

WATER CHEMISTRY OF THE MONASAVU  
RESERVOIR AND WAILOA RIVER,  
VITI LEVU, FIJI

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## ABSTRACT

The Monasavu hydroelectric scheme, situated on the Nadrau Plateau in central Viti Levu, Fiji was constructed in the period 1977-82. In 1982 filling of the dam began with minimal vegetation removal. Since filling, the dam water has been used to drive turbines in the Wailoa power station after which it is discharged into the Wailoa River. This report summarises the results of a study of the water chemistry in the Monasavu reservoir and the Wailoa River from 1982-1985, and a brief vector borne disease survey in 1985.

The studies showed that a distinct thermocline occurs in the dam in the warmer months (November-April) but the dam is effectively homothermal in the cooler months. Oxygen profile characteristics, showing no oxygen below 20-30m in the warmer months, but a more uniform pattern in the cooler months can be rationalized in terms of the temperature profiles and normal mixing behaviour. The dam behaves as a bicarbonate type lake with pH usually in the range 6-9. The major cation distribution shows a fairly constant situation. Nitrate and ammonia levels can be related to the oxygen profile pattern prevailing. There appears to be an accumulation of total phosphorus at depth in the cooler months. Sulphur levels are generally low. The amounts of ammonia and total phosphorus decreased from 1983-1985, indicating decreasing amounts of organic matter left to be decomposed at the bottom of the reservoir.

The Wailoa River was studied at three points to determine the impact of power station discharge water from August 1983. There was a marked initial impact with a distinct smell of sulphides until the end of 1983. Examination of the tailrace water indicates that considerable oxidation must occur in the power station. There was a slight build up of nitrogen and reduction in total phosphorus at sites downstream, close to the power station, but after the initial six months, the impact on the Wailoa River generally was minimal.

With improved water quality and the results of the vector-borne disease survey apparently negative, it is recommended that the monitoring be continued on a limited scale.

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INTRODUCTION

The Monasavu Hydroelectric Scheme is situated on the Nadrau Plateau in the central area of Viti Levu, the largest island in the Fiji group (Figure 1). The main dam is at an elevation of 670 to 750 m with the maximum water surface level at 745 m and is sited immediately upstream of the original Monasavu Falls where Nanuku Creek drops off the Plateau. The dammed river is known by this name above these falls but as the Wainivodi River below the falls until it flows into the Wainimala River (Figure 2). Other small weirs divert streams (which are also tributaries of the Wainimala) to the south of Nanuku Creek into a pipeline which eventually empties into the Monasavu reservoir about 4 km behind the dam wall (Figure 2). As can be seen from Figures 1 and 2 the Wainimala is one of the principal branches of the Rewa, Fiji's largest river system. Water is drawn from the reservoir at a point about 1.5 km behind the dam wall (Figure 3) and passes down a tunnel into an adjoining river valley, the Wailoa, where the power station is situated. The Wailoa is also a tributary of the Wainimala (Figure 2). The dam itself is a 85 m high rockfill dam with a wet clay core (Knight, Worner and McClung, 1982) while the power station has a capacity of 80 MW composed of four 20 MW units. Some of the statistics of the scheme are shown in Table 1.

The Nadrau Plateau lies on the transition zone between the wet eastern and relatively dry western zones of Viti Levu but most of the Monasavu catchment area is in the wetter eastern side of the Plateau. Average annual rainfall is 3600 mm distributed somewhat unevenly throughout the year as shown in Figure 5. The valley of the Nanuku is typical of those in

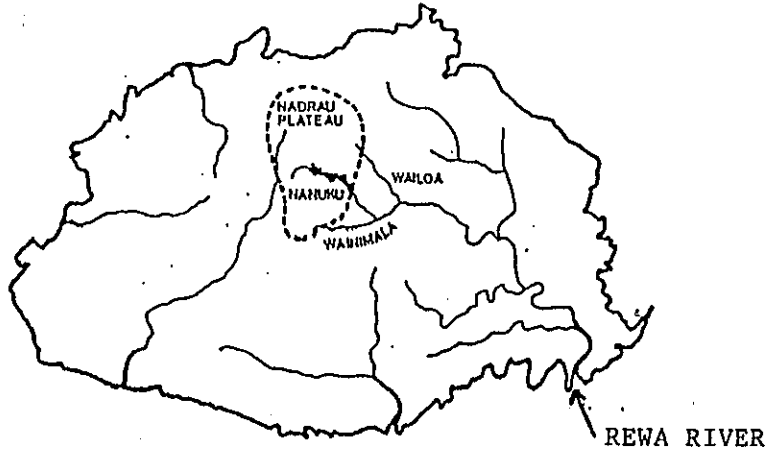


FIGURE 1 : Map showing the location of the Monasavu Hydro Power Project

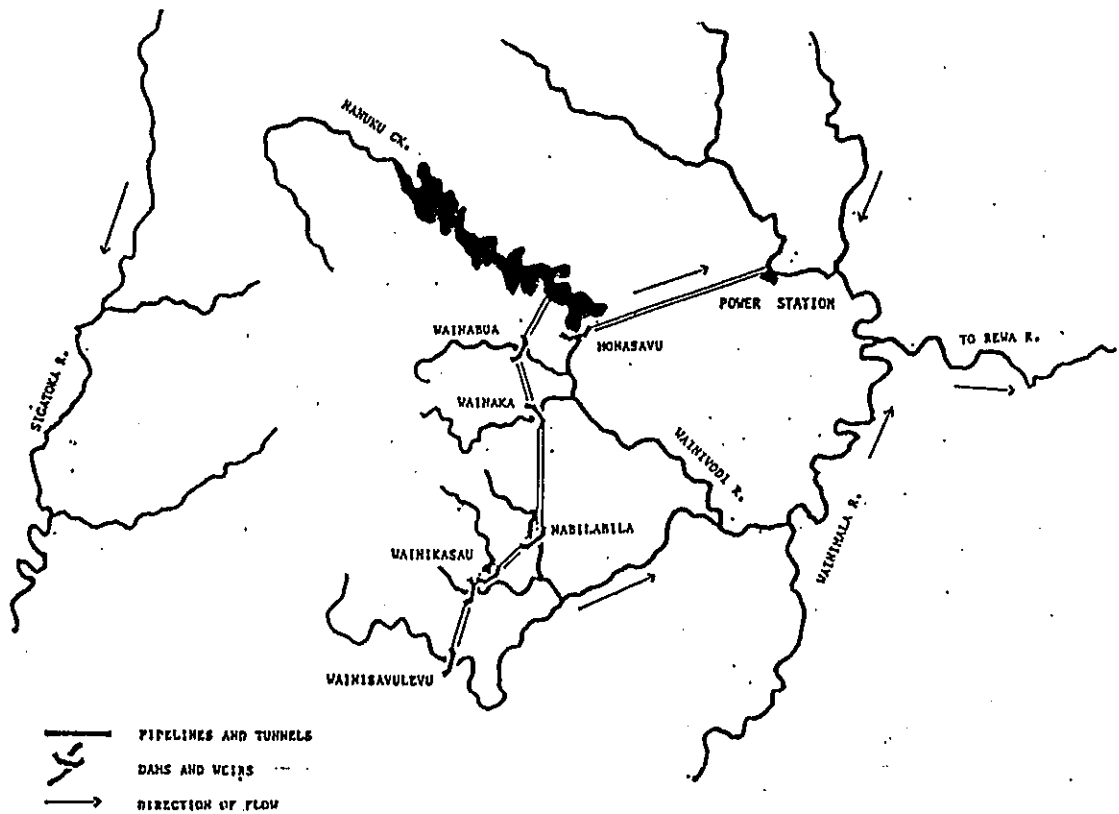


FIGURE 2 : Detailed location of tunnels, rivers and creeks in the Monasavu area

TABLE 1 : STATISTICS OF DAM AND RESERVOIR

Reservoir Length	18 km
Reservoir Width	Up to 1 km
Volume of Reservoir	142 million m <sup>3</sup>
Area of Reservoir	670 ha (6.7 km <sup>2</sup> )
Head of water above Wailoa	625 m
Generating Capacity	4 x 20 = 80 MW
Dam Height (Maximum)	85 m
Dam Height above Sea Level	750 m
Power Tunnel Length	5.4 km
Diversion Tunnel Length	11 km
Plateau Average Annual Rainfall	3600 mm

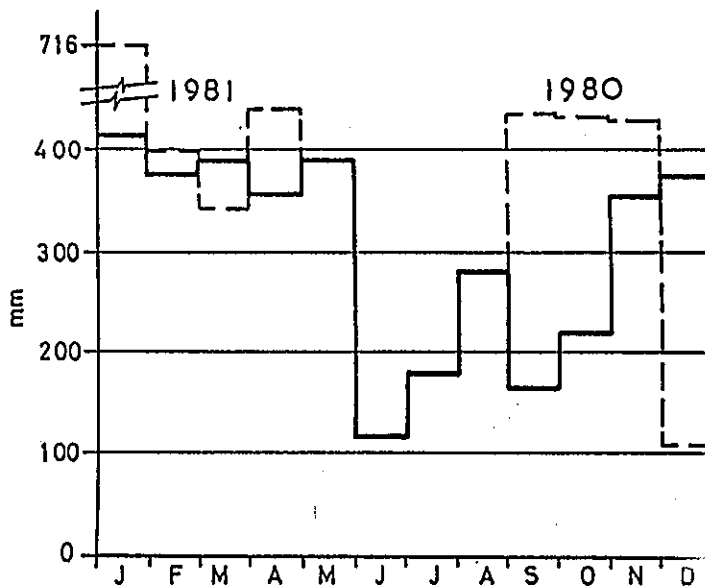


FIGURE 5

Average monthly rainfall.

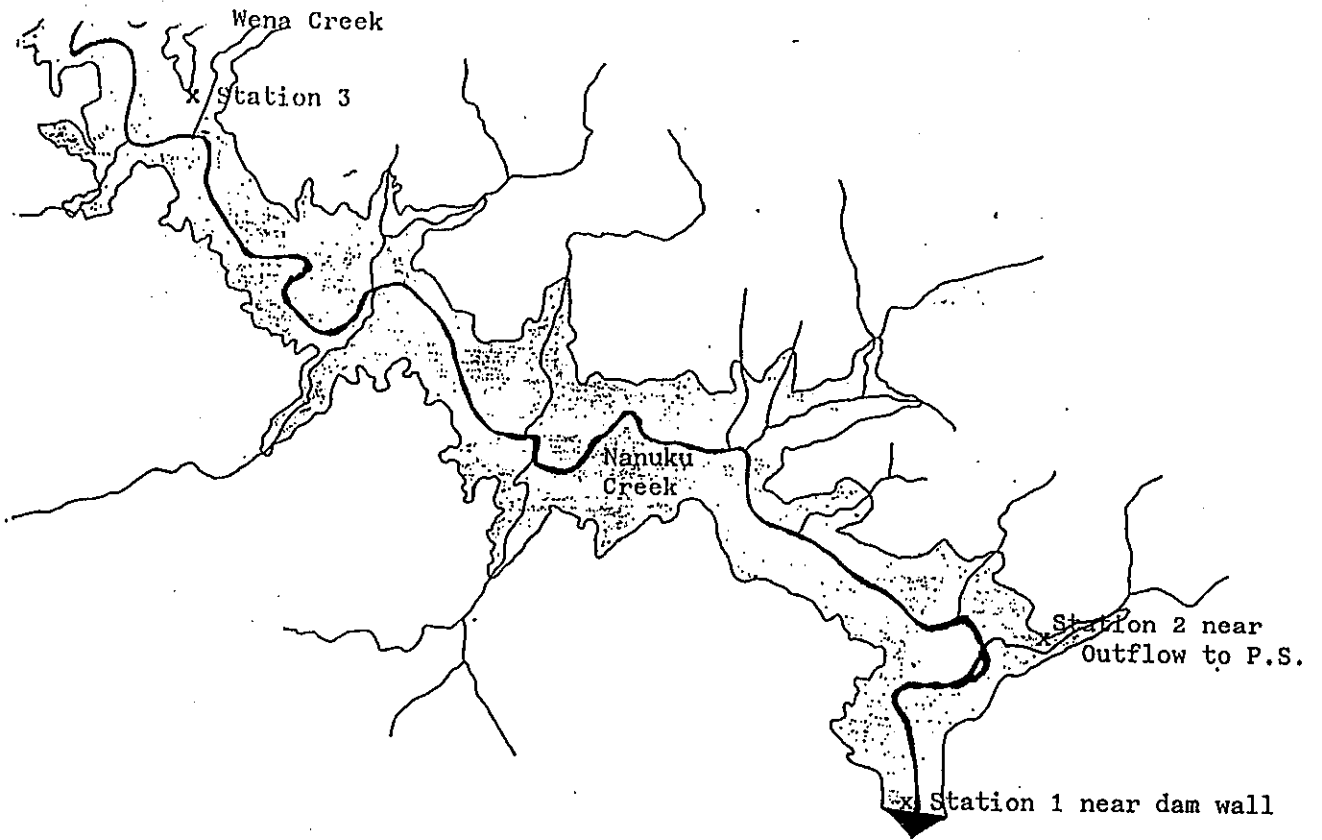


FIGURE 3 : Location of the sampling stations in the Monasavu Reservoir

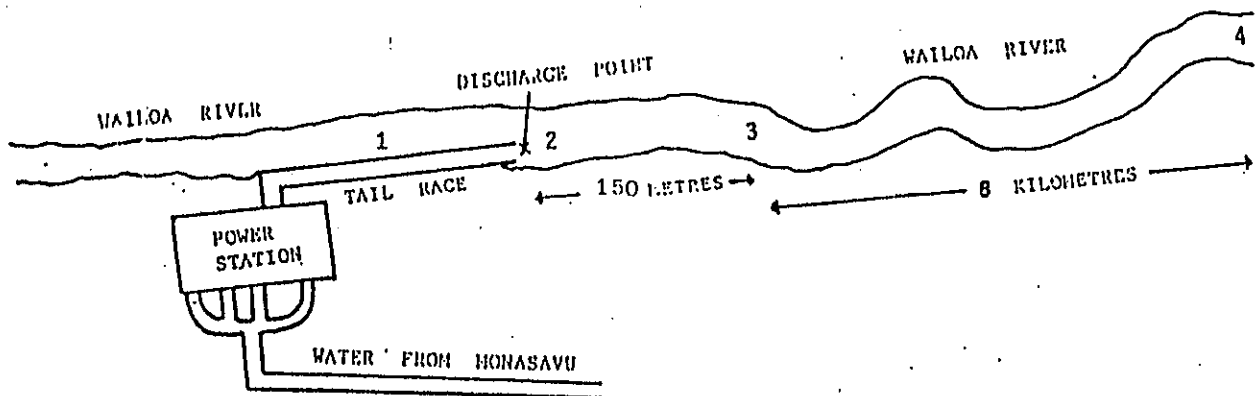


FIGURE 4 : Sampling sites along the Wailoa River

- Site : 1 100 m above P.S. discharge
- 2 Tailrace
- 3 150 m below P.S. discharge
- 4 Wailoa at Laselevu

the interior of Viti Levu with very steep sides and hence the reservoir is long and narrow and its volume is small compared to the volume of water flowing into it each year. The expected draw-down of the reservoir is thus expected to be up to 35 m especially in dry winters and when the demand on the power station begins to match the 80 MW capacity. At present the peak demand from those sections of Viti Levu connected to the scheme is only approximately 50 MW.

