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RESULTS OF THE LIMNOLOGICAL MONITORING OF THE IMPOUNDMENTS VON BACH, OMATAKO AND SWAKOPPOORT DAMS ON THE EASTERN NATIONAL WATER CARRIER

1987 - 1990

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1. INTRODUCTION

Limnology is the study of the physics, chemistry and biology of freshwater environments and the interrelationships of these. A limnological baseline survey of the major dams of the Eastern National Water Carrier **ENWC**, von Bach, Omatako and Swakoppoort was conducted from January 1984 to December 1986 and reported on in 1987 (**Bethune 1987**). The report recommended that "quarterly monitoring of the physical, chemical and biological parameters in the three dams be continued". This was done for a further four years from 1987 to 1990. In this report 1984 - 1986 is referred to as the baseline survey period and 1987 - 1990 as the monitoring period. The purpose of this progress report is to present the results of the seasonal monitoring of the three impoundments, Von Bach, Omatako, and Swakoppoort from 1987 to 1990.

2. BACKGROUND

2.1 THE LIMNOLOGICAL INVESTIGATION OF THE ENWC

Recognizing that the construction and operation of a long distance water transfer scheme such as the **ENWC** must inevitably have environmental implications, a research project to assess these was initiated in 1983. The aim of the project was to "identify limnological problems likely to affect the transport efficiency and water quality of the **ENWC** and to evaluate effective control measures" (**Bethune 1984**).

One of the projects undertaken was a baseline study of the major impoundments - Von Bach, Omatako and Swakoppoort Dams. The aim was " to establish their physical, chemical and biological characteristics prior to receiving water from the Okavango River and the Karstveld boreholes, and to use this database to monitor future limnological changes" (**Bethune 1984**).

Other projects included in the limnological investigation were: a literature survey of long-distance water transfer (**Bethune & Puz 1985**); a baseline survey (**Bethune 1991, 1992**) and fish surveys (**Bethune and Skelton 1984, Skelton & Merron 1984, 1985, 1987**) of the Okavango River; a snail survey (**Curtis 1989, 1990**); a Karstland plant ecology survey (**Chivell 1989, 1990, Heyns 1991**) and an investigation into animal mortalities in the canal (**Steering Committee 1987, Schlettwein 1988, de Wet 1990, du Plessis & Bethune 1992**).

2.2 THE EASTERN NATIONAL WATER CARRIER

The Eastern National Water Carrier, **ENWC**, is an integrated long-distance water supply scheme designed to eventually supply water from northern water sources such as the Karstland boreholes and the perennial Okavango River via a series of aqueducts and storage impoundments to the drier central regions of Namibia. Basically the **ENWC** will consist of four components:

The first component was the construction of two storage dams on the Swakop River and a pumping scheme to link these to Windhoek. Von Bach Dam has a storage capacity of 53 Mm^3 and was completed in 1971, and Swakoppoort Dam, 55 km downstream, holds 70 Mm^3 of water and was completed in 1977.

The second component was the construction of Omatako Dam and linking it via a pumping scheme to Von Bach Dam. Omatako Dam which has a 4 km long earthfill embankment was completed in 1981 and can store 40 Mm^3 of water.

The third component, the Grootfontein-Omatako Canal scheme was completed in 1987. The canal is 263 km long of which 203 km is an open parabolic canal section and the rest consists of 23 inverted syphons. The canal links the Karstland Borehole Scheme near Grootfontein with the Omatako Dam. The whole Karstland Area could potentially deliver approximately 15 Mm^3/a.

The final component, not yet constructed, will be the 250 km Okavango-Grootfontein pumping main which will finally link the **ENWC** to the Okavango River. This will have a flow capacity of 2 - $3m^3/s$ and will initially serve as a standby source to facilitate the optimal utilization of the water sources of the **ENWC** in the interior of Namibia.

In 1989, a pipeline was constructed from Swakoppoort Dam to serve Karibib and the Navachab Gold Mine and possibly other centres further to the west. Eastwards expansion is also possible as the **ENWC** can be designed to link with the Eastern Region via Otjivero Dam on the White Nossob River. **Figure 1**, opposite gives a map showing the location of the **ENWC**.

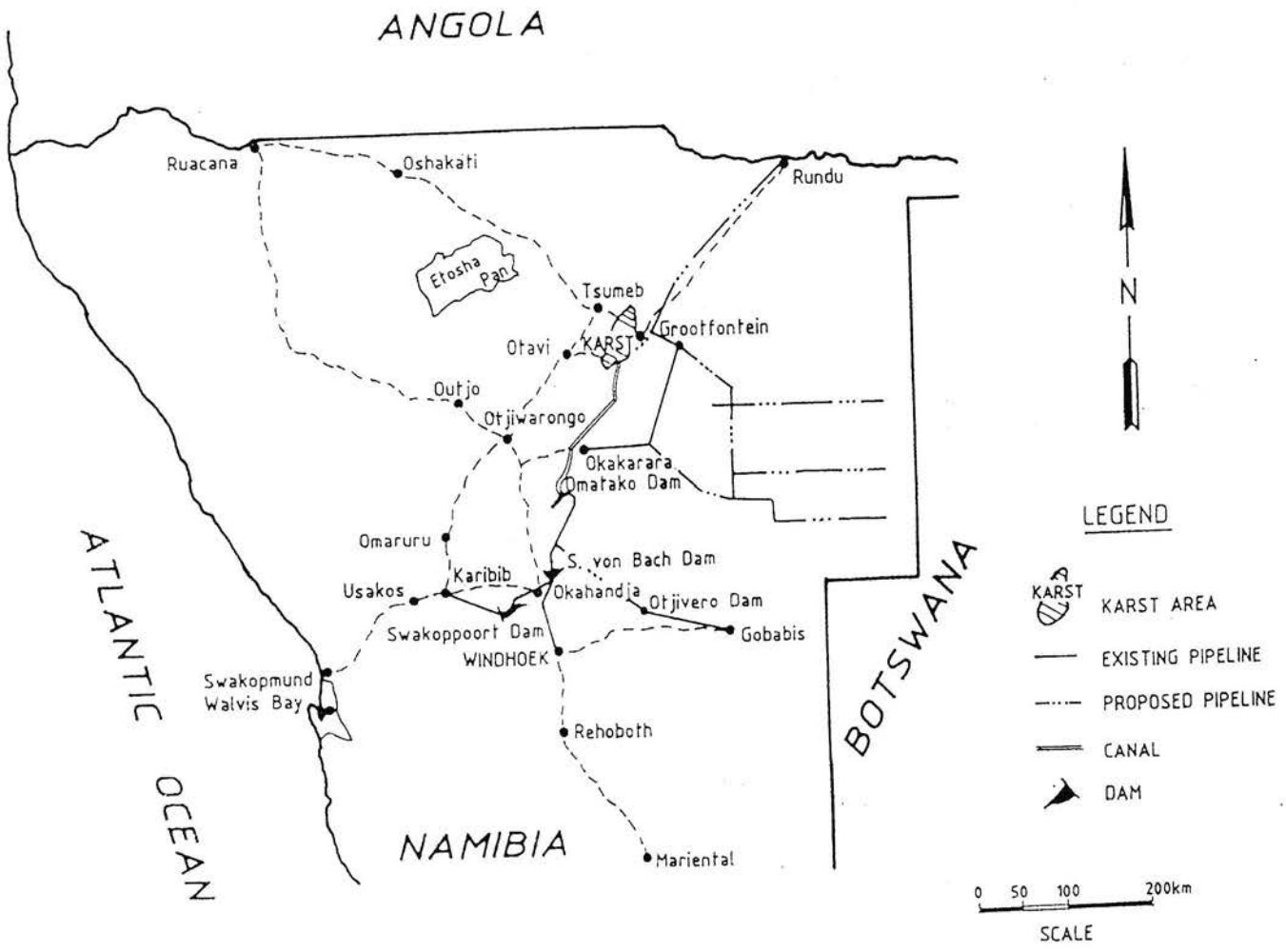

FIGURE 1. THE EASTERN NATIONAL WATER CARRIER.

2.3 BASIC LIMNOLOGICAL TERMS AND CONCEPTS

Before discussing the three impoundments, Von Bach, Omatako and Swakoppoort Dams on the **ENWC**, it is necessary to define some limnological terms:

2.3.1 THERMAL STRATIFICATION:

Most southern African impoundments and lakes stratify each summer. This means that warmer, less dense layers of water successively overlie cooler, more dense bottom layers. Three horizontal density zones can be distinguished by their temperature differences:

the **epilimnion** which is the warm surface layer heated by the sun and mixed by the wind.

the **metalimnion** which is characterised by persistent, steep temperature and density gradients that form a barrier between the other two zones. The **thermocline** is the level within the metalimnion where this temperature change is most marked.

the **hypolimnion** which is the cold, deep layer isolated from the air and surface waters due to the density difference.

As air temperatures decrease in autumn, stratification breaks down. Water temperatures in the epilimnion decrease and approach those of the hypolimnion. The zones are no longer separated by a density gradient. Wind and gravity combine to mix the water creating a thermally homogenous water column i.e. the water temperature is the same from top to bottom. This breakdown in stratification and the resultant sudden increase in diffusion is called **overturn**. The water remains mixed throughout the winter months and stratification is gradually re-established in spring as surface temperatures increase.

2.3.2 OVERTURN

Stratification may be disrupted by heavy summer inflows, the turbid, denser runoff from rivers flows in beneath the epilimnion and the resultant turbulence can be sufficient to cause **overturn**. In shallow impoundments, strong winds too can disrupt stratification.

Nutrients released from decaying organic matter, accumulate in the hypolimnion during the summer months. These are isolated from the epilimnion during stratification. At overturn, they are again made available to the surface waters.

2.3.3 CLASSIFICATION

Impoundments that are stratified in summer and mixed in winter i.e. stratified and mixed once a year are termed **monomictic**. Those which stratify and mix more often are called **polymictic**.

2.3.4 DISSOLVED OXYGEN CONCENTRATIONS

The distribution of dissolved oxygen concentrations in an impoundment can be linked to thermal stratification patterns. The main sources of oxygen in water are aquatic plants and diffusion from the air. In summer the epilimnion is well supplied with dissolved oxygen, but for most of the summer months concentrations are low in the hypolimnion. Organic matter from the epilimnion "rains" into the hypolimnion and decomposes. This gradually depletes the oxygen in the hypolimnion and conditions may become **anaerobic.** Immediately after the autumn overturn, oxygen levels are low throughout the water column but increase gradually through winter.

The **oxycline** is the depth at which the effect of aeration due to wind action at the surface is cancelled by the rate of oxygen uptake. This can be several meters above the thermocline.

2.3.5 PRODUCTIVITY

Primary production i.e plant and algal growth, is dependent on sunlight and is usually confined to the upper layers of the impoundment. The depth to which sunlight penetrates is called the **euphotic zone**. This is narrower in turbid waters.

Limnologically water-bodies can be classified into three types depending on how productive they are:

Oligotrophic waters have low nutrient concentrations and minimal primary production. Chlorophyll *a* * concentrations are less than $3\mu g/\ell$.

Mesotrophic waters are more productive and have chlorophyll *a* values of 2 - $15\mu g/\ell$.

Eutrophic waters have high nutrient concentrations and excessive primary production, often causing problem algal blooms or macrophyte mats and chlorophyll *a* concentrations of 10 - 500 $\mu g/\ell$. Nuisance conditions can be expected at values higher than 20 $\mu g/\ell$ (**Hart & Allanson 1984**).

2.3.6 ALGAL BLOOMS

An **algal bloom** is a sudden dramatic increase in algal growth. These blooms follow nutrient inputs either from river runoff which contains dung and other organic material which accumulated in the river beds during the dry season, or nutrients released from the hypolimnion when the water is mixed after overturn.

Problems associated with algal blooms include unpleasant tastes and odours as well as water purification difficulties and are usually confined to the euphotic zone.

* Chlorophyll a values are used as a measure of the amount of algae present

2.4 THE IMPOUNDMENTS

The main results of the 1984 - 1986 baseline limnological survey of the three impoundments on the **ENWC** (**Bethune 1987**) are included in the following descriptions of the three dams, Von Bach, Omatako and Swakoppoort.

2.4.1 VON BACH DAM

The S Von Bach Dam on the Swakop River near Okahandja is the oldest impoundment on the **ENWC**. It has a full supply capacity of 53,370 Mm^3, a maximum depth of 30 m and a surface area of 4 894 000 m^2. Average water withdrawal increased sharply from 31 000 m^3/day in 1987 to almost 43 000m^3/day in 1990. The water is purified at the Von Bach Purification Plant and used to supply the Windhoek and Okahandja Municipalities and some small holdings near the pipeline.

Von Bach Dam is situated within a small game park, "The Von Bach Recreation Resort" which is managed by the Ministry of Wildlife, Conservation and Tourism. There are facilities for day and overnight visitors. It is a popular venue for angling and water sports.

Until 1978 good inflows kept the dam almost full, a severe drought which lasted until early 1983 depleted the water reserves and during the baseline survey period (1984 - 1986) water levels rose but the dam did not overflow. Inflows were received each summer during the monitoring period (1987 - 1990) but the dam did not overflow.

Water was pumped from Omatako Dam for the first time in 1984 when 9,4331 Mm^3 was pumped from April to July. A further 4,8663 Mm^3 was pumped during June and July 1985, 7,6561 Mm^3 from June to August 1990 and 18,300 Mm^3 from May to November 1991.

The baseline survey (**Bethune 1987**) conducted from January 1984 to December 1986 showed that for most of the year the water in Von Bach Dam was relatively clear. Exceptions were turbid inflows from the Swakop River rains and after inflows from Omatako Dam during the winters of 1984 and 1985. Turbidity caused by river inflows soon settled out but the finer suspensoids introduced with Omatako water took up to a month after pumping to settle out.

During the baseline survey period both the temperature and oxygen isopleths showed that Von Bach Dam developed a stable thermal stratification in summer and that the waters were isothermal in winter allowing oxygen to be evenly distributed throughout the water column. This monomictic pattern is typical of most southern African impoundments. Inflows caused a temporary disturbance particularly when the water-level in the dam was fairly low. Although very little oxygen ($\leq$ 2 mg/ℓ) was available below the thermocline (5-8 m from the water surface), the hypolimnion never became anaerobic. The thermocline deepened each year as the dam filled.

