INSTITUTE OF APPLIED SCIENCES

THE UNIVERSITY OF THE SOUTH PACIFIC

WATER QUALITY MONITORING FOR THE MONASAVU RESERVOIR, THE FIVE WEIRS AND THE WAILOA RIVER IN 2001

IAS TECHNICAL REPORT NO. 2002/10

by

Bale Tamata

August, 2002

EXECUTIVE SUMMARY

It is interesting how the Monasavu Water Quality Monitoring programme has been affected by the political climate in Fiji. The landowners protest at Monasavu had caused some of the cancellation of the studies (mid-1998). The last report was submitted in May 2000, amidst the unrest and uncertain political situation in Fiji, but just days before the coup of May 19, 2000. In that report, we had stated that "...it appears that the routine monitoring of the Monasavu Hydro-electric scheme for the year 2000 will again be disrupted or even impossible. Only time will tell." History confirmed that indeed the 2000 Monitoring Programme had to be cancelled because of the coup. After the situation improved in 2001, monitoring resumed in August 2001. This report covers the 2001winter and summer monitoring.

The sampling sites remained the same as in previous years: three sites at three depths in the Monasavu reservoir, the five weirs, and three sites along the Wailoa River. The methods of the study are no different from the established IAS methods normally used in previous studies.

The year 2001 had been a particularly dry year for the region. The Dam level at the Monasavu reservoir fell from 745 m (above mean sea level) in January 2001 to below 720 m (amsl) in December 2001, the lowest level for the dam in a long, long time. The winter monitoring conducted in August 2001 showed evidence of the prolonged dry spell, with lowering of the dam level and exposure of much of the remaining tree trunks, a sight not usually seen in the dam. There was also a marked reduction in the presence of macroalgae at the weir sites and the water was very clear with up to 4m visibility. These unusual observations may have been the resultant of dry weather. Apart from this, the water quality remained relatively good: the parameters like dissolved oxygen, Total Suspended Solids (TSS), the nutrients and the metals iron and manganese remained within the usual low range as has been observed in previous studies. The main points from the 2001 Monitoring were:

In the Monasavu Reservoir:

- While temperature of the water in the reservoir has not changed much in the last five years, the level of dissolved oxygen has been generally much lower than usual, especially at the bottom of site 1, the deepest site sampled. It would appear that over the years, organic matter and the remains of decaying vegetation have accumulated at site 1, the deepest part of the reservoir. The decomposition of the organic matter continues to influence dissolved oxygen levels at the bottom of the dam.

- Nutrient levels again remain relatively low at all sites. For several years now, the concentrations of the main nutrients have stabilised around a certain range which is very low. This is most probably due to the control of the catchment and the restriction of logging and other activities in the area.

- Levels of metals iron and manganese remain low in the water column except at the bottom of site 1. The accumulation of sediment which is the sink for the metal

oxides, at the deepest parts of the dam (site 1) may explain the elevated levels of the metals at this site.

In the Wailoa River

- The flow and volume of the Wailoa River is such that any impact of the Power station (which would have been recorded at the Tailrace), is quickly absorbed. As a result, the levels of dissolved oxygen, alkalinity and the nutrients do not vary significantly at the three sites along the Wailoa River, upstream of the plant, at the Tailrace and at Laselevu village.

- A possible new source of pollution, not related to the Power Station is the sewage effluent seeping into the Wailoa River at the Tailrace site. This explains the high ammonia levels at the Tailrace. Future monitoring should consider this new pollution source.

- There appears to be a new trend in the unusually high level of the metal iron at the Tailrace sample. This could be investigated further in future monitoring.

At the Weirs

- The nutrients have remained at the same sort of level as those from past studies - this shows that no new sources of nutrients have entered the system. On the whole, water quality was good.

- It appears that the biological control of the water weeds by the Ministry of Agriculture a few years ago is working. At least during winter, there was marked reduction in the growth of the weeds at the weirs. This can only be confirmed by the FEA engineers monitoring the flow of the water from the weirs to the reservoir. The reduced algal growth may also be a resultant of the prolonged dry weather that affected Fiji during 2001.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

WATER QUALITY MONITORING FOR THE MONASAVU RESERVOIR, THE FIVE WEIRS, AND THE WAILOA RIVER IN 2001

1.0 INTRODUCTION

Water quality monitoring of the Monasavu Dam, the five weir sites, and the Wailoa River has been conducted twice yearly by the Institute of Applied Sciences, University of the South Pacific, for almost two decades now. 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. The weirs have been monitored since 1990. The study of invertebrates, in particular the aquatic gastropods has been a small part of the monitoring.

Since 1998, there have been numerous disruptions to the monitoring routine. These have caused cancellation of monitoring and many delays. The 1998 mid-year sampling (winter 1998) was cancelled due to problems involving landowners. Overhaul works and repair works at the reservoir delayed the summer monitoring scheduled for January 2000 to March 2000. Soon after submission of the last report in May 2000, the coup was staged on May 19, 2000. This caused the cancellation of the 2000 monitoring (winter and summer). In 2001 when the situation settled down, monitoring resumed, following discussion between FEA and the IAS. The winter monitoring for 2001 was conducted in August 2001 and the summer monitoring was conducted in January 2002. This report covers the results of the 2001 monitoring. Table 1 below summarises the progress of monitoring from 1998 to January 2002.

Table 1. Record of Water Quality Monitoring For Monasavu Reservoir and Weirs

YEAR	WINTER	SUMMER	REMARKS
1998	Cancelled	Deferred from Dec. to Jan 1999	Landowner dispute caused cancellation
1999	July 1999	Delayed from Dec. to March 200	Overhaul works at the dam caused delay
2000	Cancelled	Cancelled	Coup of May 2000 caused cancellation
2001	Conducted in August 2001	Conducted in January 2002	This report covers these studies

The following figures show the location of the Monasavu hydroelectric project in Viti Levu (Fig. 1), and the detailed map of the location of the dam, weirs and the feeder creeks/rivers around the reservoir (Fig. 2).

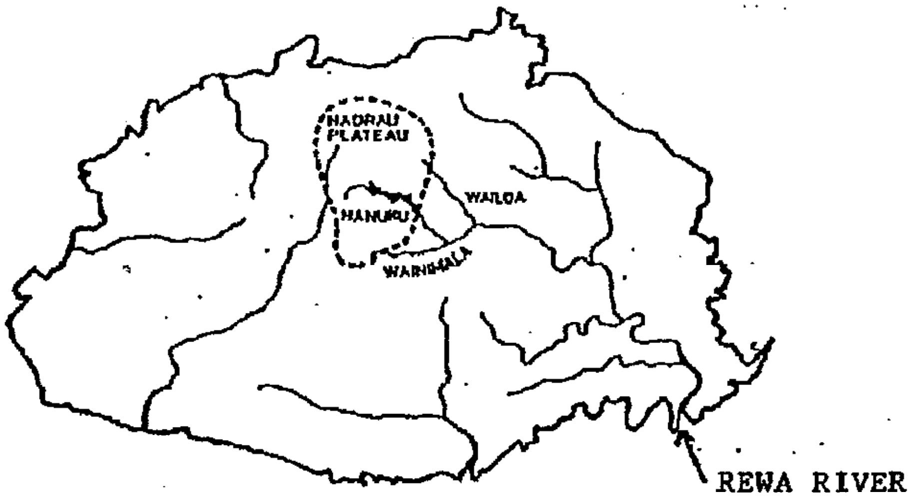


Figure 1. Map of Viti Levu showing the location of the Monasavu Hydroelectric scheme