In light of the history of environmental problems suffered by large dams throughout the world it was felt from an early stage in the planning for the scheme that some environmental impact assessment should be made (Richmond, 1977). The first effort in this direction was a survey of the biota in and near to Nanuku Creek carried out in 1977 by a team from the Institute of Natural Resources (INR) of the University of the South Pacific (USP) Raj et al., 1977). The study was carried out over 7 days in 1977 and it was only possible to produce a superficial view of long term environmental effects. In 1978 Dr Quartey, the chief executive of the Volta River Authority (Ghana), was funded by the Commonwealth Fund for Technical Cooperation, at the request of the Fiji Government, to advise the government on the environmental effects of hydro-electric schemes. In his report Quartey recommended further environmental work and noted the possible public health implications of the reservoir with special note of filariasis, malaria, yellow fever and bilhazia (Quartey, 1978). A further study was carried out by INR in 1979 (Ryland et al., 1979) to record the physical characteristics and biota of Wainisavulevu Creek before work on that diversion scheme was commenced. As for the Nanuku study, this study was very limited in time although a more detailed record of the taxonomy of the species found was attempted. The visits of Dr Tom Petr of FAO in 1981 and 1982 to assess the fisheries potential of the reservoir led to renewed interest in following the environmental changes of the area

as the reservoir filled and to study the limnology of the new lake (Petr, 1981, 1982a, 1982b).

Early in 1982 one of the authors of the present report (J. Brodie) initiated the study which forms its subject. A loose agreement was entered into by INR, the Fiji Electricity Authority (FEA) and the Fisheries Division of the then Ministry of Agriculture and Fisheries (MAF) (now called the Ministry of Primary Industries). FEA provided accommodation and meals at Koro-ni-o (the construction village) and a boat and fuel on the reservoir. MAF provided transport from Suva to Monasavu and assistance from fisheries officers while INR provided water sampling equipment, personnel and analytical services. Sampling continued through 1982 on this basis while funding for the study was sought. This was provided in early 1983 by the USP Research Committee and later in 1983 by a grant from the South Pacific Regional Environment Programme (SPREP). SPREP support continued in 1984 and 1985 while in July 1984 a SPREP supported staff member (P. Gangaiya) began to coordinate the study. A much more extensive monitoring exercise became possible in 1985 when INR began to formally work for FEA on the study (and FEA funding thus became available).

The principal aims of the study were threefold: to study the water chemistry of the reservoir; to monitor the Wailoa River below the power station outfall and to monitor the public health status of the reservoir. Subsidiary aims have included: to study animals trapped by rising waters; to monitor aquatic weed introduction into the reservoir and to monitor fish populations in the reservoir. Some preliminary articles have already been published on the results of the study (Brodie, 1984; Brodie and Gibbons, 1985) and there have been papers published on some of the zoological finds in the area (Brown and Gibbons, 1986; Haynes, 1986).

## METHODS

### Sampling Procedure

Initially a considerable number of sampling stations were selected on the reservoir but within a short time these were reduced to the three shown in Figure 3. Station 1 was situated over the reservoir end of the diversion tunnel in the deepest part of the reservoir (possibly up to 80 m deep although this depth was never found during sampling). Station 2 was in front of the trash rack which covers the entrance to the tunnel through which water flows to the Wailoa power station. Station 3 lies at the junction of Nanuku and Wena Creeks some 6 km up the reservoir. Four stations were regularly sampled on the Wailoa River. Number 1 just upstream of the Power Station (i.e. natural Wailoa River water), Number 2, the tailrace water itself (i.e. reservoir water after passing through the turbines), Number 3, 150 m downstream of the junction of the river and the tailrace and Number 4 at Laselevu Village, 8 km downstream from the Power Station and approximately 2 km upstream from the junction of the Wailoa and Wainimala Rivers (Figure 4).

Three samples were normally collected from each reservoir station - one from the surface, one from one metre above the bottom and one from a depth midway between these two. Along with the Wailoa River samples these were collected approximately every two to three months from early 1982 when the dam was first closed until the end of 1985. In addition to these sampling times numerous dissolved oxygen/oxygen/temperature/depth profiles were recorded by FEA personnel beginning in 1982. Collections of biota were made at various times and in particular gastropods collections were made in 1982 and September, 1985.

Reservoir samples were collected using Nansen or Van Dorn bottles and stored in polythene bottles and returned to laboratory the same day or the next day for analysis. Dissolved oxygen and temperature were measured on site using a YSI 51B meter while pH and sulphide were also often measured on site using an Orion 407 selective ion meter with Orion glass and sulphide electrodes.

A number of other USP scientists were involved in biota collections over the four years of the study. These included Dr Paddy Ryan (Amphibians and Insects), Dr John Gibbons (Reptiles), Professor Roger Beaver (Insects), Mr Satish Choy (Crustaceans), Dr Julian Ash and Mrs Wendy Ash (Plants), Mr Stephen Roberts (Bacteria) and Miss Usha Prasad (Mosquitos). Dr Ralf Carter of the UNDP also assisted with on site water quality measurements.

### Analytical Procedures

During the course of the study a large number of different parameters were measured on different occasions. These were alkalinity, turbidity, pH, total nitrogen, total phosphorus, total sulphur, ammonia, nitrate, orthophosphate, dissolved iron and manganese, total iron and manganese, chlorophyll a, b, and c, conductivity, dissolved oxygen, hardness, sulphide, temperature, depth, chloride, calcium, magnesium, sodium, potassium, silicon and sulphate. The analytical method used for each of these was as follows:

Alkalinity was measured by titration with standard HCl to the phenolphthalein end point for carbonate alkalinity and to the bromocresol green/methyl red end point for bicarbonate alkalinity (APHA, 1980).

Turbidity was measured in a nephelometer against suspended silica standards and is thus expressed as nephelometric

turbidity units (NTU).

pH was measured on site and in the laboratory with a glass electrode standardized against buffers of pH 4, 7 and 9.

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

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

Total sulphur was determined on the perchloric acid digest using a barium sulphate turbidimetric method.

Ammonia was measured using the indophenol blue colorimetric method (APHA, 1980).

Nitrate was measured by the cadmium reduction column procedure and subsequent colorimetric measurement using sulphanilamide and N-(1-naphthyl)-ethylenediamine dihydrochloride (APHA, 1980).

Orthophosphate determination followed a standard molybdenum blue/ascorbic acid method (APHA, 1980).

Dissolved iron and manganese were determined by filtration of a sample which had been acidified immediately after collection. The filtration was done under vacuum through a 0.47  $\mu\text{m}$  membrane and iron and manganese determined by Flame Atomic Absorption Spectroscopy (FAAS) on the filtrate.

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

Chlorophyll a, b and c were determined by a spectrophotometric procedure after filtration and extraction of the filtered organic fraction (APHA, 1980).

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

Dissolved oxygen was measured on-site using a dissolved oxygen meter.

Hardness was determined by calculation from the calcium and magnesium levels.

Sulphide was determined on-site using a sulphide ion selective electrode and in the laboratory using the methylene blue colorimetric method (APHA, 1980).

Temperature was measured using a temperature probe incorporated in the dissolved oxygen meter.

Depth was measured by marks on the dissolved oxygen probe cable. Since there are almost no currents in the reservoir there were no problems of the cable being at an angle

Chloride was measured using a chloride ion selective electrode.

Calcium, magnesium, sodium and potassium were measured after suitable dilution by FAAS. Additives were used to suppress

interference and ionization effects in the determinations.

Silicon was measured using a molybdenum blue colorimetric method (APHA, 1980).

Sulphate was measured using a turbidimetric barium sulphate method.

## RESULTS AND DISCUSSION

### Dissolved Oxygen - Temperature-Depth Characteristics

The temperature and the dissolved oxygen profiles for the three stations for each of the 1985 sampling trips are given in Figures 6, 7 and 8. The profiles for the summer months (October-March) are characterised by a distinct temperature gradient with virtually no oxygen below a depth of 20 to 30 m. During the cooler months the reservoir is almost homothermal with oxygenated waters at depth. Comparison with 1984 measurements (Figure 9) shows that the reservoir behaved in a similar fashion in 1985 with one turnover during the cooler months. However, the zero oxygen level has increased from 10 to 20 m in 1984 to 20 to 30 m in 1985 indicating decreasing amounts of organic matter left at these levels for decomposition. This could also be due to the use of an aerator in the vicinity of Station 2. The temperature and oxygen profiles can be rationalised generally in terms of the local weather conditions, water movements, the morphometry of the reservoir and the biological activity within it.

Perhaps the most important parameter that influences in fundamental ways the physical, chemical and biological cycles of lakes is temperature and this therefore needs to be discussed first. Whilst there can be a number of sources of heat in a lake the most significant is that from solar radiation absorbed directly by the water. The absorbed heat

FIGURE 6: Dissolved oxygen and temperature profiles for station 1 in 1985

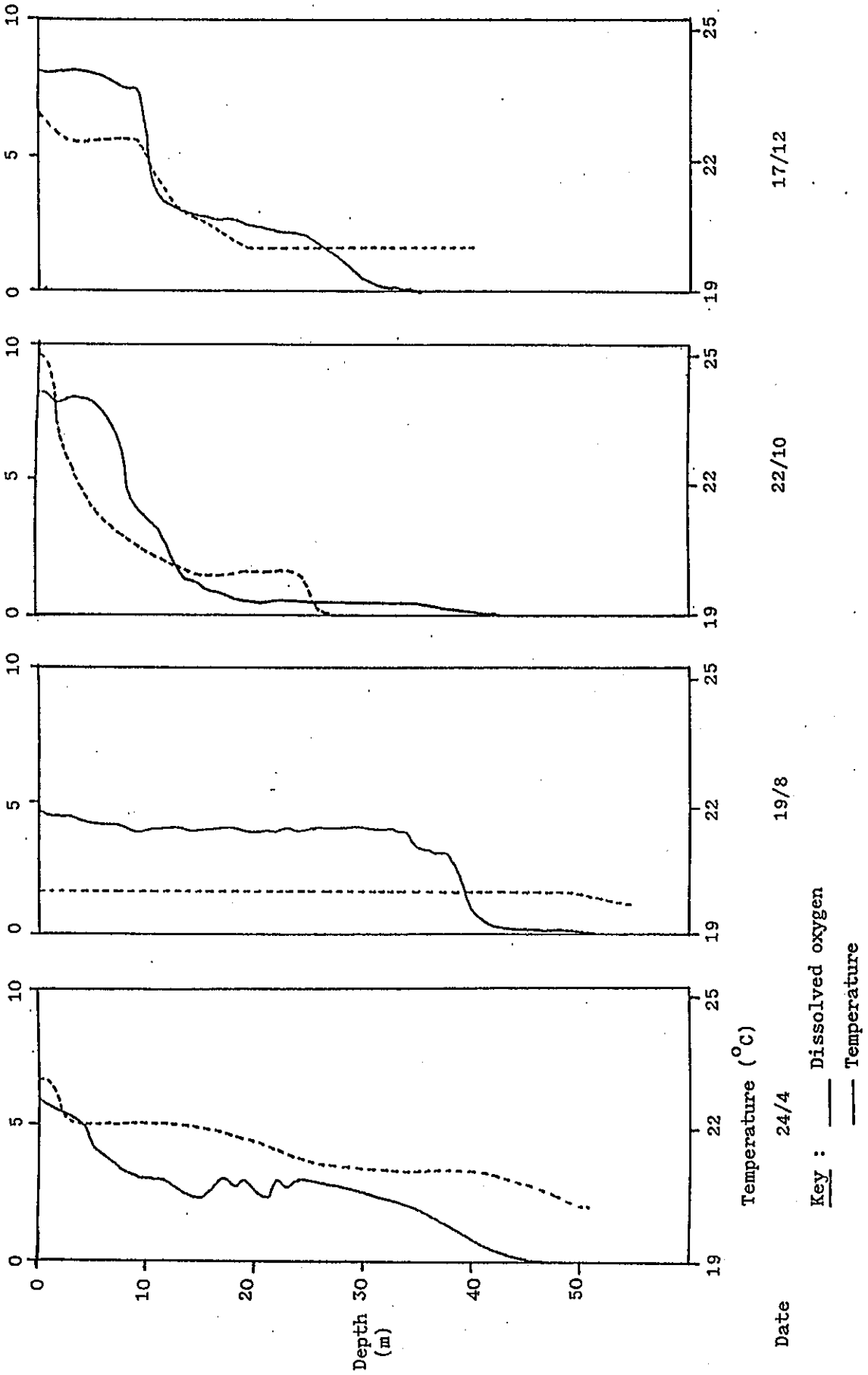
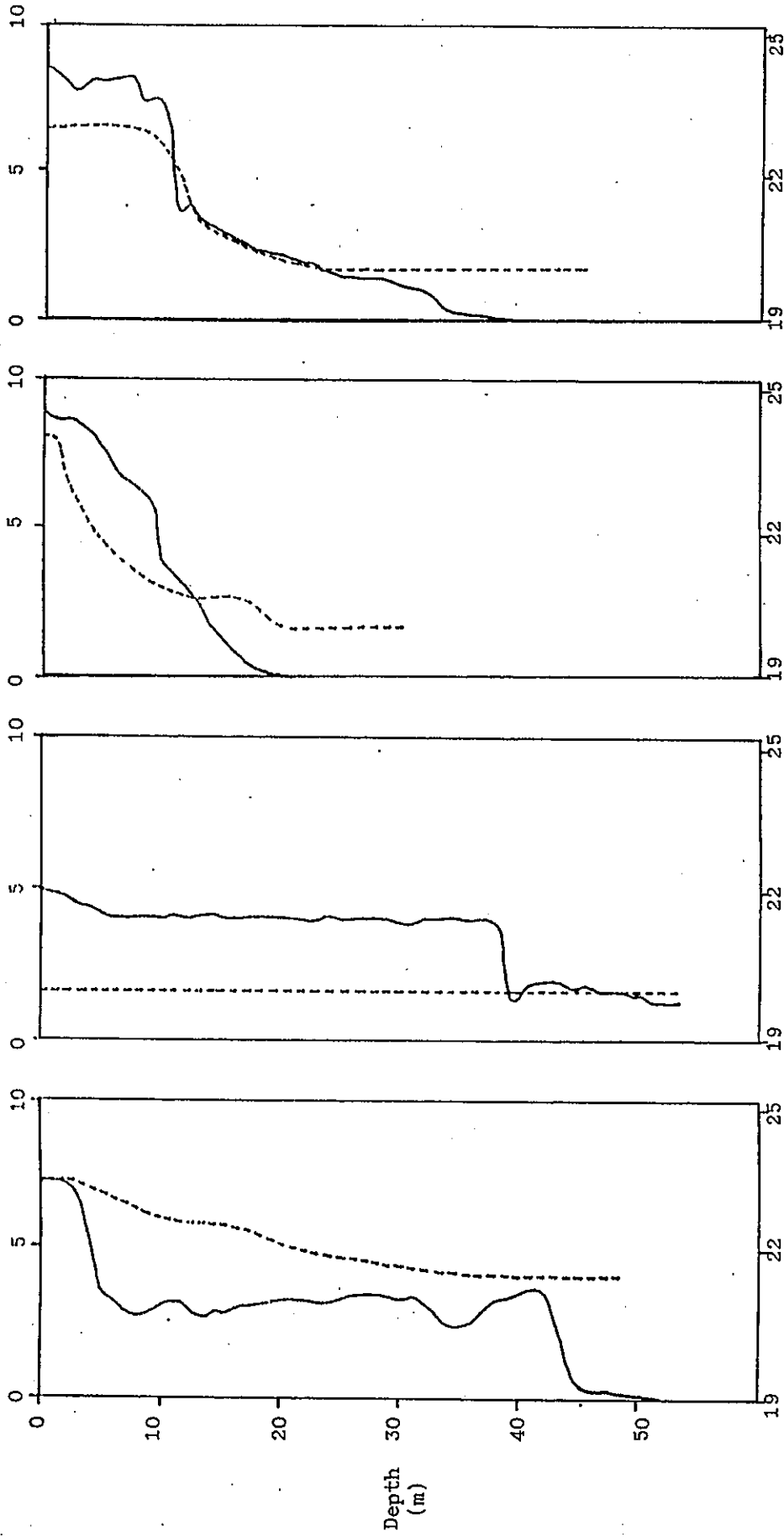


