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# RESULTS OF THE LIMNOLOGICAL MONITORING OF THE VON BACH AND SWAKOPPOORT IMPOUNDMENTS, AS WELL AS THE BASELINE AND MONITORING RESULTS OF THE OANOB IMPOUNDMENT

1992 - 1996


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## 1. INTRODUCTION

Limnology is the study of the physics, chemistry and biology (including all living entities that live directly in and closely around freshwater) of freshwater environments, as well as the interrelationship of these three.

Two earlier reports by Bethune (1987,1992) were written on the baseline survey (1984-86) and the monitoring period (1987-90) of the major dams on the Eastern National Water Carrier ENWC. The dams are von Bach, Swakoppoort and Omatako.

In the latest report (Bethune 1992), it was recommended that the monitoring should continue on a monthly basis for dams supplying water directly to purification works i.e. von Bach, and Swakoppoort once pumping to von Bach occurs and the Karibib purification plant becomes operational. Monthly measurements have continued since March 1992.

Monthly monitoring of Omatako Dam was discontinued on account of low water levels and because water is not supplied from the dam directly to purification works.

Once Oanob Dam was completed and officially opened in 1990, baseline survey work commenced and after the first year was scaled down to routine monthly monitoring. The results of the Oanob Dam baseline survey and subsequent monitoring are included in this report.

Plans to incorporate Otjivera Dam in October 1993 had to be cancelled due to low run-off and the dam's subsequent drying-out.

The purpose of this report is to present the results of the monthly monitoring of the three impoundments von Bach, Swakoppoort and Oanob from October 1992 to September 1996, as well as the fortnightly baseline survey results for Oanob Dam from Oct. 1992- Sept. 1996.

## 2. BACKGROUND

The original idea, when initiating surveys on the ENWC dams, was to include environmental studies in water resources planning, using the ENWC as an example (Bethune in Braune 1985 ). The first step was a baseline study of the dams on the ENWC to establish limnological characteristics of system elements prior to water transfer. Following steps have included the studies of water quality, impoundment limnology and transfer efficiency (Bethune in Braune 1985 ).

**FIGURE 1 : MAP SHOWING THE LOCATION OF THE THREE DAMS, VON BACH, SWAKOPPOORT AND OANOB**

## 2.1 BASIC LIMNOLOGICAL TERMS AND CONCEPTS

Before discussing the three impoundments, Von Bach, Swakoppoort and Oanob Dams, it is important to define some limnological terms :

### 2.1.1 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 density differences:

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

The *metalimnion* which is characterized by persistent, steep temperature and density gradients that form a barrier between the two zones. The *thermocline* is the level within the metalimnion where the 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.

### 2.1.2 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.

### 2.1.3 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*.

### 2.1.4 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 canceled by the rate of oxygen uptake. This can be several meters above the thermocline.

### 2.1.5 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 3μg/ℓ.

*Mesotrophic* waters are more productive and have chlorophyll *a* values of 2 - 15μg/ℓ .

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

### 2.1.6 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 an overturn.

Phenomena 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

## 2.2 THE IMPOUNDMENTS

The main results of the 1984-1986 and 1987-1990 surveys for the von Bach and Swakoppoort impoundments are included in the following descriptions. Omatako dam is not included as monitoring was not continued , instead some details of Oanob dam are given.

### 2.2.1 VON BACH

The S von Bach Dam on the Swakop river near Okahandja is the oldest of the three impoundments. It has a full supply capacity of 53 370 $Mm^3$, a maximum depth of 30 metres and a surface area of 4,894 $km^2$.

Average water withdrawal increased from 31 000 $m^3$\day in 1987 to 43 000 $m^3$\day in 1990. Daily withdrawal decreased from 53 498 $m^3$ in 1994 to 31 943 $m^3$ in 1996 , most probably due to water restrictions imposed on the central areas.
The water is purified at the von Bach purification plant and used to supply Windhoek and Okahandja Municipalities as well as some small holdings near the pipeline.

Von Bach Dam is situated within a small game park. " The von Bach Recreation [illegible]rt " is managed by the Ministry of Environment. There are facilities for day and overnight visitors. It is a popular venue for angling and water sports especially skiing.

Von Bach Dam has not spilled since 1974. Inflows were received each summer between 1984 and 1996, except for 1995 when no inflow occurred. Inflows were very low between 1992 and 1996 and consequently, the water levels remained very low.

Water was regularly pumped to von Bach from Omatako between 1984 and 1996. In the hydrological year* of 1992/93 6,05 $Mm^3$ were pumped to Von Bach, in 1993/94 it was 4,598 $Mm^3$, 1994/95 2,438 $Mm^3$ and 1995/96 2,731 $Mm^3$.

Both earlier reports on the limnological monitoring of the ENWC impoundments: 1984-1986 and 1987-1990 (Bethune 1987,1992) showed that the water in von Bach was relatively clear. Exceptions occurred after river inflows and pumping from Omatako to von Bach.The particles carried by rivers settled out more quickly than the fine suspensions from the Omatako Dam, which took up to a month to settle. The average Secchi depth for 1987-1990 (Bethune 1992) was 2,1m.

To date both the temperature and oxygen isopleths show that von Bach Dam develops a stable thermal stratification in summer and overturn occurs in winter, allowing oxygen to be evenly distributed throughout the water column. This

monomictic pattern is typical for most Southern African impoundments. Heavy inflows are capable of disturbing this stratification to such an extent, that overturn can occur a few months earlier than usual, as happened in the rainy period of 1988-89 (Bethune 1992). Although very little oxygen was present below the thermocline in summer (<1ppm) conditions never became anaerobic in the hypolimnion.

Concentrations of dissolved chemicals in the dam remained fairly stable and low between 1984 and 1990.

The Chlorophyll *a* (Chl *a* ) values of the last survey showed that the dam was becoming more enriched over time. With the exception of some isolated stands of the rooted aquatic plant of the Polygenum species, along the shore and on islands in the impoundment , no aquatic macrophytes occur in or around the dam. Draw down is too erratic to allow the establishment of marginal plants. Some vegetation has established in the seeps below the dam wall and is a potential snail habitat (Curtis 1990).

Six warm water crustacean species are present in the impoundment, of which four are endemic. The species are : *Diaphanosoma excisum* , *Daphnia laevis, Daphnia barbata, Moina micrura, Metadiaptomus colonialis,* and *Thermocyclops macracanthus* (Rayner, Silberbauer & Bethune 1995 ). Snails are found in small numbers in the seep below the wall, but not in the impoundment itself ( Curtis 1990). Six fish species occurred in the dam: *Cyprinus carpio, Micropterus salmoides, Oreochromis mossambicus, Clarias gariepinus, Tilapia sparrmanii* and *Barbus paludinosus.* The latter was first observed in the 1987-'90 survey.

*A hydrological year starts in October and ends in September the following year.

### 2.2.2 SWAKOPPOORT

The Swakoppoort Dam is situated on the confluence of the Swakop and Sney rivers, 55 km downstream of von Bach Dam. It has a capacity of 70 288 $Mm^3$ when full, a depth of 35m and a surface area of 10,543583 $km^2$. The impoundment is used for drinking water storage.

During the 1987-'90 monitoring survey 9900 $m^3$ were pumped daily from the dam to supply the Navachab mine. In the hydrological year of 1993/94 an average of 4179,1 $m^3$ were withdrawn and by 1995/96 it had risen to 27792,5$m^3$ per day. Recreation is controlled, there are limited facilities for day visitors and water sports events are sometimes held.

