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**WATER QUALITY IN THE MONASAVU
RESERVOIR, WEIRS AND WAILOA
RIVER IN 1999**

IAS TECHNICAL REPORT NO. 2001/3

by

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EXECUTIVE SUMMARY

Water quality monitoring of the Monasavu Dam, five weir sites, and the Wailoa River has been conducted twice yearly, once during summer (December) and once during winter (July) by the Institute of Applied Sciences, University of the South Pacific. The Monasavu Dam and Wailoa River have been monitored since 1983 and the weirs since 1990. During 1998, because of disputes between the FEA and the landowners, only one monitoring was completed. This was the summer monitoring which was conducted in January 1999. The winter monitoring for 1999 was completed in July and the summer monitoring in March 2000. This report covers these three monitoring trips.

The sampling sites remain the same as in previous years. Three stations (near dam wall, moored to rake, and middle of dam) at three different depths (bottom, middle, surface) were sampled within the reservoir, three stations (above power station, below power station, and Laselevu village) were sampled within the Wailoa River, and the five weirs (Wainabua, Nabilabila, Wainikasou North, Wainikasou South and Wainisavulevu).

The main issues that arose during this period of monitoring of the reservoir, Wailoa river, and weirs are as follows:

In the Monasavu Reserovir:

- Dissolved oxygen levels in the bottom waters of the reservoir during the summer 1999 monitoring were extremely low. At Site 3, this could be a result of the decomposition of organic matter.
- Levels of metals in the bottom waters have remained the same as compared to previous years.

In the Wailoa River:

- In regards to dissolved oxygen, the water is reoxygenated as it passes through the power station.
- Although alkalinity (low levels), ammonia (high levels) and Total Manganese (high levels) at tailrace vary from those at the other two sites on the Wailoa River, levels return to normal by the Laselevu village site.

At the weirs

- Parameters monitored at the weirs were at stable levels considered normal for these environments. Total Phosphorus and phosphate levels were slightly high at Wainabua and Wainisavulevu. Otherwise, water quality was good.
- A concern though is the infestation of macroalgae and water weeds at a few of the weirs which may obstruct water flow.

CONTENTS

	Page
EXECUTIVE SUMMARY	i
LIST OF FIGURES	iii
LIST OF TABLES	iv
1.0 INTRODUCTION	1
2.0 BACKGROUND	3
3.0 THE MONITORING PROGRAMME	5
3.1 Organisation	5
3.2 Location of Sampling Sites	5
4.0 METHODOLOGY	9
4.1 On-site Measurements	9
4.2 Laboratory Analyses	9
5.0 RESULTS	10
6.0 WATER QUALITY AT MONASAVU	20
6.1 The Monasavu Reservoir	20
6.2 The Wailoa River	24
6.3 The Weirs	27
7.0 SUMMARY	30
8.0 CONCLUSION	30
9.0 BIBLIOGRAPHY	31
10.0 APPENDICES	
APPENDIX 1. Temperature and Dissolved Oxygen Data for the Monasavu Reservoir for the Three Monitorings	34
APPENDIX 2. Rainfall and Dam Levels Prior to and During the Three Monitorings	37
APPENDIX 3. Photographs	41

LIST OF FIGURES

	Page
Figure 1. Map of Viti Levu showing the location of the Monasavu Hydroelectric scheme	2
Figure 2. Detailed locations of dam, tunnels, creeks, and rivers in the Monsavu area	2
Figure 3. Typical thermal stratification of a lake into the epilimnetic, metalimnetic, and hypolimnetic water strata	4
Figure 4. Oxygen profile in a stratified lake: winter condition (1), summer condition (2)	4
Figure 5. Locations of the sampling stations in the Monasavu Reservoir	6
Figure 6. Sampling sites along the Wailoa River	6
Figure 7. The Monasavu Dam and Weirs	7
Figure 8. Temperature/Dissolved Oxygen profiles for Monasavu Dam, January 1999	17
Figure 9. Temperature/Dissolved Oxygen profiles for Monasavu Dam, July 1999	18
Figure 10. Temperature/Dissolved Oxygen profiles for Monasavu Dam, March 2000	19
Figure 11. Variation of Total Nitrogen and ammonia in the Monasavu Reservoir with time of year (1999/2000)	23
Figure 12. Dissolved Oxygen levels at the three sites along the Wailoa River	25

LIST OF TABLES

		Page
Table 1.	Statistics of the Dam and Reservoir	1
Table 2.	Summary of the 1999/2000 Water Quality Monitoring Programme	8
Table 3.	Depth in meters of the 3 reservoir sites during the different Monitorings	10
Table 4A.	Water quality results for Monasavu Dam and Wailoa River – January 1999 (summer 1998)	11
Table 4B.	Water quality results for Monasavu weirs – January 1999 (summer 1998)	12
Table 5A.	Water quality results for Monasavu Dam and Wailoa River – July 1999 (winter 1999)	13
Table 5B.	Water quality results for Monasavu weirs – July 1999 (winter 1999)	14
Table 6A.	Water quality results for Monasavu Dam and Wailoa River – March 2000 (summer 1999)	15
Table 6B.	Water quality results for Monasavu weirs – March 2000 (summer 1999)	16
Table 7.	Total alkalinity ranges (mg/L CaCO ₃) in the reservoir for various years	21
Table 8.	Comparison of Total Iron and Total Manganese values (mg/L) in the bottom waters of the reservoir for various years	24
Table 9.	Comparison of data from Site 2 bottom waters and Tailrace water	26
Table 10.	Comparison of Total Iron and Total Manganese content at Site 2 bottom waters and Tailrace during the summer 1999 monitoring	27
Table 11.	Variation in dissolved oxygen levels (mg/L) at the five weirs	28
Table 12.	Presence of algae at the five weirs during the summer 1999 monitoring	29

WATER QUALITY IN THE MONASAVU RESERVOIR, FIVE WEIRS, AND THE WAILOA RIVER (1998/1999)

1.0 INTRODUCTION

The Monasavu hydroelectric scheme is situated on the Nadrau Plateau in central Viti Levu (Figure 1). The Monasavu dam is located at an elevation of 670 to 750 meters and is fed by Nanuku Creek. Water is also diverted into the dam, via a pipeline, from other creeks, Wainisavulevu, Wainikasou, Nabilabila, and Wainabua. Water from the dam is tunnelled down to the Power Station at Wailoa which has a generating capacity of 80MW (Brodie et al 1987) (Figure 2). The hydro-scheme was opened in 1983. Table 1 presents some of the important characteristics of the dam and reservoir (Gibbons and Brodie 1985).

Table 1. Statistics of the Dam and Reservoir

Reservoir Length	18 km
Reservoir Width	Up to 1 km
Volume of Reservoir	142 million cubic meters
Area of Reservoir	670 Ha
Dam Height (Maximum)	85 m

Water quality monitoring of the Monasavu Dam, five weir sites, and the Wailoa River has been conducted twice yearly by the Institute of Applied Sciences, University of the South Pacific. The monitoring is funded by the Fiji Electricity Authority (FEA) and is carried out once during summer (December) and once during winter (July). The Monasavu Dam and Wailoa River have been monitored since 1983 and the weirs since 1990. Biological studies of the fauna in the dam, which have been carried out to a lesser extent, were not carried out during this monitoring period.

During 1998, because of disputes between the FEA and the landowners, only one monitoring was completed. This was the summer monitoring which was conducted in January 1999. The winter monitoring for 1999 was completed in July and the summer monitoring in March 2000. **The 1999 summer monitoring was delayed due to overhaul works at the dam.** This report covers the results of the water quality monitoring for summer 1998 (Jan 1999), winter 1999 (July 1999) and summer 1999 (March 2000).

At the time of writing this report, the political situation in Fiji is unstable with civil unrest, particularly by the indigenous Fijians. Landowning units throughout Fiji are becoming increasingly agitated, fearing that they will lose control over their land. Included in these troubled areas is Monasavu. Therefore it appears that the routine monitoring of the Monasavu hydroelectric scheme for the year 2000 will again be disrupted or even impossible. Only time will tell.

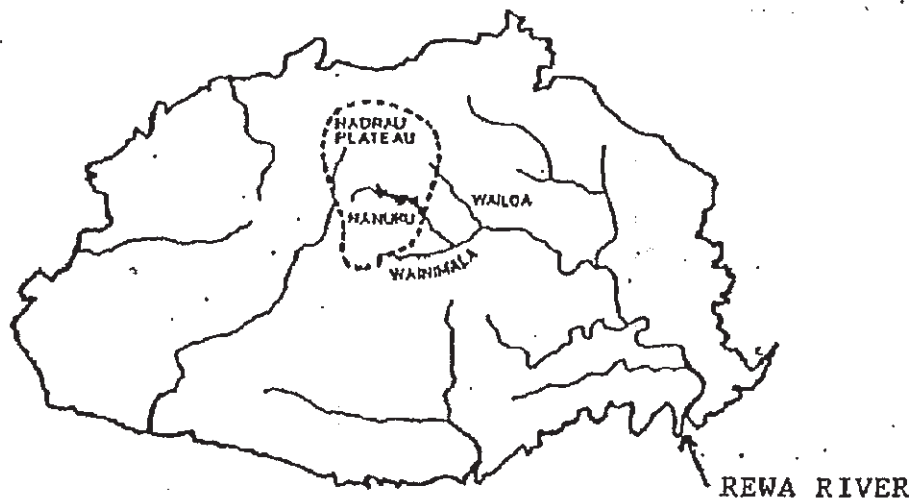


Figure 1. Map of Viti Levu showing the location of the Monasavu Hydroelectric scheme