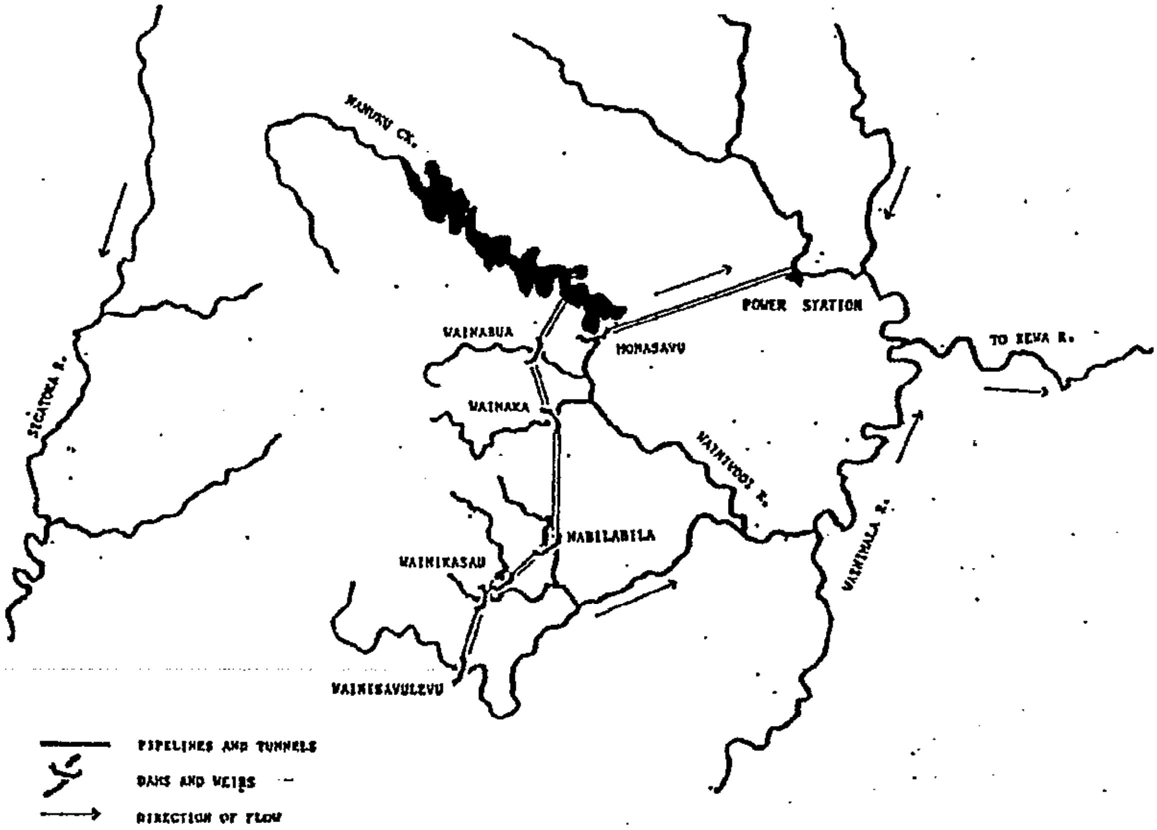


Figure 2. Detailed locations of dam, tunnels, creeks, and rivers in the Monasavu area

2.0 BACKGROUND

The principal aims of the study are threefold:

- to monitor the water chemistry in the reservoir;
- to monitor the Wailoa River upstream from the power station, at the tailrace and at Laselevu Village; and
- to monitor the water quality at 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 have always been monitored : 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 stepped in to assist by releasing a number of herbivorous fish in the weirs.

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).

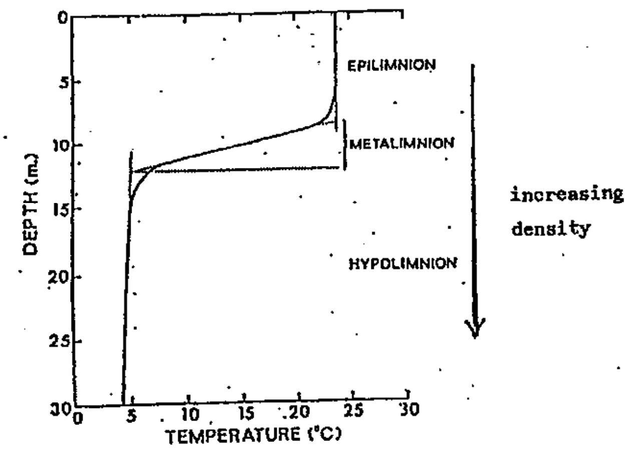


Figure 3. Typical thermal stratification of a lake into the epilimnetic, metalimnetic, and hypolimnetic water strata (Wetzel 1975)

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.

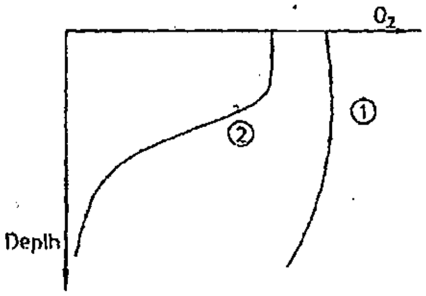


Figure 4. Oxygen profile in a stratified lake: winter condition (1), summer condition (2) (Jorgensen and Johnson 1989).

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, 2001

3.1 Organisation

After a lapse of one year (2000), water quality monitoring at the Monasavu Reservoir and the weirs feeding into the reservoir was resumed after consultation between the FEA and the Institute of Applied Sciences. The political unrest in Suva led to the cancellation of the 2000 monitoring programme. The 2001 Monitoring programme consisted of visits in August 2001 representing the winter monitoring, and in January 2002 representing the summer monitoring for 2001. For each visit, three staff of the Environment Unit at the IAS traveled the Sawani/Serea Road to Monasavu, returning the next day. The condition of the road was still a concern to us and the issue has been raised with the FEA.

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.

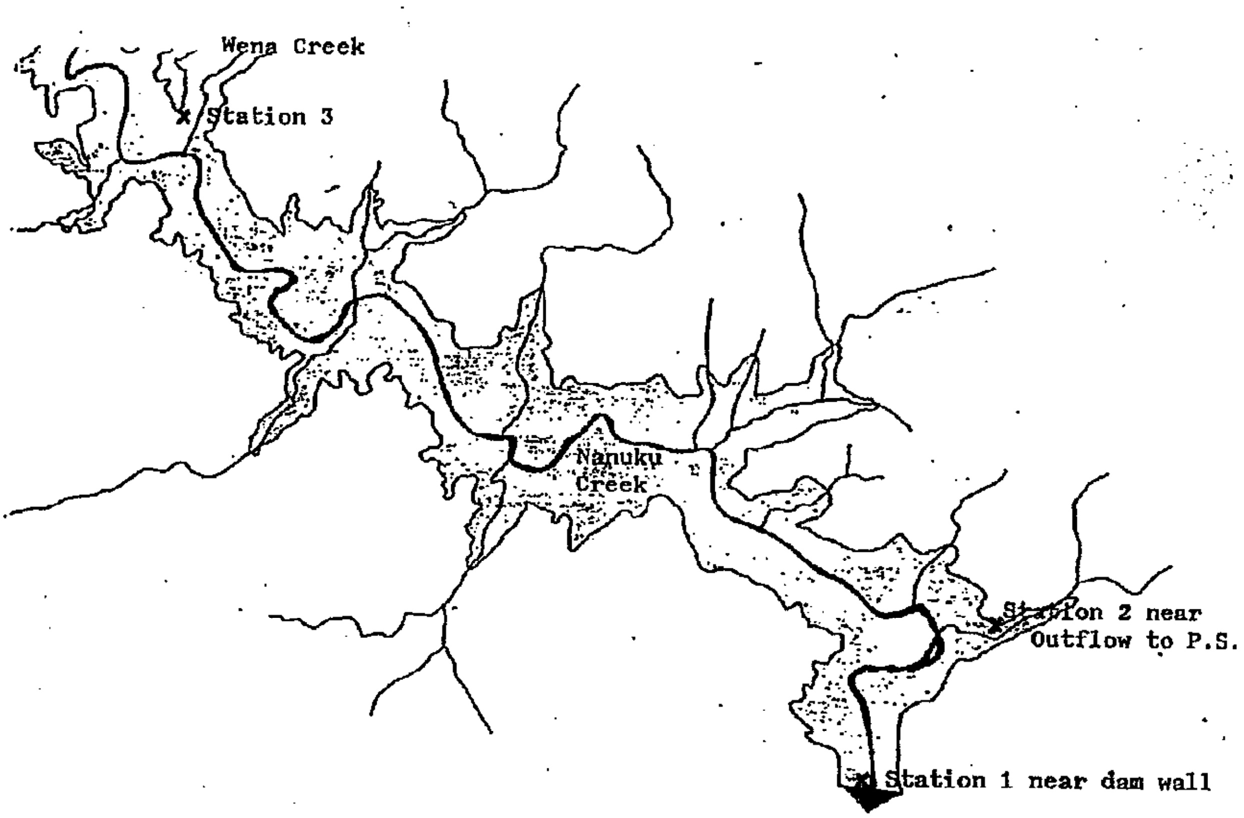


Figure 5. Locations of the sampling stations in the Monasavu Reservoir.

