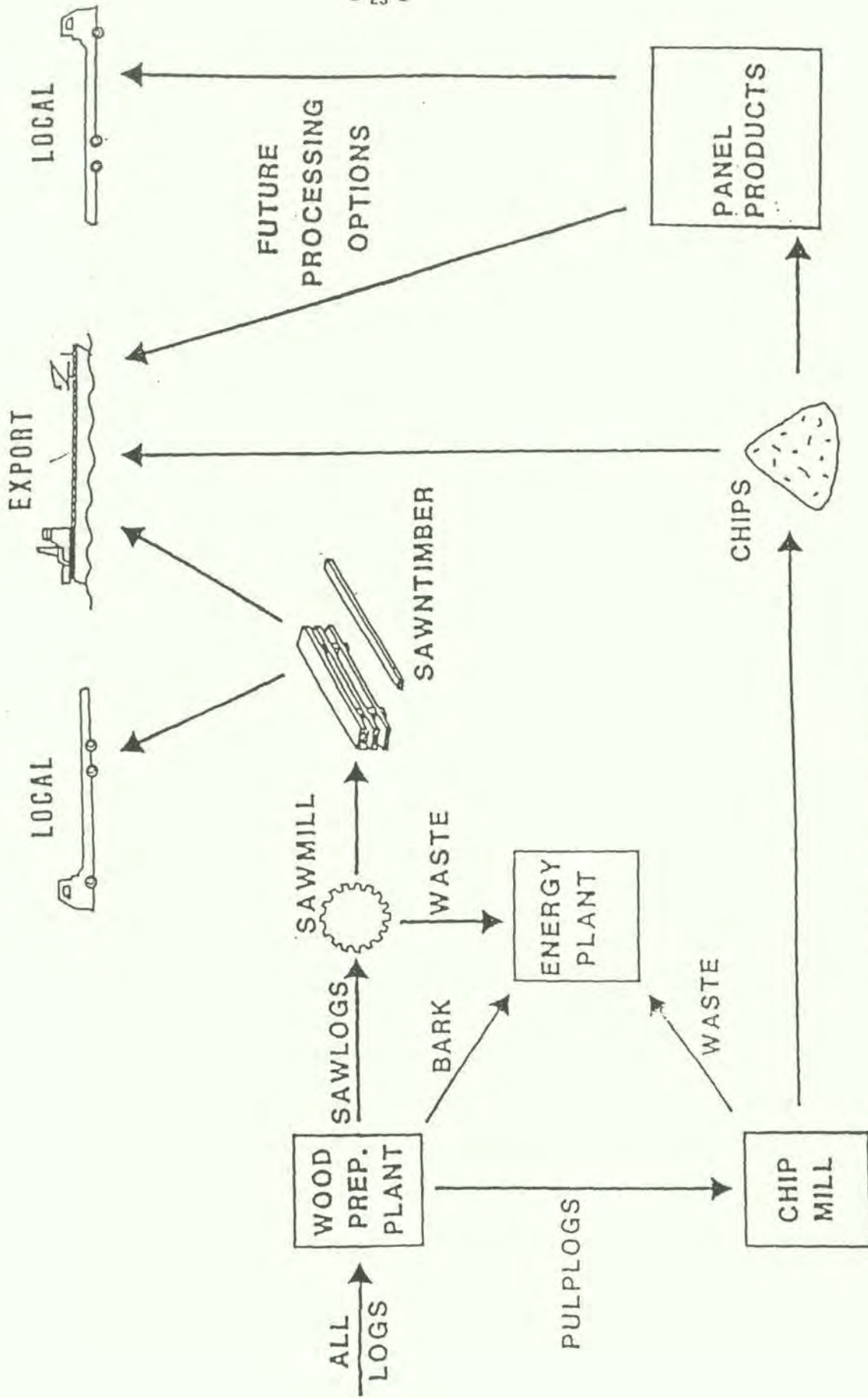


Figure 5. Sawmill and chipmill process

the likely effects are difficult to predict at the present time. They would become evident once water abstraction is started. It is likely that the location of the salt wedge could move upstream, thereby upsetting the present situation.

The water abstracted will be used for log spraying, cooling and boiler feed, dilution of aqueous chemicals, steaming timber and for potable supplies.