The concentrations of dissolved chemicals in the dam remained fairly stable and low (TDS 69 - 124 mg/ ℓ). The nutrient concentrations and the chlorophyll *a* values were typical of a mesotrophic impoundment (**Walmsley & Butty 1980**). Ten algal species were identified from the dam, one of these *Anabaena circinalis* caused algal blooms and resultant water purification problems in September 1984 and in February 1985.

During the baseline survey period the water levels in Von Bach Dam fluctuated between 19 and 28m. These fluctuations are too great to support marginal plants, but the seep below the dam was densely vegetated. Zooplankton collected and counted during 1984 confirmed that Von Bach was a fairly productive impoundment. Six crustacea species were identified. Very few snails were found in the dam due to the lack of suitable vegetation, they preferred the seep below the wall. Five fish species occurred in the dam, *Cyprinus carpio* (carp), *Micropterus salmoides* (Largemouth bass), *Oreochromis mossambicus* (Mocambique tilapia), *Clarias gariepinus* (sharptooth catfish) and *Tilapia sparrmanii* (banded tilapia). The first three are exotics. Many birds nested on or near Von Bach Dam. Of particular interest were the large numbers of pelicans, white-breasted cormorants, reed cormorants and the African jacanas found in the seep below the dam.

2.4.2 OMATAKO DAM

Omatako Dam which is situated on the Omuramba Omatako is relatively small and shallow compared to the other **ENWC** impoundments. It has a maximum surface area of 13 009 214 m^2 and a maximum depth 11m. It has a full supply capacity of 45 595 m^3. is used for water storage and serves as the link between the Grootfontein-Omatako canal and Von Bach Dam.

The dam received very little water prior to the baseline survey. Good inflows were received during the baseline survey period (1984 - 1886) and the dam overflowed in January 1985. During the monitoring period (1987 - 1990) inflows were received each summer but the dam did not overflow. Water was pumped to Von Bach Dam in 1984, 1985, 1990 and 1991 together with high evaporative losses each summer (1735 mm/annum net evaporation) caused large water level fluctuations of up to 7.4 m.

The baseline survey (**Bethune 1987**) showed that Omatako Dam was extremely turbid (Secchi depth 0.15 m) and not deep enough to allow a stable stratification to develop in summer. Any stratification was periodically disrupted by strong winds and inflows making Omatako Dam typically polymictic. Anaerobic conditions were never found.

With the exception of fairly high SiO_2 concentrations (up to 8.5 mg/ℓ) which characterized Omatako water, the concentrations of major ions were not high (TDS 72 - 158 mg/ℓ) and the water quality was good. Fluctuations in chemical concentrations were due to the diluting effect of river inflows during the rains and concentration caused by high evaporation rates. Both effects were particularly noticeable at low water-levels. Nutrient levels were within the lower ranges typical of unenriched waters.

Chlorophyll *a* concentrations were usually below 10μg/ℓ suggesting that although the nutrients were available, algal growth was limited by the lack of light in these turbid waters. This did not prevent an algal bloom with a chlorophyll *a* concentration of 65.3 μg/ℓ in August 1984. Similarly the zooplankton counts were low (less than 30 000 animals/m^3) and included species typical of turbid water such as *Lovenula falcifera.* Only two fish species were found in the dam, *Clarias gariepinus* (sharptooth catfish) and *Oreochromis mossambicus* (Mocambique tilapia).

2.4.3 SWAKOPPOORT DAM

Swakoppoort Dam, the deepest of the three impoundments is situated on the confluence of the Swakop and Sney rivers, 55 km downstream of Von Bach Dam. When full it has a capacity of 70,288 Mm^3, a depth of 35 m and a surface area of 10 543 583 m^2. It is used for drinking water storage and at present supplies 9 900 m^3/day to Navachab gold mine near Karabib. In future it will supply Karibib, possibly other towns in the west and will be linked to the central region's supply network. Recreation is controlled, there are limited facilities for day visitors and water sport events are held from time to time.

Swakoppoort Dam did not receive any substantial inflows until early 1984. Good summer rains (January to April) between 1984 and 1989 insured regular annual inflows peaking in February. The dam overflowed for the first time in 1988 and again in 1989.

The baseline survey (**Bethune 1987**) revealed that Swakoppoort Dam was monomictic. Both thermal and oxygen stratification developed in spring (September/October) and the impoundment remained stratified throughout summer. A thermocline occurred between 2 and 12 m and a more distinct oxycline was recorded at 4 m. During summer oxygen concentrations in the hypolimnion were often less than 1 mg/ℓ but did not become anaerobic. In winter (June-September) temperatures tended to be homogenous as did oxygen concentrations. The good summer inflows at the beginning of each year disrupted stratification. The turbid, denser runoff from the rivers flowed in beneath the epilimnion and the turbulence was sufficient to cause overturn.

The impoundment was very clear with only brief spells of turbidity following rainwater inflows from the Swakop and Sney rivers in summer. With the exception of the first few months of the baseline survey when the dam contained very little water, the concentrations of cations and anions remained fairly stable, altered only slightly by dilution caused by inflowing rainwater and concentration due to evaporation. The concentrations of major chemicals tended to be slightly higher than in the other two impoundment, (TDS 125 - 326 mg/ℓ while nutrient concentrations were similar. The chlorophyll *a* values in Swakoppoort Dam were often above 10 μg/ℓ. Algal blooms occurred as a result of spring overturn in August 1984, and due to nutrient rich inflows from rivers in December 1984.

During the baseline survey period (1984 - 1986) Swakoppoort Dam supported a large floating mat of *Spirodela*, a small floating angiosperm which often covered as much as 10% of the water surface in mats up to 15 cm thick. It was feared that decomposition of these plants and the reduction of available light to the water column due to shading could seriously impair the quality of the water and cause anaerobic conditions during summer particulary at the wall. The plants were a physical hindrance to navigation and recreation and could block water drawoff inlets.

Biologically, Swakoppoort was found to be the most productive of the three impoundments on the ENWC. It supported the greatest variety of algae (22 species) and had the highest chlorophyll values. It supported a mass of floating vegetation up to 40 ha at times and had the densest population of zooplankton (more than 50 000 animals/m^3 at times) and supported large colonies of cormorants, red-knobbed coots, Egyptian geese and a variety of ducks. Three bream species were introduced into the dam by the then Department of Nature Conservation, *Tilapia sparrmanii* (banded tilapia), *Tilapia rendalli* (redbreast tilapia) and *Oreochromis macrochir* (greenhead tilapia) a fourth species *Oreochromis mossambicus* (Mocambique tilapia) was also found in the dam.

2.5 SUMMARY

To sum up, the 1984 - 1986 baseline survey revealed that Von Bach Dam is a typically monomictic, mesotrophic, clear water impoundment with a stable chemistry and that the main water quality changes are caused by turbid inflows from both the catchment and Omatako Dam and by periodic algal blooms.

Omatako Dam is a typical, shallow, polymictic impoundment and generally less productive than the other ENWC impoundments on account of its high turbidity. Water quality problems were related to the high turbidity, fine suspensoids and periodically to algal blooms.

Swakoppoort was found to be monomictic, chemically stable and very productive. Water quality problems were caused by the dense *Spirodela* mats which were feared, could cause anaerobic conditions to develop in the hypolimnion during summer.

TABLE 1. GENERAL CHARACTERISTICS OF THE THREE IMPOUNDMENTS ON THE EASTERN NATIONAL WATER CARRIER (ENWC).

IMPOUNDMENT	S VON BACH	OMATAKO	SWAKOPPOORT
CONSTRUCTED	1967 - 1971	1980 - 1981	1977 - 1979
USAGE	Drinking water storage and supply Recreation	Drinking water storage and supply	Drinking water storage and supply Recreation
LOCATION:			
District:	Okahandja	Otjiwarongo	Okahandja
Farm:		Quickborne	Sneyrivier 20
$^1/_4$° Grid:	SE 2217 Aa	SE 2117 Aa	SE 2216 Ba
Locality:	21°S 17°E	21° 11'S 17° 12'E	22° 13'S 16° 30'E
Altitude:	1320 m	1348 m	1104 m
CATCHMENT:			
Rivers:	Swakop, Satan's	Omuramba-Omatako	Swakop, Sney, Otjiseru, Okahandja, Otjihavera
Area:	2920 km^2	5320 km^2	8400 km^2
Usage:	Cattle & Game farming. Nat. Reserve	Cattle & Game farming.	Cattle, Game & Vegetable farming.
FULL SUPPLY:			
Height above mean sealevel:	1350,00 m	1358,00 m	1139,00 m
Depth:	30,00 m	11,00 m	35,00 m
Capacity:	53,37 10^{6}m^3	45,12 10^{6}m^3	70,29 10^{6}m3
Surface Area:	4894 000 m^2	13009 214 m^2	10543 583 m^2
LIMNOLOGICAL SURVEY:	1984-Ongoing	1984-1990	1984-1990

Table 1 on page 12, opposite, compares some of the general characteristics of the three dams on the ENWC. Table 2 below, compares the general chemistry of all three the ENWC impoundments during the baseline survey period (1984 - 1986).

TABLE 2: A COMPARISON OF GENERAL WATER CHEMISTRY TRENDS IN THE ENWC IMPOUNDMENTS FROM 1984 - 1986.

CHEMICAL	VON BACH	OMATAKO	SWAKOPPOORT
CONDUCTIVITY μS/cm	162 - 218	165 - 293	214 - 366
TDS mg/ℓ	69 - 124	72 - 158	125 - 326
Total Alkalinity mg/ℓ	75 - 107	53 - 136	93 - 232
pH	7 - 8.8	7.2 - 8.8	6.9 - 8
Cl^- mg/ℓ	1.7 - 4.7	1 - 7	6.4 - 15.6
Na^+ mg/ℓ	1.2 - 6.1	1 - 11	8.3 - 17.2
K^+ mg/ℓ	5.4 - 9.2	3.3 - 10.6	6.8 - 20
$SO_4^=$ mg/ℓ	0.3 - 5.8	1.3 - 11.5	2.6 - 10.3
Ca^{++} mg/ℓ	54 - 79	34 - 80	65 - 142
Mg^{++} mg/ℓ	13 - 22.3	13 - 33	17 - 49
SiO_2 mg/ℓ	1.7 - 4.9	1 - 7	6.4 - 15.6

The values used in **Table 2** are the minimum and maximum mean monthly concentrations recorded. The maximum values for Swakoppoort Dam were recorded in January 1984 and reflect the extreme drought conditions prior to the first substantial inflows.

3. MONITORING PROCEDURE

3.1 MONITORING SITES

The three major impoundments on the **ENWC**, Von Bach, Omatako and Swakoppoort Dams were monitored quarterly from 1987 - 1990. Three sites on each impoundment were monitored, a wall site (1), an open basin site (2), and inflow site (3). These are indicated on the maps in **Figures 2** below and in **Figures 3 and 4** opposite on page 15.

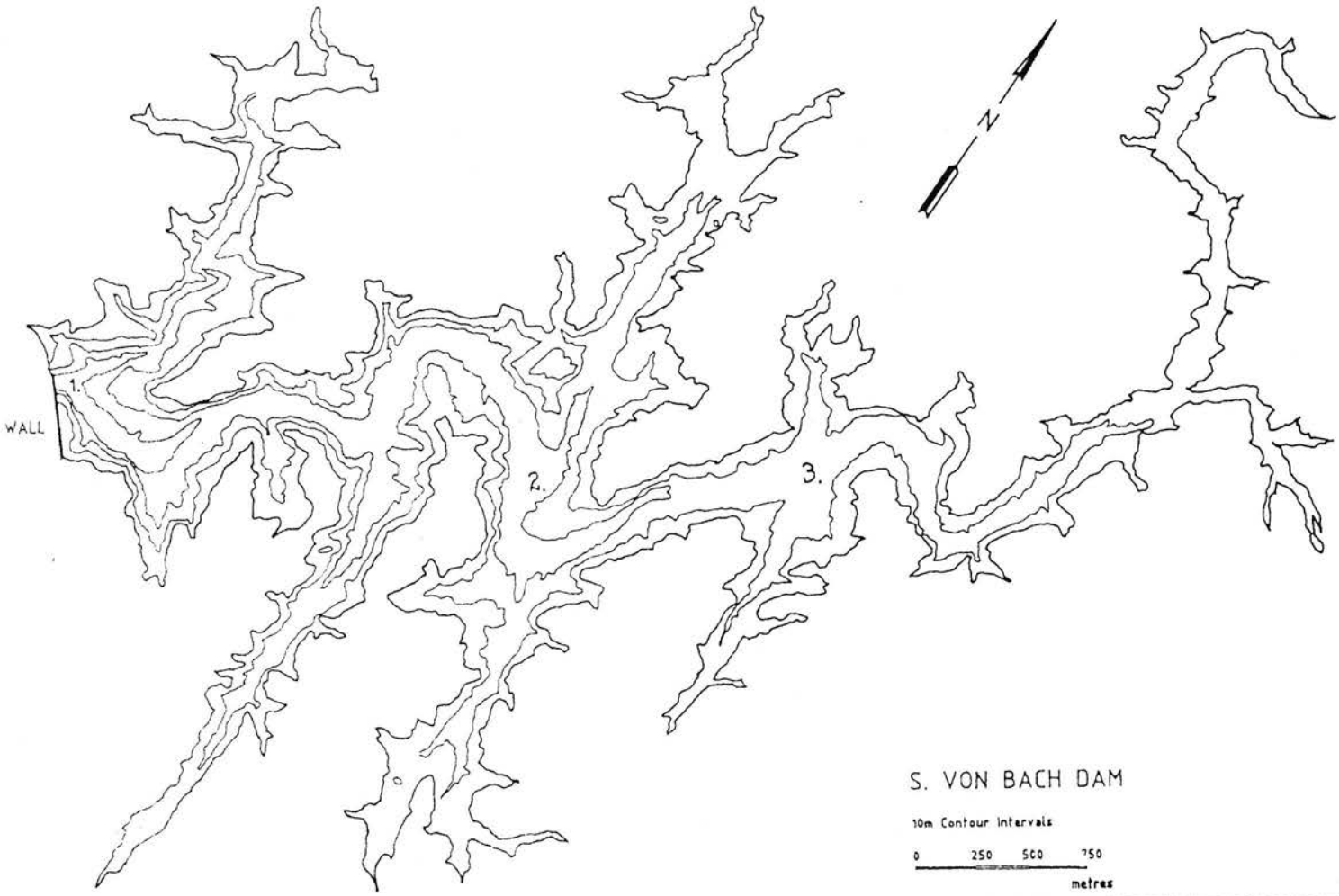

FIGURE 2: MAP OF VON BACH DAM SHOWING THE MONITORING SITES.