FIGURE 7 : Dissolved oxygen and temperature profiles for station 2 in 1985



Temperature (°C)

Date      24/4      19/8      22/10      17/12

Key : — Dissolved oxygen  
 - - - Temperature

FIGURE 8 : Dissolved oxygen and temperature profiles for station 3 in 1985

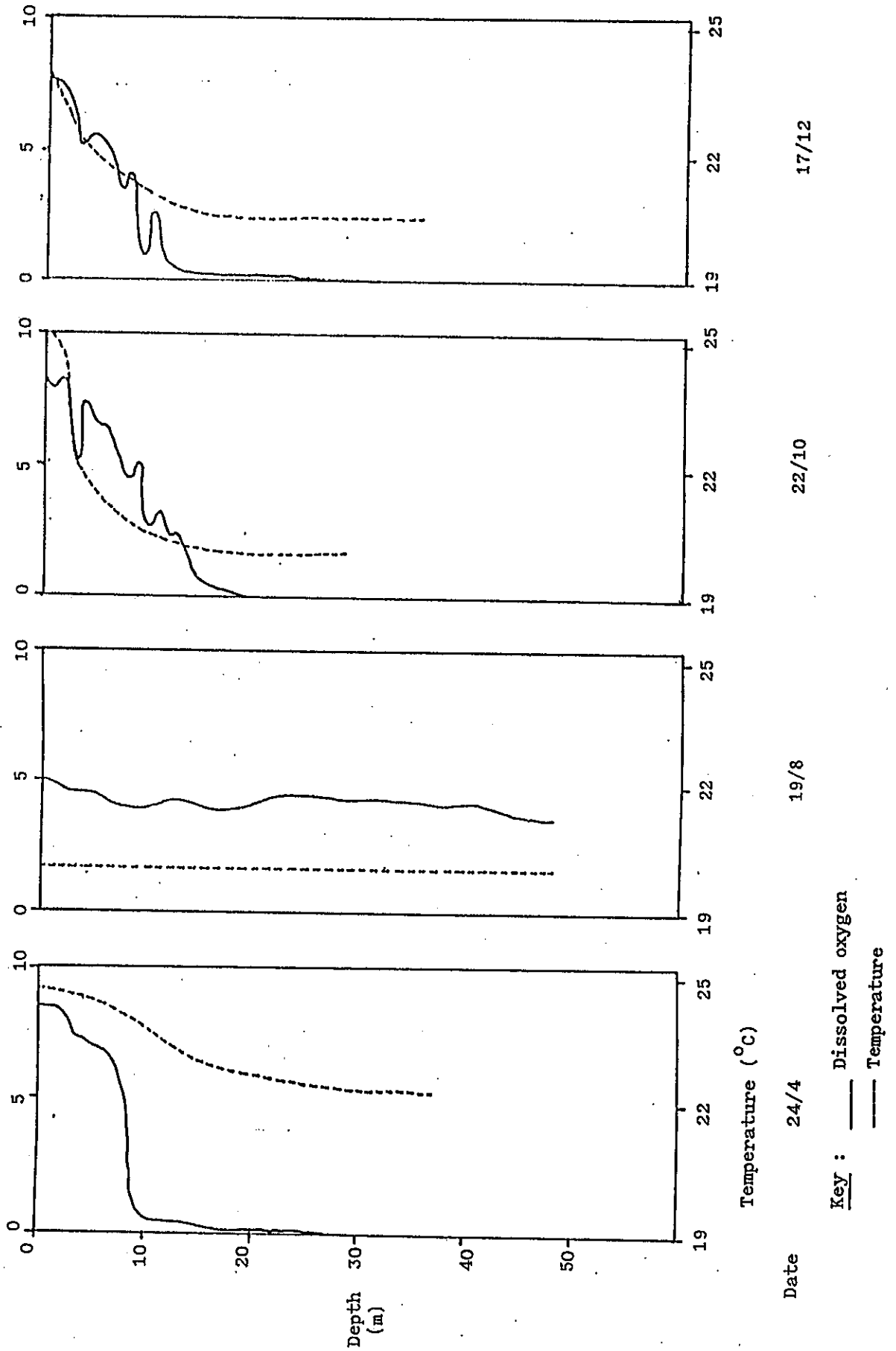
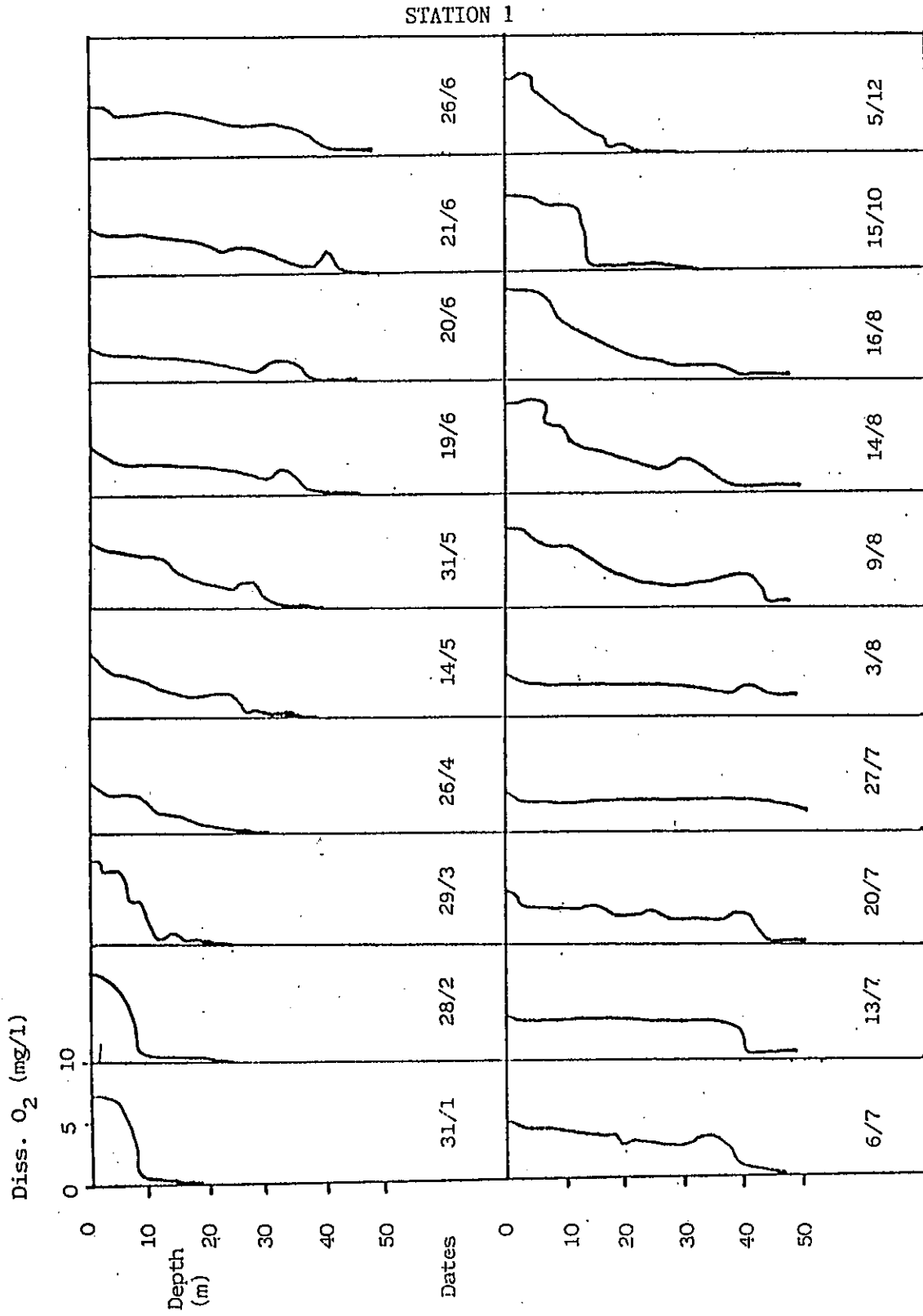


FIGURE 9: 1984 DEPTH/DISSOLVED OXYGEN PROFILES



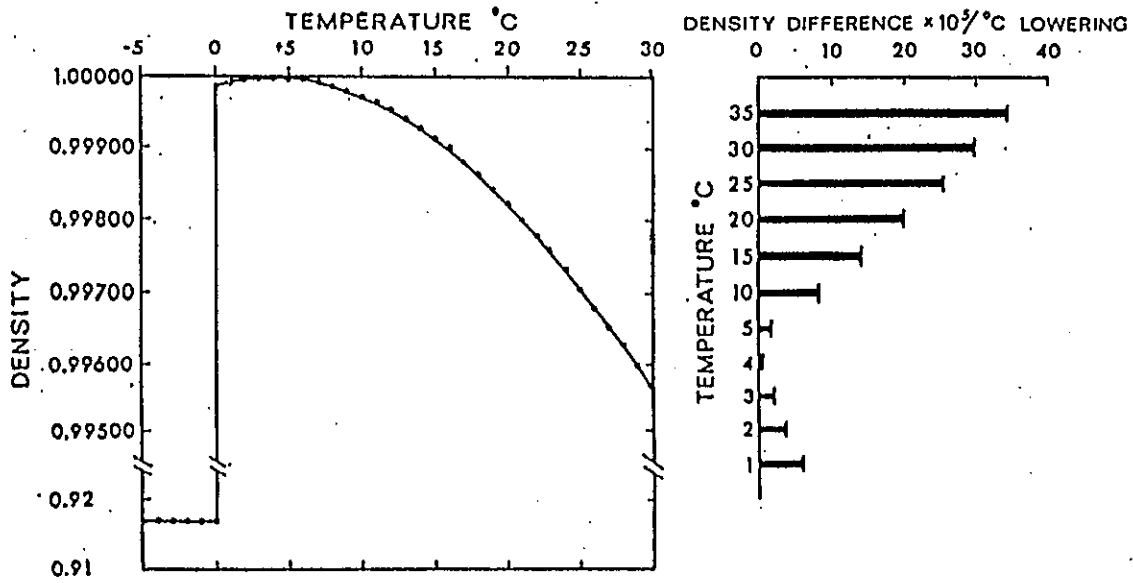


FIGURE 10: Density as a function of temperature for distilled water at 1 atm. The density difference per  $^\circ\text{C}$  lowering is shown in the righthand portion of the figure at various temperatures. (Origin : Wetzel, 1975).

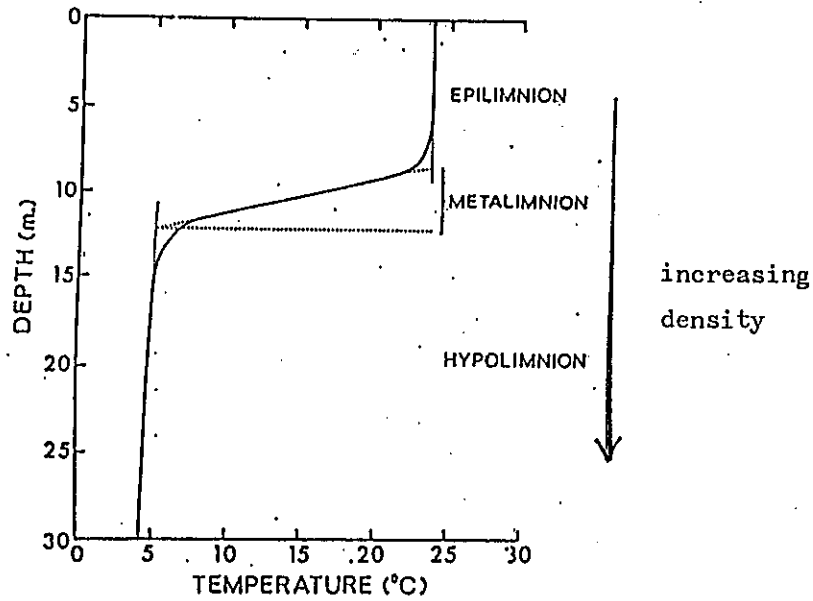


FIGURE 11: Typical thermal stratification of a lake into the epilimnetic, metalimnetic and hypolimnetic water strata. (Origin : Wetzel, 1975).

can be distributed in the water column through either conduction or turbulence. However, the thermal conductivity of water is very low and is not adequate to explain the observations made. Turbulence or mixing is therefore the major factor affecting temperature distribution in lakes (Payne, 1980). The marked thermal stratification in the summer months suggest strong resistance of the water column to mixing and is mainly density related. Summer temperatures are normally higher and cause surface waters to heat up more rapidly than the distribution of heat by mixing. As the surface waters heat and become less dense with respect to underlying waters, the relative thermal resistance to mixing increases markedly. Figure 10 which shows density as a function of temperature for distilled water at 1 atmosphere indicates clearly that density difference per  $^{\circ}\text{C}$  increases with increasing temperature. A difference of only a few degrees is sufficient to prevent complete circulation of the entire water column (Wetzel, 1975).