Swakoppoort dam received it's first substantial inflow early 1984. Inflow occurred annually in the rainy seasons between 1984 and 1996, with the dam overflowing 1988 and '89. The last two years, 1995 and '96 provided minimal inflows due to drought and the dam level was low at the end of the '92-'96 monitoring period.

Both earlier reports (Bethune 1987, 1992 ) show that Swakoppoort Dam is monomictic. Both thermal and oxygen stratification develops in spring and the impoundment remains stratified during summer. In summer oxygen concentrations below the thermocline were often below 1 mg\ℓ but the impoundment did not become anaerobic. In winter, following overturn, temperature was homogenous, as were oxygen concentrations. Good inflows in the rainy season often disrupted the summer stratification of the dam, causing early overturn.

Previous surveys show that Swakoppoort Dam is very clear with short periods of turbidity caused by inflows in the rainy season. Especially after the *Spirodela* mats washed over the wall in 1989, the dam increased in clarity.

In the 1984-'90 period the cation and anion concentrations remained stable. Major chemicals remained stable at slightly higher concentrations than at von Bach Dam. Nutrient concentrations remained similar. The Chl *a* values of Swakoppoort given in the last two reports are relatively high, often above 10µg\ℓ (Bethune 92).

Algal blooms were activated by nutrient inputs from river inflows in the summer seasons (December -April ), due to overturn in autumn and increasing spring temperatures. From 1984-1989 Swakoppoort Dam was partly covered with a floating mat of *Spirodela*, a small floating angiosperm. It was feared that the water quality of the impoundment could be affected by these plants. The dense mats especially at the wall could contribute to anaerobic conditions during summer and decrease the light availability to the water column.

Biologically, the Swakoppoort Dam was found to be the most productive of the three dams surveyed in the earlier surveys, as it had the highest Chl *a* values and supported a great variety of algae.

Four cosmopolitan crustacean species exist in the impoundment : *Daphnia pulex, Daphnia leavis, Ceriodaphnia dubia* and *Moina micrura*. There is also a specie of Rotifers, namely *Brachionus quadridentatus*.
Swakoppoort dam supports large bird colonies particularly in the inflow sections where cormorants and heron nest in dead trees.
Six fish species occurred in the 1987 - 1990 period: *Tilapia sparrmanii, Tilapia rendalli, Oreochromis macrochir, Oreochromis mossambicus, Clarias gariepinus* and *Barbus paludinosus*. The two last ones were not found in the baseline study of 1984-1987.

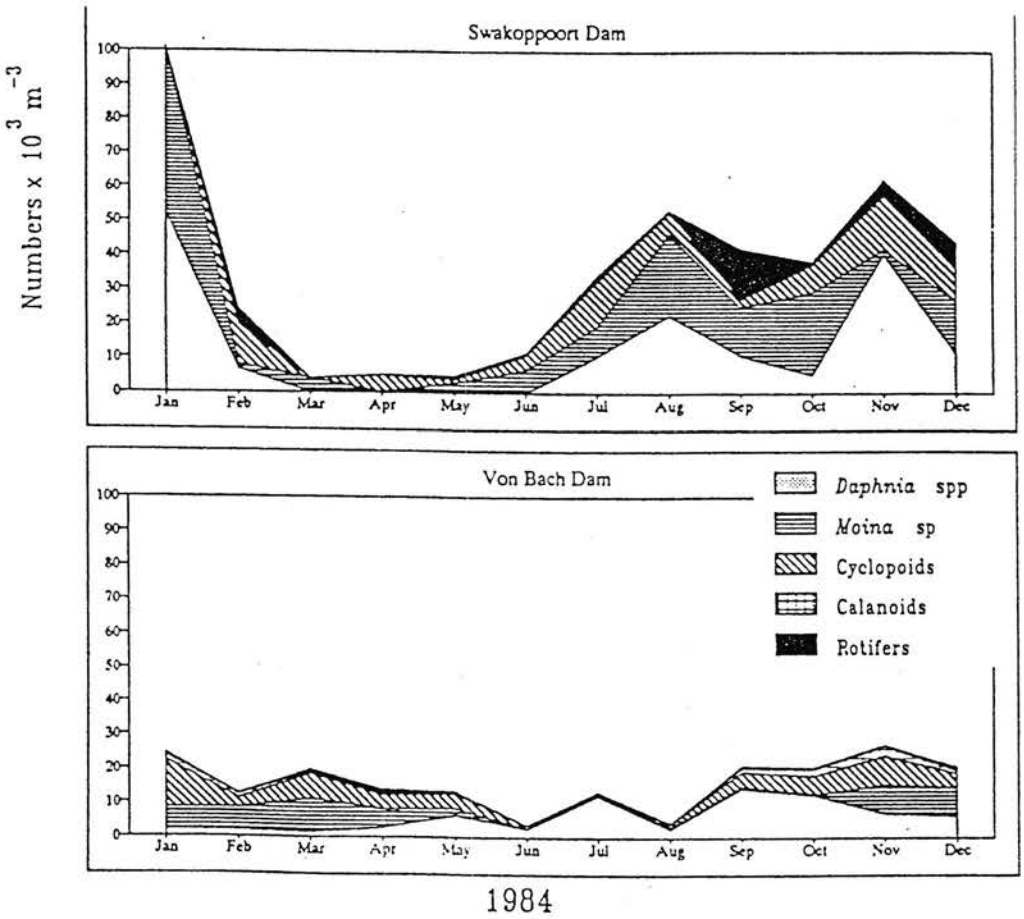


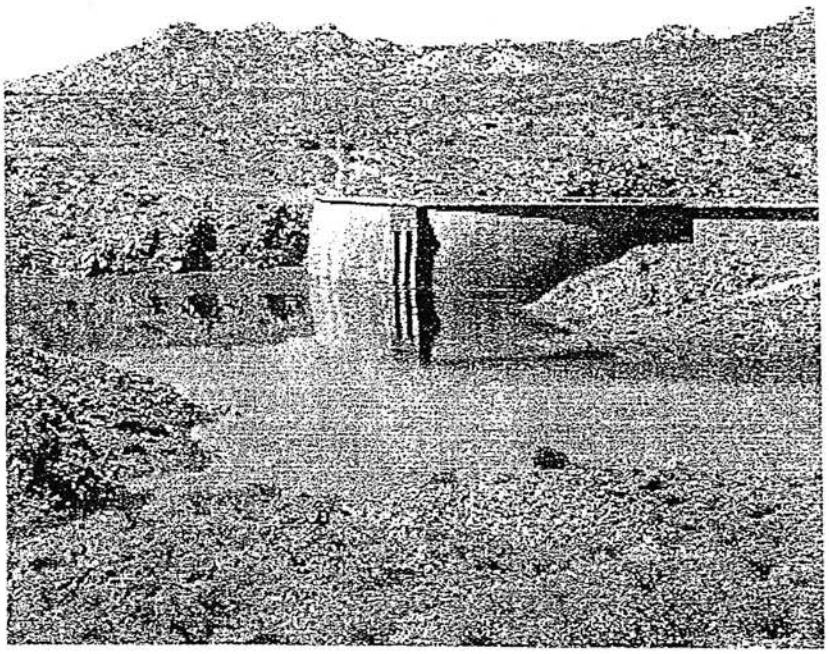

**FIGURE 2** : GRAPHIC REPRESENTATION OF TAXA COMPRISING TOTAL ZOOPLANCTON COUNTS IN TWO IMPOUNDMENTS, JAN. - DEC, 1984 (adapted from Rayner *et al.*1995)

2.2.3 OANOB DAM

The Oanob Dam on the Oanob river near Rehoboth, completed in 1990, is the youngest of the three dams. It has a full supply capacity of 35Mm$^3$, a maximum depth of 55m, making it the deepest of the three dams and a surface area of 2,65 km$^2$.