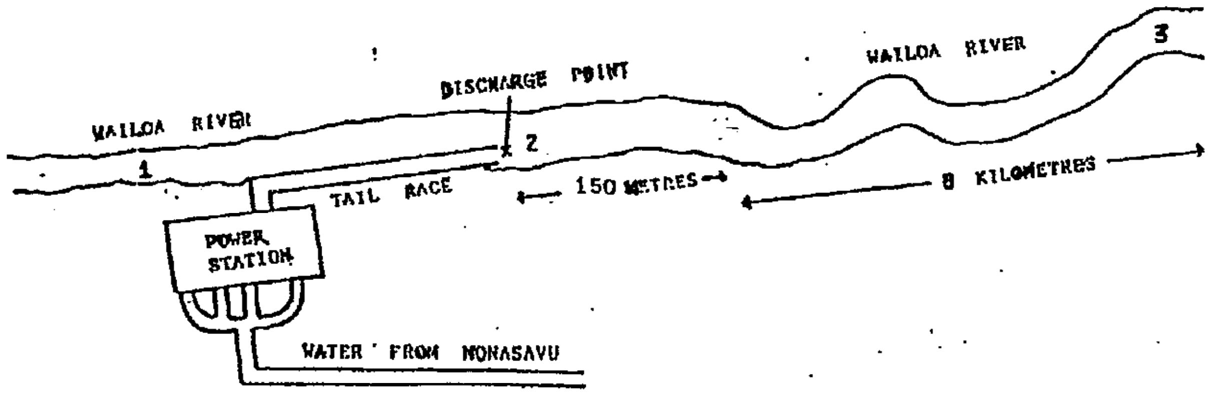


Figure 6. Sampling sites along the Wailoa River.
Site 1: 100 m upstream of power station discharge
Site 2: Tailrace (power station discharge water)
Site 3: On the Wailoa River at Laselevu village

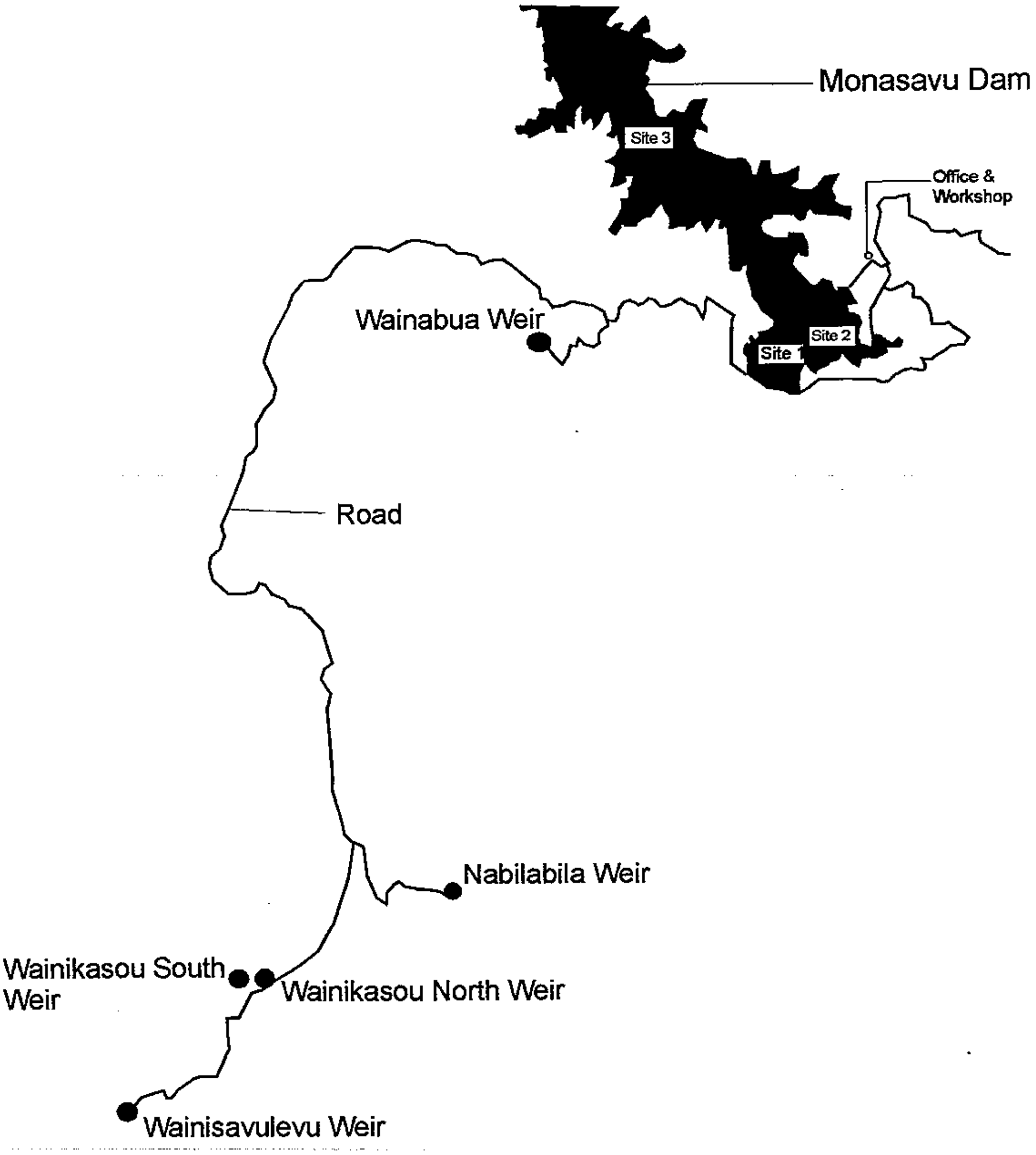


Figure 7. The Monasavu Dam and Weirs

Table 2. Summary of the 2001 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)	August 27th 2001 January 23rd 2002	pH, conductivity, clarity, depth temperature/dissolved oxygen profiles, GPS readings, turbidity, salinity	pH, total alkalinity, Nitrate, Ammonia, Total P, Phosphate, Total Suspended Solids
Wailoa River	3 sites	Above Wailoa Power Station Below Wailoa Power Station (tailrace water) Near Laselevu Village downstream	August 28th 2001 January 24th 2002	pH, conductivity. temperature, dissolved oxygen, turbidity, salinity, clarity	Total alkalinity, Nitrate, Ammonia, Total P, Phosphate, Manganese, Iron, Total Suspended Solids
Weirs	5 weirs	Wainabua Nabilabila Wainikasou North Wainikasou South Wainisavulevu	August 27th 2001 January 23rd 2002	pH, conductivity, temperature, dissolved oxygen, clarity, turbidity, salinity	Total alkalinity, total suspended solids, Nitrate, Total P, Phosphate, ammonia

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 2001 Monitoring are presented in Tables 4 and 5. The dissolved oxygen and temperature profiles for each of the three stations in the reservoir are shown in Figures 8 – 9, with the data tabulated in Appendix 1.

The depth of the reservoir varied between the monitorings (Table 3.)