The water is then divided into three regions of different temperatures which resist mixing with each other as shown in Figure 11. The temperature difference between the epilimnion and the hypolimnion in the Monasavu reservoir can be as high as  $6^{\circ}\text{C}$  during the summer months and thus marked thermal stratification during these months is observed. In late summer and in the cooler months falling air temperatures cause loss of heat from the surface waters more rapidly than inputs from solar radiation. Surface waters get cooler and their temperatures and therefore densities approach those of the underlying waters. There is little thermal resistance to mixing and complete circulation of the water column is achieved through convection currents and wind energy resulting in effectively a homothermal water column. This explains the profiles observed in the month of August.

The oxygen profiles can be explained essentially in terms of the temperature profiles. The solubility of oxygen in water decreases with increasing temperature. However, higher dissolved oxygen contents in the surface waters are noted in the summer months because resistance to mixing of the different layers leads to oxygen concentration in the upper layer or the epilimnion. Diffusion of oxygen in water is a very slow process and does not play a major role in oxygen distribution. Any oxygen present in the hypolimnion is used for bacterial respiration and oxidative processes in decomposition of the underlying organic matter. The hypolimnetic oxygen content of highly eutroptic lakes is depleted within a few weeks after summer stratification begins and the bottom layers remain anaerobic throughout the summer months. The mixing of the different layers in the cooler period ensures a redistribution of the dissolved oxygen throughout the entire water column.

### Chemical Characteristics

Tables 2 to 21 summarize the analytical data gathered from 1982 to the end of 1985. Brief comments on a number of the parameters are discussed below.

### The Monasavu Reservoir

As far as the physical state of the reservoir is concerned, the surface of the water is becoming relatively free from dead tree branches and visual observations made during sampling trips have indicated the water at the bottom of the reservoir is getting clearer. The turbidity measurements for 1985 reported in Table 2, although not suggesting any major trend with time of the year show that turbidity still increases with depth, resulting mainly from decaying organic matter and possibly from the action of the bottom waters on loose sediments.

pH in the Monasavu Reservoir

The pH of fresh water systems is closely related to the carbon content. A majority of the carbon in fresh water systems occurs as equilibrium products of carbonic acid. The pH of these waters results from the  $H^+$  ions of the dissociation of carbonic acid and  $OH^-$  ions of the hydrolysis of bicarbonate ions. Although the exchange of carbon dioxide of the water with that of the atmosphere is rapid and relatively complete in aerated open water of lakes, the distribution of carbon dioxide and pH with depth is altered by microbial metabolism in stratified zones of lakes. The range of pH for the Monasavu lake is between 6 and 9 as shown in Figure 12. This would make it a bicarbonate type lake, regulated by the carbon dioxide-bicarbonate-carbonate buffering system.

TABLE 2 : TURBIDITY IN THE MONASAVU RESERVOIR IN 1985

Sampling Date	April	August	October	December
STATION 1 SFC	1	<2	4	2
MID	1	<2	2	2
BTM	42	120	20	4
STATION 2 SFC	1	<2	2	4
MID	2	<2	2	2
BTM	64	4	4	8
STATION 3 SFC	1	<2	4	4
MID	1	<2	2	2
BTM	16	80	10	2

TABLE 3 : ANALYTICAL DATA FOR MONASAVU WATER SAMPLES 7/4/82

Determination	Nanuku Creed 21.9°C (11.30 am)	Wailoa Power Stn. 25.6°C (2.00 pm)	Wainimala, Matinasau 26.9°C (2.20 pm)
pH	7.2	6.8	7.5
NO <sub>3</sub> <sup>-</sup> (mg/l)	0.5	0.4	0.35
Cl <sup>-</sup> (mg/l)	2.9	3.1	2.8
Ca (mg/l)	5.6	6.8	6.2
Mg (mg/l)	2.4	2.3	2.7
Na (mg/l)	3.6	5.2	5.0
K (mg/l)	2.1	2.0	1.5
Fe (mg/l)	0.5	0.2	0.25
Mn (mg/l)	<0.05	0.05	0.05
Si (mg/l)	7	7	11
Conductivity (μS)	60	67	69
PO <sub>4</sub> <sup>-3</sup> (μg/l)	<37	<37	<37

TABLE 4 : ANALYTICAL DATA FOR MONASAVU WATER SAMPLES 21/5/82

	Station 1	Station 1	Station 2	Station 2	Station 3	Station 4	Matainasa	Waihoa
	Top	Bottom	Top	Bottom				
pH	6.4	6.3	6.9	6.2	6.6	6.4	6.5	6.4
Conductivity (µS)	82.1	65.1	73.4	67.6	69.3	70.2	47.9	56.6
Cl <sup>-</sup> (mg/l)	1.6	1.3	1.8	1.6	5.2	6.6	7.4	7.2
Turbidity	6	92	6	80	12	8	164	12
S/S (for turbidity >100) (mg/l)							55	
Ca (mg/l)	7.2	7.0	6.6	7.0	7.0	6.4	4.8	5.8
Mg (mg/l)	3.9	1.9	2.5	3.5	1.9	3.5	1.0	1.9
Na (mg/l)	9.5	5.0	4.9	3.8	3.7	4.2	3.7	4.3
K (mg/l)	1.6	1.7	1.9	1.5	1.8	2.5	0.4	0.3
Fe (mg/l)	<0.1	0.1	0.2	0.2	0.3	0.2	0.3	0.4
NO <sub>3</sub> <sup>-</sup> (mg/l)	4.4	5.0	3.0	3.4	4.6	4.4	6.8	6.6
PO <sub>4</sub> <sup>-3</sup> (µg/l)	22	59	22	52	37	29	74	29
Total P (µg/l)	170	95	86	56	34	60	52	36
Total N mgN/l	12.4	9.3	26.3	17.3	11.4	38.8	36.6	23.4
Total S mgS/l	2.0	<0.5	0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Mn (mg/l)	<0.1	<0.1	0.1	0.1	<0.1	0.2	<0.1	0.2
Chlorophyll (mg pigment/m <sup>3</sup> )								
a	0	22	5	8	40	36		25
b	18	0	2	6	0	3		37
c	58	0	2	15	26	11		97
Temp. (°C)	21.1	20.5	20.8	20.6	21.2	21.4		

TABLE 5 : ANALYTICAL DATA FOR MONASAVU WATER SAMPLES 30/6/82

	Station 1 Top	Station 2 Top	Station 3 Top	Station 4 Top	Matainasau	Wailoa
pH	7.35	7.42	7.34	7.32	7.85	7.95
Conductivity (µS)	87.6	76.5	74.6	74.1	74.2	70.2
Total N mg N/l	2.3	1.8	1.1	1.1	0.25	1.2
Total P µg P/l	84	36	24	36	12	12
PO <sub>4</sub> <sup>3-</sup> mg/l	<37	<37	<37	<37	<37	<37
NO <sub>3</sub> <sup>-</sup> mg/l	8.5	8.0	6.0	6.2	7.2	7.0
Cl <sup>-</sup> mg/l	3.4	3.5	3.4	3.2	3.0	3.2
Turbidity	<2	<2	<2	<2	<2	<2
NH <sub>3</sub> mg/l	0.04	0.04	0.012	0.012	0.025	<0.01
SO <sub>4</sub> mg/l	2.5	1.5	1.0	1.0	2.0	2.0
Ca mg/l	6.0	5.2	5.8	5.6	5.6	3.1
Mg mg/l	2.0	3.2	2.9	2.5	2.1	2.3
Na mg/l	7.5	5.3	4.5	5.0	5.3	4.2
K mg/l	2.4	2.6	2.9	2.8	0.9	1.6
Mn mg/l	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Fe mg/l	0.75	1.0	1.2	0.75	0.75	1.0
Temp. (°C)	20.8	20.8	21.6	21.0		

Air Temperature 18.5°C



TABLE 7 : ANALYTICAL DATA FOR MONASAVU WATER SAMPLES 18/10/82

	STATION 1		STATION 2		STATION 3		Station 4	Wailoa	
	Top	Bottom	Top	Bottom	Top	Bottom			
Conductivity	67.8	61.2	67.9	79.9	67.8	72.5	68.5	63.2	
PO <sub>4</sub> (µg/l)	30	132	48	320	60	90	48	60	
Alkalinity	32	28	29	31	31	33	33	29	
Chlorophyll	a	4.1	0.92	2.7	3.4	5	5.6	2.3	1.1
	b	1.4	1.1	0.05	0	3.2	3.6	0	0
	c	6.0	0	0	0	1.8	0.65	0	2.1

TABLE 8 : ANALYTICAL DATA FOR MONASAVU WATER SAMPLES 26/2/83

	STATION 1		STATION 2		STATION 3		Wailoa	Laselevu
	Top	Bottom	Top	Bottom	Top	Bottom		
Turbidity	4	160	4	400	6	120	2	2
pH	6.80	6.40	6.50	6.80	6.90	5.95	8.40	8.20
NO <sub>3</sub> (mg/l)	0.062	0.25	0.37	0.12	0.062	0.12	0.31	0.37
NH <sub>3</sub> (mg/l)	0.16	0.76	0.09	0.46	0.08	0.99	0.34	0.16
Alkalinity (mg CaCO <sub>3</sub> /l)	26	43	27	42	27	34	39	39

TABLE 9 : ANALYTICAL DATA FOR MONASAVU WATER SAMPLES 22/7/83

	pH	Turbidity	NO <sub>3</sub> mg/l	NH <sub>4</sub> mg/l	T.N. mg/l	T.P. µg/l	Total Hardness	Total Alkalinity	Total Fe	Total Mn
Station 1 Top	7.5	3	0.043	0.04	3.9	<6	27	25	0.26	3.1
Station 1 Mid	7.2	8	0.043	0.98	4.2	<6	78	37	5.62	5.1
Station 1 Bottom	8.3	10	0.23	0.83	3.9	20	94	78	7.96	4.8
Station 2 Top	7.4	4	0.043	0.001	4.7	36	27	25	1.46	3.6
Station 2 Mid	7.1	6	0.16	0.05	8.1	62	24	23	2.30	2.2
Station 2 Bottom	7.2	12	0.043	0.83	10.9	<6	39	45	3.56	3.6
Station 3 Top	7.1	4	0.043	<0.001	4.2	<6	31	25	1.32	3.4
Station 3 Bottom	6.8	20	0.071	1.66	8.1	340	31	37	14.96	4.6
Station 4 Top	7.2	4	0.043	0.010	3.9	<6	31	25	1.02	2.8
Wailoa River at Wailoa P.S.	8.9	4	0.19	0.005	15.8	78	43	37	1.68	1.4
Wailoa River at Laselevu	9.0	4	0.16	<0.001	6.8	<6	63	41	0.42	1.4
Wainimala River below Laselevu	8.7	2	0.10	<0.001	7.8	20	43	41	0.86	2.0

TABLE 10 : ANALYTICAL DATA FOR MONASAVU WATER SAMPLES 25/8/83

	pH	Turbidity	NO <sub>3</sub> mg/l	NH <sub>3</sub> mg/l	T.N. mg/l	T.P. µg/l	Total Hardness	Total Alkalinity	Total Fe	Total Mn
Wailoa River at Laselevu	7.5	2	0.081	0.019	1.16	100	25	33	0.014	0.75
Wailoa River at Wailoa P.S.	7.6	2	0.136	0.019	0.90	106	25	34	0.013	0.79
Station 1 - Surface	7.1	2	0.078	0.085	2.15	84	19	29	0.015	0.34
Station 2 - Surface	7.5	2	0.037	0.012	1.50	82	20	27	0.050	0.16
Station 3 - Surface	7.3	2	0.155	0	1.40	140	19	26	0.060	1.43
Station 4 - Surface	7.3	2	0.040	0	2.18	236	20	26	0.006	<0.01

TABLE 11 : ANALYTICAL DATA FOR MONASAVU WATER SAMPLES 29/8/83

	pH	Turbidity	NO <sub>3</sub> mg/l	NH <sub>3</sub> mg/l	T.N. mg/l	T.P. µg/l	Total Hardness	Total Alkalinity	Total Fe	Total Mn
Wailoa River at Wailoa P.S.	7.5	6	0.347	0.011	2.35	314	22	29	0.49	1.87
Wainimala below Laselevu	7.3	16	0.365	0.011	1.45	374	16	28	0.01	3.97
Station 1 - Surface	7.2	2	0.027	0.080	1.90	160	20	27	1.46	1.70
Station 1 - 26 m	8.0	13	0.019	0.163	0.95	460	50	57	0.73	2.75
Station 1 - 53 m	7.0	98	0.015	0.153	2.80	800	52	70	2.62	8.49
Station 2 - Surface	7.4	20	0.020	0.055	2.65	380	24	32	1.46	1.70
Station 2 - 24 m	7.4	2	0.028	0.187	1.20	408	21	27	0.79	1.87
Station 2 - 48 m	6.9	15	0.025	0.190	1.88	60	32	43	1.48	5.58
Station 3 - Surface	7.4	2	0.040	0.010	2.25	200	18	25	0.25	1.19
Station 3 - 12 m	7.0	2	0.068	<0.005	1.30	58	20	26	0.73	1.03

TABLE 12 : ANALYTICAL DATA FOR MONASAVU WATER SAMPLES 7/12/83

	pH	Turbidity	Total P µg/l	Total N mg/l	Alkalinity mg/l	Total Fe mg/l	Total Mn mg/l
Wailoa River - Upstream power station	7.7	3	66	8	25	0.23	<0.1
Wailoa River - Power station tail race	6.7	4	152	10	32	7.13	0.1
Wailoa River - Power station 50m downstream tail race	6.9	6	70	8	32	3.01	<0.1
Wailoa River above Laselevu	7.7	4	56	7	29	0.80	<0.1
Station 1 - Surface	7.2	4	16	3	23	0.58	<0.1
Station 1 - Bottom	6.7	100	28	10	57	5.00	1.1
Station 2 - Surface	7.2	4	28	10	23	0.88	<0.1
Station 2 - Bottom	6.7	12	86	7	27	4.24	0.1
Station 3 - Surface	7.1	4	40	9	25	0.80	<0.1
Station 3 - Bottom	6.6	4	76	7	27	8.04	0.1
Station 4 - Surface	6.9	6	84	6	25	1.02	<0.1

TABLE 13 : ANALYTICAL DATA FOR MONASAVU WATER SAMPLES 16/3/84

Sample	Total Fe (mg/l)	Total Mn (mg/l)	Total S (mg/l)	Total N (mg/l)
1	0.03	0.01	0.08	14
2	0.10	0.07	1.1	21
3	0.06	0.04	0.17	43
4	0.09	0.06	0.63	10
5	0.08	0.05	1.6	11

1. Wailoa River immediately upstream of power station
2. Power station tail race
3. Wailoa River 50m downstream of power station
4. Wailoa River 150m downstream of power station
5. Wailoa River at Laselevu