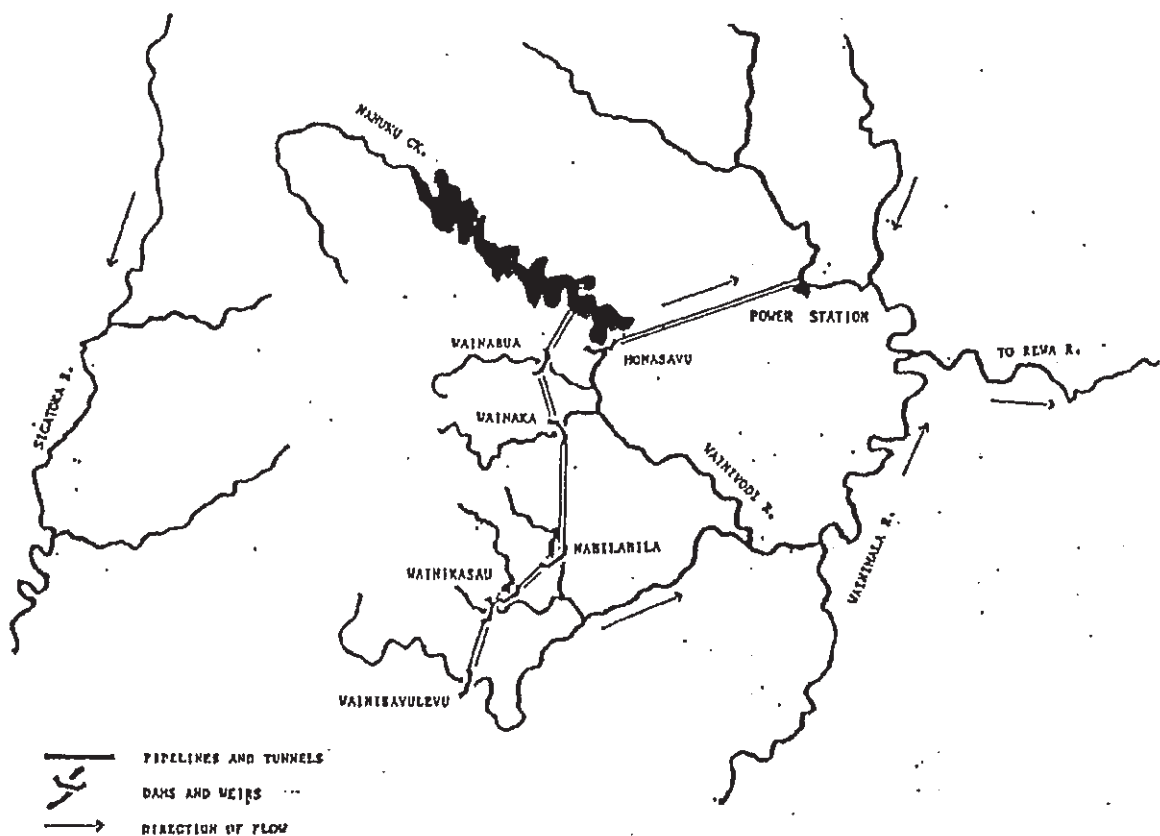


Figure 2. Detailed locations of dam, tunnels, creeks, and rivers in the Monasavu area

2.0 BACKGROUND

The principal aims of the study are fourfold:

- to monitor the water chemistry in the reservoir;
- to monitor the Wailoa River below the power station and the outfall;
- to monitor the public health status of the reservoir; and
- to monitor the water quality of the weir sites.

The Wailoa River receives water channeled from the reservoir to the Power Station. To assess the impact of the Power Station on the Wailoa River, three monitoring stations were established: a site upstream from the Power Station, one at tailrace (discharge point for the Power Station), and one site several kilometers downstream from tailrace at Laselevu Village.

The aim of the monitoring at the weir sites is to establish if logging in the catchment area is having an impact on the quality of the water in the creeks feeding the reservoir. In previous years, large aquatic weeds have become a problem at some of the weirs, clogging the weirs and disrupting the flow of water to the main reservoir. The appropriate section (Weed Control) of the Ministry of Agriculture is addressing this problem.

Over the years, results of water chemistry analysis have indicated a gradual improvement in the quality of water in the reservoir (Morrison et al 1990, Lloyd et al 1993, Tamata et al 1995). The water quality in the dam, Wailoa River and five weir sites has been good. The monitoring programme over the last 15 years has highlighted a number of trends in the water quality of the dam, the Wailoa River, and the weirs. Established trends include:

- a) Water levels in the dam are usually lower in winter when it is the dry season.
- b) Water quality within the dam has been improving over the years (Chand and Fung 1996). Nutrient levels and other parameters within the dam are generally within the standards recommended for Fiji under the Recreation Water Criteria (NEMP 1992).
- c) There is normally a seasonal variation in temperature within the Monasavu reservoir. During summer, surface waters temperatures are usually higher contrasting sharply with cooler, more dense waters below. Stratification thus occurs due to thermal resistance to mixing resulting in the formation of different layers (Chand and Fung 1996). During winter (July), the cooler temperatures disrupt this stratification, thus the temperature range is relatively homothermic (Figure 3).

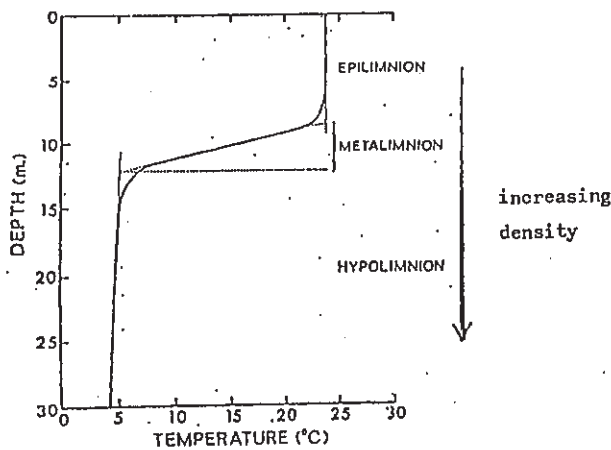


Figure 3. Typical thermal stratification of a lake into the epilimnetic, metalimnetic, and hypolimnetic water strata (Wetzel 1975)

- d) As a result of poor circulation in the water column in the summer, low oxygen levels prevail in the bottom layers due to the thermocline barrier and decomposition and respiration activities that use up oxygen. In winter, the distribution of dissolved oxygen is more uniform (Figure 4). Dissolved oxygen is always higher at the surface due to the combination of atmospheric aeration, turbulence, and photosynthetic processes of algae and phytoplankton.

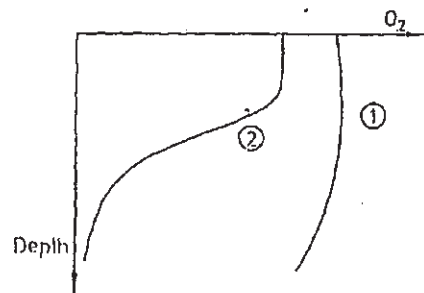


Figure 4. Oxygen profile in a stratified lake: winter condition (1), summer condition (2) (Jorgensen and Johnson 1989).

- e) Total alkalinity and pH have remained fairly stable during both winter and summer over the years within the dam.
- f) Concentrations of ammonia, nitrates and phosphates are usually low at the surface where dissolved oxygen levels are high and phytoplankton activity is prominent in using up the nutrients. Levels increase towards the bottom as dissolved oxygen levels decrease and phytoplankton presence is less prominent. Nutrient levels seem to be slightly higher in the summer. This increased nutrient level may be due to increased rainfall and corresponding washout of nutrients from the soil surrounding the dam.
- g) Over the years, the concentrations of the metals iron and manganese have decreased to very low levels and there is so far little risk of metal deposition on machinery in the power station. Levels are highest at depth and increase slightly during the summer when dissolved oxygen is low in the bottom layers. At low dissolved oxygen levels, the oxidised states of the metals become reduced releasing the metal elements into the water column.

3.0 THE MONITORING PROGRAMME, 1998 -1999

3.1 Organisation

The twice yearly monitoring of the Monasavu reservoir, weirs, and Wailoa River was carried out in 1999 and 2000. The winter monitoring for 1998, scheduled for July 1998, was cancelled due to a landowner/FEA conflict, which led to the occupation of the site, by the police and army. The summer monitoring for 1998 was carried out on January 13th and 14th 1999. The winter monitoring for 1999 was carried out on July 28th and 29th 1999 and the summer monitoring for 1999 on the 8th and 9th of March 2000. The re-scheduled monitoring visits were approved by the FEA Engineer in charge (Roshan Ali). It was agreed that instead of reporting on the single summer monitoring for 1998, the three visits (summer 1998, and winter and summer 1999) were to be reported together, thus this report.

3.2 Location of Sampling Sites

The sampling sites remain the same as in previous years. Three stations at three different depths (bottom, middle, surface) were sampled within the reservoir, three stations were sampled within the Wailoa River, and five weirs were monitored. The locations of these sites are shown in Figures 5, 6 and 7. The details of the sites and parameters monitored at each site are summarised in Table 2. Nutrients were measured for the first time in the weirs in 1999 and during the 1999 summer monitoring metals were again monitored. Metals were not monitored in the summer 1998 and winter 1999 monitoring because of their low levels during previous visits.

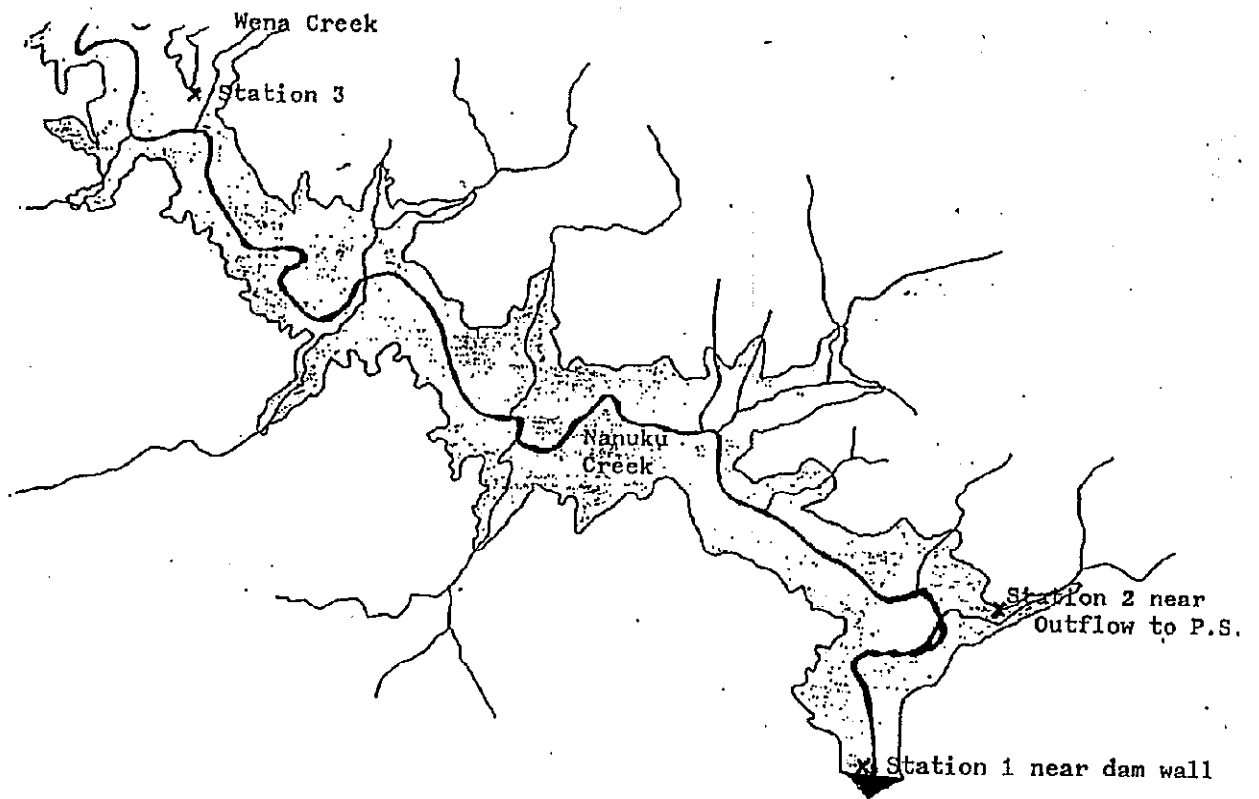


Figure 5. Locations of the sampling stations in the Monasavu Reservoir.