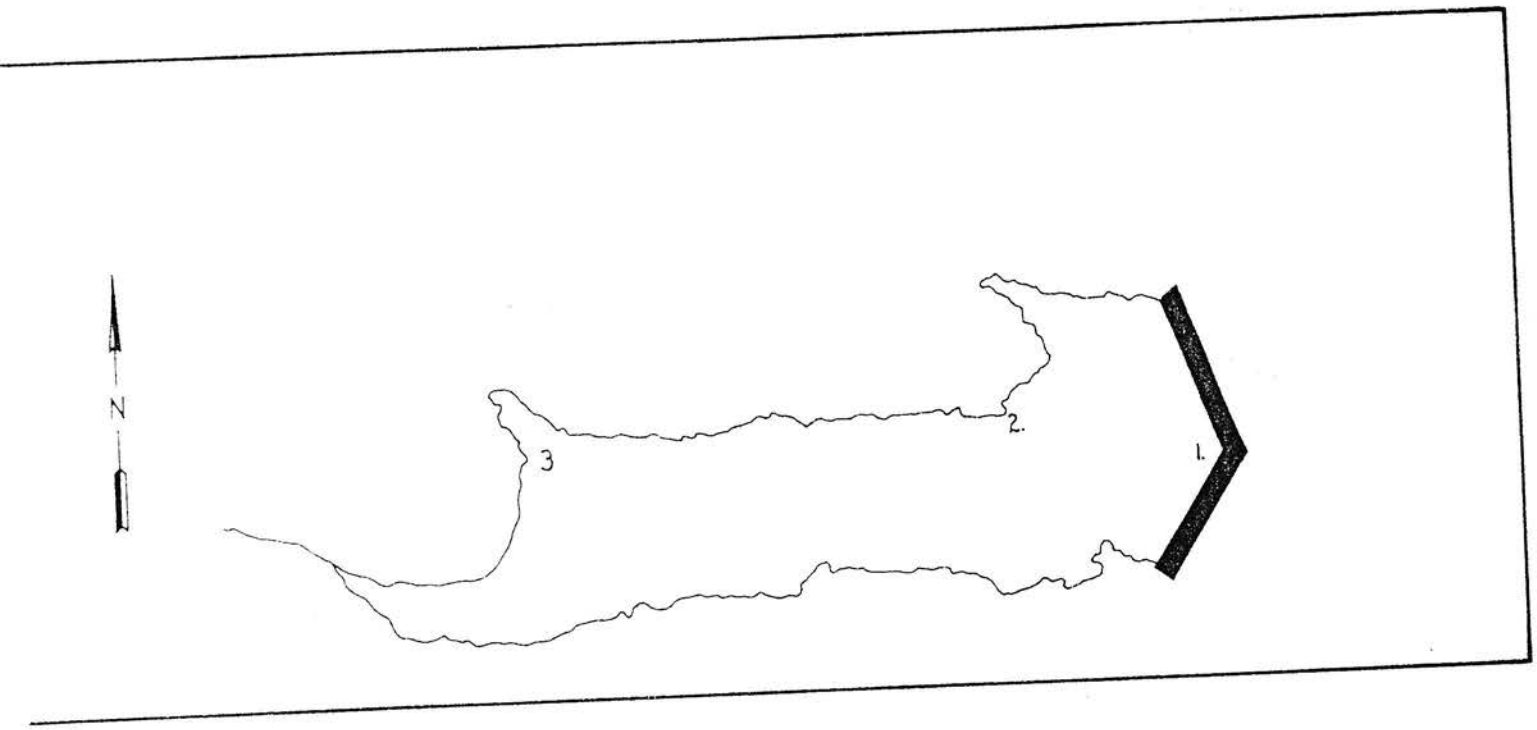

FIGURE 3: MAP OF OMATAKO DAM SHOWING MONITORING SITES

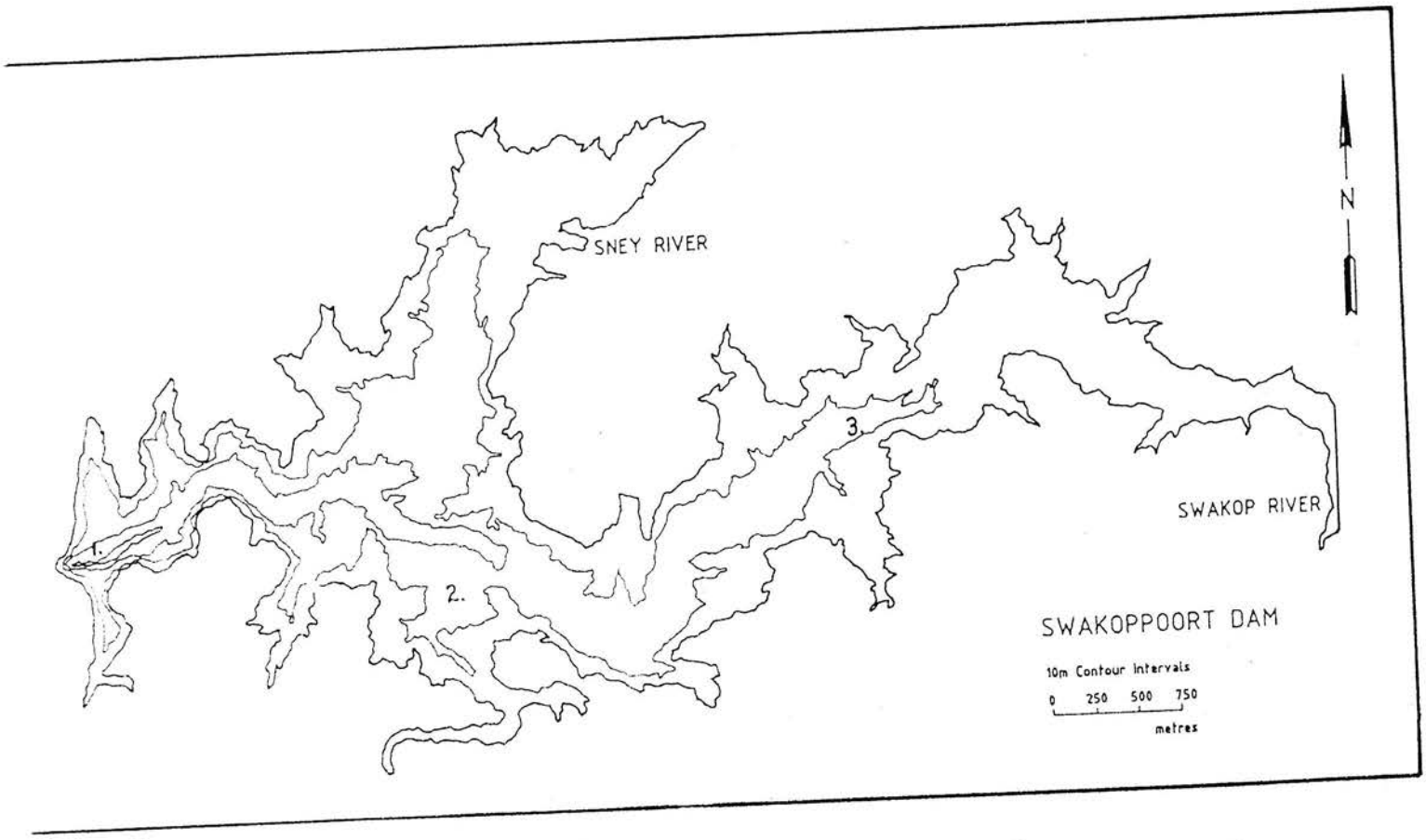

FIGURE 4: MAP OF SWAKOPPOORT DAM SHOWING MONITORING SITES

3.2 MONITORING METHODS

In situ measurements of temperature, dissolved oxygen concentrations, Ph and conductivity were taken and water samples were collected from the surface and at a depth of 10 metres using a 5 litre Von Doorn water sampler.

Oxygen concentrations and temperatures were measured at half metre depth intervals using a YSI Model 54A dissolved oxygen meter, which was air calibrated prior to use. Field Ph measurements were taken just under the surface using a Orion 301 portable meter, whilst conductivity was similarly measured using a WTW Lf 91 portable meter.

The transparency of the water was measured with a Secchi disc. This is a disc with a diameter of 25 cm with alternate black and white quadrants. The maximum depth at which the disc is visible to an observer at the water surface, is measured.

Routine chemical analysis were done by the chemical laboratory for Total Alkalinity, Conductivity, Turbidity, Ph, TDS, Na^+, K^+, SO_4^{2-}, Ca^{2+}, Mg^{2+}, SiO_2, F^- and Cl^-. The methods are based on the standards set by the American Public Health Association (**1980**).

Nutrient analysis for: NO_2-N, NO_3-N, NH_4-N, Total Organic-N,
PO_4-P, Organic soluble-P and Total organic-P were done by the biochemical laboratory at Aigams and based on the methods of Golterman, Clymo & Ohnstad (**1987**) and Mackereth, Heron & Talling (**1978**).

Chlorophyll *a* concentrations were determined using the method recommended by Sartory (**1982**).

4. RESULTS AND DISCUSSION

4.1 PHYSICAL CHARACTERISTICS

4.1.1 WATER TRANSPARENCY

Water transparency in Von Bach and Omatako dams remained similar to those measured during the baseline survey but improved in Swakoppoort Dam after the *Spirodela* disappeared.

VON BACH DAM:

Von Bach dam remained relatively clear throughout the monitoring period and had an average Secchi depth of 2.1 m which deepened to 3.4 m in November 1990. Turbid inflows from the Swakop and Satan's rivers occurred during the rainy season (January & February) reducing Secchi depths to 0.5 m. The turbid inflow from Omatako Dam (June - August 1990) also reduced transparency.

OMATAKO DAM:

Omatako Dam remained highly turbid due to the constant mixing of the water and resultant resuspension of fine bottom sediments. Secchi depths were usually between 0.3 and 0.5 m and the only exception was in August 1989 when a Secchi depth of 1,7 m was recorded at the wall site.

SWAKOPPOORT DAM:

Swakoppoort Dam remained the clearest of the three impoundments with a Secchi depth of about 2.2 m for most of the year and a mid-summer maximum of up to 4.9 m (November 1989 & 1990). Water clarity decreased drastically with river inflows in January and February (Secchi depths 0.5 - 0.9 m). During 1987 and the first half of 1988 dense mats of *Spirodela* covered up to 10% of the surface area. When the dam overflowed early in 1988 a large proportion of the plants were flushed out. Although reduced, the mats were soon re-established. The cold winter retarded growth so that by October 1988 no dense mats were seen and the second overflow in February 1989 flushed out the few remaining plants.

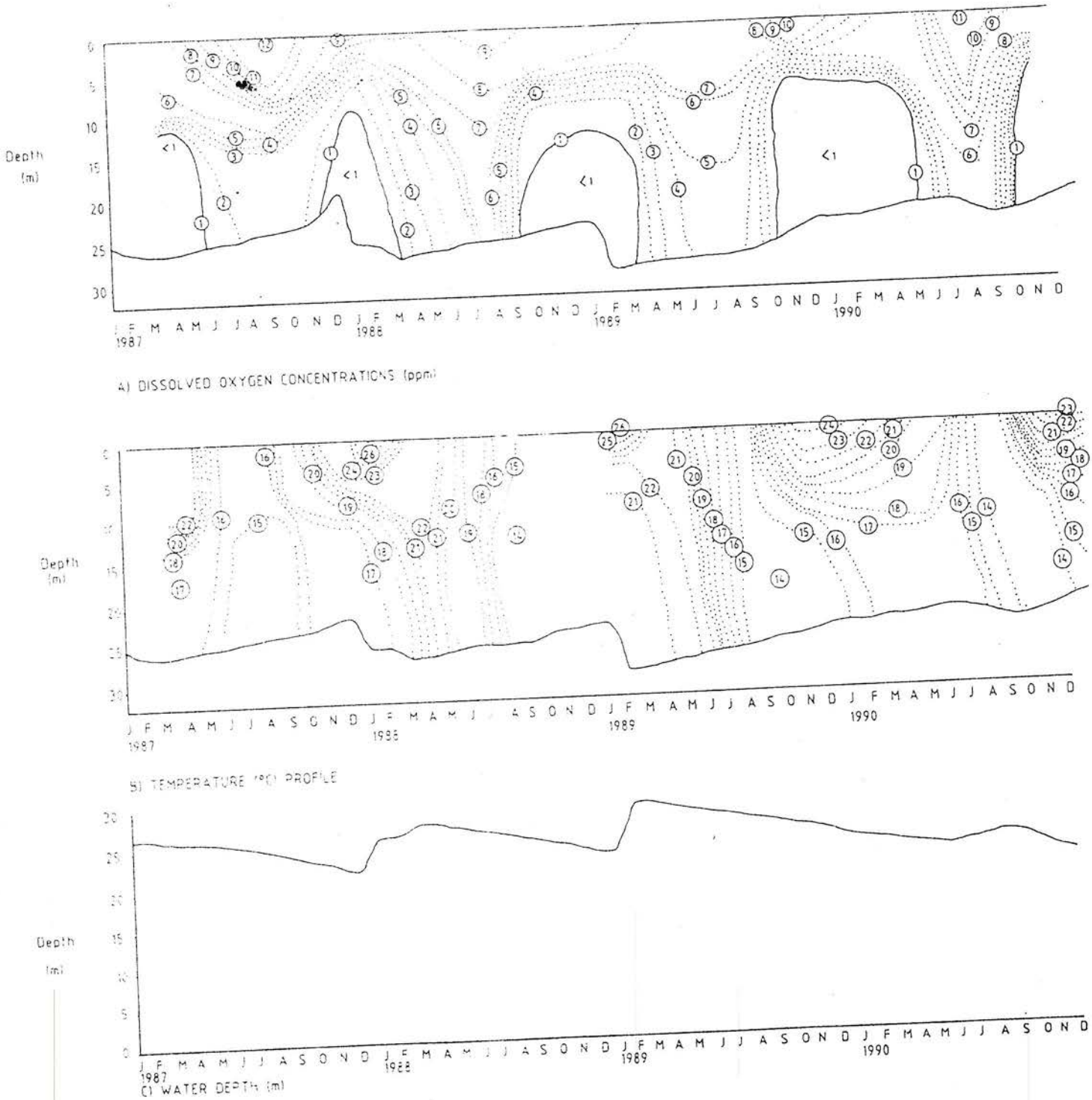

FIGURE 5: VON BACH DAM WATER LEVELS (A) TEMPERATURES WITH DEPTH (B) AND DISSOLVED OXYGEN CONCENTRATIONS (C) AT THE WALL 1987 - 1990.