TABLE 14 : ANALYTICAL DATA FOR MONASAVU WATER SAMPLES 15/8/84

	Stn. 1 Surface	Stn. 1 Mid	Stn. 1 Bottom	Stn. 2 Surface	Stn. 2 Mid	Stn. 2 Bottom	Stn. 3 Surface	Stn. 3 Mid	Stn. 3 Bottom	Mailoa Above P.S.	Mailoa Tailrace	Mailoa 150m Below P.S.	Mailoa at Laselevu
Total Alkalinity (mg/l CaCO <sub>3</sub> )	20	21	114	22	19	22	21	20	23	24	37	20	28
Turbidity	4	6	48	6	6	7	8	4	6	6	4	6	13
pH	7.3	6.7	7.0	7.3	7.0	6.7	7.2	6.8	7.2	7.1	7.5	7.1	5.1
Total N (mg/l)	5.4	5.4	6.8	3.6	4.7	5.2	4.1	4.2	2.8	4.4	7.9	4.0	5.1
Total P (µg/l)	90	40	1120	48	50	76	72	52	96	100	60	62	108
Total S (mg/l)	5.7	5.0	4.7	4.2	6.3	5.7	5.3	3.3	-	5.3	7.5	7.5	3.3
NO <sub>3</sub> <sup>-</sup> (mg/l)	0.01	0.37	0.10	0.04	0.14	0.02	0.31	0.31	0.06	0.26	0.29	0.20	0.06
NH <sub>3</sub> (µg/l)	9.4	15.1	1770	3.8	5.7	89.7	1.89	5.7	302	<0.1	51.9	28.3	61.4
Chlorophyll a	2.5	6.8	2.9	2.7	-	3.5	2.7	5.7	5.0	0.57	1.4	2.0	0.25
b	0.75	0.32	4.2	1.3	-	2.2	11.7	7.4	3.7	5.5	9.4	0.84	1.7
c	10.3	2.2	11.5	4.0	-	18.0	1.3	35	6.2	13.4	12.7	2.1	11.7
Dissolved Mn (mg/l)	<0.015	<0.015	0.2	<0.015	<0.015	<0.015	<0.015	<0.015	0.02	<0.015	<0.015	<0.015	<0.015
Total Mn (mg/l)	<0.015	0.02	0.10	<0.015	0.02	0.04	<0.015	0.02	0.94	0.02	0.01	0.02	0.02
Dissolved Fe (mg/l)	0.28	0.05	0.59	0.02	0.02	0.20	0.10	0.10	0.10	0.28	0.02	0.14	0.22
Total Fe (mg/l)	0.36	0.05	24.8	0.27	0.36	0.41	0.80	0.29	0.11	0.36	0.19	0.24	0.31
Temperature (°C)	23.0	20.5	20.0	23.0	21.0	20.0	23.0	20.5	20.0	20.0	21.2	21.5	
Dissolved O <sub>2</sub> (mg/l)	8.4	2.6	0	8.2	3.3	0.1	8.4	2.6	0	8.5	7.5	9.6	
Depth (m)	0	20	40	0	22	45	0	20	40	0	0	0	

TABLE 15 : ANALYTICAL DATA FOR MONASAVU WATER SAMPLES 16/10/84

	Stn. 1 Surface	Stn. 1 Mid	Stn. 1 Bottom	Stn. 2 Surface	Stn. 2 Mid	Stn. 2 Bottom	Stn. 3 Surface	Stn. 3 Mid	Stn. 3 Bottom	Wailoa Above P.S.	Wailoa Tailrace	Wailoa 150m Below P.S.	Wailoa at Laselevu
Turbidity	5	5	46	5	5	10	5	10	24	3	6	5	4
pH	7.50	6.95	6.78	7.07	6.79	6.70	6.98	6.58	6.83	7.65	6.83	6.89	7.40
Total N (mg/l)	4.8	3.8	5.5	2.9	2.9	4.6	3.9	3.1	3.2	3.4	3.8	3.7	4.5
Total P (µg/l)	24	60	400	28	24	108	24	16	40	72	24	32	64
Total S (mg/l)	1.5	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Chlorophyll a	9.41	0	0.25	14.9	9.54	3.9	12.1	0.03	14.6	2.7	0	1.14	15.5
b	5.21	0	1.71	5.21	0.49	0.95	0.98	0.92	3.2	0.59	0	16.7	1.31
c	5.01	0	11.7	14.9	0	0.91	6.09	13.6	12.1	11.2	0	42.4	12.10
Total Alkalinity (mg/l CaCO <sub>3</sub> )	24.5	23.6	111.2	23.1	22.3	28.4	21.7	25.6	23.1	45.7	23.6	27.3	31.7
NH <sub>3</sub> (µg/l)	<20	48	2380	<20	23	478	<20	160	290	<20	110	75	<20
Total Fe (mg/l)	0.2	0.2	6.2	<0.2	0.4	2.0	0.3	0.8	1.1	0.3	0.6	0.5	0.4
Total Mn (mg/l)	<0.1	0.1	1.6	<0.1	0.1	0.7	<0.1	0.3	0.3	<0.1	0.3	0.3	0.1
Dissolved Fe (mg/l)	<0.2	<0.2	3.6	<0.2	0.2	2.0	<0.2	0.8	1.1	<0.2	0.6	0.5	0.4
Dissolved Mn (mg/l)	<0.1	0.1	1.6	<0.1	0.1	0.7	<0.1	0.3	0.3	<0.1	0.3	0.3	0.1

TABLE 16 : ANALYTICAL DATA FOR MONASAVU WATER SAMPLES 6/12/84

	Stn. 1		Stn. 2		Stn. 3		Stn. 3		Stn. 3		Stn. 3		Stn. 3		Stn. 3	
	Surface	Mid	Surface	Mid	Surface	Mid	Surface	Mid	Surface	Bottom	Tailrace	Below P.S.	Above P.S.	Wailoa at Laselevu		
Total Alkalinity (mg/l CaCO <sub>3</sub> )	35.7	14.6	23.2	24.2	27.7	26.9	24.0	26.9	28.4	25.7	33.0	27.7	29.9			
Turbidity	8	7	12	8	7	6	8	6	8	6	4	6	7			
pH	7.5	7.1	6.9	6.7	6.4	6.6	6.9	6.6	6.5	5.7	7.1	6.8	7.1			
Total N (mg/l)	2.5	2.1	<0.1	<0.1	0.1	<0.1	2.0	<0.1	1.9	3.2	2.0	2.2	<0.1			
Total P (µg/l)	14	30	20	<6	32	30	30	30	20	46	24	26	28			
Total S (mg/l)	1.3	2.0	<1.0	1.7	1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0			
NH <sub>3</sub> (µg/l)	40.6	67.1	34.2	50.1	136	37.3	30.2	37.3	108	67	120	102	84			
PO <sub>4</sub> (µg/l)	25	49	49	49	74	49	49	49	49	49	74	74	49			
NO <sub>3</sub> (mg/l)	0.019	0.019	0.019	0.056	0.025	0.019	0.019	0.019	0.019	0.019	0.26	0.12	0.14			
Dissolved Fe (mg/l)	<0.2	<0.2	<0.2	<0.2	0.2	<0.2	<0.2	<0.2	0.2	<0.2	<0.2	<0.2	<0.2			
Dissolved Fe (mg/l)	<0.2	<0.2	<0.2	<0.2	0.2	<0.2	<0.2	<0.2	1.4	<0.2	<0.2	<0.2	<0.2			
Total Mn (mg/l)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1			
Dissolved Mn (mg/l)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1			
Chlorophyll a (mg/m <sup>3</sup> )	<0.01	0	<0.01	<0.01	<0.01	<0.01	0	<0.01	0	<0.01	0	<0.01	0			
Chlorophyll b (mg/m <sup>3</sup> )	<0.01	0	<0.01	<0.01	<0.01	<0.01	0	<0.01	0	<0.01	0	<0.01	0			
Chlorophyll c (mg/m <sup>3</sup> )	0.01	0	<0.01	<0.01	<0.01	0.02	0	0.02	0	0.01	0	0.02	0			

TABLE 17 : ANALYTICAL DATA FOR MONASAVU WATER SAMPLES 24/4/85

	Stn. 1 Surface	Stn. 1 Mid	Stn. 1 Bottom	Stn. 2 Surface	Stn. 2 Mid	Stn. 2 Bottom	Stn. 3 Surface	Stn. 3 Mid	Stn. 3 Bottom	Wailoa Above P.S.	Wailoa Tailrace	Wailoa 150m Below P.S.	Wailoa at Laselevu
Total Alkalinity mg/l CaCO <sub>3</sub>	18.0	14.6	36.3	18.1	15.8	15.8	17.8	17.4	18.0	33.0	15.1	21.9	26.1
Turbidity	1	1	42	1	2	64	1	1	16	1	1	2	1
pH lab on site	6.60	5.85	6.42	6.60	6.70	6.40	6.70	5.80	6.40	7.01	6.75	7.36	7.34
Total N (mg/l)	1.3	2.2	3.0	1.5	1.5	2.0	1.5	1.5	2.0	1.3	1.5	1.4	1.2
Total P (µg/l)	28.0	33.2	14.0	55.2	95.2	70.0	24.0	55.6	72.0	84.0	55.6	55.2	56.0
Total S (mg/l)	0.67	<0.3	3.84	1.00	<0.3	<0.3	1.84	0.83	2.67	1.47	1.00	0.33	<0.3
NO <sub>3</sub> <sup>-</sup> (mg/l)	<0.01	0.66	0.10	0.04	0.42	0.36	0.01	0.11	<0.01	0.29	0.57	0.38	0.26
NH <sub>3</sub> (µg/l)	<10	<10	950	<10	<10	197	<10	76	360	<10	<10	<10	<10
Chlorophyll a	2.67	0.94	0.93	2.11	0.86	2.06	2.45	0.89	0.51	0.34	0.32	0.57	0.23
Chlorophyll b	2.22	0.21	0.28	1.52	1.15	1.83	0.29	0.33	1.96	3.19	1.21	0.25	0.08
Chlorophyll c	3.97	1.18	1.05	7.71	4.54	5.79	3.14	0.22	0	0	0	0	0
Dissolved Mn (mg/l)	<0.1	<0.1	1.8	<0.1	<0.1	1.0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Total Mn (mg/l)	<0.1	<0.1	1.8	<0.1	<0.1	1.1	<0.1	<0.1	0.2	<0.1	<0.1	<0.1	<0.1
Dissolved Fe (mg/l)	<0.2	0.4	9.6	<0.2	0.2	2.2	0.2	0.4	2.0	<0.2	0.3	0.2	<0.2
Total Fe (mg/l)	0.5	0.5	10.8	0.4	0.5	2.6	0.2	0.4	2.1	<0.2	0.4	0.3	<0.2
Temperature (°C)	23.0	21.0	20.0	23.5	22.0	21.5	24.5	22.5	22.0	23.5	22.5	23.0	
Dissolved O <sub>2</sub> (mg/l)	5.9	1.9	0	7.0	3.0	0.3	8.4	0.2	0	8.2	7.9	7.8	
Depth (m)	0	34	68	0	23	45	0	22	45	0	0	0	

TABLE 18 : ANALYTICAL DATA FOR MONASAVU WATER SAMPLES 12/6/85

SAMPLE	1	2	3	4
pH	7.1	6.7	7.4	7.3
Turbidity	3.8	<2.0	2.0	2.2
Nitrates mg/l	0.10	0.25	0.40	0.19
Ammonia $\mu\text{g NH}_3/\text{l}$	64	84	104	130
Phosphate $\mu\text{g PO}_4/\text{l}$	<18	<18	61	<18
Total iron mg/l	0.4	<0.2	<0.2	0.2
Dissolved iron mg/l	0.4	<0.2	<0.2	<0.2
Total manganese mg/l	0.2	<0.1	<0.1	0.1
Dissolved manganese mg/l	0.2	<0.1	<0.1	0.1
Total nitrogen mg/l	2.0	2.5	1.6	2.1
Total sulphur mg/l	<1.0	<1.0	<1.0	<1.0
Total alkalinity mg/l	30	31	46	32

Samples 1 Tailrace  
 2 Laselevu  
 3 100m above Power Station  
 4 150m below Power Station

TABLE 19 : ANALYTICAL DATA FOR MONASAVU WATER SAMPLES 19/8/85

	Stn. 1 Surface	Stn. 1 Mid	Stn. 1 Bottom	Stn. 2 Surface	Stn. 2 Mid	Stn. 2 Bottom	Stn. 3 Surface	Stn. 3 Mid	Stn. 3 Bottom	Waioa Above P.S.	Waioa Tailrace	Waioa Below P.S.	Waioa at Laselevu
Total Alkalinity (mg/l CaCO <sub>3</sub> )	18	18	48	16	18	18	18	18	19	34	17	20	24
Turbidity	<2	<2	120	<2	<2	4	<2	<2	80	<2	<2	<2	<2
pH on site	7.15	7.20	7.20	7.11	7.21	7.20	7.21	7.30	7.10	8.15	7.20	7.59	8.0
Total N (mg/l)	2.1	1.8	3.5	2.4	1.5	1.8	1.5	1.8	1.9	1.4	1.8	1.6	1.4
Total P (µg/l)	30	18	165	30	28	53	38	33	180	60	63	43	43
Total S (mg/l)	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
NO <sub>3</sub> <sup>-</sup> (mg/l)	0.05	0.12	0.53	0.04	0.11	0.10	0.18	0.56	0.12	0.23	0.56	<0.01	0.08
NH <sub>3</sub> (µg/l)	<20	<20	1625	30	30	30	<20	30	30	30	20	20	20
Chlorophyll mg/m <sup>3</sup>	a 0.55 b 5.08 c 27.6	0.28 2.50 13.8	0.88 1.27 7.90	2.27 3.11 11.5	3.26 5.40 25.3	0.57 0.61 5.51	0.71 4.68 15.0	0.23 2.77 10.4	0.25 2.80 13.6	5.86 12.4 30.6	2.38 5.82 41.7	0.70 4.20 21.8	0.28 2.77 10.4
Dissolved Mn (mg/l)	0.1	0.1	0.9	0.1	<0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	<0.1
Total Mn (mg/l)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Dissolved Fe (mg/l)	0.2	0.2	0.9	0.2	0.2	0.3	0.3	0.2	0.6	0.4	0.3	0.3	0.3
Total Fe (mg/l)	0.5	0.2	0.9	0.5	0.4	0.6	0.5	0.7	1.4	0.4	0.4	0.3	0.4
Temperature (°C)	20	20	19.7	20	20	20	20	20	20	20	21	21	21
Dissolved O <sub>2</sub> (mg/l)	4.7	4.0	0	4.9	4.0	1.6	5.0	3.9	4.2	8.1	5.8	8.0	8.0
Depth (m)	0	30	60	0	20	40	0	15	30	0	0	0	0