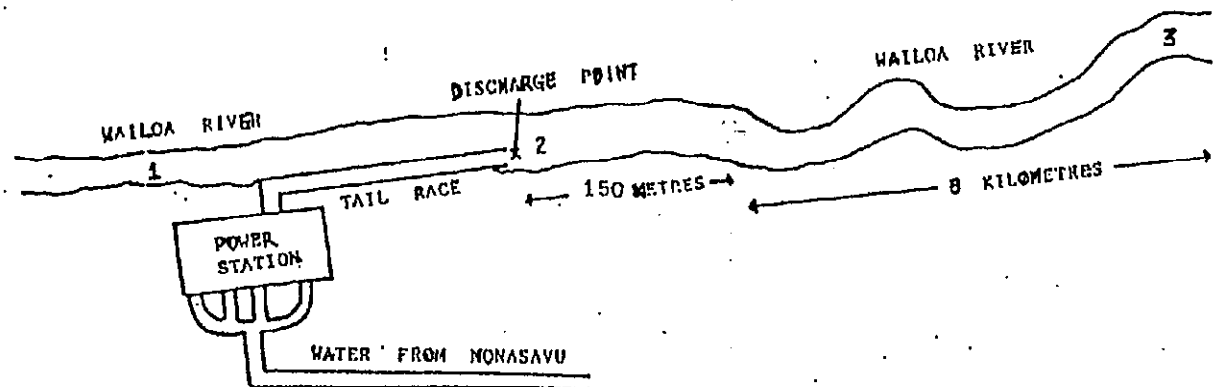


Figure 6. Sampling sites along the Wailoa River.
 Site 1: 100 m upstream of power station discharge
 Site 2: Tailrace (power station discharge water)
 Site 3: On the Wailoa River at Laselevu village

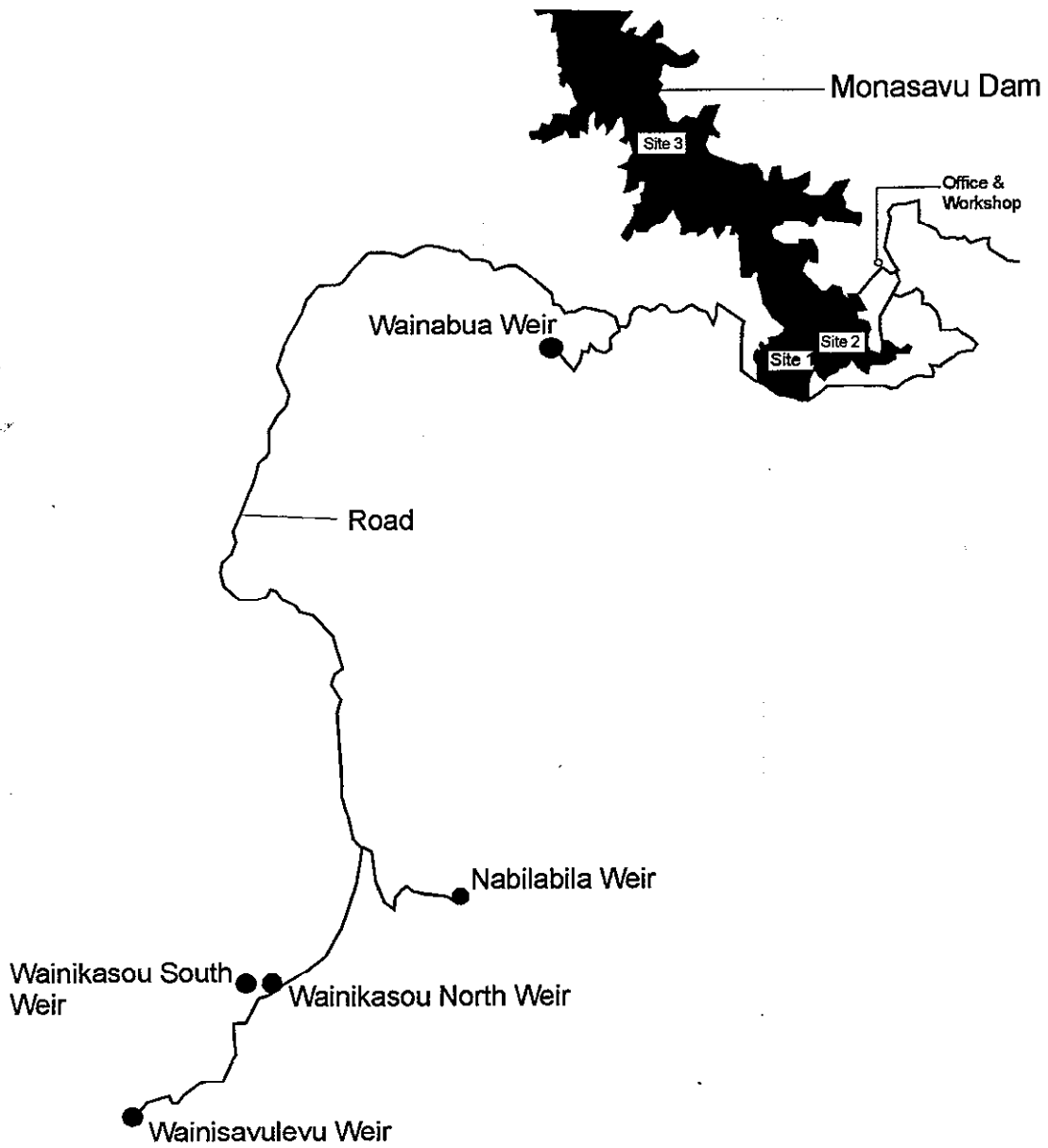


Figure 7. The Monasavu Dam and Weirs

Table 2. Summary of the 1999/2000 Water Quality Monitoring Programme

Location	Number of Sites Monitored	Description of Sites	Dates monitored	Parameters measured On-site	Parameters measured in Lab
Reservoir	3 sites each at 3 depths (surface, middle, bottom)	Site 1 – Near the float near dam wall Site 2 – Moored to rake at outflow to power station Site 3 – Middle of Dam (near Wena Ck junction)	Jan 13 th , 1999 July 28 th , 1999 March 9 th , 2000	pH, clarity, depth temperature/dissolved oxygen profiles, GPS readings, turbidity	pH, total alkalinity, Total N, Nitrate, Ammonia, Total P, Phosphate,
Wailoa River	3 sites	Above Wailoa Power Station Below Wailoa Power Station (tailrace water) Near Laselevu Village downstream	Jan 14 th , 1999 July 29 th , 1999 March 8,9 2000	pH, clarity, temperature, dissolved oxygen, turbidity	Total alkalinity, Total N, Nitrate, Ammonia, Total P, Phosphate,
Weirs	5 weirs	Wainabua Nabilabila Wainikasou North Wainikasou South Wainisavulevu	Jan 13 th , 1999 July 28 th , 1999 March 8 th , 2000	pH, temperature, dissolved oxygen, clarity, turbidity	Total alkalinity, total suspended solids, total dissolved solids, Total N, Nitrate, Total P, Phosphate,

4.0 METHODOLOGY

4.1 On-site Measurements

At all sites temperature, dissolved oxygen, pH, and turbidity were measured in the surface waters using a Horiba Multimeter. The multimeter was calibrated on-site. At the three stations within the dam, temperature and dissolved oxygen were also measured at 1 meter intervals down to the bottom with a YSI Model dissolved oxygen meter. Water clarity was determined at all sites using a white and black secchi disc. The depth of the water at each station in the dam was determined using the secchi disc. At the weirs the presence of macroalgae was also noted.

4.2 Laboratory Analyses

Water samples were collected in clean acid-washed (10% HCl) plastic bottles and stored in ice. At the reservoir (dam) sites water samples were collected from three depths: near the surface, mid-depth, and bottom waters. A depth sampler was used to collect the water samples from the mid-depth and bottom waters. At the weir sites and Wailoa River sites water samples were collected from the surface waters only.

These samples were brought back to the laboratory within 24 hours and analysed for various parameters. A description of each analysis was given in the 1996 report (Chand and Fung). These procedures have remained the same.

Alkalinity was measured by titration with standard 0.01 HCl to the phenolphthalein end point for carbonate alkalinity and to the bromocresol green/methyl red end point for bicarbonate alkalinity (APHA 1992). pH was measured using the Orion Model 250 pH meter.

Nitrate concentration was measured using the Cadmium Reduction/Colorimetric method and measurement of absorbance on the UV Spectrophotometer at 543 nm (IAS Methods of Analysis of Water, 1992).

Ammonia was analysed using the phenate method. Absorbance was measured on the spectrophotometer at 660 nm (APHA 1992).

Dissolved phosphate was measured using the Molybdenum blue-Colorimetric method and measurement of absorbance on the UV Spectrophotometer (IAS Methods 1992).

Total suspended and dissolved solids were measured using the Filtration/Gravimetric method (APHA 1981).

Metals were analysed by direct Atomic Absorption/Emission Spectrometry (APHA 1992).

Total Nitrogen (TN) obtained using the Titrimetric determination method (APHA 1981, IAS WC 26.1, 1992) and Total phosphorus (TP) was determined using a method based on a perchloric acid digestion followed by determination of phosphate using the Murphy-Riley method (IAS WC 34 1992).

5.0 RESULTS

The data on the water chemistry for the reservoir, weirs and Wailoa River for the summer 1998, and winter and summer monitoring for 1999 are presented in Tables 4 – 6. The dissolved oxygen and temperature profiles for each of the three stations in the reservoir are shown in Figures 8 – 10, with the data tabulated in Appendix 1.

The depth of the reservoir varied between the three monitorings (Table 3.) Dam levels were higher in 1999 than in previous years, and was especially high in March 2000.

Table 3. Depth in meters of the 3 reservoir sites during the different monitorings

<i>Site</i>	<i>January 1999</i>	<i>July 1999</i>	<i>March 2000</i>
Site 1- Moored to floaters near dam wall	43 m	44m	65.2 m
Site 2 – Moored to rake	23 m	25 m	41 m
Site 3 – Middle of dam	15m	12 m	11.8 m

The dam level corresponds to the amount of rainfall as seen in Appendix 2. During 1998, there was a drought thus dam levels were low in January 1999. 1999 was an especially wet year thus dam levels during March 2000 were very high.