4.1.2 HYDROLOGY

VON BACH DAM:

During the monitoring period (1987 - 1990) water levels in Von Bach Dam fluctuated as shown in **Figure 5** (a) opposite on page 18. Summer rains in February and March 1988 and 1989 brought substantial inflows. (7,151 Mm^3 early in 1987, 22,744 Mm^3 January to April 1988, 25,002 Mm^3 from December 1988 to February 1989 and 4,082 between January and April 1990. Water was transferred from Omatako Dam once during the monitoring period in 1990 when 7,6561 Mm^3 was pumped between 7 June and 22 August. Water was again transferred in 1991 when 18,3 Mm^3 was pumped between 16 May and 19 November (**RR/92/5**). During the 1987/88 season 31 000 m^3/day was withdrawn to supply the central region, this increased to 31 700 m^3/day in 88/89 and then to 38 400 m3/day in 1989/90 and finally to 43 250 m^3/day in 1990/91.

OMATAKO DAM:

Water level fluctuations in Omatako Dam are shown in **Figure 6 (a)** overleaf on page 20. Inflows were received each summer, 10,004 Mm^3 in February and March 1987, 14,447 Mm^3 in January 1988, 17,370 Mm^3 from November 1988 to May 1989 and 14,345 Mm^3 between January and April 1990. Water losses were due to the volumes pumped to Von Bach Dam and to evaporation.

SWAKOPPOORT DAM:

Figure 7 (a) on page 22, shows water level fluctuations for Swakoppoort Dam for the same period. Swakoppoort Dam overflowed in early 1988 (23 645 Mm^3) and again in February 1989 (11,484 Mm^3). Inflows were due to summer rains. These contributed 14,500 Mm^3 in 1987, 51,924 Mm^3 in 1988, 25,365 Mm^3 in 1989 and 6,749 Mm^3 in 1990. Since October 1989, approximately 9 900 m^3 has been withdrawn daily from Swakoppoort Dam to supply Navachab Mine. Swakoppoort Dam is connected to Von Bach to enable water transfers between these two impoundments. Should the need arise water from Swakoppoort Dam can be used to augment the supply to the central region. Water quality and productivity changes will need to be carefully monitored during and after such water transfers so that operation procedures can be adapted if necessary.

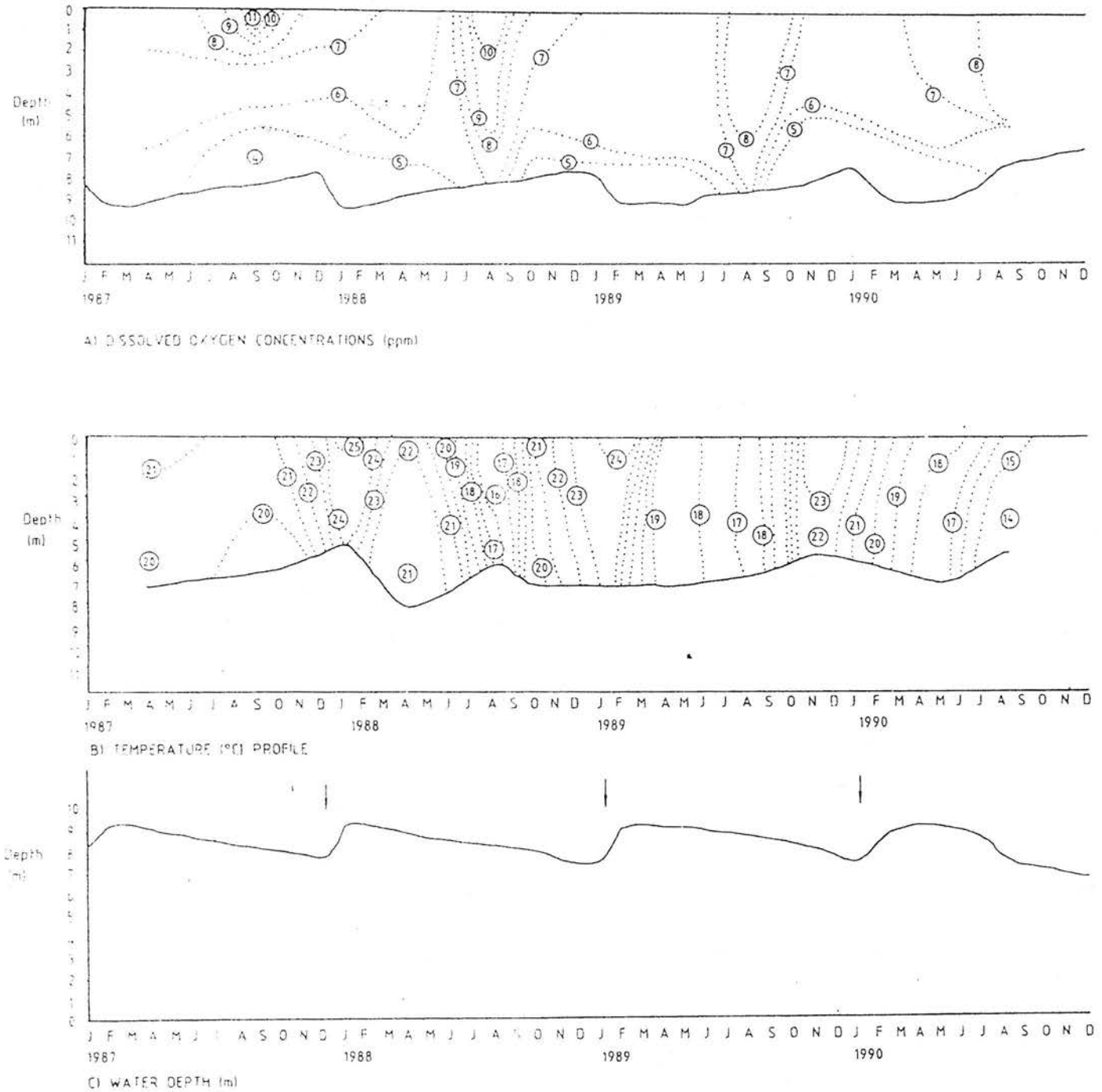

FIGURE 6: OMATAKO DAM WATER LEVELS (A), TEMPERATURES WITH DEPTH (B) AND DISSOLVED OXYGEN CONCENTRATIONS AT THE WALL 1987 - 1990.

4.1.3 TEMPERATURE

The temperature profiles in **Figures 5,6,& 7** (b) on pages 18, 20 and 22 respectively, show the thermal changes throughout the water column in each of the impoundments during the monitoring period. The horizontal isopleths show the summer stratification period and the vertical isopleths indicate isothermal periods of circulation throughout the water column.

VON BACH DAM

Figure 5 (b) on page 18 shows that, as in the baseline survey, Von Bach Dam was stratified in the summer from October - April, but that the thermocline was deeper varying between 5 and 10 metres. As previously, the autumn overturn in April/May was followed by four months of isothermal conditions and stratification was gradually re-established in September/October. The maximum surface water temperature was 26°C. In winter water temperatures gradually declined from 21°C to 14°C. In summer the hypolimnion was never colder than 17°C.

OMATAKO DAM:

As shown in **Figure 6 (b)** on page 20 opposite, Omatako Dam rarely stratified, except for short periods in mid-summer. For most of the year water temperatures were the same throughout the water column. These isothermal conditions were caused by strong winds which mixed the shallow impoundment. Water temperatures varied from 25°C in surface waters in mid-summer to 14°C in winter.

SWAKOPPOORT DAM:

Like Von Bach Dam, Swakoppoort Dam, **Figure 7 (c)** overleaf on page 22, was monomictic. Thermal stratification developed in spring (September/October) and the impoundment remained stratified throughout the summer with a thermocline between 8 - 12 m. Stratification was temporally disrupted by heavy summer inflows in January and February 1988 and in February 1989. In winter (June-September) temperatures tended to be homogenous and varied from 22°C to 15°C. The highest temperature recorded was 27°C in January 1988 and in summer the hypolimnion was never colder than 17°C.

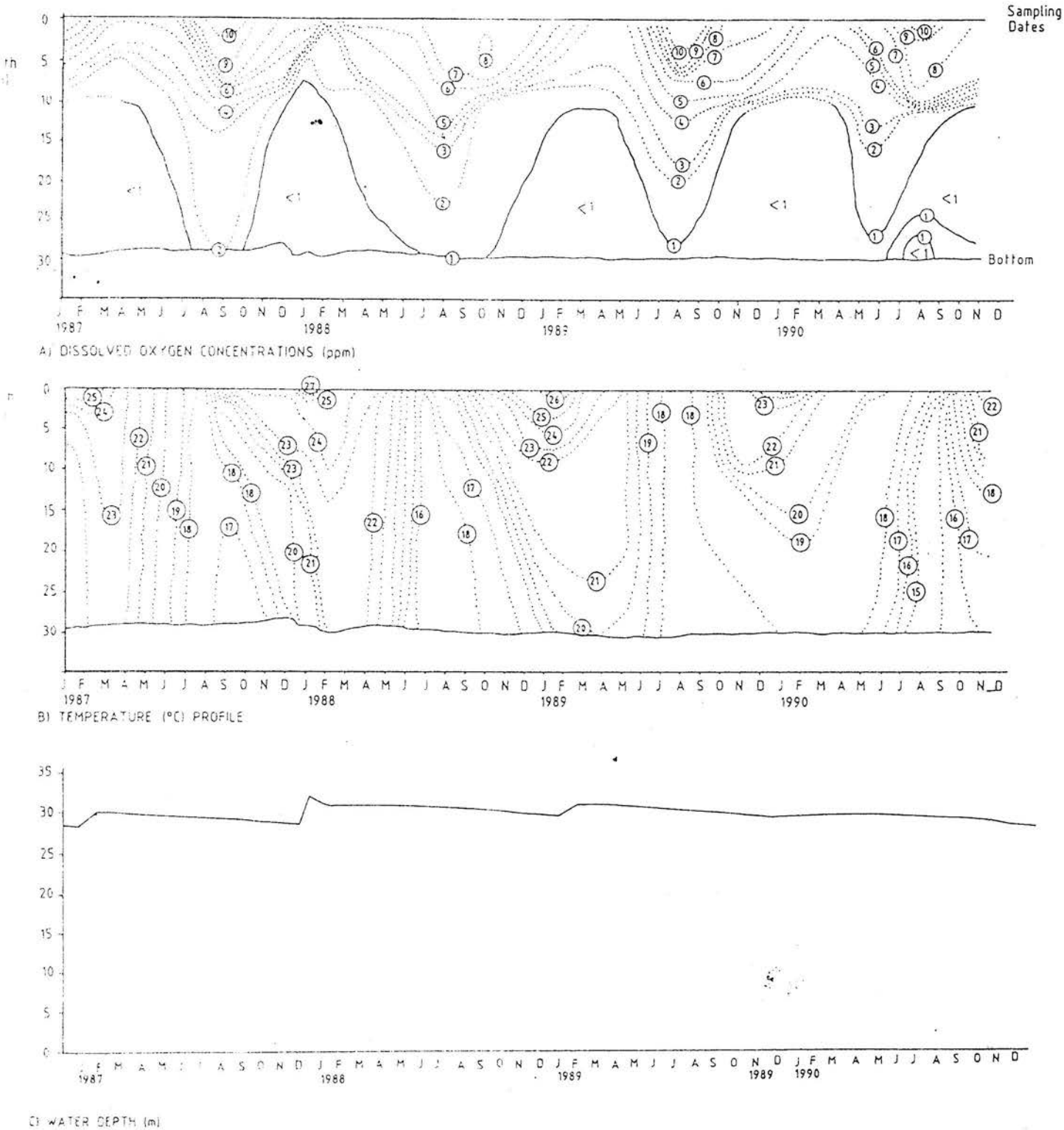

FIGURE 7: SWAKOPPOORT DAM WATER LEVELS (A), TEMPERATURES WITH DEPTH (B) AND DISSOLVED OXYGEN CONCENTRATIONS AT THE WALL 1987 - 1990.

4.2 CHEMICAL CHARACTERISTICS

4.2.1 DISSOLVED OXYGEN CONCENTRATIONS

Dissolved oxygen is essential for the respiration of many aquatic animals and the solubility of many chemicals. **Figures 5,6 & 7 (c)** on page 18, 20 and 22 respectively, illustrate the oxygen profiles for the dams from 1987 to 1990. The horizontal isopleths show the summer stratification period with higher oxygen levels nearer the surface and a decrease in the hypolimnion as the available oxygen was used up. The vertical isopleths indicate the winter mixing period.

VON BACH DAM:

As illustrated in **Figure 5** (c) on page 18, Von Bach Dam displayed a clear pattern of summer stratification and winter mixing. In summer the surface waters were well aerated and there was very little oxygen in the hypolimnion, often less than 1 ppm. The oxycline depth varied from year to year (10m in 1987, 5m in 1988 and 1990, 8m in 1990). Heavy inflows early in 1988 and 1989 disrupted stratification and caused an early overturn compared to 1987 and 1990 when stratification did not break down until early June.

OMATAKO DAM:

Due to the polymictic nature of Omatako Dam, oxygen levels remained relatively high throughout the water column, decreasing slightly in winter when primary production and hence oxygen production decreased. **Figure 6 (c)** on page 20, shows that the oxygen levels were never less than 4 ppm.

SWAKOPPOORT DAM:

In Swakoppoort Dam, as illustrated in **Figure 7 (c)** opposite on page 22, oxygen stratification developed in spring (September/October) and the impoundment remained stratified throughout summer. The distinct oxycline between 8 and 10 m was somewhat deeper than during the baseline survey. Oxygen levels in the hypolimnion remained very low and anaerobic conditions were recorded in August/September 1990. In 1988 and 1989 stratification was disrupted early by heavy river inflows.