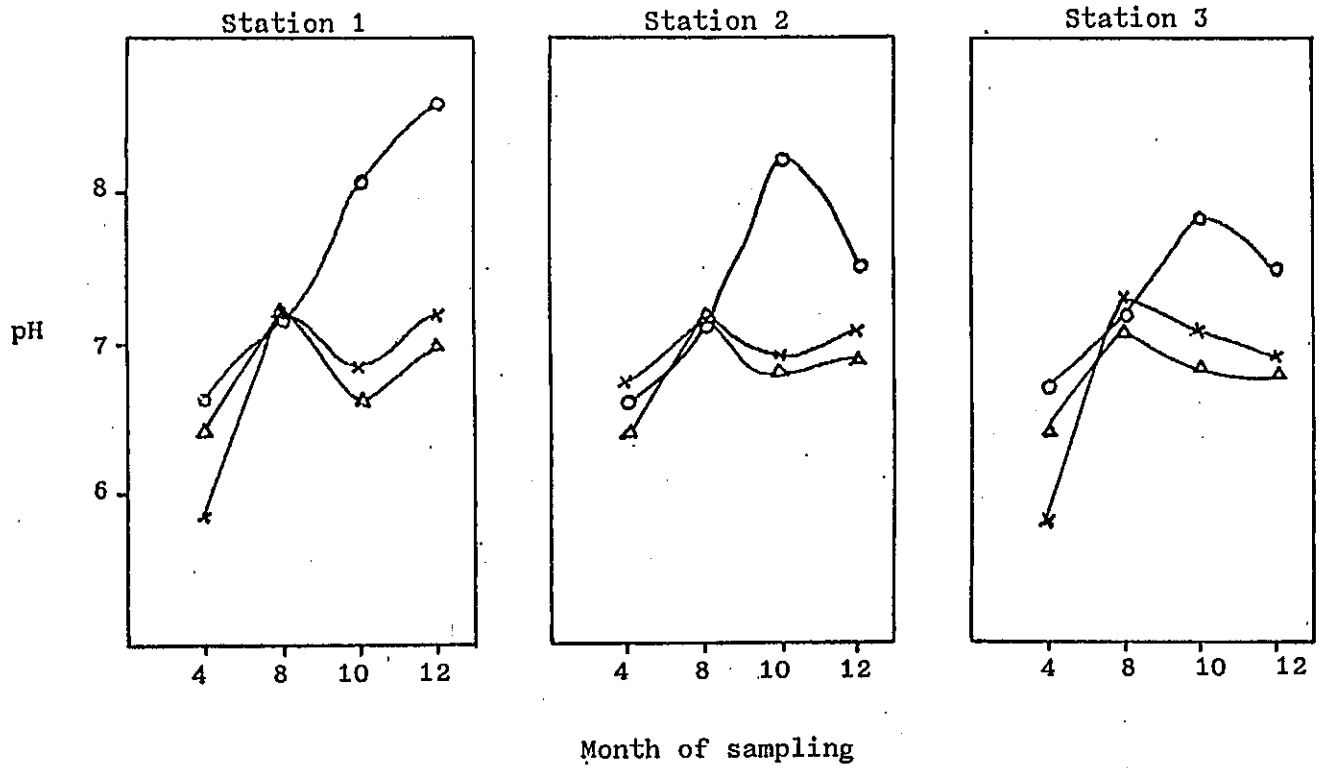
TABLE 20 : ANALYTICAL DATA FOR MONASAVU WATER SAMPLES 23/10/85

	Stn. 1 Surface	Stn. 1 Mid	Stn. 1 Bottom	Stn. 2 Surface	Stn. 2 Mid	Stn. 2 Bottom	Stn. 3 Surface	Stn. 3 Mid	Stn. 3 Bottom	Wailoa Above P.S.	Wailoa Tailrace	Wailoa 150m Below P.S.	Wailoa at Laselevu
Total Alkalinity (mg/l CaCO <sub>3</sub> )	20	26	51	26	31	20	20	25	26	41	31	31	31
Turbidity	3.6	2.0	20.2	4.2	2.2	4.0	3.8	2.0	10.4	1.8	2.0	2.0	2.4
pH lab on site	8.10	6.85	6.60	8.22	6.91	6.89	7.85	7.12	6.81	7.92	7.10	7.10	7.85
Total N (mg/l)	5.9	2.3	5.6	2.2	6.4	4.3	4.4	4.5	8.2	5.8	6.5	5.6	5.5
Total P (µg/l)	38	40	190	32	34	26	36	40	120	58	32	46	56
Total S (mg/l)	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	1.8	<1.0
NO <sub>3</sub> <sup>-</sup> (mg/l)	0.04	0.35	0.02	0.02	0.07	0.12	0.03	0.08	0.05	0.14	0.07	0.15	0.14
NH <sub>3</sub> (µg/l)	20	27	800	20	53	60	33	27	275	35	75	94	33
Chlorophyll a (mg/m <sup>3</sup> )	0.20	0.40	0.57	0.31	0.31	0.11	0.68	0.80	1.57	0.03	0.29	0.36	0.29
b	0.46	2.10	0.84	0.67	0.67	0.17	0.96	1.22	2.42	0.82	0.89	3.02	0.89
c	2.69	5.70	2.12	2.44	2.44	0.42	3.22	2.28	8.45	1.90	2.93	13.40	2.93
Dissolved Mn (mg/l)	0.10	0.10	1.10	0.10	0.10	0.22	0.10	0.10	0.20	0.10	0.40	0.20	0.10
Total Mn (mg/l)	0.10	0.10	1.12	0.10	0.10	0.30	0.10	0.10	0.63	0.10	0.40	0.22	0.12
Dissolved Fe (mg/l)	0.30	0.20	0.40	0.30	0.20	0.60	0.20	0.30	1.5	0.20	0.90	0.20	0.40
Total Fe (mg/l)	0.30	0.40	8.2	0.30	0.40	0.70	0.20	0.30	5.6	0.30	0.90	0.60	0.40
Temperature (°C)	25	19	19	24	21	20	26	21	20	22	22	22	22
Dissolved O <sub>2</sub> (mg/l)	8.8	0.4	0	8.8	0.7	0	8.8	2.2	0	8.8	6.8	9.2	9.2
Depth (m)	0	30	59	0	16	32	0	12	23	0	0	0	0

TABLE 21 : ANALYTICAL DATA FOR MONASAVU WATER SAMPLES 17/11/85

	Wailoa Above P.S.	Wailoa Tailrace	Wailoa at Laselevu
Total Alkalinity (mg/l CaCO <sub>3</sub> )	29	19	24
Turbidity	2.8	4.0	3.0
pH            lab on site	7.90	7.15	7.05
Total N (mg/l)	2.7	2.8	3.3
Total P (µg/l)	60	44	50
Total S (mg/l)	<1.0	<1.0	<1.0
NO <sub>3</sub> <sup>-</sup> (mg/l)	0.15	0.05	0.14
NH <sub>3</sub> (µg/l)	20	124	30
Chlorophyll    a	0.86	0.63	0.23
b	1.70	1.38	0.33
c	5.10	4.20	0.85
Dissolved Mn (mg/l)	0.10	0.18	0.10
Total Mn (mg/l)	0.10	0.52	0.10
Dissolved Fe (mg/l)	0.20	1.0	0.60
Total Fe (mg/l)	0.20	1.0	0.64
Temperature (°C)			
Dissolved O <sub>2</sub> (mg/l)	8.5	8.0	
Depth (m)	0	0	0

FIGURE 12 : Variation of pH with time of year during 1985 in the Monasavu River



Key

- o surface
- x mid
- Δ bottom

The total inorganic carbon, which is derived by the equilibrium established between atmospheric carbon dioxide, the bicarbonate-carbonate system, contributions from metabolic respiration and decomposition and utilization in photosynthesis, is distributed evenly with depth during periods of circulation (in the winter months) thus explaining the minimal variability in pH with depth at this time of the year.

The photosynthetic utilization of carbon dioxide in excess of respiration in the trophogenic zone (upper layers) tends to reduce the carbon dioxide content and to increase pH which explains the relatively higher pH values of the surface waters. In the bottom layers of the reservoir there is degradation of organic matter, microbial methane fermentation, nitrification of ammonia and sulphide oxidation during aerobic periods. As the hypolimnion becomes anoxic decomposition becomes anaerobic together with denitrification and reduction of sulphate to sulphide. The combination of the decomposition processes results in a net increase in the carbon dioxide content of the hypolimnetic waters and a decrease in pH as observed in the summer months. Since the lethal effects of most acids begin to appear near pH 4.5 (Wetzel, 1975) the pH of the bottom waters of the Monasavu Reservoir which was never below 5.5 during 1985 is not a cause for concern. The difference in pH between the different layers is only slight (about 1 pH unit) indicating the strong buffering capacity of the system.

### Major Cations

Data for the major cations shows a fairly constant situation. The conductivity was in the range 60-90  $\mu\text{S}$  and the levels of the major cations are summarised below:

Ca <sup>2+</sup>	1.6 - 7.2 mg/l
Mg <sup>2+</sup>	1.9 - 4.0 mg/l
K <sup>+</sup>	1.5 - 2.9 mg/l
Na <sup>+</sup>	3.5 - 9.5 mg/l
Cl <sup>-</sup>	1.6 - 6.6 mg/l
Alkalinity	18 - 114 mg CaCO <sub>3</sub> /l

The wide range for the alkalinity is due to very high values being obtained for some bottom samples. For surface and mid-level samples the range is 18-36 mg CaCO<sub>3</sub>/l.

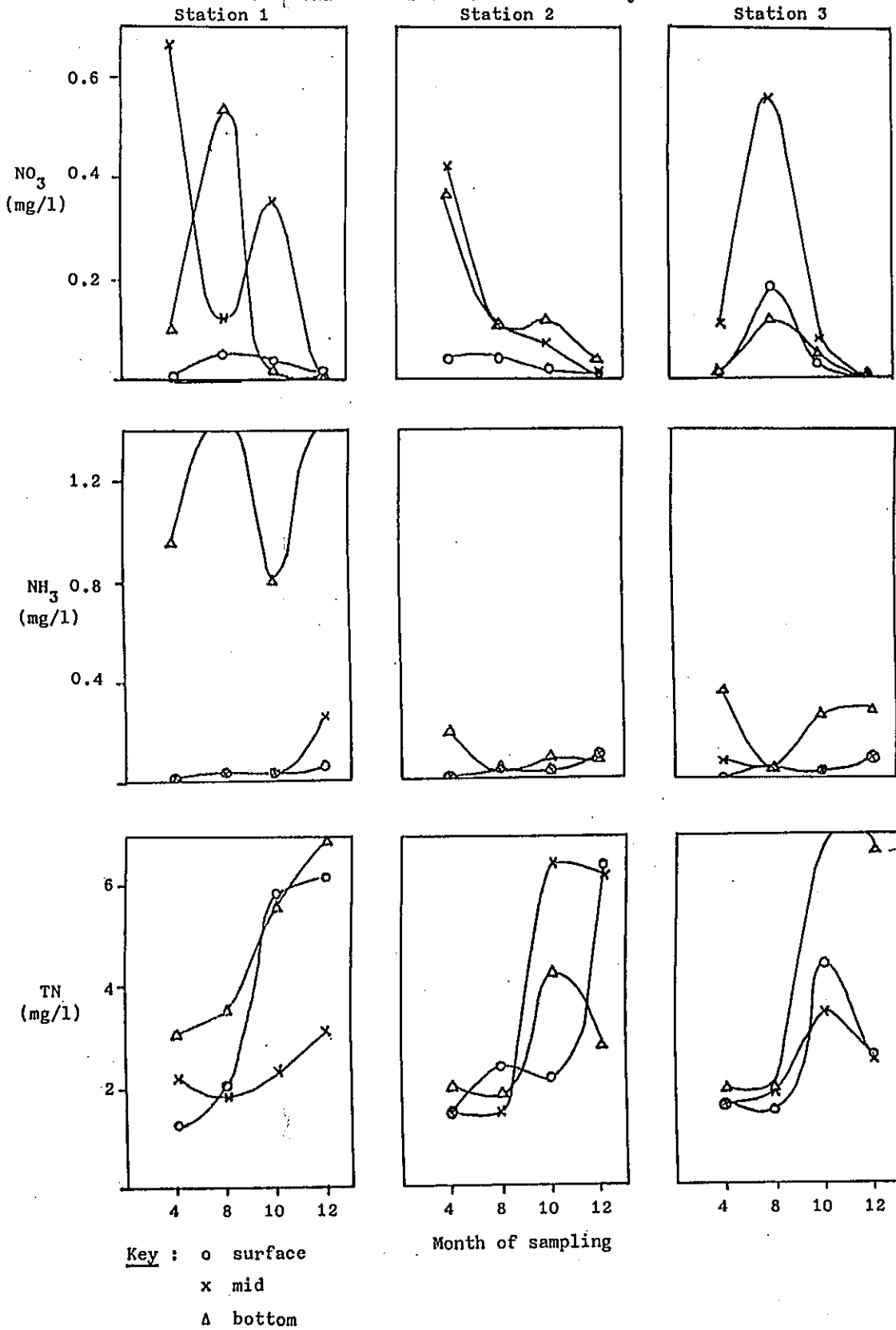
Comparison of these values with those for tropical lakes elsewhere in the world (Talling and Talling, 1965; Beadle, 1981) shows that the Monasavu reservoir is of relatively similar composition to other relatively low salinity lakes. Ionic balance calculations (where possible) show reasonable agreement between cationic and anionic charge for most samples.