Average water withdrawal increased gradually from 4887,5m$^3$\day in 1992-1993 to 5808,95m$^3$\day in 1995-1996. However in October 1996, withdrawal had dropped to 4792m$^3$\day. The water is purified at the Oanob purification works west of Rehoboth. The dam supplies the town Rehoboth with water. Recreational facilities are available for day and overnight visitors. Included in this are : Chalets, barbeque and camping facilities, a restaurant and watersport equipment hire.

The report will discuss the baseline study of the young dam and subsequent monitoring for the period 1992-'96.



Photograph of Oanob Dam

**TABLE 1** : GENERAL CHARACTERISTICS OF THE THREE IMPOUNDMENTS

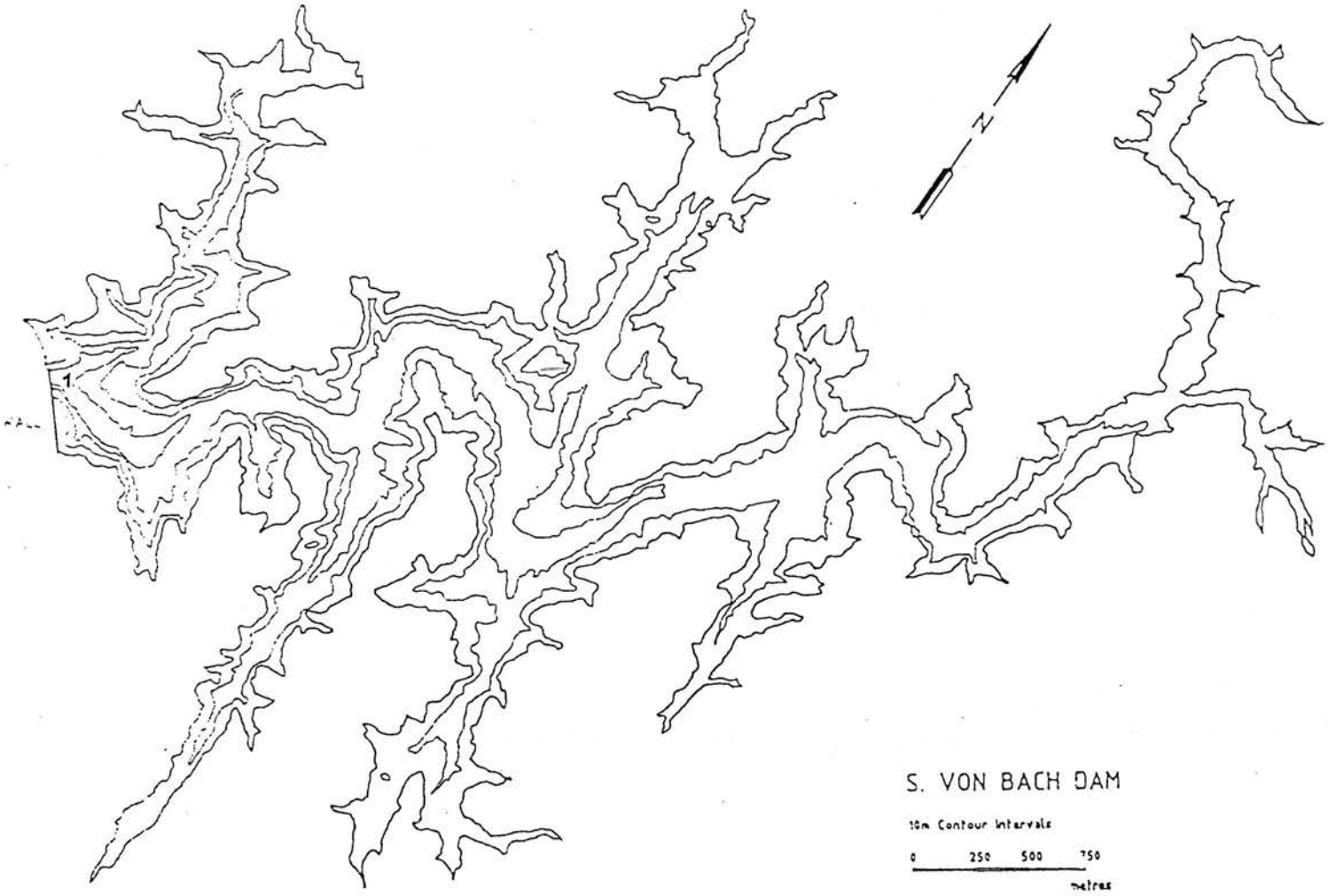
| 'OUNDMENT | S VON BACH | SWAKOPPOORT | OANOB |
|---|---|---|---|
| NSTRUCTED | 1967 - 1971 | 1977 - 1979 | 1986 - 1990 |
| AGE | Drinking water storage and supply Recreation | Drinking water storage and supply Recreation | Drinking water storage and supply Recreation |
| CATION | | | |
| gion | Otjozondjupa | Otjozondjupa | Hardap |
| trict | Okahandja | Okahandja | Rehoboth |
| 'm | Ovitoto | Sneyrivier 20 | Sandputs |
| Grid | SE 2217 Aa | SE 2117 Aa | SE 2317 Ac (not updated |
| cality | 21°S 17°E | 22°13'S 16°30'E | 23°39'S 17° .08'E |
| itude | 1320 m | 1104 m | 1398 m |
| TCHMENT | | | |
| vers | Swakop, Satan's | Swakop, Sney, Otjiseru, Okahandja Otjihavera | Oanob |
| ea | 2920 km2 | 8400 km2 | 2730 km2 |
| age | Cattle & Game farmin Nature reserve | Cattle, Game and Vegetable farming | Cattle & Goat farming |
| ILL SUPPLY | | | |
| ight above mean alevel | 1350 m | 1139 m | 1453 m |
| pth | 30 m | 35 m | 55 m |
| pacity | 53,37 Mm3 | 70,29 Mm3 | 35,00 Mm3 |
| rface Area | 4,894 km2 | 10,543583 km2 | 2,65 km2 |
| MNOLOGICAL SURVEY | 1984 - ongoing | 1984 - ongoing ( break in '92 | 1992 - ongoing |