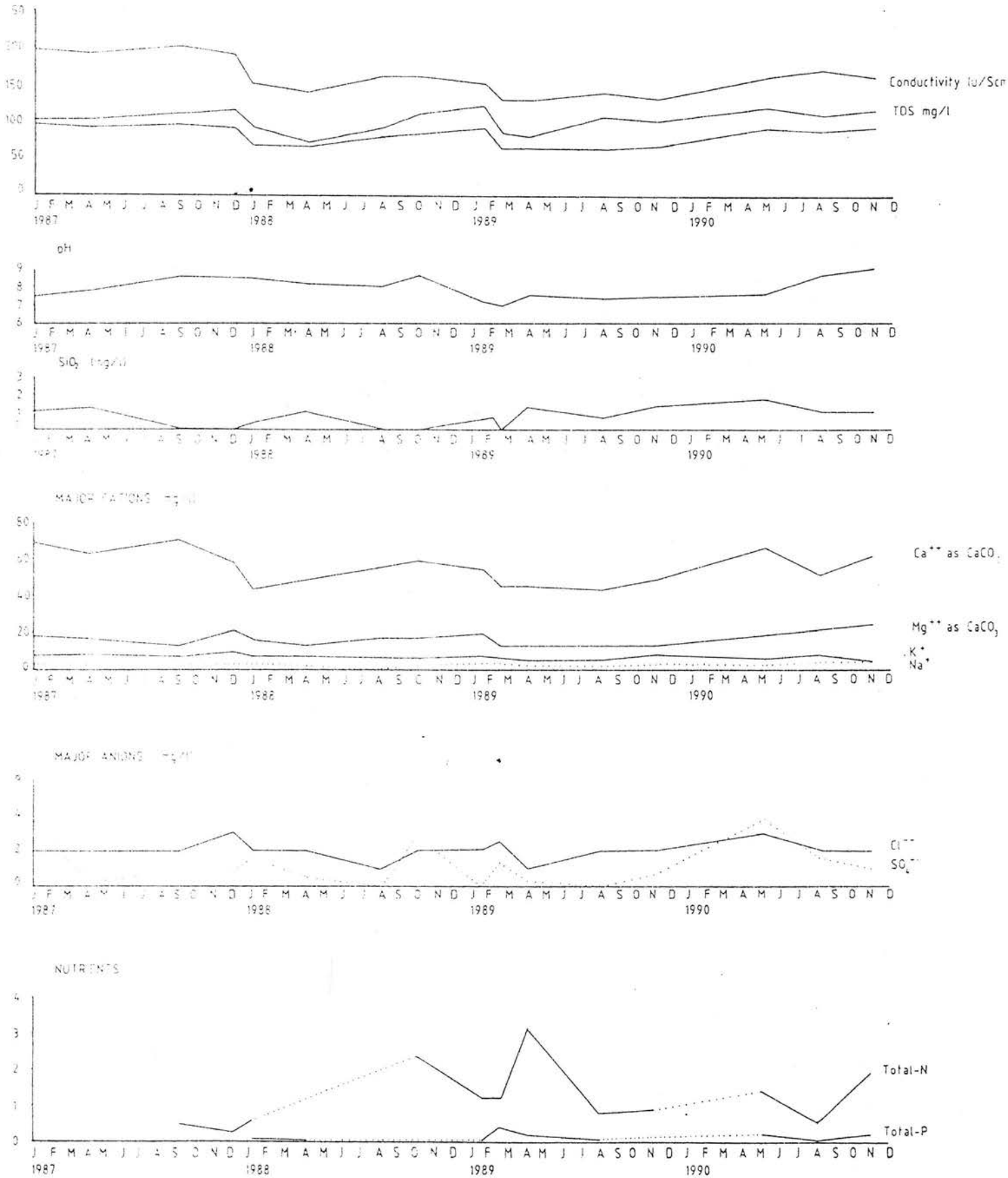

FIGURE 8: WATER CHEMISTRY TRENDS IN VON BACH DAM 1987 - 1990

4.2.2 CONCENTRATIONS OF MAJOR CHEMICALS AND NUTRIENTS

The water chemistry of an impoundment is determined by the geology and vegetation cover of its catchment area and by the chemical and biological reactions within the dam. Nutrient availability (Phosphates and nitrogen) are often linked to stratification patterns. These relatively low concentrations of nutrients are essential to aquatic plant growth and hence the productivity of the impoundments. During the monitoring period sampling was not frequent enough to detect and correlate chemical changes in detail. These results therefor reflect the overall trends. Nutrient concentrations were often too low to be detected by the analytical methods used. The mean values and standard deviations of the major chemicals and nutrients for each sampling date in each of the impoundments during the monitoring period are given in the **Addendum: Tables 1 to 6** at the end of this report.

VON BACH DAM:

Figure 8 on page 24 opposite shows that the concentrations of most of the chemicals in Von Bach Dam remained fairly constant throughout the monitoring period. Heavy rainwater inflows early in 1988 and 1989 had a diluting effect, reflected by the decrease in conductivity, TDS, and alkalinity values. Changes during the second half of 1990 could be attributed to inputs from Omatako Dam. Ph, calcium, and magnesium showed a slight increase. These effects are dealt with in detail in a separate report (**RR/92/5**).

Compared to the results of the baseline survey (1984 - 1986) the water chemistry of Von Bach Dam has remained essentially the same. Mean conductivity ranged from 115 - 200 μS/cm, TDS from 73 - 125 mg/ℓ, Alkalinity from 59 - 96 mg/ℓ and Ph was usually between 7 and 8 but increased when Omatako water was received.

The concentrations of the major chemicals remained low, sodium was usually between 1 and 3 mg/ℓ, Potassium between 5 and 10 mg/ℓ, sulphates less than 3,8 mg/ℓ, calcium 43 to 68mg/ℓ, magnesium 13 to 24 mg/ℓ, silica oxide less than 1.6 mg/ℓ and chlorine usually below 3 mg/ℓ. The nutrient concentrations too remained low. The dramatic increases in total Nitrogen in November 1988 and 1990, and April 1989 were related to algal blooms in the impoundment.

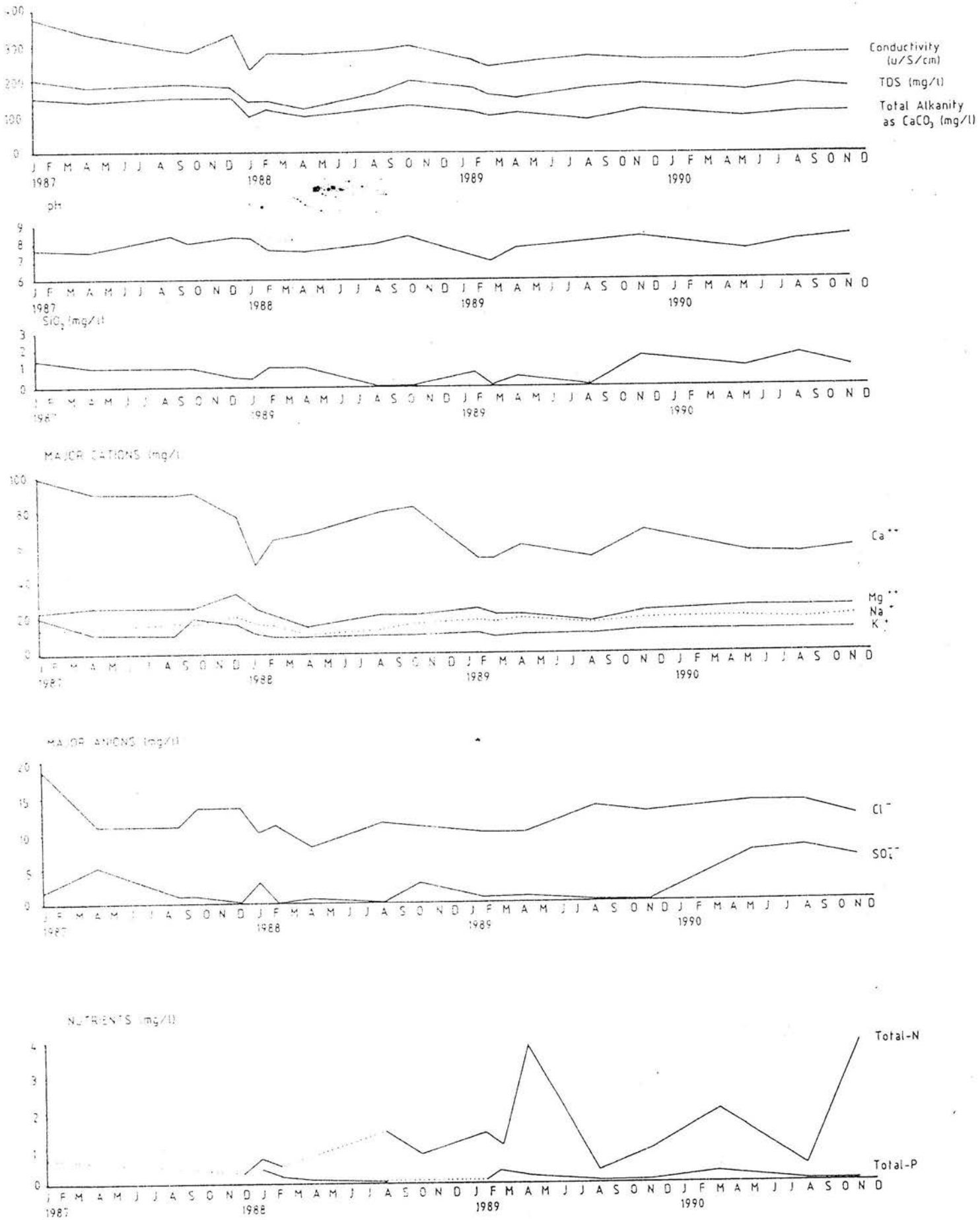

FIGURE 9: WATER CHEMISTRY TRENDS IN OMATAKO DAM 1987 - 1990

OMATAKO DAM:

Figure 9 on page 26 opposite indicates some of the water chemistry trends detected in Omatako Dam during the monitoring period. Rainwater inflows in February/March each year had a diluting effect on the chemical concentrations in the dam. These are reflected by decreases in conductivity, total alkalinity, Ph, calcium and magnesium.

Mean conductivity ranged from 139 - 273 μS/cm and was usually above 200 μS/cm, TDS ranged from 130 to 158 mg/ℓ, and total alkalinity from 90 to 134 mg/ℓ. Although the Ph varied from 6.3 to 8.6 it was usually above Ph 8. The concentrations of the major ions remained relatively low. Sodium ranged from 5,5 to 12 mg/ℓ, potassium from 7,6 to 13,2mg/ℓ, sulphates were usually less than 5,1 mg/ℓ, calcium between 48 and 80 mg/ℓ, magnesium between 27 and 44 mg/ℓ, silica oxide less than 4,5 mg/ℓ and chlorine between 2 and 4,6 mg/ℓ.

Nutrient concentrations remained low and the increases in total nitrogen concentrations could to linked to algal blooms which followed inflows in April 1989 and 1990.

SWAKOPPOORT DAM:

Figure 10 on page 28 overleaf shows changes in water chemistry in Swakoppoort Dam for the period 1987 - 1990. As with the other impoundments river inflows temporarily diluted chemical concentrations in October 1987, January/February 1988 and 1989 and less so early in 1990.

Compared to the other two impoundments, the overall chemical concentrations were highest in Swakoppoort Dam. Conductivity varied from 202 - 368 μS/cm, TDS from 115 to 205mg/ℓ and total alkalinity from 99 to 146 mg/ℓ. Like Von Bach the Ph was usually between 7 and 8. The concentrations of major ions also tended to be higher.

Peaks in nutrient concentrations were linked to algal blooms in March/ April 1989 and 1990. These followed heavy inflows which brought in nutrients and by disrupting stratification made further nutrients available from the hypolimnion to boost algal growth in the surface waters. The algal bloom in November 1990 resulted from the autumn overturn.

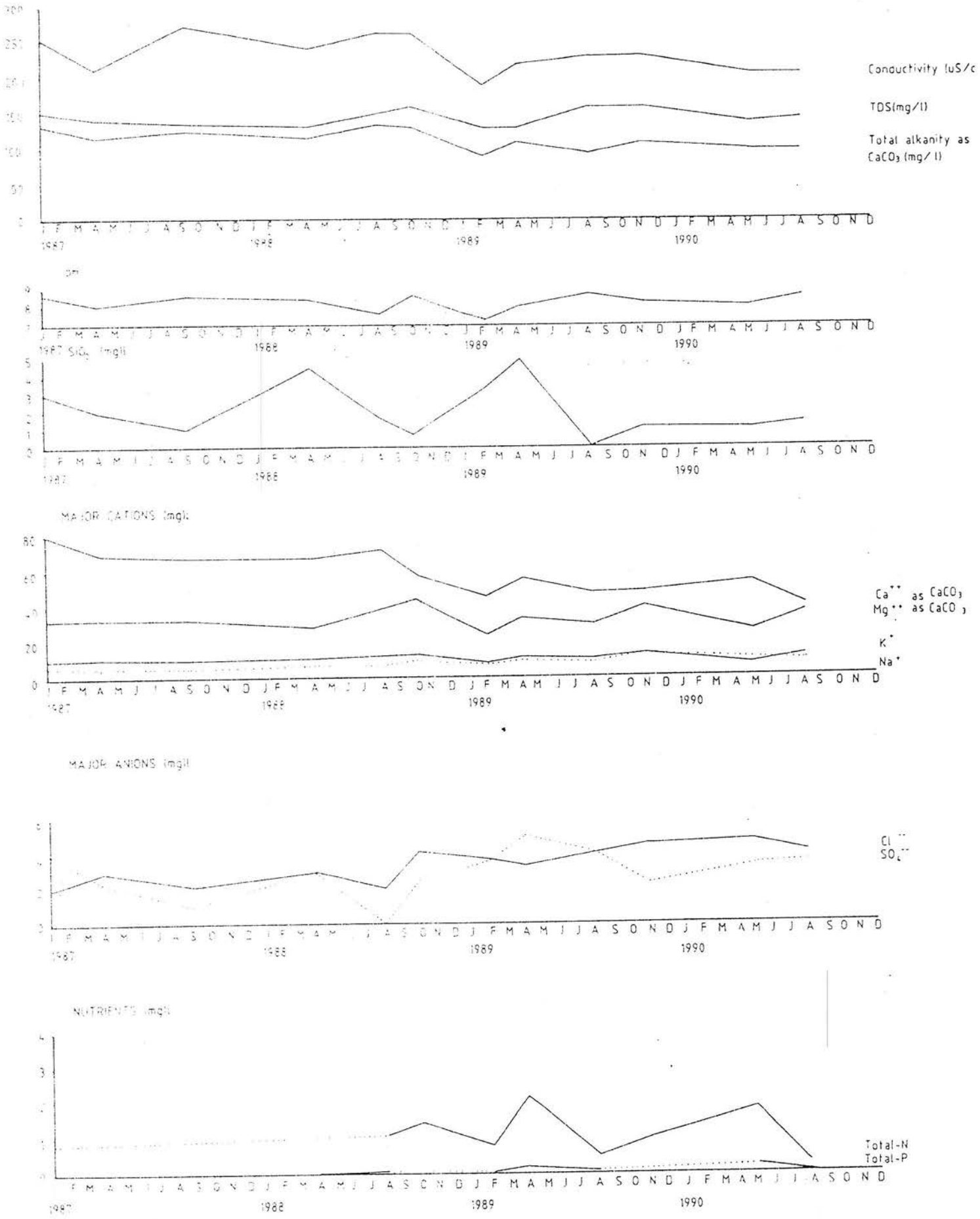

FIGURE 10: WATER CHEMISTRY TRENDS IN SWAKOPPOORT DAM 1987-1990

Table 3 below compares the general water chemistry of all three the **ENWC** impoundments during the monitoring period.