## Nutrients

### i) Nitrogen

Figure 13 gives the variation of the different forms of nitrogen in the water with time of the year for the three stations. The surface waters at all stations are characterised by low levels of nitrate (NO<sub>3</sub><sup>-</sup>) throughout the year because of high photosynthetic activity and subsequent consumption of nitrate. Sufficient quantities of oxygen at the surface prevent the formation of ammonia (NH<sub>3</sub>) as a decomposition product thereby explaining its observed low levels. In the cooler months the higher levels of oxygen at depth allow the oxidation of settled and underlying organic matter and ammonia to nitrates which explains the general reduction in ammonia content and increase in the nitrate

FIGURE 13 : Variations of nitrate, ammonia and total nitrogen content of the Monasavu Reservoir with time of year in 1985

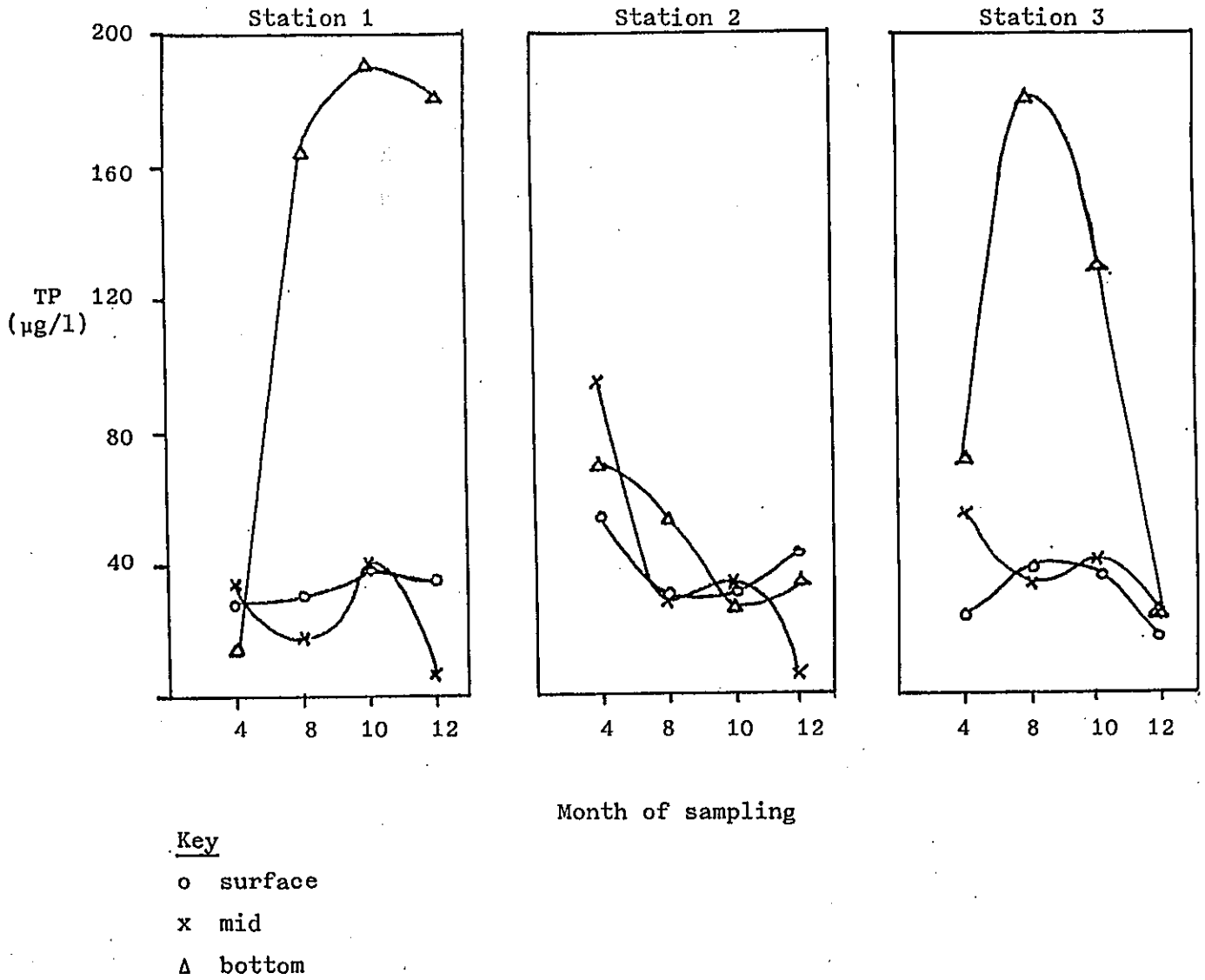


content at depth. As a result of higher levels of oxygen and nitrate at all depths the rate of production of organic forms of nitrogen could increase, to explain the observed increases in total nitrogen (TN) at all depths through the cooler season and into the warmer months and the general reduction of nitrates due to consumption. The stable stratification in the warmer months prevents reoxygenation at depth, explaining further reduction in the nitrate content and increases in the ammonia content due to hetero-trophic bacterial decomposition of organic matter. The trends observed at Station 2 generally do not conform to the above description possibly because the continuous outflow from this point to the power station does not allow sufficient time for patterns to develop at depth.

ii) Phosphorus

Unlike the many forms of nitrogen in lake systems, the only significant form of inorganic phosphorus is orthophosphate ( $\text{PO}_4^{3-}$ ). However, a very large proportion (over 90%) of the phosphorus is usually bound organically in organic phosphates and cellular constituents in the living particulate matter. Total phosphorus (TP) which includes both organic and inorganic phosphorus consists of the phosphorus in suspension in particulate matter and the phosphorus in dissolved form. The total phosphorus concentration of most uncontaminated surface waters is between 10 to 50 g/l (Wetzel, 1975) and it is noted that the surface concentrations in the Monasavu reservoir are generally within this range (Figure 14). TP builds at depth, particularly in the winter months because of greater decomposition of the underlying organic matter and the subsequent mobilization of the phosphorus into the surrounding water. The circulation of the entire water

FIGURE 14 : Variation of total phosphorus with time of year for the Monasavu Reservoir



column in the winter months allows the movement of mobilized forms of phosphorus (possibly phosphates) into the upper layers where they are used up for metabolic processes. This action combined with the unavailability of more supplies of phosphorus in the bottom layers in the summer months because of anoxic conditions results in a net decrease in the phosphorus content of the bottom layers during the later phases of summer stratification. The behaviour of Station 2 is again uncharacteristic for reasons already discussed.

### iii) Sulphur

The predominant form of sulphur in the oxidized state is sulphate. At the surface this is assimilated by biota for protein synthesis. Any decomposition of organic matter results in the release of hydrogen sulphide which under oxic conditions is quickly oxidised to sulphate and reused. This explains the low levels of total sulphur of the surface waters.

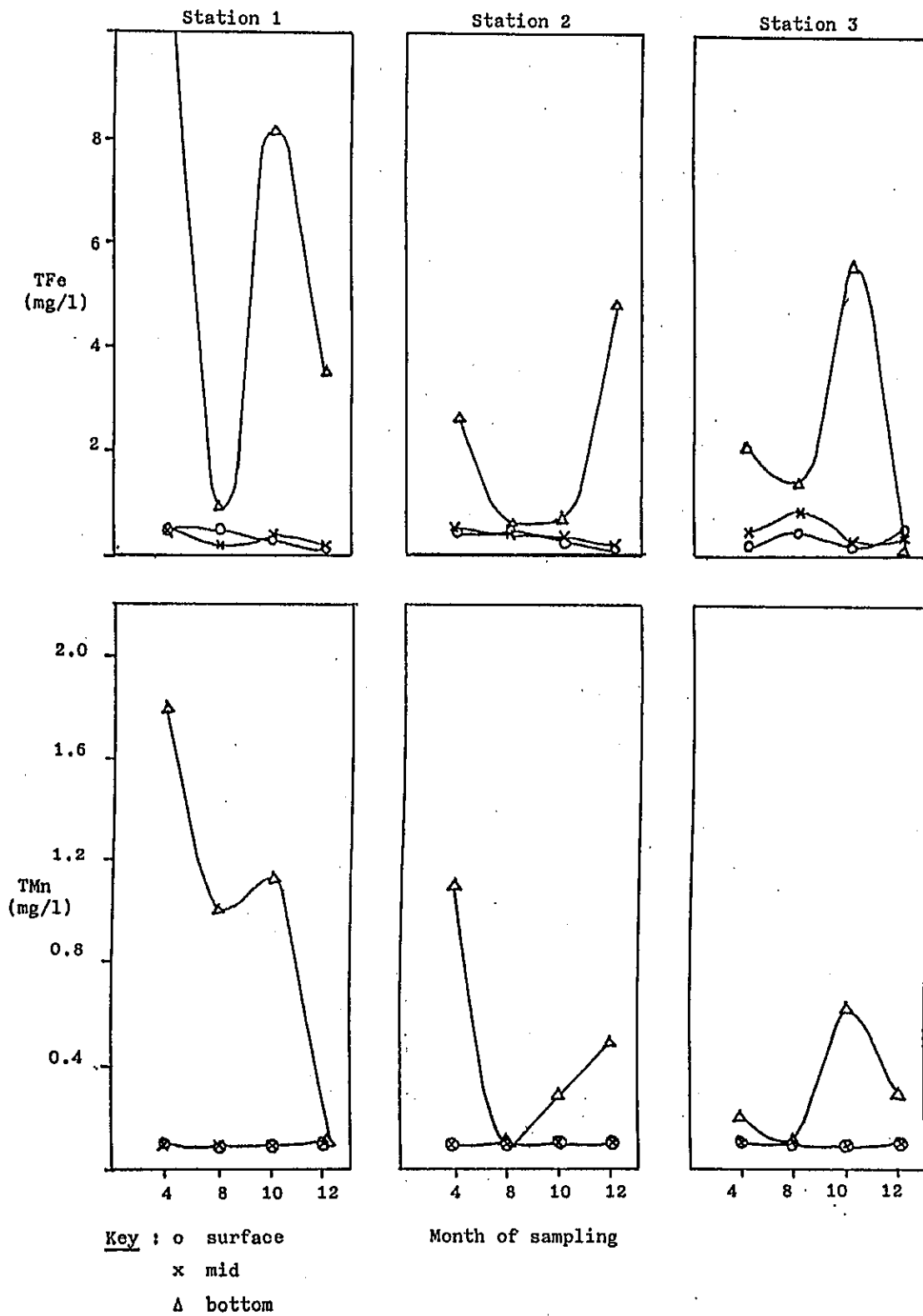
However, sedimentation of particulate organic matter to depth and its subsequent decomposition as well as the decomposition of the underlying organic matter releases hydrogen sulphide which is not oxidised to sulphate under the predominant anoxic conditions. Iron (II) and other transition metal ions which are also solubilised under anoxic conditions react with sulphides to form insoluble metallic sulphides under neutral or alkaline pH conditions and which are then incorporated into sediments. This explanation accounts for the low levels in total sulphur observed at depth.

iv) Iron and Manganese

Dissolved iron and manganese is that fraction of these metals which passes through a 0.5  $\mu\text{m}$  size filter and is assumed to be "in solution". Total iron and manganese includes both the dissolved and particulate fractions and by definition should always be greater than or equal to the dissolved fraction which is the case with the Monasavu data. The trends observed in the total concentrations of these metals may be seen in Figure 15.

The cycling of iron and manganese is regulated to a large extent by the seasonal variations in dissolved oxygen content of the water. Ionic forms of iron and manganese are oxygenated water are exceedingly low. They usually exist as insoluble forms in particulate matter which settle to the deeper parts of the reservoir, thus explaining the relatively low levels of these metals from the surface to the middle of the reservoir. Normally iron and manganese form strong complexes with many organic molecules and an enrichment of these elements is commonly found in surface waters with a high content of dissolved organic matter (Wetzel, 1975). However, since the levels of iron and manganese in the surface and middle layers of the reservoir are very close to their respective detection limits further explanation of any differences is not justified. The seasonal variations in iron and manganese are most pronounced in the bottom of the reservoir. In the de-oxygenated waters of the hypolimnium iron (II) and manganese (II) ions diffuse readily from the sediments and accumulate in the bottom waters. During the turnover of the winter months when oxygen is present at these depths the iron (II) and manganese (II) ions are oxidised, subsequently precipitated and returned to the sediments in form of particulate matter. Figure 15

FIGURE 15 : Variations in total iron and manganese with time of year in the Monasavu Reservoir



shows this effect quite clearly. The reintroduction of the summer stratification reestablishes the migration of these ions into solution and an increase is observed. As the decomposition in the hypolimnion continues throughout the period of stratification and the water is further deoxygenated, hydrogen sulphide is released by bacterial decomposition of sulphur containing organic compounds. Iron (II) and other metallic ions which are present in solution in significant quantities at this stage react with sulphide to form metallic sulphides which are very insoluble under normal lake conditions. A depletion of these metals in the later phases of summer stratification for stations 1 and 3 is thus explained. Station 2 does not exhibit such a behaviour because of complications set in by the outflow to the power station.

v) General

Comparison of the 1985 data with that for 1984 shows little change in the surface composition of reservoir. Differences are more prominent for the bottom sections of the reservoir, especially where nutrients are concerned. Although the total nitrogen values do not show any marked variations from 1984 to 1985, the nitrate content at depth is seen to increase, particularly during the winter months. The amounts of ammonia and total phosphorus on the other hand, decreased in 1985. This could be indicative of the decreasing amounts of organic matter left to be decomposed at the bottom of the reservoir.

**The Wailoa River**

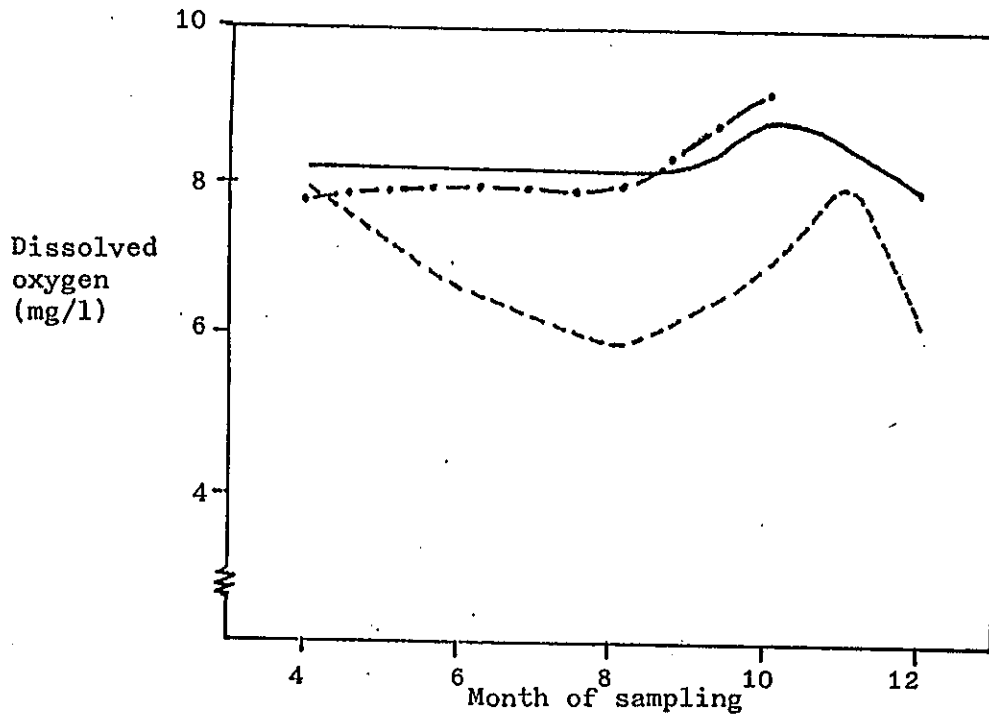
The point from which the water is drawn to the Wailoa power station is located near the bottom of the reservoir, close to

Station 2 and according to the conditions prevalent in the reservoir the power station would normally be receiving water of very low dissolved oxygen content throughout the year and especially during the summer months. As well as low dissolved oxygen the water would contain other constituents characteristic of the anoxic deeper waters of the reservoir, for example, relatively high concentrations of iron and manganese, ammonia and possibly hydrogen sulphide.