## 3. MONITORING PROCEDURE

### 3.1 MONITORING SITES

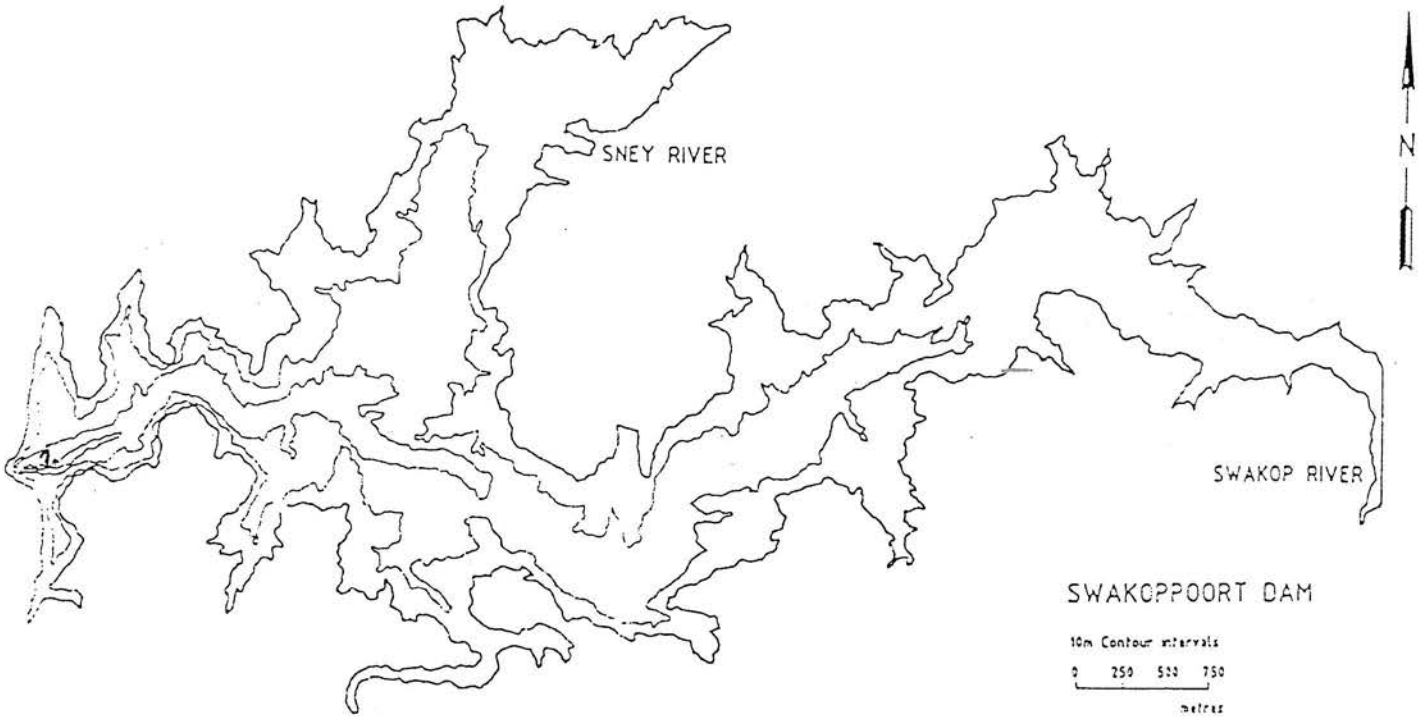
Swakoppoort and von Bach Dam were monitored once monthly at the dam wall, from October 1992 until September 1996.Oanob dam, since it is new, was measured twice monthly at the sites marked on the map for a year (Oct. 1992-Sept. 1993) to establish a baseline, since then the wall site has been monitored monthly.

Figures 2,3 and 4 show the 10m contours of each Dam, as well as the monitoring sites.



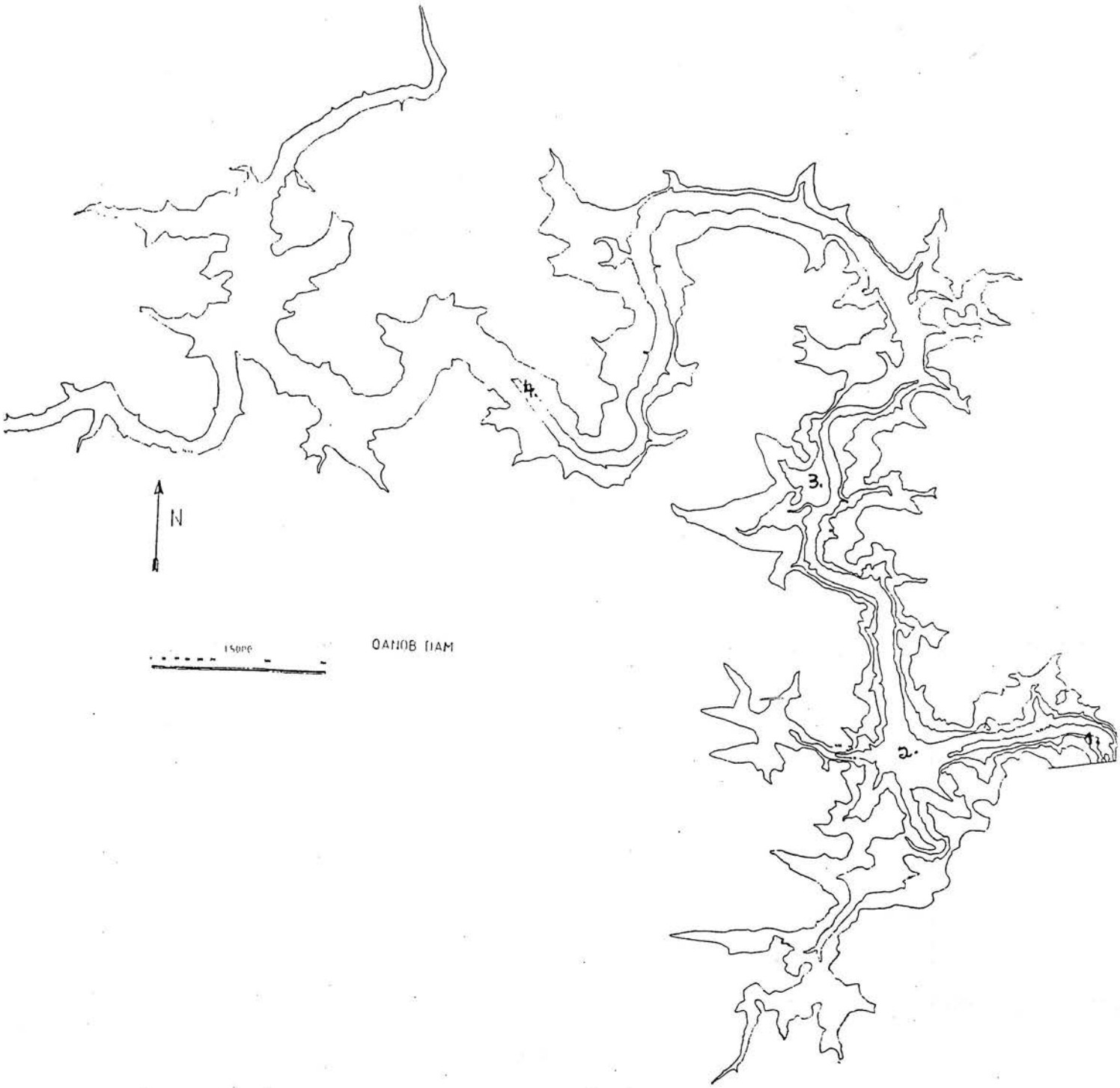

1. Monitoring site

FIGURE 3: MAP OF VON BACH DAM




1. Monitoring site

**FIGURE 4** : MAP OF SWAKOPPOORT DAM




1 - 4: Monitoring sites

**FIGURE 5** : MAP OF OANOB DAM

## 3.2. MONITORING METHODS

Measurements of temperature and oxygen concentrations were taken on site, water samples were collected at the surface as well as at a depth of 10m, using a 1 or 5 litre Van Doorn water sampler.

Oxygen concentrations and temperature measurements were taken every ½ meter, using a Y.S.I. model 54A dissolved oxygen meter, that was air calibrated prior to use.

Water transparency is measured with the help of a Secchi disc. This disc has a diameter of 25cm with alternate black and white quadrants. The observer at the surface measures the maximum depth at which the disc is visible.