TABLE 3: A COMPARISON OF GENERAL WATER CHEMISTRY TRENDS IN THE ENWC IMPOUNDMENTS FROM 1987 - 1990.

CHEMICAL	VON BACH	OMATAKO	SWAKOPPOORT
CONDUCTIVITY μS/cm	123 - 200	139 - 273	202 - 368
TDS mg/ℓ	73 - 125	130 - 158	115 - 205
Total Alkalinity mg/ℓ	59 - 96	90 - 134	99 - 146
Ph	7 - 8	above 8	7 - 8
Cl^- mg/ℓ	below 3	2 - 4,6	8 - 18
Na^+ mg/ℓ	1 - 3	5,5 - 12	10 - 20
K^+ mg/ℓ	5 - 10	7,6 - 13,2	9 - 20
$SO_4^=$ mg/ℓ	below 3,8	below 5,1	below 7,5
Ca^{++} mg/ℓ	43 - 68	48 - 80	48 - 99
Mg^{++} mg/ℓ	13 - 24	27 - 44	15 - 25
SiO_2 mg/ℓ	below 1,6	below 4,5	below 1,7

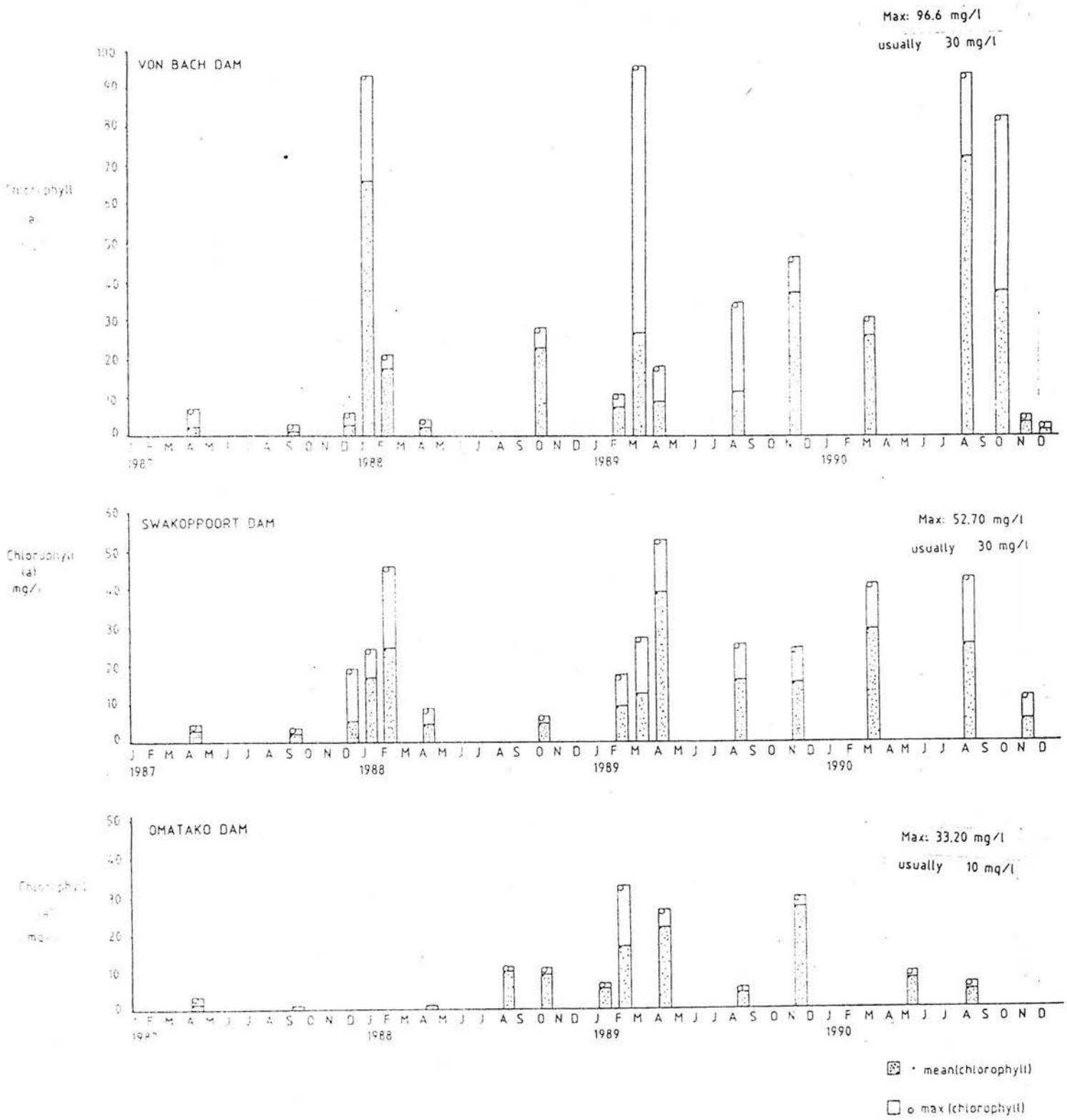

FIGURE 11: CHLOROPHYLL *a* CONCENTRATIONS IN VON BACH (A), SWAKOPPOORT (B) AND OMATAKO DAMS (C) 1987 - 1990.

4.3 BIOLOGICAL CHARACTERISTICS

4.3.1 ALGAE

Chlorophyll *a* values can be used as a measure of the amount of algae in the water. **Figure 11** on page 30 opposite gives the chlorophyll *a* concentrations recorded in each of the three dams during the monitoring period. This record is too discontinuous to distinguish clear trends and correlations. Sampling was more frequent in the summer months particularly during algal blooms and inflow periods. The gaps indicate months not sampled.

VON BACH DAM:

Von Bach Dam showed clear peaks in January 1988, October 1988, March 1989 and August 1990. October 1988 and March 1989 peaks corresponded with increases in total nitrogen but the August 1990 peak corresponded with a decrease in nutrients, perhaps reflecting a growth phase when most of the available nutrients had been taken up by the algae.

The highest chlorophyll *a* value (96,6 μg/l) was recorded from Von Bach Dam. In Von Bach dam a third of the recorded values exceeded 30 $\mu g/\ell$ and a little more than half exceeded 20$\mu g/\ell$. These chlorophyll *a* values were much higher than those recorded during the baseline survey when the maximum recorded was 20 $\mu g/\ell$ and concentrations rarely exceeded 10 $\mu g/\ell$. This is an indication that Von Bach is becoming increasingly enriched. More problem algal blooms can be expected with substantial inputs from Swakoppoort Dam.

OMATAKO DAM:

Increases in chlorophyll *a* concentrations recorded in Omatako Dam in October 1988, and April/May 1989 and 1990 corresponded to nutrient increases but the November 1989 peak did not. The April/May peak also corresponded with an increase in silica oxide values which may indicate a simultaneous diatom bloom. The maximum chlorophyll *a* value was 33,2 $\mu g/\ell$ which was the only concentration exceeding 30 $\mu g/\ell$. A quarter of the recorded values exceeded 20 $\mu g/\ell$ but most did not exceed 10 $\mu g/\ell$, confirming that due to its high turbidity Omatako Dam remains the least productive of the three impoundments.

SWAKOPPOORT DAM:

Similarly to Von Bach, the chlorophyll *a* concentrations in Swakoppoort Dam in March/April 1989 and 1990 corresponded to nutrient peaks and in August 1990 to a decrease in available nutrients. The maximum value was 52.7 $\mu g/\ell$ and a quarter of the recorded values exceeded 30 $\mu g/\ell$, half exceeded 20 $\mu g/\ell$ and two thirds exceeded 10 $\mu g/\ell$, confirming that Swakoppoort is the most productive of the three impoundments and the most likely to experience algal blooms.

4.3.2 HIGHER PLANTS

The three **ENWC** impoundments supported few higher plants (macrophytes). These included *Spirodela* (duckweed) on Swakoppoort Dam which eventually disappeared early in 1989, some *Lagarosphon* (oxygen weed) in the shallow bays of Swakoppoort Dam and dense marginal stands of the floating stemmed buckweed, *Polygonum* which covered large areas of Omatako Dam in May 1990. A few isolated clumps of *Polygonum* also occurred on Von Bach Dam.

Although there are several permanent, well-vegetated seepage ponds below the dam wall of each impoundment, no detailed survey of the vegetation has been undertaken. Below Von Bach Dam the dominant plants are *Typha capensis* (bulrushes) and *Polygonum* whilst *Phragmites* (reeds) and *Cyperus* species (sedges) occur in the seeps below Swakoppoort Dam. Below Omatako Dam several well-vegetated canals collect seepage water from a very marshy area where the water table is high.

4.3.3 SNAILS

With the exception of snails, little work was done on the animals living in, or dependent on, the three impoundments on the **ENWC** during the monitoring period.

A detailed survey of the snails in and below the three impoundments was included in the State Museum investigation into the national distribution of freshwater snails and snail-borne diseases, that was conducted from February 1986 to April 1989 for the Department of Water Affairs (**Curtis 1986, 1990, In Press**).

Two species of snails which carry livestock paramphistomiasis were found in all three dams. *Bulinus tropicus* in fairly large numbers in Omatako Dam, sporadically in Swakoppoort Dam and one was found on a buoy in Von Bach Dam. *Bulinus forskali* was found in low numbers in the seepage pools below all three dams.

The final report (**Curtis 1990**) warns that the seepage pools below the dam walls are ideal sites for snails to become established and are environmentally suitable for disease-carrying snails which could be introduced from the Okavango River via the **ENWC** unless precautions are taken. These precautions include regularly clearing the vegetation in the seeps, keeping humans and livestock away from the seepage ponds and monitoring the snail populations in them annually. Maintenance teams regularly clear away vegetation which hampers flow in the marshy channels below Omatako Dam and in the main channel below Von Bach Dam. Although human access is limited except at Von Bach, livestock had been seen drinking at all the seeps.

The recommendation of the State Museum report (**Curtis 1990**) that the seepage ponds below the dams be monitored annualy should be implemented. A one-off survey of the vegetation in these seeps is also needed.

4.3.4 FISH

Although not specifically monitored, eight fish species occur in the three dams (**Bethune & Roberts 1991, Von Holtzhausen 1991, Van Zyl pers. comm.**).

VON BACH:

Von Bach Dam supports populations of *Cyprinus carpio*, *Micropterus salmoides*, *Oreochromis mossambicus*, *Clarias gariepinus*, *Tilapia sparrmanii* and *Barbus paludinosus* (straightfin barb). The latter, was not observed during the 1984 -1986 baseline survey.

OMATAKO DAM:

As observed during the baseline survey only two fish species were found in Omatako Dam, *C. gariepinus* and *O. mossambicus* ,the later is not indigenous to the region. This species is genetically similar to an Okavango species *Oreochromis andersonii* (Threespot tilapia) and favours a similar quiet, partially vegetated detritus-rich habitat. Although the possibility that fish from Omatako Dam would reach the Okavango River via floods in the Omuramba Omatako is a remote one, it is feared that should *O. mossambicus* enter the Okavango system, it would provide both direct competition and a source of genetic pollution to endemic Okavango stock (**Bethune & Skelton 1984**).

During 1991 a fishing concession was granted and 550 kg of sharptooth catfish (*C. gariepinus*) were caught during August and September. Despite the low price paid (18c/kg) difficulties were experienced operating profitably at this scale. A more appropriate way to reduce fish prior to pumping might be to issue several fishing permits to individuals living near the dam, to encourage them to use low-intensity methods e.g. hand-lines, long-lines and beach seines and to allow them to sell their catches in the immediate vicinity of the dam.

SWAKOPPOORT DAM:

The six fish species found were *T.sparrmanii*, *T.rendalli*, *O. mossambicus*, *O. macrochir*, *C. gariepinus* and *B. paludinosus*. The latter two were not found during the baseline survey.

There is little quantitative data available on the fish populations in these three dams and further attention should be given to determine fish production rates and sustainable yields. At Omatako Dam a system of low-cost, labour-intensive, low-intensity fish cropping for local easily accessible markets should be developed. Care must be taken to avoid the transfer or introduction of alien fish species via the **ENWC (Bethune & Skelton 1984)**.

4.3.5 BIRDS

Although bird counts were not included during the monitoring period, the results of recent wetland bird counts on Von Bach, Omatako and Swakoppoort Dam are given to show that all three impoundments support a wide diversity and large numbers of birds. The counts were conducted in co-operation with the Ministry of Wildlife, Conservation and Tourism as part of an International Wetland Bird Programme (**IWBP**).

VON BACH:

Von Bach counts were low compared to the other two impoundments. In July 1991, 630 birds and 14 species were counted and in February 1992, 460 birds and 23 species were observed (**Simmons 1991, personal observation**).

OMATAKO DAM:

During a single survey in July 1991, 2 482 birds and 29 species were counted on Omatako Dam (**Simmons 1991**).

SWAKOPPOORT DAM:

In a single survey in February 1992, 2 065 birds and 21 species were counted on Swakoppoort Dam (**Personal observation**).

The twice-yearly bird counts on the impoundments are an important contribution to an international wetland bird census. This type of international co-operation should be actively encouraged.

4.4 EXPANSION OF LIMNOLOGICAL BASELINE STUDIES

A good database on the limnology of the three impoundments on the Eastern National Water Carrier has been built up since 1984. Similiar studies should be conducted on all our State impoundments to expand this limnological database. Priority should be given to dams which directly serve water purification works such as Oanob Dam near Rehoboth, Otjivero Dam which serves Gobabis and Naute Dam near Keetmanshoop.