Examination of Figure 16 which compares the dissolved oxygen content of the tailrace water with that in other parts of the river shows that although the dissolved oxygen content of the tailrace water is lower than that of the river water around it, it is not as low as the dissolved oxygen content of the deeper waters at Station 2. Obviously the water is significantly oxygenated at the power station and therefore does not impose any major effect on the dissolved oxygen content of the river. About 150m below the tailrace, the dissolved oxygen content of the water returns to levels present in the river water before contact with the tailrace is made.

The effect of the pH of the tailrace water on the rest of the river illustrated in Figure 17 shows that although the pH of the tailrace has always been slightly lower than the pH of the water 100m above it, it does not have any significant effect on the pH of the water at the sites further downstream. The oxygenation of the water at the power station would also oxidise the ammonia, the hydrogen sulphide and the reduced forms of iron and manganese. Although there was a noticeable smell of sulphides when the power station initially came on line there has been a notable lack of any distinct smell of hydrogen sulphide at the power station since the end of 1983. This is not due entirely to oxygenation of the water but rather to the decreasing levels of organic matter left in the reservoir to be decomposed.

FIGURE 16 : Dissolved oxygen in the Wailoa River during 1985



Key (to Figs. 14 and 15)

- Site 100 m above Power Station
- - - At tailrace
- · - · 150 m below Power Station
- · · · At Laselevu

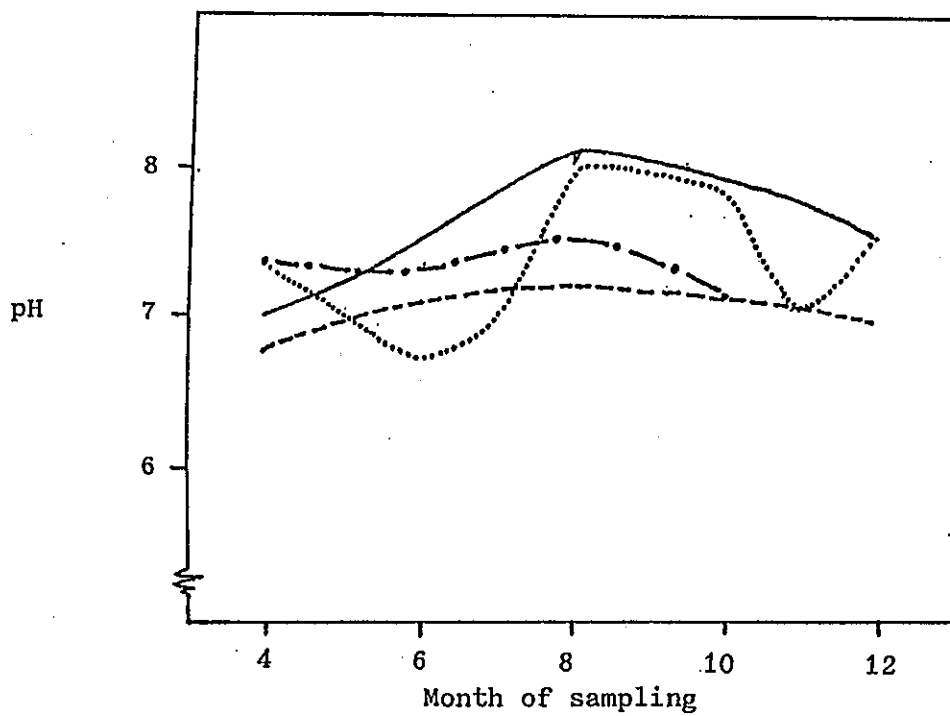


FIGURE 17 : Variation in pH in the Wailoa River during 1985

Examination of the data available shows that the ammonia content of the tailrace water is very much lower than that of the Station 2 bottom waters and is not significantly higher than or different from the ammonia content of the water at the site 100m above tailrace. The tailrace total nitrogen content is consistently higher than and the total phosphorus content generally lower than those in the water 100m upstream (Table 22). The net effect is a slight build up of total nitrogen and a slight reduction in total phosphorus levels at the two sites below the tailrace.

TABLE 22 : TOTAL NITROGEN AND PHOSPHORUS LEVELS IN THE WAILOA RIVER

Sampling Date	Total Nitrogen (mg/l)				Total Phosphorus ( $\mu\text{g/l}$ )			
	100 m Above	Tail-Race	150 m Below	Lase-levu	100 m Above	Tail-Race	150 m Below	Lase-levu
24/4/85	1.3	1.5	1.4	1.2	84	56	55	56
24/6/85	1.6	2.0	2.1	2.5	160	130	150	140
19/8/85	1.4	1.8	1.6	1.4	60	63	43	43
23/10/85	5.8	6.5	5.6	5.5	58	32	46	56
14/11/85	2.5	2.8		3.3	60	44		50
18/11/85	3.2	4.2		5.3	50	43		50

A close inspection of the figures given in Table 23 shows that the total iron and manganese content of the tailrace is generally lower than that of the bottom waters of Station 2. The loss occurs possibly at the power station. When the water gets oxygenated, the reduced forms of these metals get

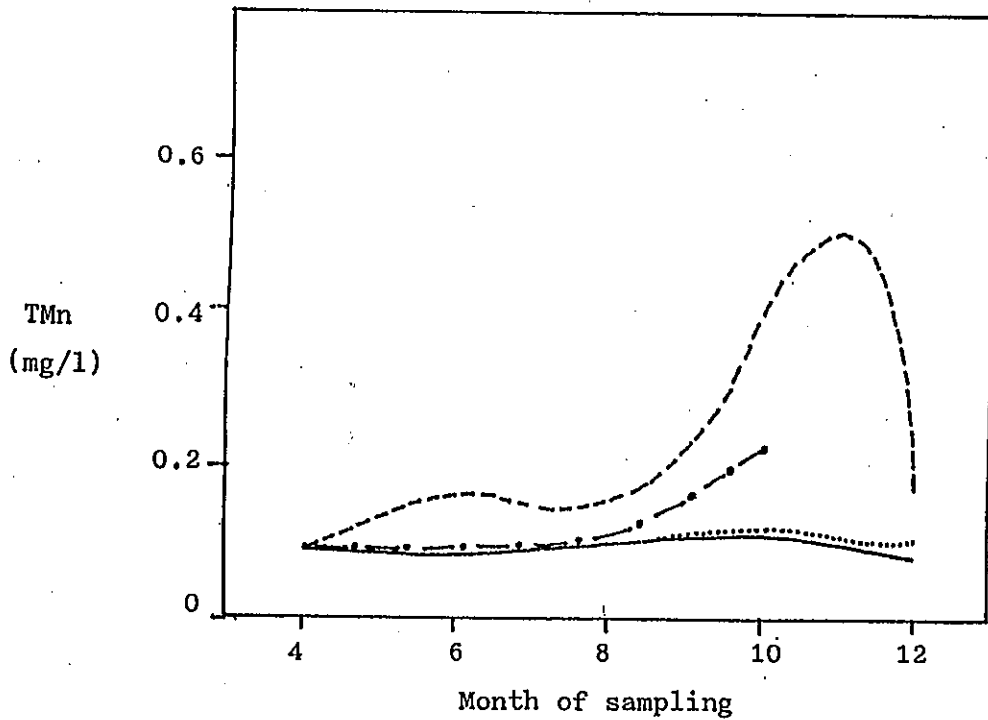
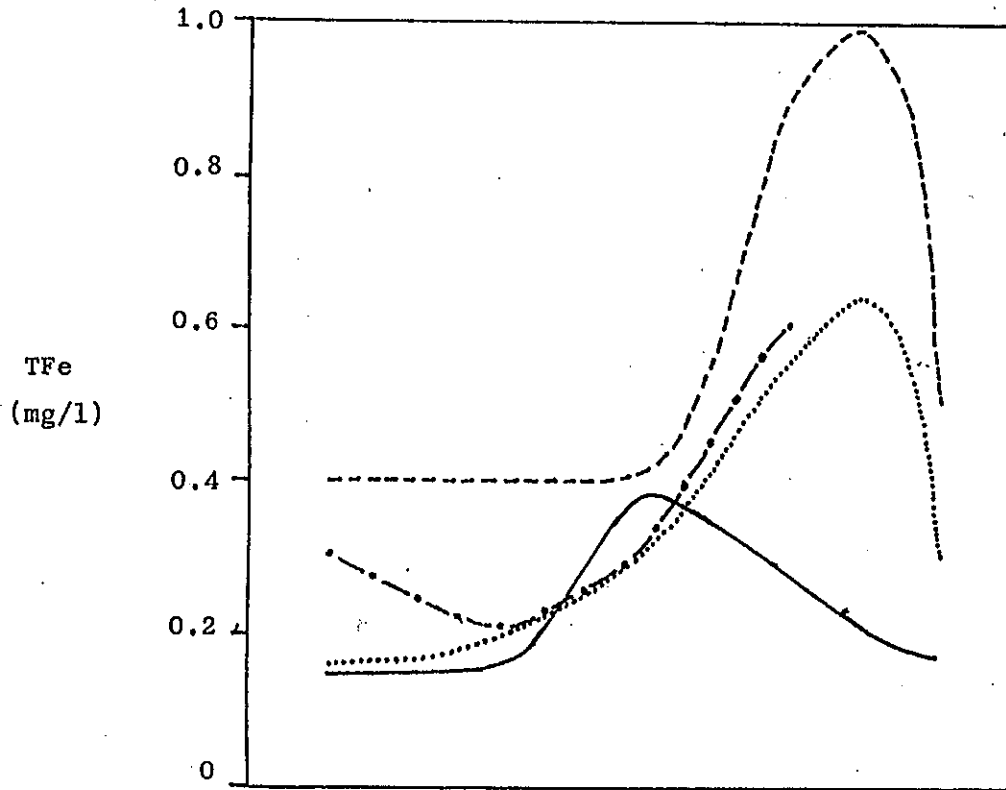
oxidised and precipitate out as insoluble particulates. This should be a cause for concern for FEA as deposition of such material could impose mechanical problems at the power station. It appears that such a problem arose once in 1984 when INR was called on to analyse the material depositing on the cooling fins in the tailrace.

TABLE 23 : COMPARISON OF THE IRON AND MANGANESE CONTENT OF THE TAILRACE AND STATION 2 BOTTOM WATERS

Sampling Date	Total Iron (mg/l)		Total Manganese (mg/l)	
	Station 2 Bottom	Tailrace	Station 2 Bottom	Tailrace
24/4/85	2.2	0.4	1.1	<0.1
19/8/85	0.6	0.4	0.1	0.1
24/10/85	0.7	0.9	0.3	0.4
17/12/85	4.8	0.5	0.5	0.2

The effect of the iron and manganese content of the tailrace water on the rest of the river is illustrated in Figure 18. It shows that the water at points below the tailrace is higher in Fe and Mn than at a point above it, the effect being more pronounced in the summer months. It is difficult to assess the effect of this on the aquatic environment with the data available. It would be advisable to monitor any long term effects that may eventuate.

FIGURE 18 : Distribution of total iron and manganese in the Wailoa River in 1985



Key

- Site 100 m above Power Station
- - - At tailrace
- · - 150 m below Power Station
- · · · At Laselevu

VECTOR-BORNE DISEASE SURVEY

Dr Alison Haynes, a biologist from the School of Pure and Applied Sciences, USP and Ms Usha Prasad, a medical anthropologist attached to the Institute of Natural Resources carried out a survey on 19/20 September and 23 October, 1985 respectively of the Monasavu area for possible disease hosts. Each of their reports is included in this section.

Gastropods in Lake Monasavu in September, 1985

by Dr Alison Haynes

Lake Monasavu was visited on 19 and 20 September, 1985, in order to find if any gastropod snail populations were living in the lake, and if so, to discover if they were hosts to any trematode worms.

Rocks, stones and vegetation near the shore were searched for gastropods (water snails). Other animals present were also noted. A search was made where the shore could be reached by boat and where the water was reasonably shallow. Most freshwater snails feed on the film of microscopic algae and fungi which covers rocks and rotting vegetation. This film of microorganisms is not present in the deep parts of the lake where light can not penetrate.

Two species of Gastropods (Mollusca) were found:

- (1) a small pulmonate limpet called Ferrissia noumeensis which is less than 4 mm long.
- (2) a larger left handed pulmonate snail called Physastra nasuta. All specimens found were less than 6 mm high, although they do reach 20 mm. Neither species was abundant.

Two other benthic invertebrate species were observed. A predatory leech of the family Erpobdellidae, possibly of the genus Vivabdella. These were quite abundant as 2 to 3 were found under most rocks. The other invertebrate species was an encrusting Bryozoa. This formed a mat on the underside of many rocks especially those on the edge of the dam. Shoals of small Tilapia were observed. In July and December, 1982 when the lake was filling, the water snail Physastra nasuta was the most abundant invertebrate in the lake. Since then their numbers have declined drastically, probably because they are being eaten by Tilapia and leeches.

The snail Physastra nasuta is closely related to Bulinus globosus which is host to the blood fluke, Schistosoma mansoni. This trematode worm causes Schistosomiasis (Bilharzia). During the visit to Lake Monasavu all Physastra nasuta were collected and taken to the laboratory at the School of Pure and Applied Sciences where they were dissected and examined for trematode worms. No trematodes of any kind were found.

The common prosobranch snail Melanoides tuberculata, which is found in ditches, ponds, streams and rivers throughout Viti Levu and which is present in the streams of the Nadrau plateau was absent from Lake Monasavu. This may have been due to insufficient dissolved oxygen in the lake. This snail is known to be host to the lungfluke, Paramonostomium aegyptiacum in Egypt although it is not known to carry any disease in Fiji.

Mosquitos in the Monasavu Lake area

by Ms Usha Prasad

The purpose of the visit to Monasavu Reservoir was to locate and identify the species of mosquitos found in the area. Over the 36 hour period, only one species of mosquito- Tripteroides (tripteroides) Purpuratus Edwards - was found (also the sample size consisted of only one mosquito). The species was identified according to Belkin's, The Mosquitos of the South Pacific. It also appears that this mosquito species is not anthrophilic (blood sucking) but is rather a nectar feeder.

None of the Aedes stegomyia species common to Fiji inland areas, were found in or around the bass camp. An attempt to monitor "unknown" peak biting hours (early morning and evening) also proved with negative results.

**CONCLUSIONS**

The trends observed in the water quality of the Monasavu Reservoir and Wailoa river in 1985 were similar to those of 1984. The operation of an aerator near Station 2 in the reservoir did not seem to have any marked effect on the dissolved oxygen content of deeper waters during summer. However, indications are that the water at the bottom of the reservoir improved in quality as evidenced by the notable lack of smell of hydrogen sulphide at the power station.

The oxygenation of the water at the power station helps in restoring conditions characteristic of oxic waters so that its effect on the Wailoa River is minimal. The deposition of particulate iron and manganese at the power station as a

result of oxygenation could present problems in the future if left unchecked.

With the improved water quality and the results on the vector-borne disease survey apparently negative it is suggested that monitoring be continued on a limited scale.

#### ACKNOWLEDGEMENTS

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