TABLE 4A. WATER QUALITY RESULTS FOR MONASAVU DAM AND WAILOA RIVER – JANUARY 1999 (summer 1998)

	Site 1 Surface	Site 1 Middle	Site 1 Bottom	Site 2 Surface	Site 2 Middle	Site 2 Bottom	Site 3 Surface	Site 3 Middle	Site 3 Bottom	Wailoa Above PS	Wailoa Tailrace	Wailoa Laselevu
pH	8.4	6.8	6.6	8.5	7.4	6.9	8.9	6.8	6.8	7.3	6.8	7.7
Temperature (°C)	24.9	23	19	25.1	24.5	23	26.4	25	24	24.7	24.0	25.2
Dissolved Oxygen (mg/L)	6.1	5.6	4.8	6.8	5.8	5.6	6.5	5.8	5.7	8.26	8.59	8.41
Turbidity (NTU)	6	-	-	6	-	-	6	-	-	3	178	Unstable
Clarity (m)	2	-	-	2.2	-	-	1.7	-	-	-	-	-
Total alkalinity (mg/L CaCO ₃)	15.7	16.5	27.9	15.5	16.4	11.8	15.4	20.5	19.3	26.0	16.0	24.6
Total N (µg/L)	312.2	202.9	197.3	96.3	269.4	67.7	75.8	61.8	267.0	149.6	59.1	76.8
Nitrate as NO ₃ (µg/L)	<34	<34	<34	<34	<34	<34	<34	<34	<34	<34	<34	<34
Ammonia as NH ₃ (µg/L)	<12.2	<12.2	482.8	<12.2	<12.2	16.5	<12.2	<12.2	88.2	<12.2	57.9	<12.2
Total P (µg/L)	<20	<20	31.7	<20	<20	<20	<20	<20	<20	<20	<20	<20
Orthophosphate as PO ₄ (µg/L)	<20	<20	22.5	<20	<20	<20	<20	<20	<20	<20	<20	<20
Total Fe (Iron)	na	na	na	na	na	na	na	na	na	na	na	na
Total Mn (Manganese)	na	na	na	na	na	na	na	na	na	na	na	na
Depth (m)	na	na	43	na	na	20	na	na	15	na	na	na

TABLE 4B. WATER QUALITY RESULTS FOR MONASAVU WEIRS – JANUARY 1999 (summer 1998)

	Wainabua	Nabilabila	Wainaikasou North	Wainikasou South	Wainisavulevu
pH	7.4	7.5	7.4	7.3	6.3
Temperature (°C)	20.9	20.7	20.9	20.7	20.9
Dissolved Oxygen (mg/L)	6.8	8.32	8.63	8.25	7.24
Turbidity (NTU)	0.1	1	3	1	22.5
Clarity (m)	3.4	1.5	>1	2	<1
Total alkalinity (mg/L CaCO₃)	18.4	27.0	20.7	20.7	8.6
Total Suspended Solids (mg/L)	8	16	5	15	16
Total Dissolved Solids (mg/L)	77	95	85	79	53
Total N (µg/L)	131.6	140.0	174.3	235.5	37.2
Nitrate as NO₃ (µg/L)	<34	<34	<34	<34	<34
Total P (µg/L)	77.1	45.4	<20	1.5	<20
Orthophosphate as PO₄ (µg/L)	27.2	<20	<20	<20	<20

TABLE 5A. WATER QUALITY RESULTS FOR MONASAVU DAM AND WAILOA RIVER – JULY 1999 (winter 1999)

	Site 1 Surface	Site 1 Middle	Site 1 Bottom	Site 2 Surface	Site 2 Middle	Site 2 Bottom	Site 3 Surface	Site 3 Middle	Site 3 Bottom	Wailoa Above PS	Wailoa Tailrace	Wailoa Laselevu
pH	7.95	-	-	7.85	-	-	6.11	-	-	6.02	6.75	6.6
Temperature (°C)	22.1	20.1	19.0	22.5	20.9	20	23.1	21	20.6	21.4	21	23
Dissolved Oxygen (mg/L)	9.8	2.9	0.7	10.2	8	3.8	8.9	4.7	3	8.73	8.6	9
Turbidity (NTU)	10(unst)	-	-	10 (unst)	-	-	10 (unst)	-	-	2	1	4
Clarity (m)	1.2	-	-	1.2	-	-	1	-	-	1.5 (bottom)	1.75	1 (bottom)
Total alkalinity (mg/L CaCO ₃)	16.8	15.4	37.2	16.3	16.5	15.7	18.1	16.7	16.3	31.3	16.0	22.5
Total N (mg/L)	0.57	0.35	1.08	0.32	0.88	0.86	0.09	6.41	0.57	0.51	0.55	1.00
Nitrate as NO ₃ (µg/L)	<34	69.2	59.0	38.8	41.5	64.1	93.1	77.7	<34	<34	45.8	<34
Ammonia as NH ₃ (µg/L)	<12.2	<12.2	3241	12.6	22.8	<12.2	40.7	16.2	34.3	<12.2	19.3	41.1
Total P (µg/L)	<20	<20	273.9	<20	<20	<20	<20	<20	<20	-	<20	20.6
Orthophosphate as PO ₄ (µg/L)	<20	<20	271.9	<20	<20	<20	<20	<20	<20	-	<20	<20
Total Fe												
Total Mn												
Depth (m)	-	-	44	-	-	25	-	-	12	-	-	-

TABLE 5B. WATER QUALITY RESULTS FOR MONASAVU WEIRS – JULY 1999 (winter 1999)

	Wainabua	Nabilabila	Wainaikasou North	Wainikasou South	Wainisavulevu
pH	7.09	6.94	6.68	6.80	6.75
Temperature (°C)	19.5	19.5	19.4	19.5	19.2
Dissolved Oxygen (mg/L)	8.5	8.8	8.03	8.83	8.28
Turbidity (NTU)	10 (unst)	10 (unst)	10 (unst)	10 (unst)	10 (unst)
Clarity (m)	1.25	1.25	0.75	1.25	1.30
Total alkalinity (mg/L CaCO₃)	16.4	18.0	20.3	17.7	9.8
Total Suspended Solids (mg/L)	7	10	7	8	4
Total N (mg/L)	0.15	0.26	0.32	0.22	0.14
Nitrate as NO₃ (µg/L)	<34	<34	<34	<34	38.0
Total P (µg/L)	61.7	45.2	<20	44.1	<20
Orthophosphate as PO₄ (µg/L)	59.8	42.6	<20	42.5	<20

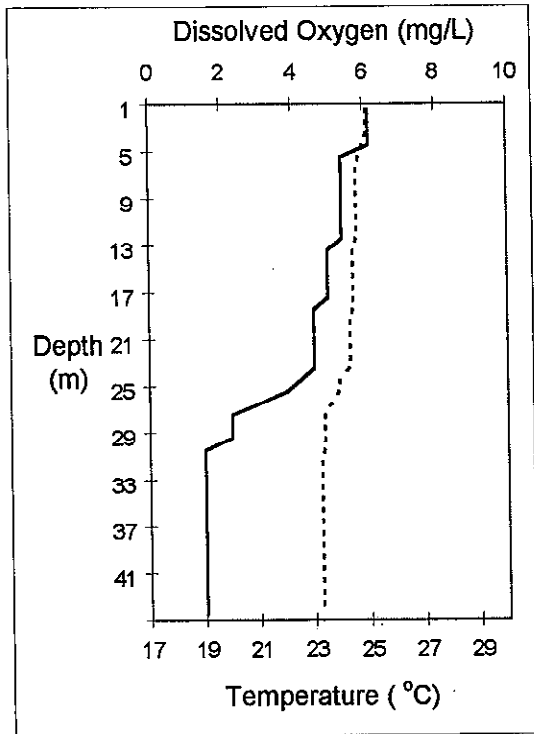
TABLE 6A. WATER QUALITY RESULTS FOR MONASAVU DAM AND WAILOA RIVER – MARCH 2000 (summer 1999)

	Site 1 Surface	Site 1 Middle	Site 1 Bottom	Site 2 Surface	Site 2 Middle	Site 2 Bottom	Site 3 Surface	Site 3 Middle	Site 3 Bottom	Wailoa Above PS	Wailoa Tailrace	Wailoa Laselevu
pH	8.2	6.6	6.6	8.5	6.6	6.4	8.9	6.8	6.4	7.9	6.9	7.8
Temperature (°C)	25.5	22.3	na	25.5	22.7	na	26.6	25.1	23.9	25	22.8	25.9
Dissolved Oxygen (mg/L)	8.02	0.74	na	8.3	1.71	na	7.7	0.83	0.01	8.36	7.66	8.69
Turbidity (NTU)	2	-	-	1	-	-	3	-	-	1	2	3
Clarity (m)	2.7 m	-	-	3 m	-	-	2 m	-	-	~3 m	3m (bottom)	0.5 m (bottom)
Total alkalinity (mg/L CaCO ₃)	16	15	33	17	16	18	16	20	18	37	18	24
Total N (mg/L)	0.47	0.21	1.87	0.24	<0.01	0.67	1.09	0.54	0.01	0.44	0.22	0.14
Nitrate as NO ₃ (mg/L)	<0.034	<0.034	0.18	<0.034	<0.034	<0.034	<0.034	<0.034	<0.034	0.04	<0.034	0.04
Ammonia as NH ₃ (mg/L)	<0.01	0.03	1.12	<0.01	0.01	0.03	<0.01	<0.01	0.02	<0.01	0.05	<0.01
Total P (mg/L)	<0.018	<0.018	0.2	<0.018	<0.018	<0.018	<0.018	<0.018	<0.018	0.043	<0.018	<0.018
Orthophosphate as PO ₄ (mg/L)	<0.018	<0.018	0.14	<0.018	<0.018	<0.018	<0.018	<0.018	<0.018	0.03	<0.018	<0.018
Total Fe (mg/L)	-	-	5.07	-	-	0.38	-	-	0.26	<0.2	<0.2	<0.2
Total Mn (mg/L)	-	-	0.47	-	-	<0.2	-	-	<0.2	<0.2	0.23	<0.2
Total Suspended Solids (mg/L)	6	9	11.5	8	10	8	22	35.5	22	3	6	3
Depth (m)			65.2			41			11.8	3 - 4	3	0.5

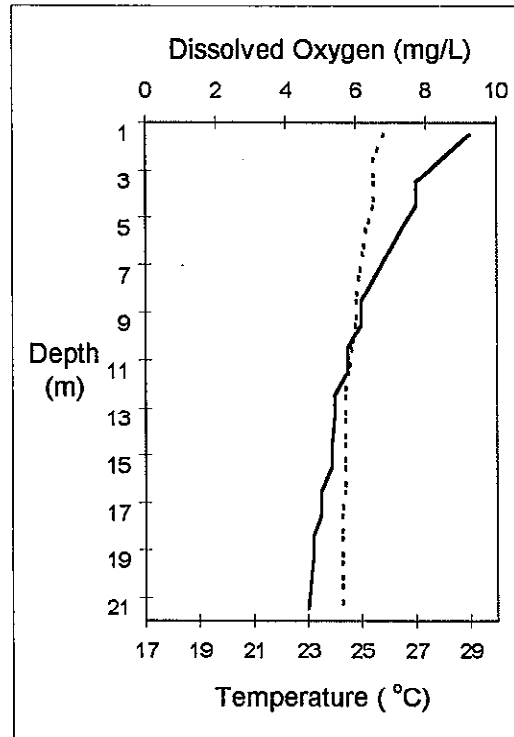
TABLE 6B. WATER QUALITY RESULTS FOR MONASAVU WEIRS – MARCH 2000 (summer 1999)