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

Site	*August 2001*	*January 2002*
Site 1- Moored to floaters near dam wall	51 m	49 m
Site 2 – Moored to rake	30m	29 m
Site 3 – Middle of dam	20 m	14 m

TABLE 4A. WATER QUALITY RESULTS FOR MONASAVU DAM AND WAILOA RIVER – AUGUST 2001 (winter 2001)

	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	6.9	6.7	8.2	7.2	7.1	8.8	7.0	7.1	8.1	7.2	8.3
Temperature (°C)	23.1	20.4	na	23.2	20.6	20.2	24.2	20.7	20.4	22.4	21	23.7
Conductivity (mS/cm)	0.04	-	-	0.04	-	-	0.042	-	-	0.096	0.041	0.057
Dissolved Oxygen (mg/L)	11.16			10.53			11.72			9.8	9.42	10.87
Clarity (m)	1.8			2.1			1.5			2	2	
Total alkalinity (mg/L $CaCO_3$)	21	20	42	20	20	20	20	21	19	49	18	60
Nitrate as NO_3 (mg/L)	<0.034	<0.034	0.14	<0.034	<0.034	<0.034	<0.034	0.06	0.08	0.05	0.04	0.05
Ammonia as NH_3 (mg/L)	0.02	0.16	5.4	<0.012	0.12	0.08	0.02	0.2	0.11	<0.012	0.09	0.02
Total P (µg/L)	0.03	<0.018	0.2	<0.018	<0.018	<0.018	<0.018	<0.018	<0.018	0.04	<0.018	0.02
Orthophosphate as PO_4 (µg/L)	<0.018	<0.018	0.2	<0.018	<0.018	<0.018	<0.018	<0.018	<0.018	0.04	<0.018	<0.018
Total Fe (Iron) (mg/L)			14.2			1.8			<0.3	<0.3	<0.3	<0.2
Total Mn (Manganese) (mg/L)			1.2			<0.2			<0.2	<0.2	<0.2	<0.2
Total Suspended Solids (mg/L)	10.5	2	31.5	5	2	32.5	10	1	1	<1	1	<1
Depth (m)			51			30			20			

TABLE 4B. WATER QUALITY RESULTS FOR MONASAVU WEIRS – AUGUST 2001 (winter 2001)

	Wainabua	**Nabilabila**	**Wainaikasou North**	**Wainikasou South**	**Wainisavulevu**
pH	8.2	8.5	7.4	7.3	6.8
Temperature (^oC)	18.3	19.6	20.1	20.5	20.01
Dissolved Oxygen (mg/L)	9.3	9.72	9.75	10.04	8.97
Conductivity (mS/cm)	0.065	0.062	0.059	0.01	0.026
Clarity (m)	5	2	2	2	2
Total alkalinity (mg/L $CaCO_3$)	30	42	<1	32	12
Total Suspended Solids (mg/L)	4	4	4	4	7
Nitrate as NO_3 (mg/L)	0.05	<0.034	<0.034	<0.034	<0.034
Total P (mg/L)	0.06	0.04	0.03	<0.018	<0.018
Orthophosphate as PO_4 (mg/L)	0.06	0.04	0.03	<0.018	<0.018

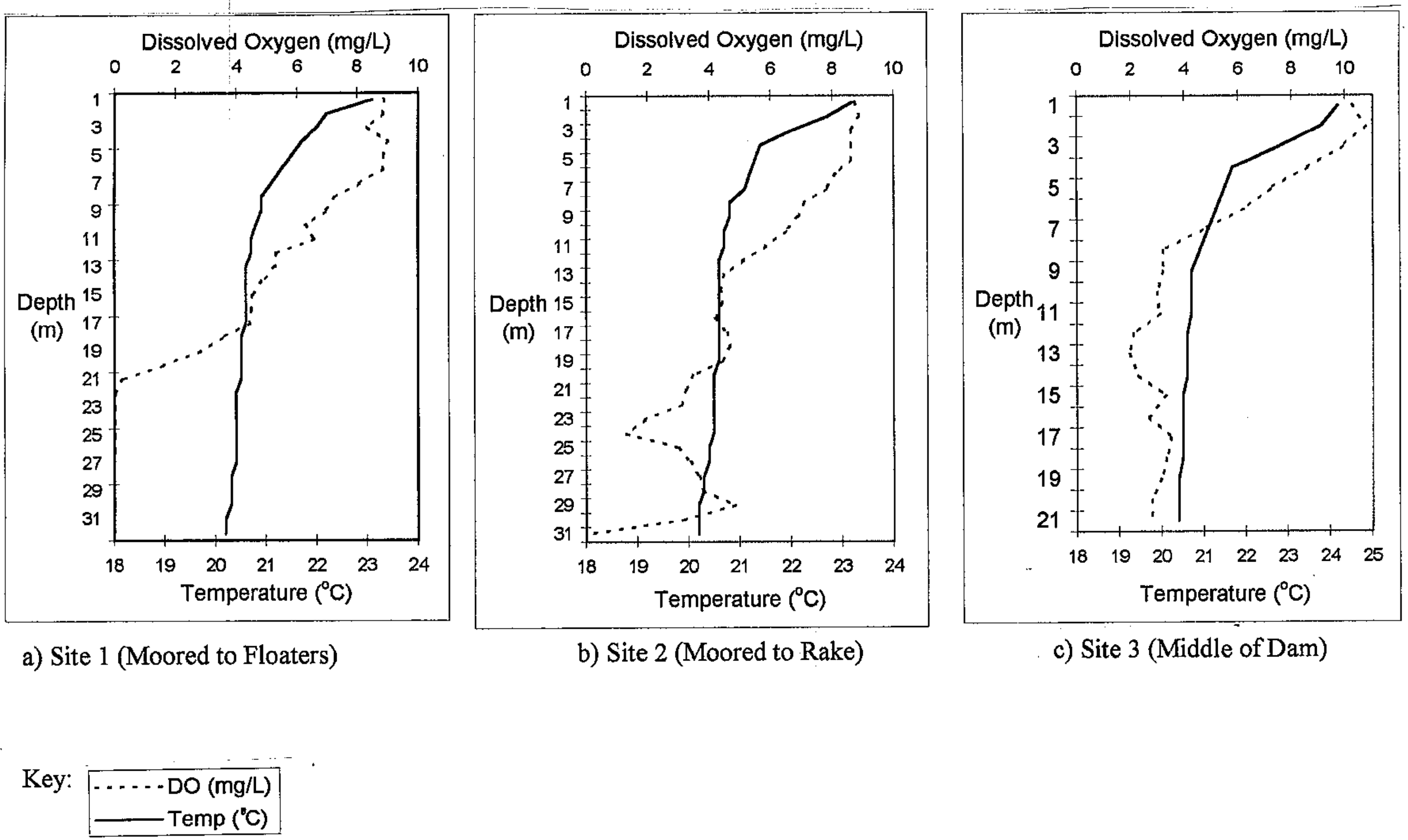
TABLE 5A. WATER QUALITY RESULTS FOR MONASAVU DAM AND WAILOA RIVER – JANUARY 2002 (summer 2001)

	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	7.4	6.5	6.5	7.3	6.9	6.6	7.9	6.9	6.8	9.7	9.6	9.3
Temperature (°C)	24.1	22.5	21.2	24.1	23.2	22.4	25.3	23.9	23.2	23.7	23.2	24.2
Dissolved Oxygen (mg/L)	8.36			8.12			7.78			8.28	7.88	8.55
Clarity (m)	1			1			1.2			1	2	1.5
Total alkalinity (mg/L $CaCO_3$)	17	17	34	16	16	15	17	20	19	8	18	10
Nitrate as NO_3 (μg/L))	<0.034	<0.034	0.845	<0.034	<0.034	<0.034	<0.034	<0.034	0.039	0.055	0.054	0.044
Ammonia as NH_3 (μg/L)	0.540	0.449	0.789	<0.012	0.160	0.549	0.343	0.017	0.400	0.015	0.525	<0.012
Total P (μg/L)	<0.018	<0.018	0.032	<0.018	<0.018	<0.018	<0.018	<0.018	<0.018	0.03	<0.018	<0.018
Orthophosphate as PO_4 (μg/L)	<0.018	<0.018	0.07	<0.018	<0.018	<0.018	<0.018	<0.018	<0.018	0.02	<0.018	<0.018
Total Fe (mg/L)			7.4			1.2			0.6	0.3	8.9	1.2
Total Mn (mg/L)			1.6			0.7			<0.2	<0.2	<0.2	<0.2
Total Suspended Solids (mg/L)	2	3	38	3	3	24	7	10	5	9	17	9
Depth (m)			49			29			14			

TABLE 5B. WATER QUALITY RESULTS FOR MONASAVU WEIRS – JANUARY 2002 (summer 2001)

	Wainabua	**Nabilabila**	**Wainaikasou North**	**Wainikasou South**	**Wainisavulevu**
pH	8.4	7.3	8.2	8.6	8.6
Temperature (^{o}C)	20.6	20.9	20.9	20.9	20.7
Dissolved Oxygen (mg/L)	8.7	8.6	8.2	8.0	7.7
Conductivity (mS/cm)	0.04	0.04	0.04	0.04	0.019
Clarity (m)	<1	1.5	2	2	<1
Total alkalinity (mg/L $CaCO_3$)	15	12	6	8	5
Total Suspended Solids (mg/L)	8	5	2	7	5.6
Nitrate as NO_3 (mg/L)	0.053	0.040	0.047	<0.034	0.047
Total P (mg/L)	0.05	0.03	0.04	<0.018	<0.018
Orthophosphate as PO_4 (mg/L)	0.04	0.03	0.03	<0.018	<0.018