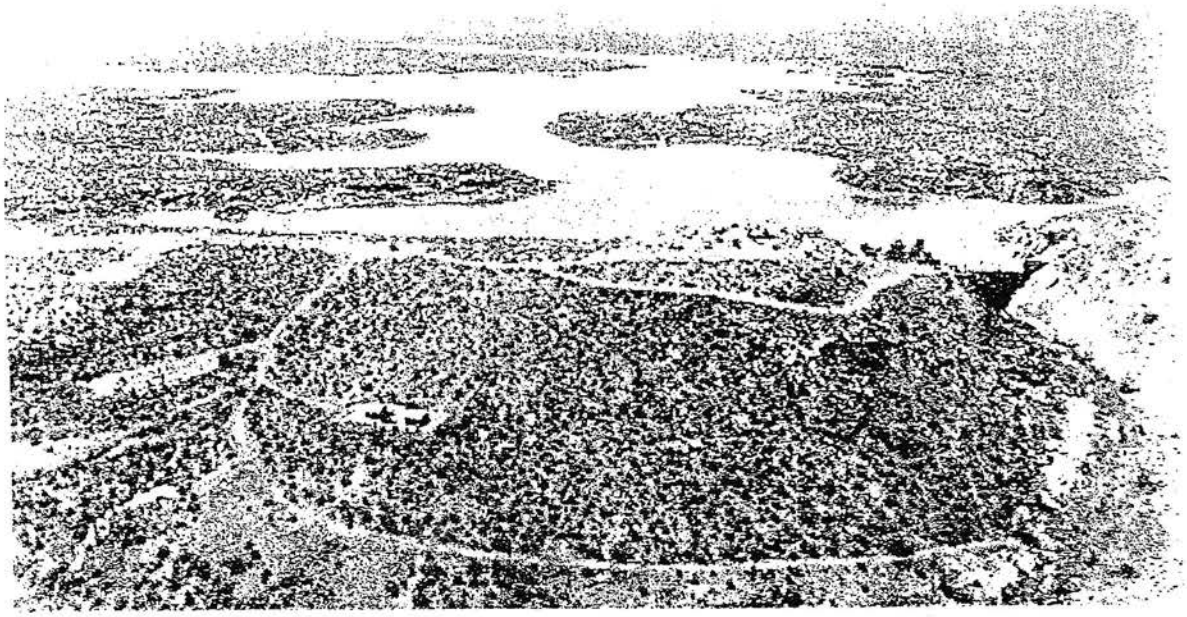
Routine chemical analyses were done by the chemical laboratory for total Alkalinity, Conductivity, Turbidity, pH, TDS, Na, K, $SO_4$,Ca, Mg, $SiO_2$, F and Cl. The methods are based on the standards set by the American Public Health Association (1980).

Nutrient analysis for $NO_2$-N, $NO_3$-N, Total Organic-N, $PO_4$-P, Organic soluble-P and Total organic-P were done by the biochemical laboratory at Aighams using a Photometer SQ 118, produced by Merck .

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

To assist and keep the Division Operations informed of the conditions in the impoundments, monthly status reports on each impoundment were prepared by the Research Division and submitted to the Head of Operations following each survey trip. This was to advise on stratification, algal blooms and suggest suitable withdrawal depths to avoid water quality problems at the purification works.

Wetland bird counts were conducted in January and April each year. All wetland birds on the impoundment were identified and counted. Numbers of species and numbers of each were recorded and the results made available to the International Wetland Bird Programme (IWBP).



Photograph of Swakoppoort Dam

# 4. RESULTS AND DISCUSSION

## 4.1 PHYSICAL CHARACTERISTICS

### 4.1.1 WATER TRANSPARENCY

Water transparency in the von Bach and Swakoppoort Dams has decreased since the last monitoring period. Conditions in Oanob remained similar for the baseline study from October 1992 to September 1993 and the monitoring time from October 1993 to September 1996.

**Von Bach**

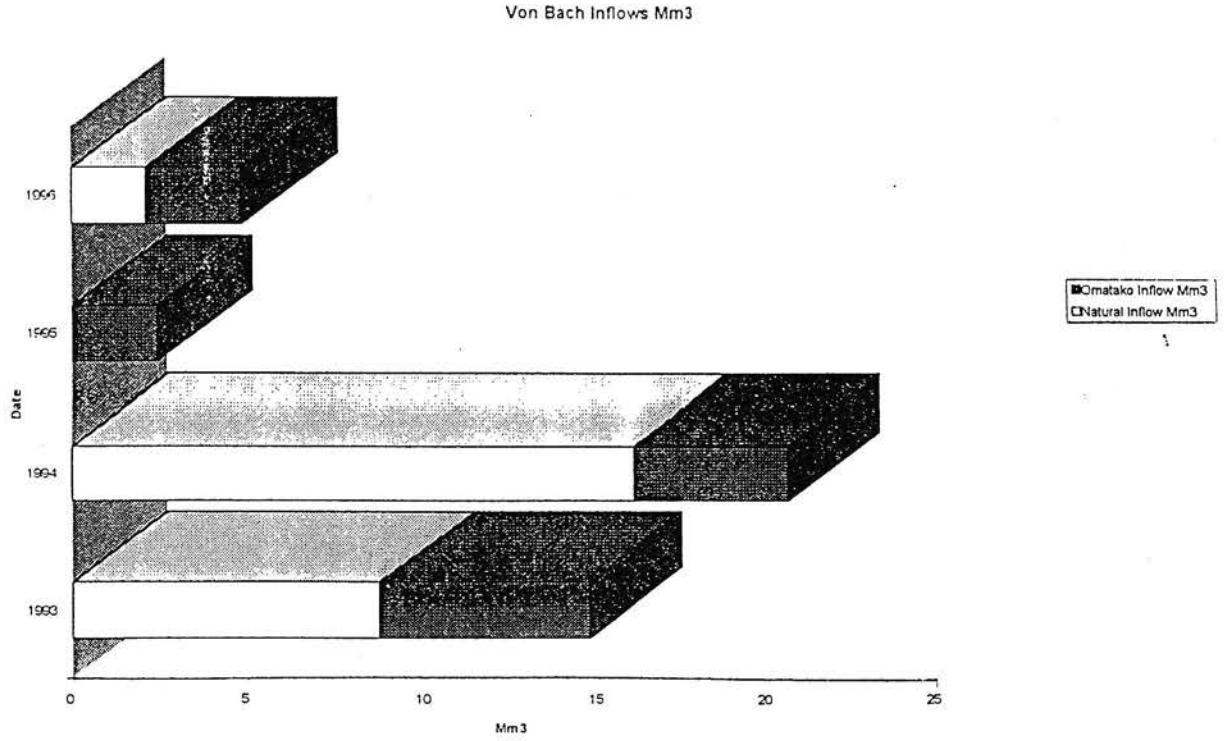
Von Bach was the most turbid of the three dams with an average Secchi depth of 1,18m. River, as well as Omatako inflows and blooms reduced transparency to Secchi depths as low as 5cm (February 1993). Clearest conditions were recorded at 3,4m Secchi depth in November 1994.
In figure 11b on page 33, turbidity values are available.