	Wainabua	Nabilabila	Wainaikasou North	Wainikasou South	Wainisavulevu
pH	6.8	7.3	7.3	6.6	7.4
Temperature (°C)	22.4	22.9	22.9	22.5	22
Dissolved Oxygen (mg/L)	7.69	7.77	7.66	8.37	7.35
Turbidity (NTU)	32	0	0	0	2
Clarity (m)	4 m (bottom)	~ 4 m	4 m	3m	2m
Total alkalinity (mg/L CaCO₃)	10	22	24	23	20
Total Suspended Solids (mg/L)	2.5	2	5.5	1	3
Total N (mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01
Nitrate as NO₃ (mg/L)	<0.034	<0.034	<0.034	<0.034	<0.034
Total P (mg/L)	<0.018	0.032	0.02	0.033	0.06
Orthophosphate as PO₄ (mg/L)	<0.018	0.03	<0.018	0.021	0.053

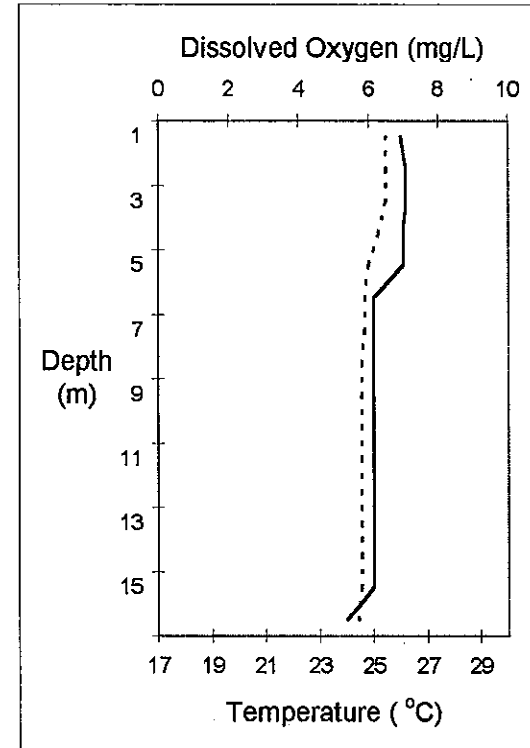
FIGURE 8. TEMPERATURE/DISSOLVED OXYGEN PROFILES FOR MONASAVU DAM, January 1999 (Site 1,2,3)



a) Site 1 (Moored to Floaters)



b) Site 2 (Moored to Rake)



c) Site 3 (Middle of Dam)

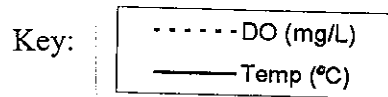
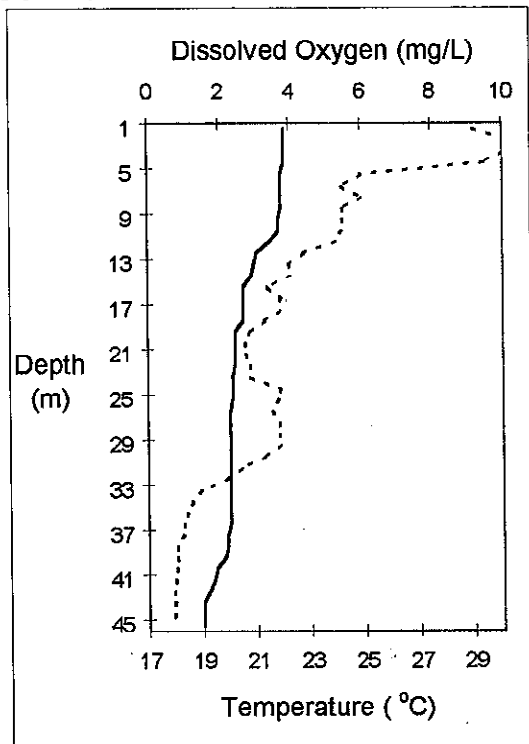
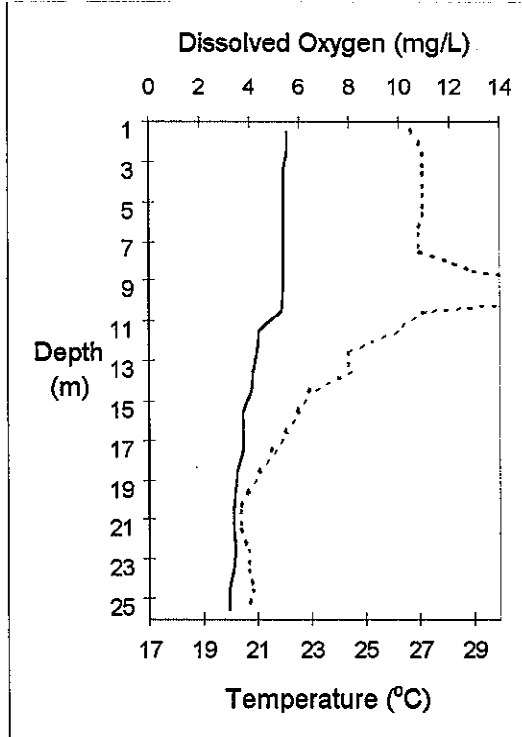


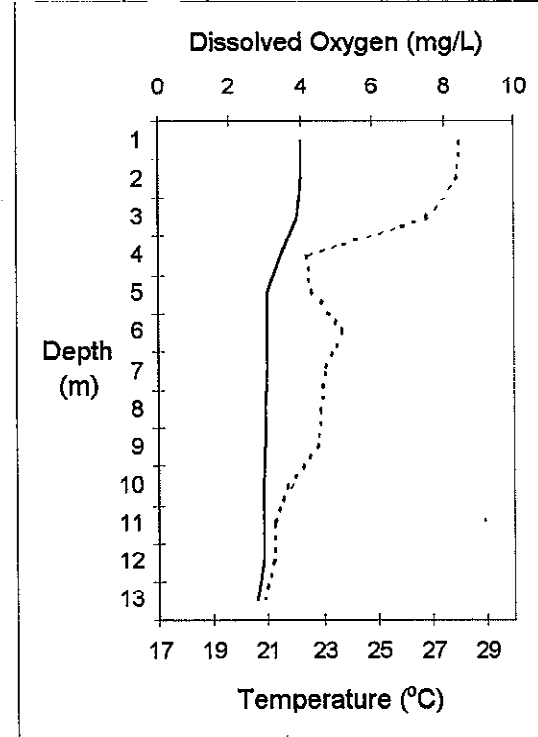
FIGURE 9. TEMPERATURE/DISSOLVED OXYGEN PROFILES FOR MONASAVU DAM, July 1999 (Site 1,2,3)



a) Site 1 (Moored to Floaters)



b) Site 2 (Moored to Rake)



c) Site 3 (Middle of Dam)

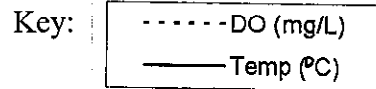
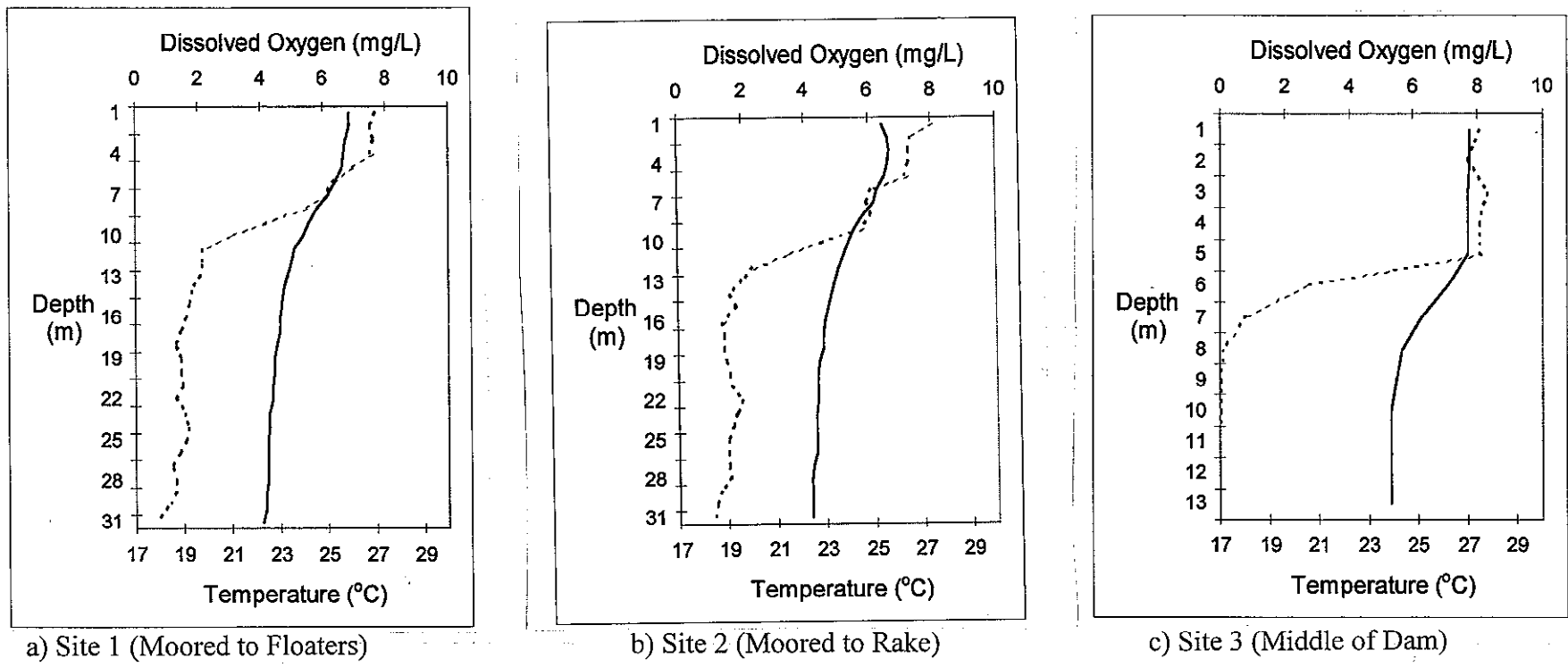


FIGURE 10. TEMPERATURE/DISSOLVED OXYGEN PROFILES FOR MONASAVU DAM, March 2000 (Site 1,2,3)



Key:
 - - - - - DO (mg/L)
 ——— Temp (°C)

6.0 WATER QUALITY AT MONASAVU

6.1 The Monasavu Reservoir

(a) *Temperature and Dissolved Oxygen Profiles*

During the 1998 summer monitoring there was a large range in water temperature with the surface water being between 24 and 29°C and cooling towards the bottom to 19 to 24°C. Site 1 was the deepest thus had the lowest temperature in the bottom waters. A layering of the water was noticed at Site 1 and 2 with the thermocline situated a depth of about 4 to 7 meters (Figures 8a, b, c). Dissolved oxygen (DO) levels, however, were fairly uniform throughout the water column at all sites. At the surface, DO levels were around 6 to 7 mg/L and decreased to around 5 to 6 mg/L in the bottom waters. This pattern is not typical of previous summer monitoring where thermal stratification leads to a rapid decrease in DO with depth. Major sources of dissolved oxygen are atmospheric re-aeration, where oxygen is transported from the air into the water during turbulence at the air water interface and photosynthesis, where carbon dioxide is converted to organic matter producing oxygen. As a result, DO is usually higher in the surface waters.