FIGURE 8. TEMPERATURE/DISSOLVED OXYGEN PROFILES FOR MONASAVU DAM, August 2001 (Site 1,2,3)

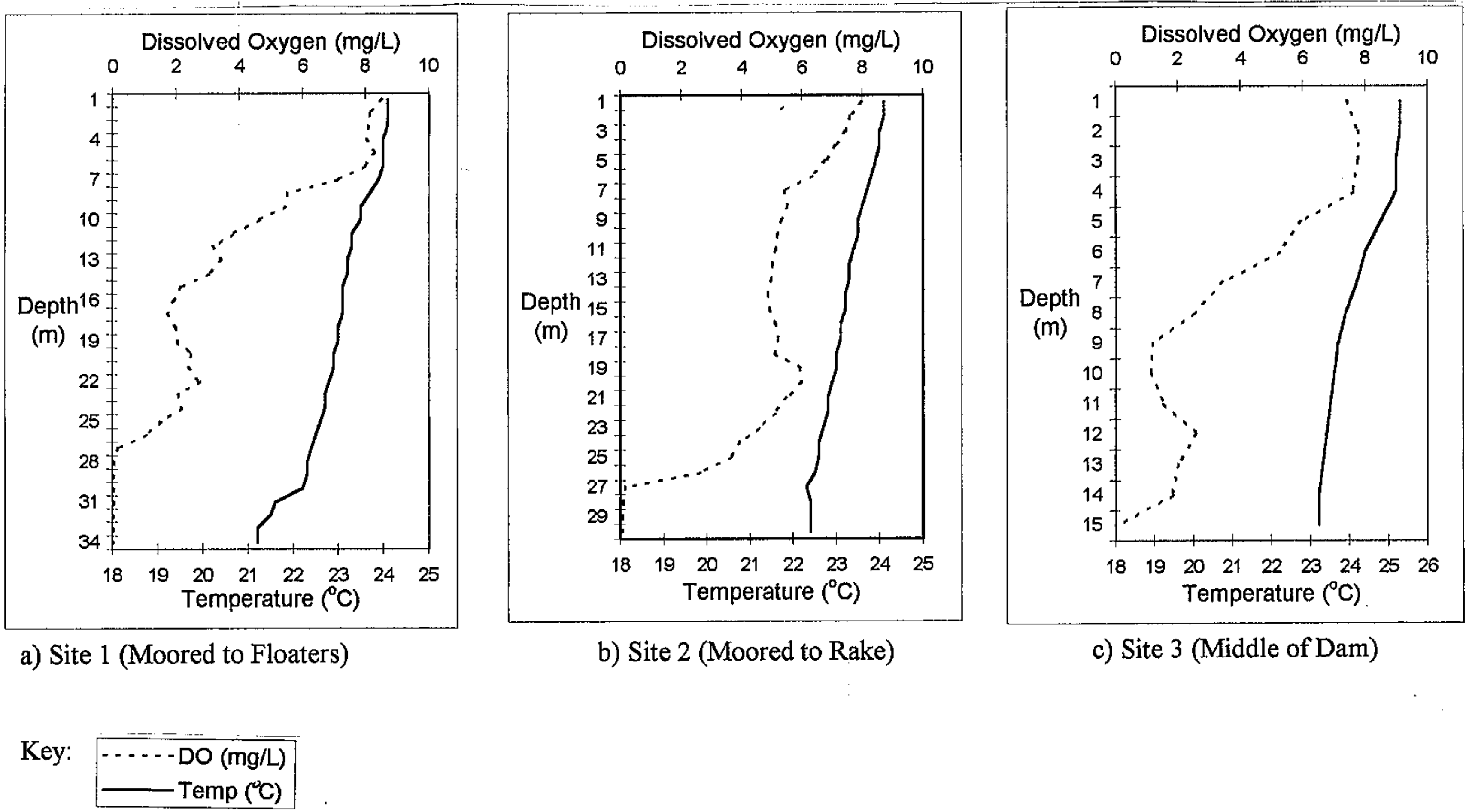


a) Site 1 (Moored to Floaters)

b) Site 2 (Moored to Rake)

c) Site 3 (Middle of Dam)

FIGURE 9. TEMPERATURE/DISSOLVED OXYGEN PROFILES FOR MONASAVU DAM, January 2002 (Site 1,2,3)



a) Site 1 (Moored to Floaters)

b) Site 2 (Moored to Rake)

c) Site 3 (Middle of Dam)

6.0 WATER QUALITY AT MONASAVU

6.1 The Monasavu Reservoir

(a) Temperature and Dissolved Oxygen Profiles

During the <u>2001 winter monitoring</u> conducted in August, the temperature values within the reservoir were fairly constant throughout the water column at all three sites (Figures 8a, b, c). Surface temperatures were between 23 and 24 °C declining very slightly towards the bottom to values around 20 °C. The temperature ranges for sites 1, 2 and 3 were 2.9, 3.0 and 3.8 °C respectively. 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, decreasing steadily with increasing depth. The deeper the water column, the more intense the stratification in the DO levels. This is most obvious for site 1. Site 2 is similar to site 1 except that at the bottom at site 2, the flow of the water out through the channel to the Power Station creates much turbulence and mixing. This causes the DO levels towards the bottom (from 25m to 30m) to fluctuate and is slightly higher (3 - 4 mg/L) than for site 1 (around 0 mg/L). Site 3 on the other hand being the shallowest of the three sites, has greater mixing at depth and DO levels were around 2.8 mg/L at the bottom.

During the <u>2001 summer monitoring</u> (in January 2002), the range of temperature values throughout the water column was again small, even though the overall temperatures were slightly higher than in winter as expected. Interestingly though, the temperature ranges for each site were lower for summer than in winter. The temperature ranges for sites 1, 2 and 3 were 2.9, 1.7 and 2.1 °C respectively. Surface temperatures were between 24 and 25 °C declining towards the bottom to values between 21 and 23°C. Dissolved oxygen levels again varied considerably with depth. DO values at the surface were between 7 and 8 mg/L and decreased rapidly to a depth of around 4 to 7 meters (Figures 9a, b, c). The lowest DO values obtained in the bottom waters were between 0.01 and 0.1 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 of pH for the three sites within the reservoir during 2001 winter monitoring ranged from 6.7 (site 1 bottom) to 8.8 (site 3 surface). The values for the 2001 summer monitoring ranged from 6.5 (site 1 mid-depth and bottom) to 7.9 (site 3 surface). 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.

(c) Clarity & Turbidity

The clarity of the water in the reservoir is always influenced by the quality of the water in the weirs and the prevailing weather condition. In the winter when it is usually drier, the clarity is often better than in summer when precipitation is higher. This was observed during the 2001 monitoring: clarity was between 1.5 and 2.1 m in winter, and 1.0 and 1.2 m in summer. Similar values were noted in the weirs. For recreational waters, the recommended minimum visibility is 1.2 meters (NEMP 1992).

(d) Total Alkalinity

Total alkalinity values measured during winter 2001 were between 19 and 42 mg/L $CaCO_3$ in the reservoir. Results during summer 2001 were in the range of 15 to 34 mg/L $CaCO_3$. These values are within the usual range for the reservoir, as has been observed in the recent past (from 1995, see Table 6 below). The highest $CaCO_3$ levels are again found at the deepest part of the reservoir, at bottom of site 1.

Table 6. Total alkalinity ranges (mg/L $CaCO_3$) in the reservoir for various years

Year	Winter	Summer
2001	19-42	15-34
2000	cancelled	cancelled
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

(e) Nutrients

Nitrates, and Ammonia

Total Nitrogen was not assessed during the monitoring in 2001. In the last report, it was noted that Total Nitrogen levels did not show any distinct pattern of distribution in the reservoir.

For nitrates, the levels were generally low with most sites recording <0.034 mg/L. Only three samples recorded some nitrates: site 1 bottom and site 3 middle and bottom. A similar situation was seen during the summer monitoring with only two samples recording some nitrates: site 1 bottom and site 3 bottom. The rest of the samples had <0.034 mg/L. 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 reduced photosynthetic activity.