Each impoundment should be surveyed fortnightly for the first year and then monthly for a further 2-3 years in order to establish a good, scientifically sound baseline. The equipment to do these surveys is available and the Research Division can initiate studies on one dam each year. It is suggested that surveys commence on Oanob Dam in October 1992 and on Otjivero Dam in October 1993. For impoundments further away from Windhoek such as Hardap Dam and Naute Dam it may be feasible to train operators stationed at these dams to do the fortnightly monitoring and collecting of water samples. They will need to be supplied with Oxygen and Temperature metres, Secchi discs, conductivity, Ph metres and sampling bottles as well as the relevant data sheets.

5. CONCLUSIONS

Although the three year baseline survey (1984 - 1986) of the three impoundments on the ENWC - Von Bach, Omatako and Swakoppoort Dams established their physical, chemical and biological characteristics satisfactorily, a further four years of monitoring (1987 - 1990) has confirmed the findings of the baseline survey and indicated some changing trends. Although broad trends could be followed, quarterly monitoring is considered insufficient for limnological surveys and fortnightly or at least monthly intervals should be used in future limnological projects.

VON BACH DAM remained a typically monomictic impoundment with a relatively stable chemistry but it is becoming increasingly eutrophic. As the most immediate supply source to Windhoek, it is important to build-up a long-term record of the limnology of Von Bach Dam, therefor monthly monitoring of Von Bach dam is being continued.

OMATAKO DAM remained a typically turbid, shallow, polymictic impoundment, and generally less productive than the other dams. Monitoring was stopped at the end of 1990 but once Omatako Dam receives water from either the Karstland boreholes or the Okavango River, monthly monitoring should be resumed.

SWAKOPPOORT DAM remained a clear, monomictic, chemically stable impoundment and the most productive of the three dams monitored. The *Spirodela* problem was solved by successive overflows flushing out the plants. Anaerobic conditions in the hypolimnion were recorded in August 1990. Monitoring was stopped at the end of 1990 but monthly monitoring should be resumed once water is pumped either to Von Bach or the purification plant in Karibib becomes operational.

Finally, similar limnological baseline surveys should be done on other Namibian impoundments, starting with those which directly supply water to purification plants e.g. Oanob, Otjivero, Hardap and Naute Dams.

6. RECOMMENDATIONS

6.1 That this report be accepted as the progress report on the limnological monitoring of the three impoundments on the ENWC, Von Bach, Omatako and Swakoppoort Dams, for the period 1987 to 1990.

6.2 That monthly monitoring of Von Bach Dam be continued to provide a long-term data base of Windhoek's water supply.

RESEARCH

6.3 That the effect of the pumped Omatako Dam water on the water quality of the Von Bach Dam and the cost of purification be investigated.

RESEARCH

6.4 That monthly monitoring of Swakoppoort Dam be resumed once the Karibib purification plant is operational or when pumping to Von Bach Dam commences.

RESEARCH

6.5 That baseline limnological investigation of Oanob Dam be initiated at the beginning of the next hydrological season (October 1992), and Otjivero Dam in October 1993.

RESEARCH

6.6 That the seepage ponds below the dam walls be monitored annually to detect disease-carrying snails and that vegetation surveys be conducted in the seepages below each of the dam walls.

RESEARCH

Compiled by: S Bethune
Principal Hydrologist
Date: 30 March 1992

7. APPROVAL OF RECOMMENDATIONS

This progress report is approved for submission to the Director: Investigations and Research.

CHIEF: RESEARCH DATE: 31/3/92

I support the recommendations contained in this progress report and submit it to the Permanent Secretary for Water Affairs.

DIRECTOR: INVESTIGATIONS AND RESEARCH DATE: 15/5/92

The recommendations in this report have been decided on as follows:

Approved

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for

PERMANENT SECRETARY FOR WATER AFFAIRS DATE:

19. 10. 92

8. ACKNOWLEDGEMENTS

I would like to thank all who assisted with this monitoring programme. Dr S de Wet, Ms R Kubirske, Mr N Krone, Mr NP du Plessis, and Mr F Gariseb assisted with fieldwork. Water analysis were done by the Water Quality chemical and biochemical laboratories under the supervision of Dr J van Niekerk. Ms M Schoeman assisted with the data analysis. Mr B van Zyl of the Freshwater Fish Research Institute at Hardap Dam supplied information on the fish species in the dams. Mr K.S. Roberts and Dr S de Wet critically evaluated the draft report. Ms E. le Roux prepared the final document.

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10. ADDENDUM

TABLE 1: MEAN MONTHLY VALUES AND STANDARD DEVIATIONS OF SOME CHEMICAL CHARACTERISTICS OF WATER FROM VON BACH DAM. JANUARY 1987 - NOVEMBER 1990.

TABLE 2: MEAN MONTHLY VALUES AND STANDARD DEVIATIONS OF SOME BIOCHEMICAL CHARACTERISTICS OF WATER FROM VON BACH DAM. JANUARY 1987 - NOVEMBER 1990.

TABLE 3: MEAN MONTHLY VALUES AND STANDARD DEVIATIONS OF SOME CHEMICAL CHARACTERISTICS OF WATER FROM OMATAKO DAM. JANUARY 1987 - AUGUST 1990.

TABLE 4: MEAN MONTHLY VALUES AND STANDARD DEVIATIONS OF SOME BIOCHEMICAL CHARACTERISTICS OF WATER FROM OMATAKO DAM. JANUARY 1987 - AUGUST 1990.

TABLE 5: MEAN MONTHLY VALUES AND STANDARD DEVIATIONS OF SOME CHEMICAL CHARACTERISTICS OF WATER FROM SWAKOPPOORT DAM. JANUARY 1987 - NOVEMBER 1990.

TABLE 6: MEAN MONTHLY VALUES AND STANDARD DEVIATIONS OF SOME BIOCHEMICAL CHARACTERISTICS OF WATER FROM SWAKOPPOORT DAM. JANUARY 1987 - NOVEMBER 1990.

TABLE 1: MEAN MONTHLY VALUES AND STANDARD DEVIATIONS OF SOME CHEMICAL CHARACTERISTICS OF WATER FROM VON BACH DAM:

JANUARY 1987 - NOVEMBER 1990

CHEMICAL	1987 JAN	APR	SEP	DEC	1988 JAN	APR	AUG	OCT	1989 FEB I	FEB II	APR	AUG	NOV	1990 MAY	AUG	NOV		
UNIT	n = 5	n = 6	n = 5	n = 5	n = 7	n = 4	n = 4	n = 5	n = 4	n = 4	n = 8	n = 4	n = 6	n = 6	n = 6	n = 6		
Total Alkalinity as $CaCO_3$ mg/ℓ	95,00	90,17	94,20	93,40	66,29	64,90	78,20	83,24	86,70	63,00	64,30	59,30	69,10	92,50	86,67	96,33		
	±3,52	±2,41	±1,47	±2,80	±15,80	±11,30	±0,55	±4,20	±9,81	±3,05	±8,74	±2,82	±5,90	±10,77	±0,94	±16,63		
Conductivity (Laboratory) us/cm	196,00	160,00	172,0	162,0	150,0	123,5	128,8	166,4	172,5	127,3	117,4	160,8	149,0	179,2	184,5	189,0		
	±4,9	±5,8	±4,0	±4,0	±23,3	±10,7	±1,6	±7,7	±17,7	±1,5	±13,0	±17,7	±15,0	±21,7	±4,6	±31,7		
Conductivity (field) us/cm	@	192,5	200,3	188,2	@	144,0	160,7	160,2	153,3	127,0	130,0	142,2	133,3	160,6	174,0	159,6		
	–	±5,50	±3,30	±6,83	–	±9,51	±3,11	±7,89	±1,70	±1,8	±4,64	±5,07	±4,71	±0,47	±4,03	±5,44		
pH (laboratory)	7,52	7,65	8,28	7,28	6,91	7,40	7,80	8,04	7,15	7,03	5,90	7,80	7,45	7,70	7,88	8,0		
	±0,31	±0,08	±0,04	±0,07	±0,14	±0,12	±0	±0,05	±0,11	±0,18	±0,13	±0,07	±0,39	±0,16	±0,43	±0,75		
pH (field)	–	7,93	8,64	8,59	8,50	8,20	8,15	8,72	@	@	7,60	7,43	@	7,70	8,70	9,10		
	–	±0,18	±0,31	±0,15	±0,10	±0,12	±0,20	±0,37	–	–	±0,12	±0,26	–	±0,22	±0	±0,24		
TDS mg/ℓ	103,4	101,8	109,6	115,0	75,8	73,0	89,2	109,8	120,7	84,00	77,6	106,0	98,3	118,5	121,8	124,8		
	±6,05	±3,18	±3,20	±20,6	±14,7	±2,35	±1,30	±5,11	±12,3	±0,71	±8,57	±11,7	±10,1	±14,3	±3,13	±20,9		
Na mg/ℓ	2,40	2,0	2,0	3,40	2,57	1,75	1,0	1,90	2,75	2,0	1,88	2,0	3,0	2,67	3,83	3,67		
	±0,49	±0	±0	±0,80	±0,49	±0,43	±0	±0,20	±0,43	±0	±0,33	±0	±0	±0,47	±1,21	±0,47		
K mg/ℓ	7,06	8,0	6,60	10,00	6,71	7,00	6,00	6,10	7,00	6,00	5,38	5,00	7,83	6,33	8,00	5,17		
	±0,49	±0	±0,49	±1,10	±0,70	±0,71	±0,20	±0,20	±0	±0	±0,48	±0	±0,37	±0,47	±0	±0,37		
SO_4 mg/ℓ	3,60	0,17	1,0	0,80	1,57	0,45	*	2,80	*	1,25	0,25	*	0,67	3,83	1,67	1,0		
	±0,49	±0,37	±0	±1,60	±2,61	±0,78	–	±0,24	–	±0,43	±0,66	–	±1,49	±2,11	±0,75	±0		
Ca as $CaCO_3$ mg/ℓ	68,60	63,0	70,0	58,2	43,0	48,13	55,00	58,50	53,75	45,00	44,75	43,25	47,83	66,33	51,33	61,33		
	±3,14	±0	±0	±4,8	±11,4	±3,25	±1,77	±3,74	±8,00	±0	±6,74	±2,05	±7,10	±13,3	±0,94	±17,5		
Mg as $CaCO_3$ mg/ℓ	17,60	17,0	13,0	21,00	15,71	13,0	17,0	17,0	18,75	13,0	12,88	13,00	12,50	17,67	21,00	24,33		
	±0,49	±0	±0	±0	±3,15	±0	±0	±0	±2,05	±0	±2,26	±0	±1,12	±7,45	±0	±1,49		
SiO_3 mg/ℓ	1,0	1,17	*	*	0,43	1,0	*	*	0,70	*	1,25	0,75	1,33	1,67	1,0	1		
	± 0	±0,37	–	–	±0,49	±0	–	–	±0,76	–	±0,43	±1,30	±0,94	±0,94	±0	–		
Cl mg	2,0	2,0	2,0	3,0	0,43	1,0	*	*	2,0	2,5	1,25	2,25	2,0	3,17	2,0	2,0		
	±0	±0	±0	±1,55	0,49	±0	–	–	±0	±0,87	±0,43	±0,43	±0	±0,90	±0	±0		

@ NOT MEASURED

* TOO LOW TO DETECT WITH ANALYTICAL METHODS USED

TABLE 2: MEAN MONTHLY VALUES AND STANDARD DEVIATIONS AT SOME BIOCHEMICAL CHARACTERISTICS OF WATER FROM VON BACH DAM:

JANUARY 1987 - NOVEMBER 1990

BIOCHEMICAL UNIT	1987 SEP	DEC	1988 JAN	APR	OCT	1989 FEB I	FEB II	APR	AUG	NOV	1990 MAY	AUG	NOV
	n=5	n = 4	n = 7	n = 4	n = 5	n = 5	n = 4	n = 4	n = 8	n = 6	n = 6	n = 6	n = 6
NO_2 - N	0,01	0,02	0,10	0,03	*	0,04	*	*	*	*	0,27	<0,1	<0,1
mg/ℓ	± 0	±0,04	±0,05	±0,04	-	±0,08	-	-	-	-	±0,33	-	-
NO_3 - N	0,32	0,04	0,10	0,03	*	0,04	0,50	0,56	0,23	0,08	0,1	<0,5	<0,1
mg/ℓ	±0,04	±0,05	±0,09	±0,04	-	±0,08	±0,50	±0,68	±0,18	±0,19	0	-	-
Total - N	0,46	0,28	0,64	*	2,35	1,21	1,23	3,15	0,76	0,90	1,43	0,51	1,93
mg/ℓ	±0,30	±0	±0,25	-	±1,45	±0,52	±0,49	±1,36	±0,14	±0,42	±0,70	±0,14	±0,89
NH_4 - N	0,25	*	*	*	0,92	0,42	0,37	0,77	0,62	0,45	0,82	0,36	0,84
mg/ℓ	±0,06	-	-	-	±0,50	±0,20	±0,24	±0,36	±0,17	±0,31	±0,63	± 0,07	±0,66
Total - P	*	*	0,034	0,096	*	0,034	0,433	0,220	0,064	*	0,187	0,036	0,210
mg/ℓ	-	-	±0,029	±0,093	-	±0,20	±0,21	±0,18	±0,068	-	±0,183	±0,007	±0,158
PO_4 - P	*	*	0,029	0,090	0,018	0,055	0,086	0,070	0,006	0,02	*	0,007	0,002
mg/ℓ	-	-	±0,027	±0,092	±0,013	±0,004	±0,027	±0,063	±0,002	±0	-	±0	±0,001
Total	*	*	10,48	0,05	0,020	0,065	0,092	0,075	0,011	0,02	*	0,014	0,030
mg/ℓ	-	-	±25,12	±0,03	±0,013	±0,006	±0,028	±0,062	±0,004	±0,01	-	±0,002	±0,009