During the 1999 winter monitoring the temperature values were fairly constant throughout the water column at all three sites (Figures 9a, b, c). Surface temperatures were all around 22°C declining very slightly towards the bottom to values between 19 and 21°C. This pattern is consistent with that found in previous years during winter. Dissolved oxygen values, on the other hand, varied drastically with depth. DO values at the surface were fairly high, between 8 to 11 mg/L, but then decreased rapidly to a depth of 11 meters. DO values in the bottom waters were between 0.5 and 5 mg/L. This pattern indicates stratification in the distribution of DO throughout the water column even though there is no presence of thermal stratification. This condition is normally characteristic during summer.

During the 1999 summer monitoring the range of temperature values throughout the water column was small, but greater than that found during the 1999 winter monitoring. Surface temperatures were between 25 and 27°C declining towards the bottom to values between 22 and 24°C. As expected the water temperatures were higher than those during the winter monitoring. Dissolved oxygen again varied considerably with depth. DO values at the surface were between 7 and 8 mg/L and decreased rapidly to a depth of 8 to 11 meters (Figures 10a, b, c). The lowest DO values obtained in the bottom waters were between 0.01 and 1.2 mg/L. This indicates that thermal stratification resulted in a stratified dissolved oxygen profile in the reservoir. This pattern is normally found during summer.

(b) *pH*

The Monasavu reservoir is a typical bicarbonate-type lake, with average pH values ranging from 6 to 9. The recommended pH levels for recreational waters in Fiji is 5 to 9 (NEMP 1992).

Values for the 1998 summer monitoring ranged from 6.6 to 8.9. The values for the 1999 winter monitoring ranged from 6.11 to 7.95 and for the summer monitoring from 6.4 to 8.9. These values are within the recommended standard and are similar to previous years values. The pH values were highest at the surface and decreased with depth. This is due to greater utilisation of carbondioxide for photosynthesis in the surface waters. The pH range was slightly greater during summer.

(c) *Clarity & Turbidity*

The clarity of the water in the reservoir was generally similar to that of 1996. During summer 1998, clarity was between 1.7 and 2.2 meters, in winter 1999 between 1 and 1.2 meters and in summer 1999 between 2 to 3 meters. For recreational waters, the recommended minimum visibility is 1.2 meters (NEMP 1992) indicating fairly clear waters within the reservoir.

(d) *Total Alkalinity*

Total alkalinity values measured during summer 1998 were between 11.8 and 27.9 mg/L CaCO₃ in the reservoir. Results during winter 1999 were in the range of 15.4 to 37.2 mg/L CaCO₃ and during summer 1999, values were between 15 and 33 mg/L CaCO₃. These values are much higher than those recorded in 1997 (Ram *et al.* 1998) but fairly similar to those of 1996, 1995 and previous years (Table 7).

Table 7. Total alkalinity ranges (mg/L CaCO₃) in the reservoir for various years

Year	Winter	Summer
1999	15.4-37.2	15-33
1998	none	11.8-27.9
1997	12.9-15.7	11.7-13.6
1996	18-30	<20
1995	19-53	14-34

In the 1998 –1999 monitoring, total alkalinity was found to be the highest at the bottom of Site 1 which is the deepest site.

(e) *Nutrients*

Total Nitrogen, Nitrates, and Ammonia

The values for Total Nitrogen in the reservoir in summer 1998 ranged from 0.062 to 0.31 mg/L and there was no pattern of distribution with depth. Winter values for 1999 ranged from 0.09 to 6.41 mg/L and increased slightly with depth. Values for summer 1999 ranged from <0.01 to 1.87 mg/L and there was again no pattern of distribution with depth. TN values are usually higher during winter (Figure 11).

For nitrates, summer 1998 values were <34 µg/L for all sites. Winter 1999 values ranged from <34 to 93.1 µg/L and there was no distinct pattern of distribution with depth. At Site 1 and 2, nitrates were lowest at the surface but at Site 3 they were highest at the surface. Summer 1999 values ranged from <34 to 180 µg/L . The only

reading (180 µg/L) was detected at the bottom of Site 1. The normal pattern of nitrate distribution is that surface waters have less nitrate due to the consumption of nitrates as a result of photosynthetic activity. In addition, nitrate levels are often higher during winter due to less photosynthetic activity and higher dissolved oxygen levels. Compared to previous years values, these nitrate values were considerably lower.

Ammonia levels in summer 1998 ranged from <12.2 to 482.8 µg/L with values only detected at the bottom of each site. Winter 1999 values ranged from <12.2 to 3241 µg/L. Summer 1999 values ranged from <10 to 1120 µg/L. As in previous years, the bottom of Site 1, which is the deepest part of the reservoir, had the highest value (Figure 11). This is consistent with the trend that ammonia levels increase with depth due to anoxic conditions in bottom waters, especially during summer.

Total Phosphorus and Phosphates

Total phosphorus and phosphates remained at relatively low levels at all sites in both the summer and winter, except at the bottom of Site 1.

During the summer of 1998, TP values were <20 µg/L except for the bottom depth at Site 1 which was 31.7 µg/L. During the winter of 1999 TP values were again <20 µg/L for all sites except at the bottom of Site 1 where it was 273.9 µg/L. During summer 1999, TP values were <18 µg/L for all sites except for at the bottom of Site 1 where it was 200 µg/L. These values are consistent with the trend that TP increases at depth due to decomposition of the underlying organic matter. TP may also be higher at depth during the winter than during the summer due to an increase in dissolved oxygen, which results in an increase in decomposition.

The pattern for phosphates was similar to that for TP. During summer 1998, phosphates were <20 µg/L at all sites except for the bottom of Site 1 where it was 22.5 µg/L. During winter 1999 phosphate values were again <20 µg/L except for at the bottom of Site 1 where it was 271.9 µg/L and during summer 1999 phosphate values were <18 µg/L except for at the bottom of site 1 where it was 140 µg/L. These values are similar to those obtained in previous years and follow the trend that phosphate values are higher at depth due to their use at the surface by phytoplankton and other organisms.

General

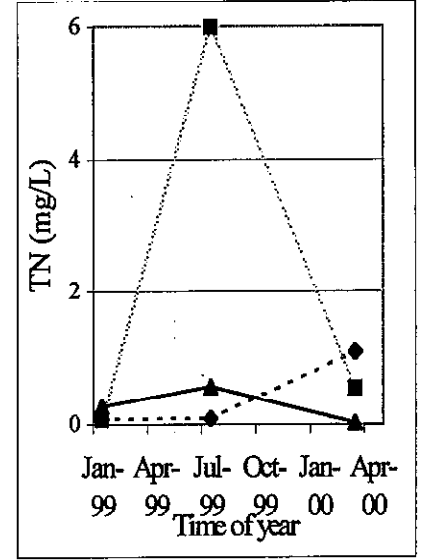
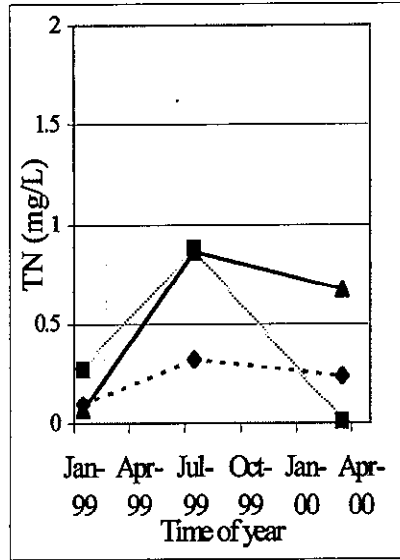
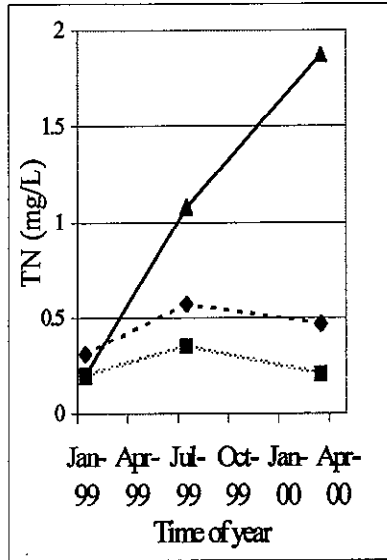
The reservoir receives a major portion of its nutrients from internal sources. Nitrate and ammonia are released as a byproduct in the decomposition of organic matter, which comprises of the cellular tissues of all organisms and from excreta from living processes (Novotny and Olem 1994). In the mid to surface waters decomposition is usually aerobic and releases nitrates, phosphates and carbondioxide into the water. These nutrients are utilised by photosynthetic organisms in the surface waters thus they are depleted of these nutrients. With increasing depth, these organisms decrease and nutrients tend to accumulate. At bottom depths, conditions are normally anaerobic. Under these conditions organic matter is broken down by bacteria into methane , carbondioxide and ammonia, thus the high ammonia concentration at bottom waters of each station.