Ammonia levels in winter 2001 ranged from <0.012 to 5.4 mg/L. The same sort of range was recorded for winter 1999 (<0.012 to 3.2 mg/L). The summer Ammonia levels ranged from <0.012 to 0.789 mg/L, again the same sort of range obtained in summer 1998 (<0.012 to 0.482 mg/L). As in previous years, the bottom of Site 1, which is the deepest part of the reservoir, had the highest value. This is consistent with the trend that ammonia levels increase with depth due to anoxic conditions in bottom waters.

Total Phosphorus and Phosphates

Total phosphorus (TP) and phosphates remained at relatively low levels at all sites in both the summer and winter. As has been the case over the years, only at the bottom of site 1, the deepest point sampled had slightly elevated levels of Total Phosphorus and phosphates.

During the winter of 2001, TP values were <0.018 mg/L for 7 out of 9 samples from the reservoir. The remaining two samples, site 1 surface and site 1 bottom recorded only slightly higher TP levels of 0.03 and 0.02 mg/L respectively. These values are similar to those from previous studies. During the summer of 2001, the TP levels were again no different from those recorded for summer 1998 and summer 1999. The TP summer levels were all <0.018 mg/L except at the bottom of site 1 with 0.032 mg/L. These values are consistent with the trend that TP increases at depth due to decomposition of the underlying organic matter, and the uptake of phosphorus near the surface by photosynthetic activities of phytoplankton.

The pattern for phosphates was similar to that for TP, with most sites recording very low concentrations except at the bottom of site 1, the deepest point sampled. During winter 2001, phosphate values were again <0.018 mg/L for 8 of the 9 sites, the exception being site 1 bottom with 0.2 mg/L. These results are identical to those recorded for winter 1999 monitoring (Thaman and Tamata, 2000). During summer 2001, phosphates were <0.018 mg/L for 8 of the 9 sites, the exception being the bottom of Site 1 where it was 0.07 mg/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 (nitrates, phosphates, Total Phosphorus) from internal sources, mainly through decomposition of organic matter in the form of remaining tree trunks and the remains of the original flora/vegetation of the reservoir area. 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 increase in concentration. At bottom depths, conditions are normally anaerobic. Under these conditions organic matter is broken down by bacteria into methane, a little carbon dioxide and ammonia, thus the high ammonia concentration at bottom waters of each station. For several years now, the concentrations of the main nutrients have more or less stabilised around a certain range which is very low. This trend would tend to indicate that ecologically, no major change has occurred in the Monasavu catchment area. As long as there is strict control over the catchment area, the current levels of the nutrients can be expected to remain unchanged in the reservoir.

(f) Total Iron and Total Manganese

During the winter 2001 monitoring, Total iron levels were between <0.3 (bottom of site 3) and 14.2 mg/L with the highest value obtained from the bottom of Site 1. Total manganese levels were all <0.2 mg/L except at bottom site 1 with a low 1.2 mg/L Mn. The results for summer 2001 for Total iron levels were very similar to the winter results, the range being 0.6 mg/L (bottom site 3), to 7.4 mg/L, the highest value again being from the bottom of site 1. The summer Total manganese results were again within the same range as that for winter, from <0.2 (bottom site 3) to 1.6 mg/L (bottom site 1). The higher level of iron and manganese in bottom waters results from the redox reactivity of the metals: oxidation of the metals at the surface. The metal oxides then precipitate out and 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.

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 7).

Table 7. Comparison of Total Iron (Fe) and Total Manganese (Mn) values (mg/L) in the bottom waters of the reservoir for various years

	Site 1		Site 2		Site 3	
Year	Total Fe	Total Mn	Total Fe	Total Mn	Total Fe	Total Mn
2001 summer	7.4	1.6	1.2	0.7	0.6	0.3
winter	14.2	1.2	1.8	<0.2	<0.3	<0.2
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

(g) Total Suspended Solids

Total suspended solids (TSS) were assessed for the three depths at each site in the reservoir. The results obtained for the 2001 monitoring are very similar to those obtained during the summer 1999 monitoring. The range of TSS values for winter was 1 - 32.5 mg/L, the highest TSS being at the bottom of site 2, and for summer, the range was 2 - 38 mg/L , the highest TSS being at the bottom of site 1.

6.2 The Wailoa River

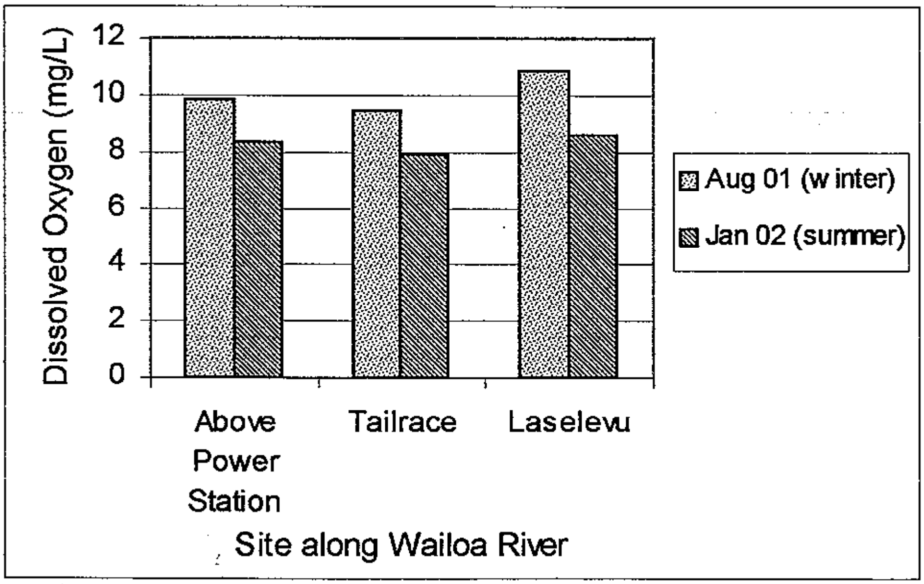
Water is drawn to the Wailoa Power station from the bottom of site 2 within the reservoir. As usual, three sites along the Wailoa River were compared to see if the power station (or the Monasavu Hydropower Plant) is having an impact on the quality of water in the river and the communities dependent on the river (Laselevu village etc.). 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 2001 monitoring. During the winter 2001 monitoring the temperature of the water varied between 21.0 and 23.7 °C. In summer, the range was 23.2 to 24.2 °C. The temperatures in winter were slightly lower than during summer, as expected.

Dissolved oxygen levels indicated well-saturated water at all three sites for the 2001 monitoring. DO levels ranged from 9.42 to 10.87 mg/L in winter 2001 (August 2001), and from 7.88 to 8.55 mg/L during summer (January 2002). There is no significant difference in DO levels along the river (Figure 10).

Figure 10. Dissolved Oxygen levels at the three sites along the Wailoa River



pH values have always been consistent in the range 6 - 9. pH values during winter 2001 ranged from 7.2 to 8.3, and during summer, from 9.3 to 9.7.

(b) Alkalinity

Alkalinity values have always fallen in the range 10 to about 50 mg/L $CaCO_3$ for all samples. The results for the three sites along Wailoa River are no different, with the exception of the sample at Laselevu during August 2001 (winter) which recorded a slightly higher alkalinity value of 60 mg/L. Values for the 2001 winter monitoring ranged from 18 to 60 mg/L $CaCO_3$, and summer 2001 values ranged from 8 to 18 mg/L $CaCO_3$.

Table 8. Comparison of data from Site 2 bottom waters and Tailrace water

Parameter		Site 2 Bottom	Wailoa Tailrace
Dissolved Oxygen (mg/L)	Winter 2001	0.05	9.42
	Summer 2001	0.07	7.88
Alkalinity (mg/L $CaCO_3$)	Winter 2001	20	18
	Summer 2001	15	18
Ammonia (µg/L)	Winter 2001	0.08	0.09
	Summer 2001	0.549	0.525

(c) Nutrients

Nitrates, and Ammonia

In winter 2001, nitrate levels at the three sites were very similar (0.04 to 0.05 mg/L), indicating little or no impact from the Wailoa Power Station. In summer, again nitrate levels were very similar at the three sites (0.044 to 0.055 mg/L) and to the results obtained 5 months earlier (August 2001). These values are also within the same range as those recorded for 1998 and 1999 and would tend to indicate an ecological equilibrium situation along the Wailoa River, as far as nitrates are concerned.