**Swakoppoort**

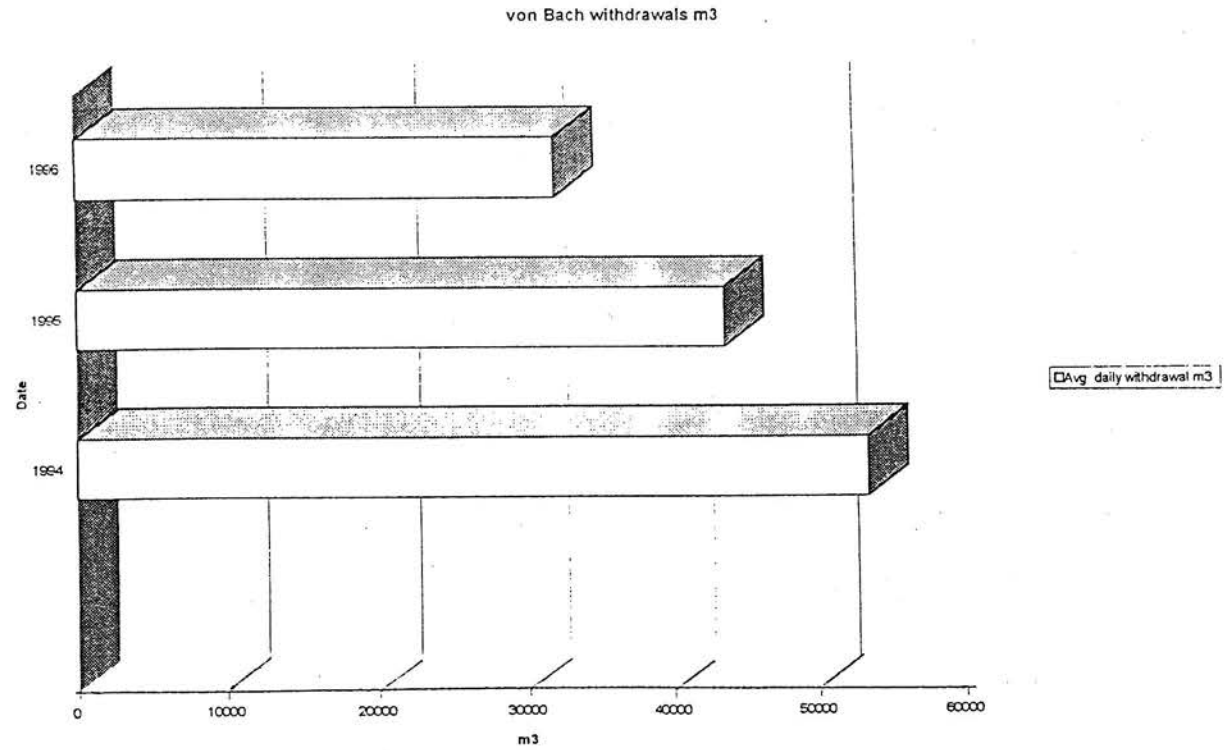
This dam's transparency has decreased greatly since the last monitoring period. Average Secchi depth now is 1,39m compared to the former 2,2m. Water clarity seemed to be influenced by river inflows (e.g. 0,17m in February 1993) as well as increased productivity and consequently occurring blooms. Maximum Secchi depth obtained was 4,56m in October 1992.
Turbidity values can be viewed in figure 12b on page 37.

**Oanob**

This is the clearest of the three dams with an average Secchi depth of 1,9m. Low transparency was recorded after heavy inflows beginning 1993 (Secchi depths 0,06- 0,5m). Blooms did not affect water transparency greatly ( see Chl *a* value for August 1995 in figure 13b. Secchi depth is 1,35m). Best conditions were measured in January 1994 with a Secchi depth of 3,1m.
Turbidity values can be viewed in figure 13b on page 39.




NOTE: The inflow data are given from one hydrological year to the next, ie. from October in the previous year to September.




Note: withdrawal data for von Bach and Swakoppoort dams were only available from January 1994 to September 1996.

Data of Oanob Dam are recorded from January 1992 to September 1996.