Figure 11. Variation of Total Nitrogen and ammonia in the Monasavu Reservoir with time of year (1999/2000)

Site 1

Site 2

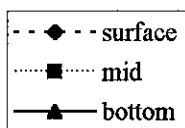
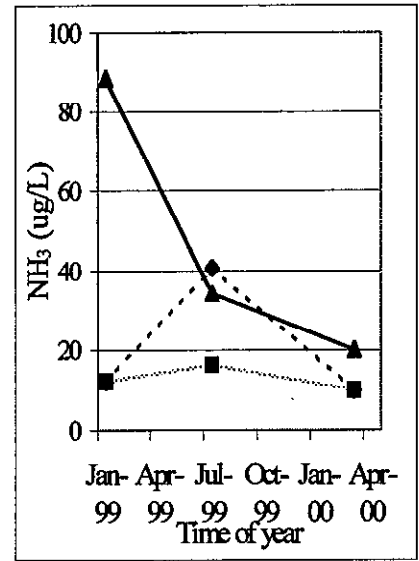
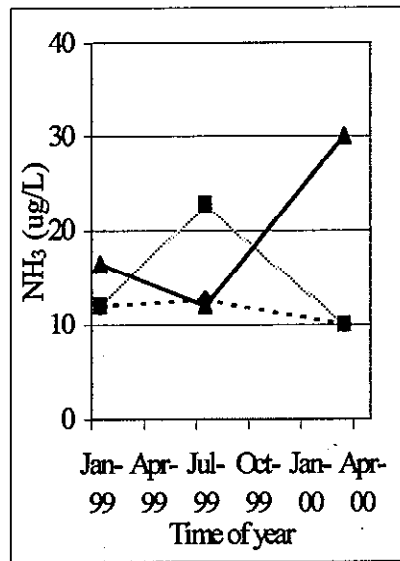
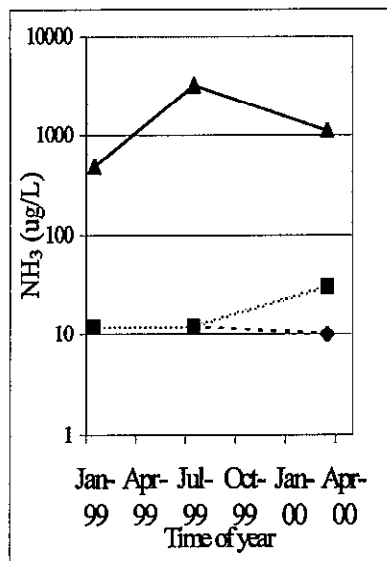
Site 3



Site 1

Site 2

Site 3



(f) *Total Iron and Total Manganese*

The levels of total iron and total manganese in the reservoir were not monitored in the 1998 summer and 1999 winter monitoring due to their very low levels in previous years. They were monitored, however, in the summer of 1999 from the bottom waters only of the 3 sites in the reservoir.

During the summer 1999 monitoring total iron levels were between 0.26 to 5.07 mg/L with the highest value obtained from the bottom of Site 1. Total manganese levels ranged from <0.2 to 0.47 mg/L, the highest value again being from the bottom of site 1. The higher level of iron and manganese in bottom waters results from the oxidation of the metals at the surface. This results in the precipitation of the metals which then sink to the bottom. In the bottom waters, anoxic conditions bring about the dissolution of iron and manganese from the sediments into the water column. In the winter when oxygen is present at depth, the ions are oxidised subsequently precipitated and returned to the sediments in the form of particulate matter. Thus there should be a decrease in the water column during winter.

The low concentrations of metals in the reservoir in general, with the exception of the deeper bottom waters, has been the trend over previous years (Table 8).

Table 8. Comparison of Total Iron (Fe) and Total Manganese (Mn) values (mg/L) in the bottom waters of the reservoir for various years

Year	Site 1		Site 2		Site 3	
	Total Fe	Total Mn	Total Fe	Total Mn	Total Fe	Total Mn
1999 summer	5.07	0.47	0.38	<0.2	0.26	<0.2
1997 summer	0.64	0.26	2.00	0.25	<0.3	<0.2
winter	0.50	0.09	15.19	0.74	0.24	<0.03
1995 summer	0.3	0.3	0.4	0.2	4.0	0.4
winter	7.0	4.2	6.9	0.6	<0.3	<0.2
1993 summer	0.84	0.38	2.1	<0.2	0.86	<0.2
winter	34	0.8	2.0	<0.2	0.97	<0.2

(f) *Total Suspended Solids*

Total suspended solids were assessed for the first time within the reservoir during the summer 1999 monitoring. Values ranged from 6 to 35.5 mg/L with the highest value recorded at mid-depth at Site 3. At this site, the water appeared murky and contained a large amount of organic suspended matter probably from the decomposing trees within the lake.

6.2 The Wailoa River

Water is drawn to the Wailoa Power station from the bottom of site 2 within the reservoir. According to the conditions prevalent in the deeper waters at site 2 in the reservoir, the tailrace water would be very low in dissolved oxygen, relatively high in total iron and ammonia and possibly contain some nutrients. Three sites along the Wailoa River were compared to see if the power station is having an impact on the quality of water in the river. A comparison between the values obtained for alkalinity,

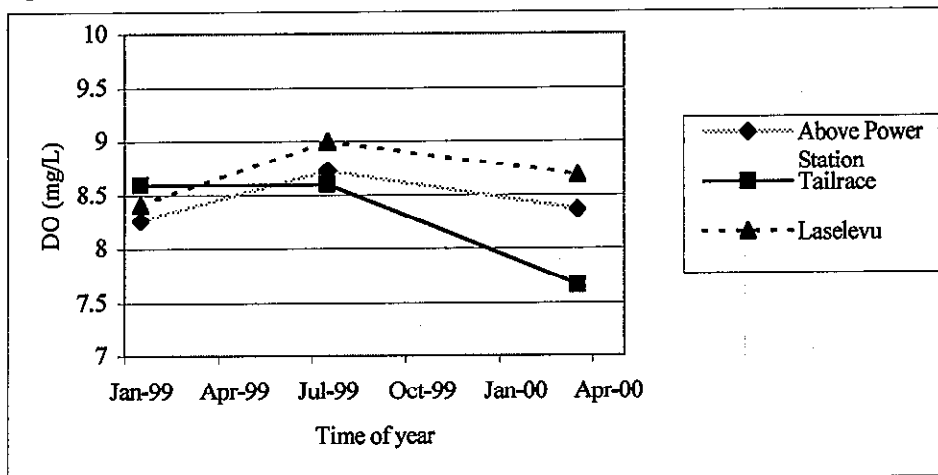
dissolved oxygen, and metals at the bottom of site 2 with those obtained at tailrace below the power station, will indicate whether water quality changes through the power station and the possibility of deposition of metals on the machinery in the power station.

(a) *Temperature, Dissolved Oxygen, pH,*

There was no significant difference in temperature for the three stations in the river during the summer 1998 and winter 1999 monitoring. During the summer 1999 monitoring the temperature of the water coming out of tailrace was at least 2°C colder than upstream, however, temperature returned to normal downstream at Laselevu village. The temperatures in winter were slightly lower than during summer.

Dissolved oxygen levels indicated well-saturated water at all three sites for the summer 1998, winter 1999, and summer 1999 monitoring. DO levels ranged from 8.26 to 8.59 mg/L during summer 1998, from 8.6 to 9.0 mg/L in winter 1999, and from 7.66 to 8.69 mg/L during summer 1999. Usually tailrace had the lowest DO level, however, levels increased downstream (Figure 12).

Figure 12. Dissolved Oxygen levels at the three sites along the Wailoa River



Values were slightly higher than in previous years and slightly higher in winter. Comparing the DO level at Wailoa Tailrace and at the bottom of Site 2 in the reservoir it seems that the water is reoxygenated as it passes through the Wailoa power station (Table 9).

pH values were fairly similar for all three sites and were similar to those of previous years. pH values during summer 1998 ranged from 6.8 to 7.7, during winter 1999 from 6.02 to 6.75, and during summer 1999 from 6.9 to 7.9.

Table 9. Comparison of data from Site 2 bottom waters and Tailrace water

Parameter		Site 2 Bottom	Wailoa Tailrace
Dissolved Oxygen (mg/L)	Summer 1998	5.6	8.59
	Winter 1999	3.8	8.6
	Summer 1999	<1.11	7.66
Alkalinity (mg/L CaCO ₃)	Summer 1998	11.8	15.7
	Winter 1999	16.0	16.0
	Summer 1999	18	18
Ammonia (µg/L)	Summer 1998	16.5	57.9
	Winter 1999	<12.2	19.3
	Summer 1999	30	50

(b) *Alkalinity*

Alkalinity values were within the range for the river and were similar to previous years results. Values for the summer 1998 monitoring ranged from 16 to 26 mg/L CaCO₃, 1999 winter values ranged from 16 to 31.3 mg/L CaCO₃, and summer 1999 values ranged from 18 to 37 mg/L CaCO₃. As in previous results alkalinity was the lowest at Wailoa Tailrace but returned to normal by Laselevu Village. As seen from Table 9 alkalinity values remained fairly similar between the bottom of site 2 reservoir and Wailoa Tailrace. Values did not vary greatly from summer to winter.

(c) *Nutrients*

Total Nitrogen, Nitrates, and Ammonia

Total nitrogen values during the summer 1998 were 0.06 to 0.15 mg/L with Wailoa Tailrace having the lowest value. TN values during winter 1999 were 0.51 to 1.0 mg/L and did not vary greatly between the three sites. TN values during summer 1999 were 0.14 to 0.44 mg/L, above the power station having the highest value.

During summer 1998, nitrates were <34 µg/L for all sites. In winter 1999, nitrates were <34 µg/L at all sites except for Wailoa Tailrace which was 45.8 µg/L. In summer 1999, nitrates ranged from <34 to 40 µg/L with tailrace having the lowest value.

Ammonia levels in summer 1998 were <12.2 µg/L except for Wailoa Tailrace which was 57.9 µg/L. During winter 1999, ammonia levels ranged from <12.2 to 41.1 µg/L, the highest value being at Laselevu. During summer 1999, ammonia levels were <10 µg/L except at Wailoa Tailrace which was 50 µg/L. In most cases, ammonia levels returned to normal by Laselevu village thus are not a concern. Comparing the values of ammonia at the bottom of site 2 and at tailrace, ammonia was higher at tailrace during the three monitorings (Table 9). This is different from the usual trend in 1994 and 1995 where ammonia is greatly reduced between the bottom of site 2 and tailrace.

Total Phosphorus and Phosphates

Total phosphorus and phosphate values were very low for all sites in both summer and winter. Total phosphorus levels during the summer 1998 monitoring were <0.02 mg/L for all sites and during winter 1999 <0.02 mg/L for all sites except for Laselevu which was 0.026 mg/L. During summer 1999, TP levels were <0.018 mg/L for all sites except for above power station which was 0.043 mg/L. Phosphate levels were <20 µg/L at all sites for both the summer 1998 and winter 1999 monitoring. During the summer 1999 monitoring phosphate levels were <18 µg/L for all sites except for above the power station where the value was 30 µg/L. These values are lower than those of 1997 and previous years.

(d) Clarity & Turbidity

Clarity at the three sites was measured in the winter 1999 monitoring and ranged from around 1m (bottom) at Wailoa Laselevu to 1.75m at Tailrace. Clarity during the summer 1999 monitoring ranged from 0.5m (bottom) at Laselevu to 3 m above the power station. Turbidity ranged from 1 to 4 during winter 1999 and 1 to 3 during summer 1999 monitoring and had improved from the summer 1998 monitoring.

(e) Total Iron and Total Manganese

Levels of total iron and manganese were not monitored in 1998 and winter 1999. In summer 1999, levels of Total Iron were <0.2 mg/L at all sites and for Total Manganese were <0.2 mg/L at all sites except at tail race where it was 0.23 mg/L. These values are relatively low and similar to the values obtained in 1997 and 1996.

Comparing the level of metals at the bottom of Site 2 in the reservoir to that at tailrace they are very similar, thus little deposition of iron on machinery through the power station must have occurred (Table 10).