During winter 2001, ammonia levels ranged from <0.012 to 0.09 mg/L. During summer, ammonia levels ranged from <0.012 to 0.525 mg/L. In both cases, the Tailrace recorded the highest level of ammonia. Usually, as noted from previous studies, ammonia levels returned to "normal", i.e. the level upstream from the Power Station, by the time flow reaches Laselevu village, thus ammonia levels are not a concern. However, a new trend is appearing and that is the elevated levels of ammonia at the Tailrace. The most probable explanation of this high ammonia level is the sewerage effluent from the power station septik tanks. This is another source of pollution in the Wailoa River which may need to be investigated further in future monitoring along the Wailoa River.

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 winter 2001 were between <0.018 and 0.04 mg/L. During summer, TP levels were <0.018 mg/L for 2 sites, and 0.03 mg/L for the site above the Power Station. These values are very similar to those recorded in 1998 and 1999. Phosphate levels were <0.018 mg/L at the two sites (Tailrace and Laselevu) for both the winter and summer 2001 monitoring. Only at the site upstream from the Power Station did the phosphate level differ, but only very slightly, recording 0.04 mg/L in winter and 0.02 mg/L in summer.

(d) Clarity

Clarity at the three sites ranged from 1m to 2m during the 2001 monitoring programme, and this is consistent with previous results (1998, 1999). Generally, the water is clearer in winter. In summer, there is increased suspended matter in the water. The increased primary production (photosynthesis) in summer also boosts the phytoplankton population which reduces water clarity.

(e) Total Iron and Total Manganese

Total iron levels were generally low, <0.2 and 0.3 mg/L on all occasions except during the summer monitoring for the Tailrace site (8.9 mg/L) and at Laselevu (1.2 mg/L. The unusually high Total iron level at the Tailrace site may need to be monitored closely in subsequent testing.

Total Manganese levels were <0.2 mg/L at all sites during both winter and summer monitoring. These results are similar to the values obtained in 1996, 1997 and in summer of 1999.

Comparing the level of metals at the bottom of Site 2 in the reservoir to that at tailrace, they are very similar. This would imply that deposition of iron on machinery in the power station did not occur. (Table 9).

Table 9. 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)	Winter 2001	1.8	<0.3
	Summer 2001	1.2	8.9
Total Manganese (mg/L)	Winter 2001	<0.2	<0.2
	Summer 2001	0.7	<0.2

6.3 The Weirs

(a) Temperature, Dissolved Oxygen, pH

As to be expected, the temperature range for summer was 20.6 - 20.9 °C, slightly higher than the range for winter 18.3 - 20.5 °C. These are the usual values for the weirs.

Dissolved oxygen levels in the weirs in 2001 were no different from previous results and they were all within the acceptable range for aquatic systems (5 mg/L or above). The DO range for winter was 7.7 - 8.7 mg/L and for summer was 8.0 - 8.7 mg/L.

Table 10. 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
2001	9.3	8.7	9.72	8.6	9.75	8.2	10.04	8.0	8.97	7.7
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 2001 were again similar to those recorded during previous studies. The acceptable range is 6 - 9 and the range of pH for winter 2001 (6.8 - 8.5) and summer (7.3 - 8.6) both satisfy the acceptable pH range.

(b) Alkalinity

In winter 2001, alkalinity values ranged from 12 to 42 mg/L $CaCO_3$ with the exception of an unusually low (<1) level at Wainikasou North. The results for winter 1999 are only slightly lower, from 9.8 to 20.3 mg/L. During summer 2001, alkalinity values were generally lower than for winter, the range being 5 to 15 mg/L $CaCO_3$, again the results are in the same sort of range as that for summer 1998 (8.6 - 27.0 mg/L $CaCO_3$) and summer 1999 (10 - 24 mg/L $CaCO_3$).

(c) Nutrients

Total Nitrogen was not measured during the 2001 monitoring.

Nitrates
Nitrate levels during winter 2001 were <0.034 mg/L in all weirs except Wainabua which had 0.05 mg/L NO_3. During summer, nitrate levels ranged from <0.034 to 0.053 mg/L. Comparing these levels with the reservoir, it is clear that sources of nitrate are within the reservoir itself and not so much from the weirs.

Total Phosphorus
Total Phosphorus in winter 2001, ranged from <0.018 to 0.06 mg/L the highest again being at Wainabua. The results for summer are almost identical to the winter results, the range being <0.018 to 0.05 mg/L TP. These results are very similar to the results of earlier studies (1998 and 1999). Comparing the levels of TP in the reservoir with the weirs during this 2001 monitoring, the ranges are very similar.

Phosphates
During winter 2001, phosphate levels ranged from <0.018 (2 sites) to 0.06 mg/L, the highest being at Wainabua. The levels of phosphates in the reservoir in winter are similar, from <0.018 to 0.2 mg/L. In summer, again 2 sites recorded <0.018 mg/L phosphate and the highest value of 0.04 mg/L was again recorded for Wainabua. Similar results were recorded for the reservoir.

(d) Clarity

Clarity at the weirs in winter 2001 varied from 2m (for 4 weirs) to 5m for Wainabua. During the summer monitoring, clarity ranged from <1m (for 2 weirs) to 2m (another 2 weirs). The usual range of clarity values has been between <1m to 5m. The local precipitation has direct effect on the clarity values.

(e) Total Suspended Solids (TSS)

The winter 2001 TSS values ranged from 4 to 7 mg/L, the higher TSS being recorded at Wainisavulevu. These results are very similar to those recorded for the weirs during the winter 1998 monitoring (4 - 10 mg/L). In summer, the TSS range was 2 to 8 mg/L, the highest TSS recorded for Wainabua. The TSS levels for summer in 1998 and 1999 are also in the same sort of range, 5 - 16 mg/L and 1 - 5.5 mg/L respectively.

(e) Aquatic Weeds

During the winter 2001 monitoring, there was a marked reduction in macroalgae growth in all the weirs and water was generally very clear with visibility of 2 to 5m to the bottom. Only at Wainikasou North was there thick growth of aquatic weeds on the banks of the creek. This situation has been caused by the spell of dry weather that affected Fiji from January to December 2001, resulting in the drop in dam level from 745 m (MSL) in January to below 720 m (MSL) in December. The level of the dam in December 2001 was the lowest level reached in a long, long time, and it was well below the "Rule Curve", the recommended curve below which, the dam should not go (FEA 2002). During the summer 2001 monitoring, the effects of heavy rainfall days before the monitoring, were obvious. The water levels were high (overflowing the tops of the weirs) and flow of water was faster than normal. The water in all the weirs were was very murky with low visibility. There was a distinctive green colour in the water which may be an indication of the increased phytoplankton population, as would be expected after a heavy rain washing out nutrients into the creeks.

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

- While temperature of the water in the reservoir has not changed much in the last five years, the level of dissolved oxygen has been generally much lower than usual, especially at the bottom of site 1, the deepest site sampled. It would appear that over the years, organic matter and the remains of decaying vegetation have accumulated at site 1, the deepest part of the reservoir. The decomposition of the organic matter continues to influence dissolved oxygen levels at the bottom of the dam.

- Nutrient levels again remain relatively low at all sites. For several years now, the concentrations of the main nutrients have stabilised around a certain range which is very low. This is most probably due to the control of the catchment and the restriction of logging and other activities in the area.

- Levels of metals iron and manganese remain low in the water column except at the bottom of site 1. The accumulation of sediment which is the sink for the metal oxides, at the deepest parts of the dam (site 1) may explain the elevated levels of the metals at this site.

7.2 The Wailoa River

- The flow and volume of the Wailoa River is such that any impact of the Power station (which would have been recorded at the Tailrace), is quickly absorbed. As a result, the levels of dissolved oxygen, alkalinity and the nutrients do not vary significantly at the three sites along the Wailoa River, upstream of the plant, at the Tailrace and at Laselevu village.

- A possible new source of pollution, not related to the Power Station is the sewage effluent seeping into the Wailoa River at the Tailrace site. This explains the high ammonia levels at the Tailrace. Future monitoring should consider this new pollution source.

- There appears to be a new trend in the unusually high level of the metal iron at the Tailrace sample. This could be investigated further in future monitoring.

7.3 Weirs

- The nutrients have remained at the same sort of level as those from past studies - this shows that no new sources of nutrients have entered the system. On the whole, water quality was good.