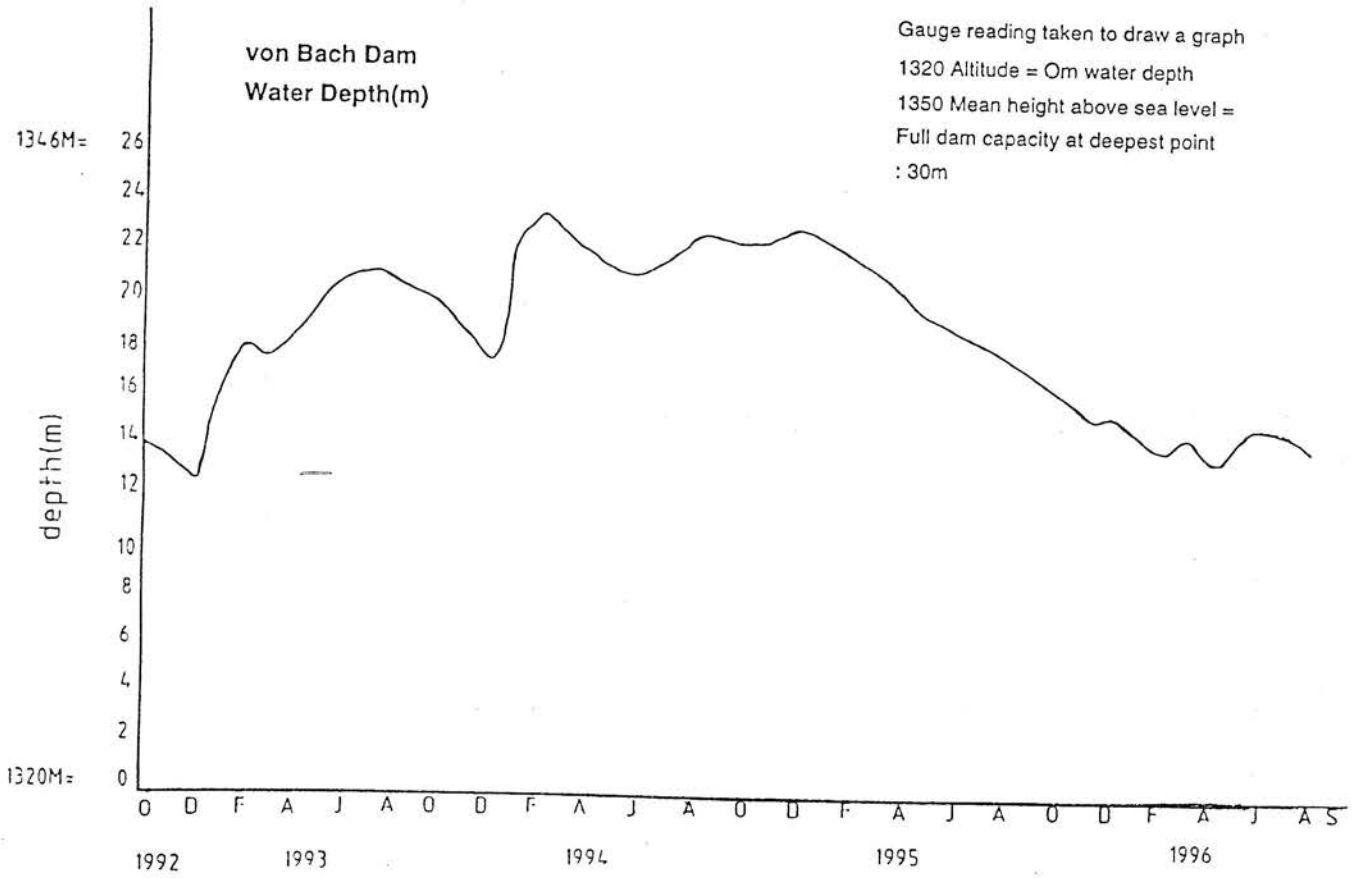
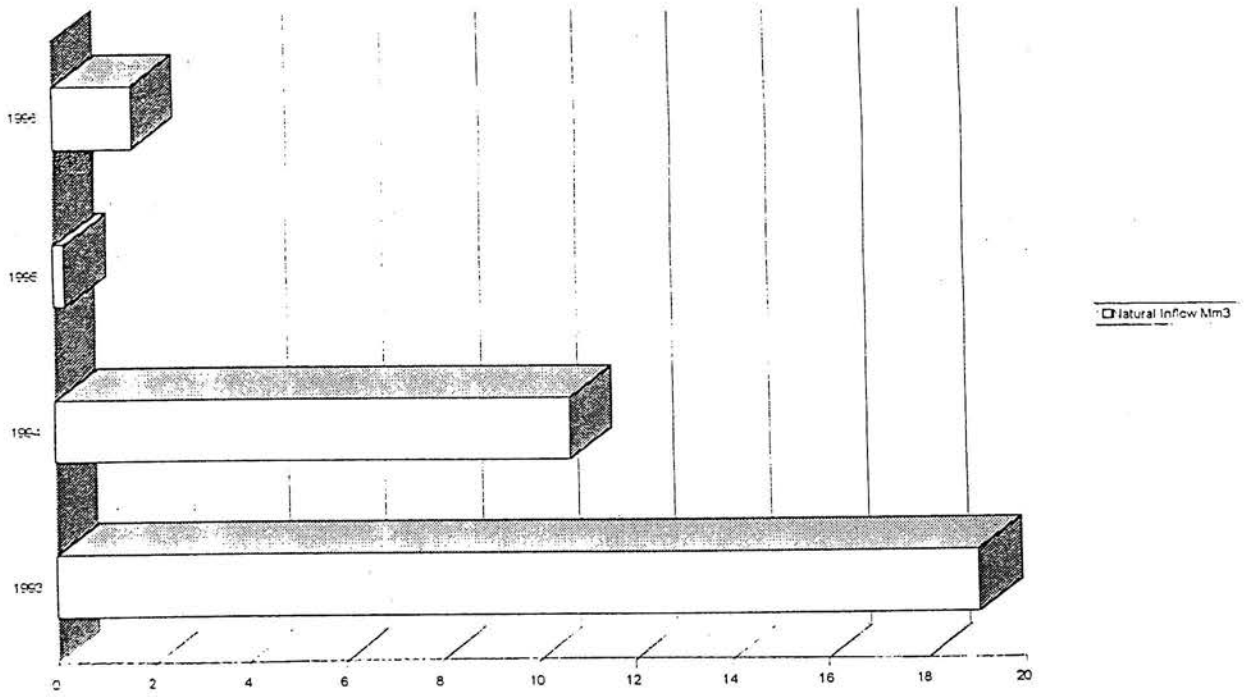
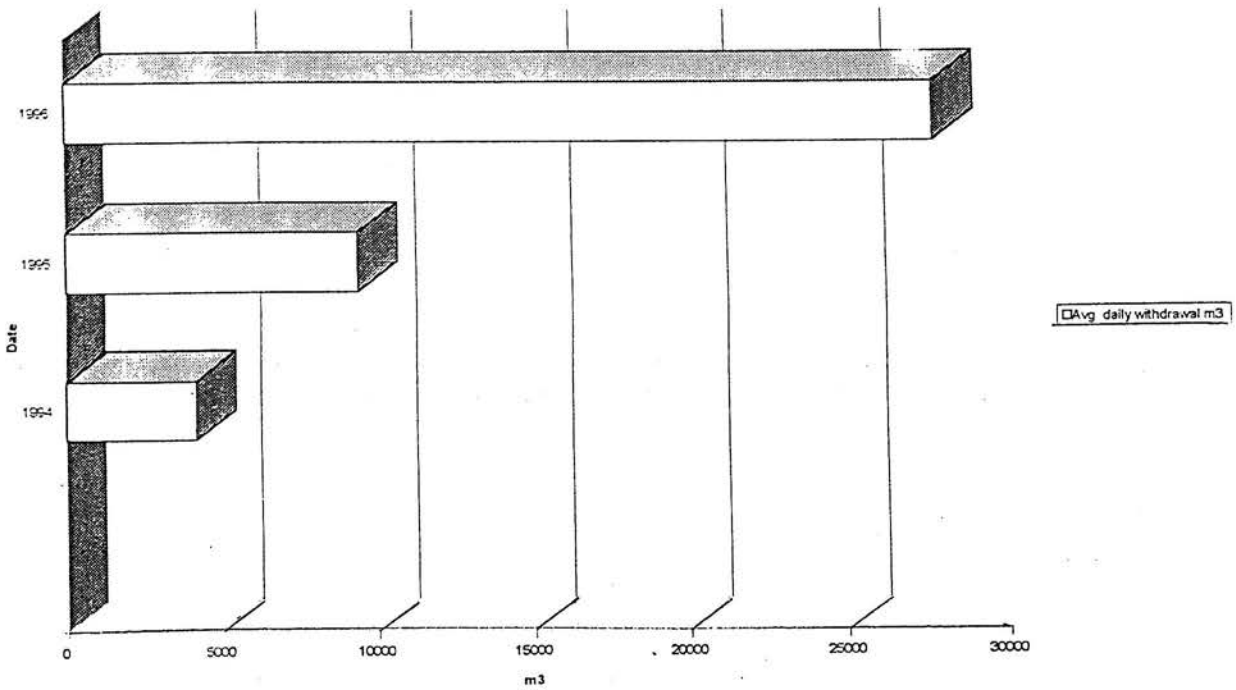