* TOO LOW TO DETECT WITH ANALYTICAL METHODS USED

TABLE 3: MEAN MONTHLY VALUES AND STANDARD DEVIATIONS OF SOME CHEMICAL CHARACTERISTICS OF WATER FROM SWAKOPPOORT DAM

JANUARY 1987 – NOVEMBER 1990

CHEMICAL	1987 JAN	APR	SEP I	SEP II	DEC	1988 JAN	FEB	APR	AUG	OCT	1989 FEB I	FEB II	APR	AUG	NOV	1990 MAY	AUG	NOV
UNIT	n = 5	n = 6	n = 6	n = 4	n = 4	n = 5	n = 8	n = 3	n = 4	n = 5	n = 5	n = 4	n = 8	n = 4	n = 8	n = 8	n = 7	n = 8
Total Alkalinity as $CaCO_3$ mg/ℓ	146,4	135,2	145,2	147,0	150,5	104,4	116,3	99,5	119,6	129,9	109,4	100,8	108,4	93,40	121,5	103,8	109,1	114,0
	±2,87	±2,91	±1,86	±2,24	±1,66	±23,8	±5,89	±20,0	±1,01	±4,01	±2,76	±2,08	±2,33	±1,87	±10,7	±12,1	±2,59	±4,36
Conductivity (Laboratory) us/cm	368	273	286	280	297	228	202	206	225	306	262	235	221	273	285	261	280	275
	±66,5	±4,7	±4,7	±0	±4,3	±31,2	±4,3	±54,5	±2,6	±5,4	±4,5	±5,1	±3,1	±2,9	±18,1	±10,4	±9,8	±6,1
Conductivity (field) us/cm	@	334	@	@	335	@	279	282	291	295	259	238	247	268	261	255	278	276
	–	±3,7	–	–	±7,8	–	±6,6	±3,5	±2,2	±3,7	±1,8	±7,0	±1,2	±3,1	±3,9	±0,8	±3,3	±3,6
pH (Laboratory)	7,7	7,48	7,53	7,95	7,30	6,94	7,43	7,57	7,73	8,2	7,3	7,03	6,15	8,20	7,53	7,59	7,81	7,60
	±0,2	±0,07	±0,11	±0,23	±0,12	±0,15	±0,07	±0,05	±0,04	±0,13	±0,13	±0,04	±0,09	±0,12	±0,26	±0,22	±0,57	±0,32
pH (field)	@	7,64	8,40	@	8,38	8,27	7,74	7,57	8,05	8,19	@	@	7,78	@	8,43	7,73	8,20	8,53
	–	±0,17	±0,14	–	±0,10	±0,05	±0,14	±0,23	±0,14	±0,10	–	–	±0,08	–	±0,30	±0,58	±0,29	±0,18
TDS mg/ℓ	205	178	179	186	182	137	141	115	157	201	183	155	146	180	188	171	185	181
	±36,7	±1,89	±4.3	±10,4	±5,7	±19,2	±2,5	±31,7	±0,8	±3,6	±3,1	±3,3	±2,0	±1,6	±11,7	±6,6	±6,3	±4,0
Na mg/ℓ	13,0	13,67	16,67	16,00	19,75	16,40	15,38	10,00	13,00	16,00	18,40	17,00	18,63	16,25	18,50	19,13	18,43	20,13
	± 0	±0,47	±0,75	±0	±0,43	±1,62	±1,11	±5,66	±0	±0,32	±1,20	±0	±0,48	±0,43	±0,71	±0,33	±0,73	±0,78
K mg/ℓ	20,0	11,00	10,33	19,00	16,25	16,40	15,38	10,00	13,00	16,00	10, 60	9,00	9,88	9,88	12,00	12,0	11,86	12,00
	±19,02	±0	±0,47	±0,71	±1,30	±1,62	±1,11	±5,66	±0	±0,32	±0,80	±0	±0,33	±0,22	±0,50	±0	±0,35	±0
SO_4 mg/ℓ	3,60	5,00	1,00	1,33	*	3,40	*	0,67	*	2,60	0,60	0,75	0,75	*	*	7,25	7,57	6,25
	±0,49	±0	±0	±0,47	-	±3,20	-	±0,47	-	±0,20	±1,20	±1,30	±1,98	-	-	±11,0	±1,92	±0,97
Ca as $CaCO_3$ mg/ℓ	99,0	89,0	89,17	89,50	77,75	48,80	64,25	67,50	78,75	82,00	52,50	53,00	89,88	53,00	68,88	56,00	55,00	59,00
	±2,00	±1,00	±1,86	±0,87	±1,79	±10,05	±0,97	±12,42	±5,15	±2,92	±3,16	±0	±1,45	±0	±13,29	±2,65	±4,31	±4,82
Mg as $CaCO_3$ mg/ℓ	23,40	25,00	25,00	25,00	33,00	24,40	21,00	15,67	21,00	21,40	24,16	21,00	21,00	17,00	22,5	25,0	25,0	25,0
	±0,80	±0	±0	±0	±0	±7,68	±0	±1,89	±2,83	±0,80	±1,68	±0	±0	±0	±1,94	±0	±0	±0
SiO_2 mg/ℓ	1,40	1,00	1,00	1,00	0,50	0,40	1,00	1,00	*	*	0,66	*	0,50	*	1,63	1,00	1,71	1,00
	±0,49	±0	±0	±0	±0,87	±0,49	±0	±0	-	-	±0,91	-	±1,00	-	±0,86	-	±0,45	±0
Cl mg/ℓ	18,60	11,00	11,00	13,50	13,50	10,40	11,00	8,33	12,50	11,00	10,40	10,25	9,94	13,50	12,63	14,38	13,71	12,00
	±17,20	±0	±0	±0,87	±0,87	±1,85	±0	±4,64	±2,06	±0	±0,80	±0,43	± 0,39	±0,87	±0,99	±0,99	±0,70	±0

@ NOT MEASURED

TOO LOW TO DETECT WITH ANALYTICAL METHODS USED

TABLE 4: MEAN MONTHLY VALUES AND STANDARD DEVIATIONS OF SOME BIOCHEMICAL CHARACTERISTICS OF WATER FROM SWAKOPPOORT DAM:

JANUARY 1987 _ NOVEMBER 1990

BIOCHEMICAL	1987 JAN	DEC	1988 JAN	FEB	APR	AUG	OCT	1989 FEB I	FEB II	APR	AUG	NOV	1990 MAY	AUG	NOV			
UNIT	n = 5	n = 4	n = 6	n = 8	n = 3	n = 4	n = 5	n = 7	n = 4	n = 4	n = 4	n = 8	n = 8	n = 7	n = 8			
NO_2 – N	*	*	0,07	*	*	0,03	*	*	*	*	*	0,14	0,24	<0,1	0,15			
mg/ℓ	–	–	±0,06	–	–	±0,04	–	–	–	–	–	±0,21	±0,25	–	±0,10			
NO_3 – N	*	*	0,11	*	*	0,33	0,02	0,25	*	1,50	*	0,15	0,1	0,5	0,34			
mg/ℓ	–	–	±0,11	–	–	±0,37	±0,04	±0,43	–	±0,87	–	±0,26	–	–	±0,63			
Total – N	0,73	0,28	0,70	0,53	*	1,44	0,76	1,42	1,07	3,82	0,36	0,90	1,95	0,46	3,86			
mg/ℓ	±0,16	±0	±0,21	±0,55	–	±0,66	±0,34	±0,56	±0,93	±2,08	±0,16	±0,35	±0,57	±0,22	±1,21			
NH_4 – N	0,31	*	*	0,22	*	0,74	0,50	1,04	0,47	0,84	0,29	0,51	0,69	0,24	1,05			
mg/ℓ	±0,06	–	–	±0,07	–	±0,12	±0,26	±0,58	±0,17	±0,58	±0	±0,22	±0,43	±0,08	±1,05			
Total – P	*	*	0,38	0,19	0,11	0,03	*	0,075	0,347	0,206	0,024	0,03	0,263	0,075	0,05			
mg/ℓ	–	–	±0,36	±0,01	±0,01	±0,01	–	±0,09	±0,14	±0,14	±0,03	±0,01	±0,272	±0,05	±0,01			
PO_4 – P	*	*	0,14	0,14	0,31	0,01	0,04	0,067	0,180	0,068	0,005	0,02	*	0,011	0,01			
mg/ℓ	–	–	±0,11	±0,02	±0,31	±0	±0,01	±0,05	±0,067	±0,05	±0,001	±0,01	–	±0,01	±0,01			
Total Dissoved – P	*	*	0,17	0,16	0,01	0,02	0,04	0,104	0,185	0,070	0,005	0,03	*	0,018	0,134			
mg/ℓ	–	–	±0,10	±0,02	±0	±0	±0,01	±0,06	±0,06	±0,05	±0,001	±0,02	–	±0,01	±0,09			

* TOO LOW TO DETECT WITH ANALYTICAL METHODS USED

TABLE 5: MEAN MONTHLY VALUES AND STANDARD DEVIATIONS OF SOME CHEMICAL CHARACTERISTICS FROM OMATAKO DAM

JANUARY 1987 - AUGUST 1990

CHEMICAL	1987 JAN	APR	SEP	1988 APR	AUG	OCT	1989 FEB	APR	AUG	NOV	1990 MAY	AUG
UNIT	n = 3	n = 6	n = 4	n = 2	n = 3	n = 3	n = 3	n = 6	n = 3	n = 4	n = 6	n = 4
Total Alkalinity as $CaCO_3$ mg/ℓ	132	116	125	116	134	131	90	108	96	118	105	103
	±0,47	±0,82	±6,1	±0,30	±2,81	± 0,86	±3,27	±4,71	±1,48	±2,82	±1,77	±1,00
Conductivity (Laboratory) us/cm	270	210	215	214	214	264	108	197	240	238	139	144
	±0	±0	±5,0	±1,5	±4,6	±0,5	±32,5	±2,9	±1,2	±6,3	±37,3	±10,9
Conductivity (field) us/cm	247	@	273	244	266	256	186	219	234	227	211	215
	±6,18	--	±0,50	±3,5	±0,8	±0,8	±0,7	±2,2	±1,9	±0	±3,1	±1,5
pH (Laboratory)	8,17	8,0	8,38	7,38	7,95	7,77	8,30	6,32	8,17	7,78	7,78	7,98
	±0,05	±0,08	±0,04	±0,05	±0,05	±0,08	±0,16	±0,18	±0,05	±0,11	±0,09	±0,15
pH (field)	8,57	@	8,58	8,35	7,64	8,62	@	8,03	8,6	8,3	8,0	8,6
	±0,05	--	±0,13	±0,15	±0,19	±0,03	--	±0,05	±0	±0,10	±0,37	±0
TDS mg/ℓ	146	139	136	130	149	157	131	130	158	157	139	143
	±6,9	±1,8	±5,4	±1,5	±3,4	±24	±21,4	±2,19	±0,94	±4,06	±3,73	±1,09
Na mg/ℓ	6,0	6,0	5,75	7,0	5,5	9,5	7,33	9,0	8,0	12,0	10,17	10,0
	±0	±0	±0,43	±0	±1,78	±0	±0,9	±0	±0	±0	±4,84	±0
K mg/ℓ	9,67	10,0	9,75	10,50	11,0	11,17	8,67	10,50	10,0	13,25	7,67	11,00
	±0,47	±0	±0,43	±0,50	±0	±0,24	±0,47	±0,76	±0	±0,43	±0,47	±0,71
SO_4 mg/ℓ	4,0	2,33	1,0	3,0	*	2,5	3,33	5,17	*	2,25	3,33	3,50
	±0,82	±0,47	±0	±0	-	±0	±0,47	±3,24	-	±0,43	±1,49	±2,06
Ca as $CaCO_3$ mg/ℓ	80,0	70,0	68,0	67,5	71,7	57,5	46,0	56,8	48,0	49,0	54,5	42,0
	±0	±0	±4,9	±0	±2,4	±0	±1,4	±2,7	±0	±2,9	±3,4	±0
Mg as $CaCO_3$ mg/ℓ	33,0	33,0	33,0	29,0	39,3	44,0	23,7	33,8	30,0	40,0	27,7	37,0
	±0	±0	±0	±0	±1,89	±0	±1,89	±1,86	±1,89	±2,0	±11,9	±0
SiO_2 mg/ℓ	3,33	2,0	0,75	4,50	1,67	0,67	3,33	1,0	*	1,0	1,0	1,25
	±0,47	±0	±0,43	±0,50	±0,47	±0,94	±0,47	±0	-	±0	±0	±0,43
Cl mg/ℓ	2,0	3,0	2,25	3,0	2,0	4,0	3,67	3,33	4,0	4,50	4,67	4,00
	±0	±0	±0,43	±0	±0	±0	±1,89	±0,47	±0	±0,87	±0,47	±1,22

@ NOT MEASURED

TABLE 6: MEAN MONTHLY VALUES AND STANDARD DEVIATIONS OF SOME BIOCHEMICAL CHARACTERISTICS OF WATER FROM OMATAKO DAM:

JANUARY 1987 – AUGUST 1990

BIOCHEMICAL	1987 JAN	1988 APR	AUG	OCT	1989 FEB	APR	AUG	NOV	1990 MAY	AUG
UNIT	n = 3	n=2	n=3	n=3	n=2	n=3	n=6	n=4	n=6	n=2
NO_2 – N	*	*	*	*	*	*	*	*	*	*
mg/ℓ	–	–	–	–	–	–	–	–	–	–
NO_3 – N	*	*	*	*	*	*	*	*	*	*
mg/ℓ	–	–	–	–	–	–	–	–	–	–
Total – N	0,79	*	1,17	1,45	0,84	2,15	0,53	1,00	1,79	0,31
mg/ℓ	± 0,07	–	±0,07	± 0,29	±0	± 1,08	±0,26	±0,15	± 0,93	±0,16
NH_4 – N	0,28	*	1,19	0,28	0,41	0,51	0,39	0,72	0,66	0,15
mg/ℓ	± 0,11	–	±0,41	± 0,11	±0,37	± 0,53	±0,14	±0,69	±0,21	±0
Total – P	*	0,067	0,021	*	0,043	0,170	0,050	*	0,208	0,027
mg/ℓ	–	±0,01	±0,008	–	±0,002	±0,087	±0,082	–	±0,227	±0,001
PO_4 – P	*	0,070	0,004	0,35	0,030	0,058	0,010	*	*	0,77
mg/ℓ	–	±0,004	±0,004	±0,19	±0	±0,004	±0,012	–	–	±0
Total Dissoved–P	*	0,073	0,012	0,61	0,038	0,068	0,012	0,01	*	0,011
mg/ℓ	–	±0,004	±0,003	±0,13	±0	±0,005	±0,12	±0	–	±0

* TOO LOW TO DETECT WITH THE ANALYTICAL METHODS USED