Table 10. Comparison of Total Iron and Total Manganese content at Site 2 bottom waters and tailrace during the summer 1999 monitoring (Feb 2000)

	Bottom Site 2	Tailrace
Total Iron (mg/L)	0.38	<0.2
Total Manganese (mg/L)	<0.2	0.23

6.3 The Weirs

(a) Temperature, Dissolved Oxygen, pH

Temperatures of the weirs were slightly higher in summer 1998 (20.7 –20.9 °C) and summer 1999 (22 –22.9°C) than in winter 1999 (19.2 – 19.5 °C) but did not vary significantly between weirs. Temperatures were slightly lower than those within the reservoir.

Dissolved oxygen levels in the weirs in summer 1998, ranged from 6.8 to 8.63 mg/L, having a greater range than in winter 1999 where DO ranged from 8.03 to 8.83 mg/L. Summer 1999 values ranged from 7.66 to 8.37 mg/L. Values were slightly higher in winter and did not vary significantly between weirs. DO values were within the acceptable range and similar to those recorded in previous years (Table 11)

Table 11. Variation in dissolved oxygen levels (mg/L) at the five weirs

Year	Wainabua		Nabilabila		Wainkasou North		Wainkasou South		Wainisavulevu	
	winter	summer	winter	Summer	winter	summer	winter	summer	winter	summer
1999	8.5	7.69	8.8	7.77	8.03	7.66	8.83	8.37	8.28	7.35
1998	-	6.8	-	8.32	-	8.63	-	8.25	-	7.24
1997	8.2	7.2	9.4	8.45	8.2	9.1	8.2	7.8	9.0	7.8
1995	8.2	8.6	9.2	9.5	8.8	9.9	8.4	11.2	8.0	8.3
1994	8.44	6.4	8.08	6.2	9.1	6.4	9.04	6.6	8.54	6.9

pH values for summer 1998 were between 6.3 to 7.5 with Wainisavulevu having the lowest pH. Winter 1999 values ranged from 6.68 to 7.09 with little difference between weirs. Summer 1999 values ranged from 6.6 to 7.4. These values are within the acceptable range of 6 to 8 reported over previous years.

(b) *Alkalinity*

Alkalinity was monitored for the first time in summer 1998 with values obtained varying from 8.6 to 27 mg/l CaCO₃. In winter 1999, values ranged from 9.8 to 20.3 mg/L Ca CO₃. In both monitorings, Wainisavulevu had the lowest alkalinity value, which was lower than in the reservoir. During summer 1999, alkalinity values ranged from 10 to 24 mg/L CaCO₃ with Wainabua having the lowest value.

(c) *Nutrients*

Total Nitrogen

Nutrients were again monitored in the weirs after a long break. Total Nitrogen levels during the summer 1998 monitoring were between 0.037 to 0.236 mg/L, for the winter 1999 monitoring from 0.14 to 0.32 mg/L, and for the summer 1999 monitoring all were <0.01 mg/L. Values are similar to that in the reservoir.

Nitrates

Nitrates were <34 µg/L in all the weirs during summer 1998, <34 µg/L in all weirs except Wainisavulevu (38.0 µg/L) during winter 1999, and <34 µg/L in all weirs during summer 1999. These values are similar to those within the reservoir.

Total Phosphorus

Total Phosphorus levels during summer 1998 ranged from <20 to 77.1 µg/L, Wainabua having the highest value. In winter 1999, TP ranged from <20 to 61.7 µg/L the highest again being at Wainabua. In summer 1999, TP ranged from <0.018 to 0.06 mg/L, the highest value being at Wainisavulevu. Values were lower than in previous years and slightly higher during summer.

Phosphates

During summer 1998, phosphate levels were <20 µg/L except at Wainabua. In winter values ranged from <20 to 59.8 µg/L, again the highest value at Wainabua. In summer 1999, phosphate values ranged from <0.018 to 0.053 mg/L, the highest being at Wainisavulevu. Phosphate levels are higher during winter than summer and as in the 1996 monitoring highest values were obtained from Wainabua. It was observed that there was a correlation between the levels of Total Phosphorus and phosphates in the weirs and the presence of algae, with those weirs with higher levels having more algae present.

(d) Clarity

Clarity at the weirs in summer 1998 varied from <1 m at Wainisavulevu to 3.4 m at Wainabua. During the winter 1999 monitoring, clarity ranged from 0.75 m to 1.3 m and during summer 1999 from 2 m to 4 m.

(e) Total Suspended Solids

TSS levels in the weirs were similar to the 1997 results in that they were lower than previous years. The summer 1998 values ranged from 5 to 16 mg/L, winter 1999 values ranged from 4 to 10 mg/L, and summer 1999 values from 1 to 5.5 mg/L. This indicates relatively clear waters.

TSS values are affected by a number of factors including amount of rainfall, stability of parent material of area, and organic matter input (Ram *et al.* 1998). The results indicate that any logging operations in the catchment area around Monasavu are having little effect on the water quality.

(e) Aquatic Weeds

During the winter 1999 monitoring, green macroalgae was observed at Wainabua, Nabilabila, and Wainikasou South. This may be *Chara excelsa* which was identified in some of the weirs during previous trips (Lloyd *et al.* 1993). During the summer 1999 monitoring algae was observed at all five of the weirs (Table 12) but was especially dominant at Nabilabila, Wainikasou South and Wainisavulevu. At Wainikasou South it formed a mat on the weir bottom.

Table 12. Presence of algae at the five weirs during the summer 1999 monitoring

Weir	Presence of Algae
Wainabua	Brown and green algae present on the sides. Greenish appearance.
Nabilabila	Algae infested. Very green.
Wainikasou North	Less macro-algae.
Wainikasou South	Massive mat of macro-algae on bottom. Greenish appearance.
Wainisavulevu	Thick Spirogyra on concrete walls and rakes.

7.0 SUMMARY

From the discussion above, the main issues that arose during this period of monitoring of the reservoir, Wailoa river, and weirs are as follows:

7.1 The Monasavu Reservoir

- Dissolved oxygen levels in the bottom waters of the reservoir during the summer 1999 monitoring were extremely low. At Site 3, this could be a result of the decomposition of organic matter. The dead trees and vegetation often seen in the reservoir are slowly diminishing due to decomposition. This could also have an effect on ammonia levels.
- Nutrient levels remain relatively low at all sites.
- Levels of metals in the bottom waters have remained the same as compared to previous years.

7.2 The Wailoa River

- In regards to dissolved oxygen, the water is reoxygenated as it passes through the power station.
- Although alkalinity (low levels), ammonia (high levels) and Total Manganese (high levels) at tailrace vary from those at the other two sites on the Wailoa River, levels return to normal by the Laselevu village site.

7.3 Weirs

- Parameters monitored at the weirs were at stable levels considered normal for these environments. Total Phosphorus and phosphate levels were slightly high at Wainabua and Wainisavulevu. Otherwise, water quality was good.
- A concern though is the infestation of macroalgae and water weeds at a few of the weirs which may obstruct water flow.

8.0 CONCLUSION

For the 1998 and 1999 monitorings, the quality of the water has been generally good in the reservoir, the weirs and the Wailoa River. Conditions are similar to or have improved from what they have been for the last five years. The infestation of algae at some of the weirs, however, is a concern. The monitoring of nutrients should be continued at the weirs in order to determine the cause of this.

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APPENDICES

APPENDIX 1. Temperature and Dissolved Oxygen Data for the Monasavu Reservoir for the Three Monitorings
Summer 1998

Depth (m)	Site 1 - Moored to Floaters		Site 2 - Moored to Rake		Site 3 - Middle of Dam	
	DO (mg/L)	Temp (C)	DO (mg/L)	Temp (C)	DO (mg/L)	Temp (C)
0	6.1	25	6.5	26	6.8	29
1	6.1	25	6.5	26.2	6.5	28
2	6.1	25	6.5	26.2	6.5	27
3	6	25	6.3	26.1	6.5	27
4	5.9	24	6	26.1	6.3	26.5
5	5.8	24	5.9	25	6.2	26
6	5.8	24	5.9	25	6.1	25.5
7	5.8	24	5.8	25	6	25
8	5.8	24	5.8	25	6	25
9	5.8	24	5.8	25	5.9	24.5
10	5.8	24	5.8	25	5.8	24.5
11	5.8	24	5.8	25	5.7	24
12	5.7	23.5	5.8	25	5.7	24
13	5.7	23.5	5.8	25	5.7	23.9
14	5.7	23.5	5.8	25	5.7	23.9
15	5.7	23.5	5.7	24	5.7	23.5
16	5.7	23.5			5.6	23.5
17	5.7	23			5.6	23.2
18	5.6	23			5.6	23.2
19	5.6	23			5.6	23.1
20	5.6	23			5.6	23
21	5.6	23				
22	5.6	23				
23	5.3	22.5				
24	5.3	22				
25	5.1	21				
26	4.9	20				
27	4.9	20				
28	4.9	20				
29	4.9	19				
30	4.8	19				
31	4.8	19				
32	4.8	19				
33	4.8	19				
34	4.8	19				
35	4.8	19				
36	4.8	19				
37	4.8	19				
38	4.8	19				
39	4.8	19				
40	4.8	19				
41	4.8	19				
42	4.8	19				
43	4.8	19				

Winter 1999

Depth (m)	Site 1-Moored to Floaters		Site 2-Moored to Rake		Site 3-Middle of Dam	
	DO (mg/L)	Temp (C)	DO (mg/L)	Temp (C)	DO (mg/L)	Temp (C)
0	9.2	22	10.5	22.1	8.5	22.2
1	10.2	22	11	22.1	8.4	22.2
2	10	22	11	22	7.5	22.1
3	9.5	22	11	22	4.2	21.5
4	6	21.9	11	22	4.3	21
5	5.5	21.9	10.8	22	5.2	21
6	6	21.9	10.8	22	4.7	21
7	5.5	21.9	13	22	4.6	20.9
8	5.5	21.8	20	22	4.5	20.9
9	5.5	21.8	11	21.9	3.7	20.8
10	5.3	21.5	9.8	21.1	3.3	20.8
11	4.4	21	8	21	3.3	20.8
12	4	20.9	8	20.9	3	20.6
13	4	20.8	6.5	20.8		
14	3.4	20.5	6	20.5		
15	3.75	20.5	5.5	20.5		
16	3.7	20.5	5	20.5		
17	3.3	20.5	4.5	20.3		
18	2.9	20.2	4	20.2		
19	2.75	20.2	3.7	20.1		
20	2.75	20.2	3.7	20.1		
21	2.9	20.2	4	20.2		
22	2.9	20.1	4	20.1		
23	3.75	20.1	4.2	20		
24	3.7	20.1	4	20		
25	3.5	20	3.8	20		
26	3.7	20				
27	3.7	20				
28	3.7	20				
29	3.3	20				
30	2.6	20				
31	2.25	20				
32	1.5	20				
33	1.25	20				
34	1.1	20				
35	1	20				
36	1	19.9				
37	0.8	19.9				
38	0.8	19.8				
39	0.8	19.5				
40	0.76	19.4				
41	0.7	19.2				
42	0.7	19				
43	0.7	19				
44	0.7	19				