Waste disposal - The following types need to be considered:

- (a) Wood treatment chemical - The active ingredients in the mixture for the pressure treatment process, usually referred to as CCA, are salts of copper, chromium and arsenic. The anti-sapstain treatment uses sodium pentachlorophenate. All these are potentially toxic chemicals which pose problems of handling and disposal. Uncontrolled disposal or leakage of these into the environment would have serious consequences (see section on status of heavy metals in the study area).
- (b) Liquid wastes - These include storm water run-off and overflows, waste oil and treated domestic sewage. The storm water run-off and overflow could get contaminated with the treatment chemicals and penetrate the local environment creating toxic levels of copper, chromium and arsenic. Waste oil residues from the mill if leaked into the environment could also pose problems. Prolonged discharge of treated domestic sewage may result in elevated levels of nutrients in the surrounding water courses and alteration in the relative productivities at the different trophic levels.
- (c) Solids - It is intended that all residues generated by the complex will be burnt to provide the energy for mill operations. Thus the only solids requiring disposal would be the wood ash derived from the burning of residues. The intention is to dispose of the ash by spreading on the forest floor. This in itself does not pose a problem as the constituents of the ash (e.g. Ca, Mg, K and Si oxides) are considered beneficial for the soil. The disturbing consideration is that some of the wood shavings will have been through the CCA treatment process and the ash would therefore contain potentially toxic copper, chromium and arsenic residuals which may eventually enter the water courses and create environmental problems arising out of heavy metal contamination effects.
- (d) Gaseous emissions - The major source of gaseous emissions would be from the wood-fired boiler. Emissions would include heat, smoke, water vapour, carbon dioxide and nitrogen oxides. The distribution of these emissions in the atmosphere would depend on the prevailing wind direction (see section "Climate"). The extent of solution of the emissions in rainfall and entry into the Vitogo and Teidamu Rivers is uncertain. Arsenic emissions from waste wood fuel could also be a problem.

5.3 Proposal for mitigation of effects

- (a) Stringent control measures need to be exercised in the treatment plants to contain all spillages and drips. The management has taken this point into consideration and an assurance has been obtained that if there is any build up of chemical sludge which requires removal and disposal, it would be drummed and returned to the supplier for reprocessing or neutralizing.
- (b) Provisions for appropriate drainage of storm water need to be made so that contact with toxic treatment chemicals is prevented. This proposal has already been considered and several concrete drains channelling storm water into the Nawawa Vise Creek of the Teidamu River have been constructed on the site. It has been confirmed that no effluent of any description would be disposed of into the storm water system. However, taking into account any unintentional leakage of treatment chemicals into the system, the Department of Town and Country Planning

of the Fiji Government, with advice from INR, has made it a requirement that all discharges into Teidamu River or any other water courses shall conform to the following guidelines:

Copper content	< 1.0 mg/l
Total Chromium content	< 2.0 mg/l
Chromium (VI) content	< 0.5 mg/l
Arsenic content	< 0.5 mg/l

It was also noted that the storm water drains to the north into the Teidamu River and no drainage is channelled into the Vitogo River from the mill site. In view of this the management has been asked to commission a small scale baseline study of the Teidamu River. This is now underway.

- (c) To prevent treated wood shavings being burnt, all chemical treatment should be deferred until the wood has been planed. This proposal has been accepted by the management which means that all shavings that are burnt in the boiler plant will be free from wood treatment chemical contamination.

6. CONCLUSIONS

A baseline study on the quality of the Vitogo River and associated area has been completed. It would appear from this report that although the sawmill and chipmill construction is likely to affect the environment in a number of ways, a lot of emphasis has been placed on water quality of the area. It should be noted, however, that a baseline study is primarily a benchmark for the future; it need neither be extensive nor all-inclusive. What it should strive for is to measure the baseline levels of those environmental parameters that are going to be most affected by the development and are important for impact assessment.

In the case of this study, water quality was considered to be most vulnerable to the planned development. The findings show that this aspect of the environment is relatively uncontaminated at the present time. With sound planning and management of the sawmill and chipmill complex, the development need not have a significant impact on the environment. The authorities concerned with the development have been extremely co-operative and agreed to consider the proposals made for mitigation of likely effects.

However, the true extent of the impact of the development on the quality of the environment will become apparent once the mill becomes operational. Some future monitoring is required for quantification of any impact.

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