- It appears that the biological control of the water weeds by the Ministry of Agriculture a few years ago is working. At least during winter, there was marked reduction in the growth of the weeds at the weirs. This can only be confirmed by the FEA engineers monitoring the flow of the water from the weirs to the reservoir. The reduced algal growth may also be a resultant of the prolonged dry weather that affected Fiji during 2001.

8.0 CONCLUSION

For the 2001 monitoring, no major change was observed for the quality of the water, when compared with results from the past few years. However, the low dam level and the predominant dry weather during most of 2001 affected the macroalgae growth. As long as there is strict control of activities like logging in the catchment area, the established levels of nutrients in the reservoir and weirs should remain and will keep in check algal growth which are a risk to the efficient flow of the water. The Tailrace sample may need to be tested for sewage pollution in future studies, and if present, it would explain the elevated ammonia levels at that site. If present, it should be monitored for health risk effects on the communities downstream like Laselevu.

9.0 BIBLIOGRAPHY

APHA-AWWA-WPCF. 1981. Standard methods for the examination of water and wastewater. *Amer. Pub. Health Assoc.*, 15th Ed.

APHA-AWWA-WPCF. 1989. Standard methods for the examination of water and wastewater. *Amer. Pub. Health Assoc.*, 17th Ed.

APHA-AWWA-WPCF. 1992. Standard methods for the examination of water and wastewater. *Amer. Pub. Health Assoc.*, 18th Ed.

Brodie, J., Gangaiya, P., Haynes, A., and Morrison, R. 1987. Water chemistry of the Monasavu Reservoir and Wailoa River, Viti Levu, Fiji. INR Environmental Studies Report No. 32.

Fiji Electricity Authority Report, Fiji Times, July 24, 2002.

Fung, C. and Chand, K. 1997. Water quality in the Monasavu Reservoir and Wailoa River in 1996. IAS Technical Report No. 97/01

Gangaiya, P., Haynes, A., Peter, W., and Green, D. 1991. Water quality in the Monasavu Reservoir and weirs and Wailoa River in 1990. IAS Technical Report No 91/3.

Gibbons, J. and Brodie, J. 1985. The environment and social impact of Monasavu hydro scheme: An appraisal. Fiji Science Journal 1 (6): 25-31.

IAS. Methods for the Analysis of Water. Institute of Applied Sciences. May 1992.

Jorgensen, S.E. and Johnson, I. 1989. *Principles of Environmental Science and Technology*. Studies in Environmental Science 33. Elsevier Science Publishing Co., New York.

Lloyd, C., Peter, W., and Haynes, A. 1993. Water quality in the Monasavu Reservoir and Wailoa River in 1992. IAS Technical Report No 93/03.

Morrison, R., Haynes, A., Peter, W., and Green, D. 1990. Water quality in the Monasavu Reservoir and Wailoa River in 1989. IAS Technical Report No 90/2.

Naidu, S., Haynes, A., and Peter, W. 1989. Water quality in the Monasavu Reservoir and Wailoa River. INR Technical Report No. 89/1.

NEMP. 1992. National Environment Management Project. TA No. 1206 – Fiji. Recommended National Environmental Quality Criteria, Final Report, Oct. 1992.

Novotny, V. and Olem, H. 1994. Water Quality: Prevention, Identification and management of diffuse pollution. Van Nostrand Reinhold, New York.

Ram, N, Tamata, B. and Haynes, A. 1998. Water quality in the Monasavu Reservoir and Wailoa River in 1997. IAS Technical Report No. 98/01

Tamata, B., Anderson, E, and William, P. 1995. Water quality in the Monasavu Reservoir and Wailoa River in 1994. IAS Technical Report 95/01.

Tamata, B., Haynes, A., and William, P. 1995. Water quality in the Monasavu Reservoir and Wailoa River in 1993. Ias Technical Report No. 94/08.

Tamata, B., Haynes, A., Chand, K., and Fung, C. 1996. Water quality in the Monasavu Reservoir and Wailoa River in 1995. IAS Technical Report No.96/01

Thaman, B. and Tamata, B., Water Quality in the Monasavu Reservoir, Weirs and Wailoa River in 1999. IAS Technical Report No. 2001/1. 32 pp+appen.

Wetzel, R.G. 1975. *Limnology.* Saunders College Publishing, Philadelphia.

APPENDICES

APPENDIX 1. Temperature and Dissolved Oxygen Data for the Monasavu Reservoir

Winter 2001

	Site 1-Moored to Floaters		Site 2-Moored to Rake		Site 3-Middle of Dam	
Depth (m)	DO (mg/L)	Temp (°C)	DO (mg/L)	Temp (° C)	DO (mg/L)	Temp (°C)
0	8.9	23.1	8.73	23.2	10.28	24.2
1	8.85	22.2	8.9	22.7	10.75	23.8
2	8.35	22	8.6	22	9.9	22.8
3	9.01	21.7	8.6	21.4	8.6	21.7
4	8.86	21.5	8.6	21.3	7.2	21.5
5	8.84	21.3	8.12	21.2	6.2	21.3
6	8.07	21.1	7.8	21.1	4.65	21.1
7	7.3	20.9	7.12	20.8	3.2	20.9
8	6.94	20.9	6.9	20.8	3.21	20.7
9	6.3	20.8	6.5	20.7	3	20.7
10	6.6	20.7	5.85	20.7	3.07	20.7
11	5.34	20.7	5.11	20.6	2.1	20.6
12	5.3	20.6	4.5	20.6	1.95	20.6
13	4.87	20.6	4.4	20.6	2.3	20.6
14	4.56	20.6	4.44	20.6	3.35	20.5
15	4.52	20.6	4.21	20.6	2.7	20.5
16	4.45	20.6	4.6	20.6	3.5	20.5
17	3.55	20.5	4.7	20.6	3.35	20.5
18	2.84	20.5	4.45	20.6	3.15	20.4
19	1.6	20.5	3.48	20.5	2.8	20.4
20	0.3	20.5	3.24	20.5	2.8	20.4
21	0.04	20.4	3.11	20.5		
22	0.02	20.4	1.9	20.5		
23	0.01	20.4	1.3	20.5		
24	0.02	20.4	3	20.4		
25	0.01	20.4	3.4	20.4		
26	0	20.4	3.69	20.3		
27	0	20.3	3.82	20.3		
28	0	20.3	4.84	20.2		
29	0	20.3	3.2	20.2		
30	0	20.2	0.05	20.2		
31	0	20.2				

Summer 2001

	Site 1-Moored to Floaters		Site 2-Moored to Rake		Site 3-Middle of Dam	
Depth (m)	DO (mg/L)	Temp (°C)	DO (mg/L)	Temp (°C)	DO (mg/L)	Temp (°C)
0	8.55	24.1	8	24.1	7.41	25.3
1	8.14	24.1	7.6	24.1	7.78	25.3
2	8.12	24.1	7.46	24	7.77	25.2
3	8.05	24	7.13	24	7.62	25.2
4	8.32	24	6.8	23.9	5.97	24.8
5	7.95	24	6.32	23.8	5.24	24.4
6	7.14	23.9	5.42	23.7	3.46	24.2
7	5.55	23.7	5.54	23.6	2.51	23.9
8	5.46	23.5	5.33	23.5	1.2	23.7
9	4.64	23.5	5.2	23.5	1.13	23.6
10	3.8	23.3	5.15	23.4	1.57	23.5
11	3.18	23.3	5.04	23.3	2.6	23.4
12	3.47	23.2	5	23.3	2.03	23.3
13	3.05	23.2	4.89	23.2	1.82	23.2
14	2.18	23.1	4.92	23.2	0.08	23.2
15	1.96	23.1	5.13	23.1		
16	1.74	23.1	5.23	23.1		
17	2.02	23	5.13	23		
18	2.06	23	5.95	23		
19	2.51	22.9	6	22.9		
20	2.4	22.9	5.53	22.8		
21	2.75	22.8	5.1	22.8		
22	2.1	22.7	4.56	22.7		
23	2.19	22.7	3.97	22.6		
24	1.52	22.6	3.66	22.6		
25	1.04	22.5	2.63	22.5		
26	0.18	22.4	0.17	22.3		
27	0.06	22.3	0.11	22.4		
28	0.04	22.3	0.08	22.4		
29	0.03	22.2	0.07	22.4		
30	0.03	21.6				
31	0.02	21.5				
32	0.02	21.2				
33	0.01	21.2				