**FIGURE 6**: INFLOWS, WATERLEVELS AND WITHDRAWALS AT THE VON BACH DAM

Swakoppoort Natural Inflows




Swakoppoort withdrawals m3



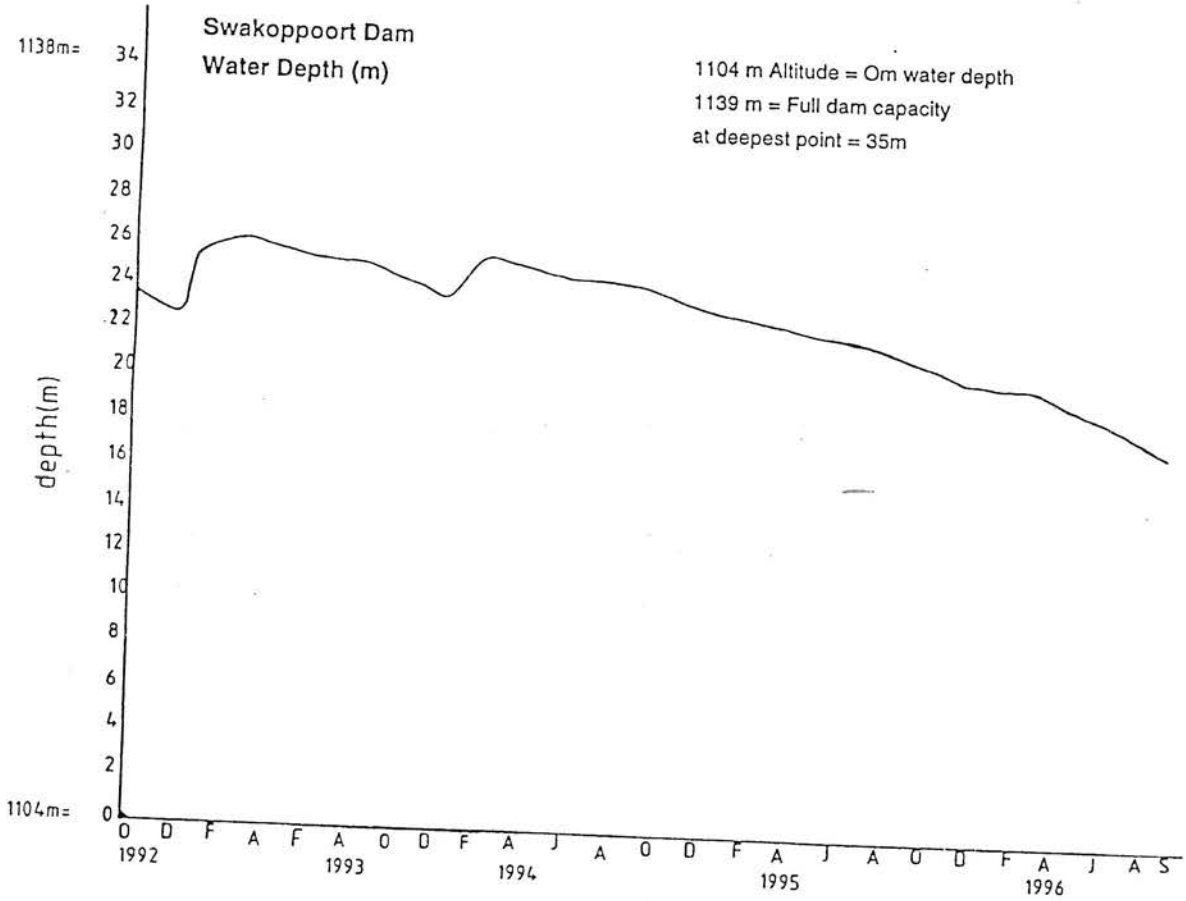
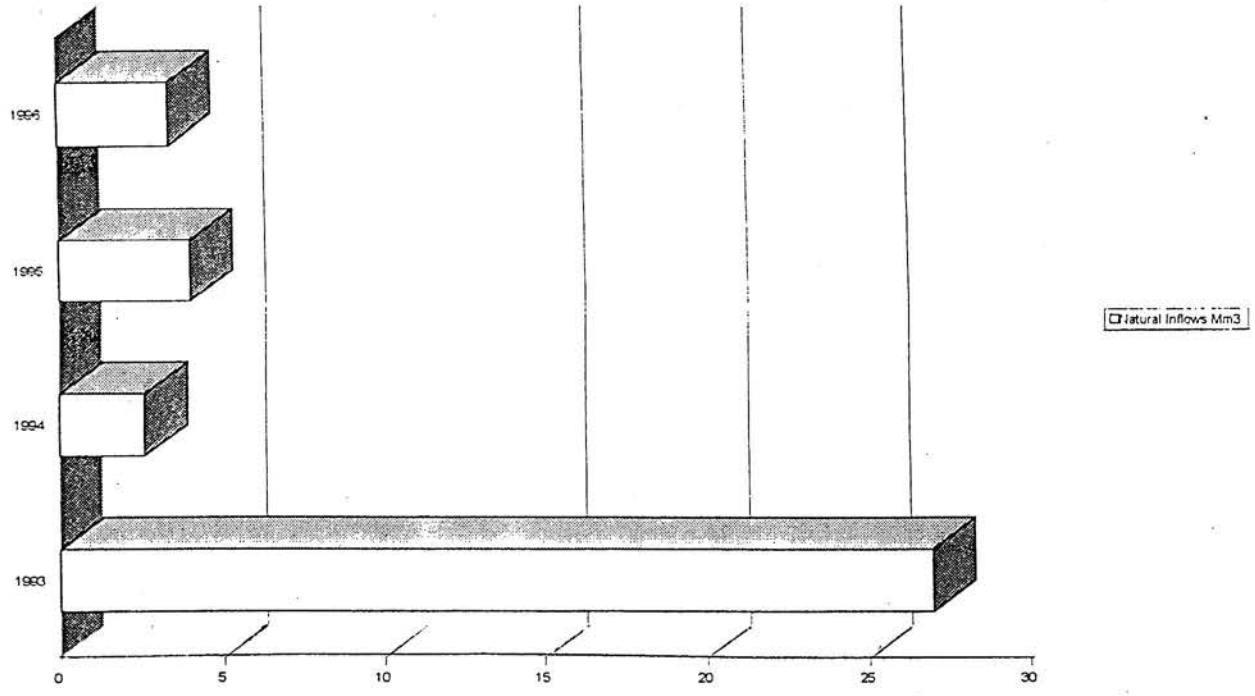
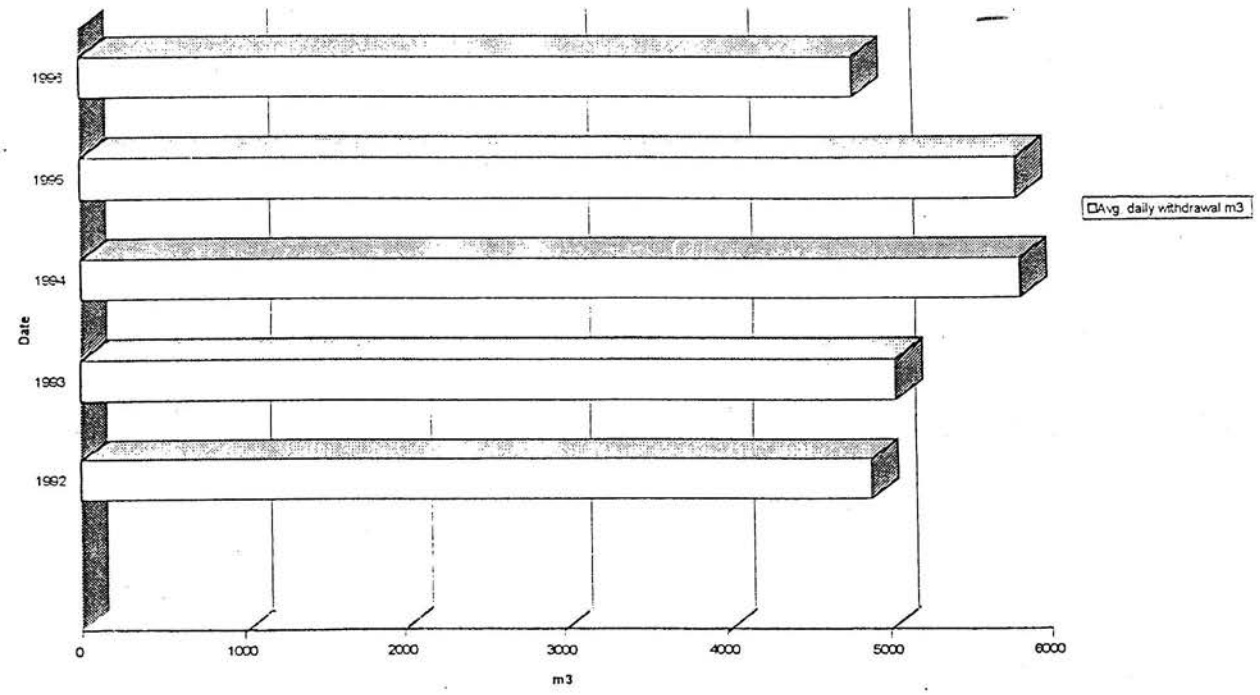



**FIGURE 7** : INFLOWS, WATERLEVELS AND WITHDRAWALS AT THE SWAKOPPOORT DAM

Oanob Natural Inflows




Oanob withdrawals m3



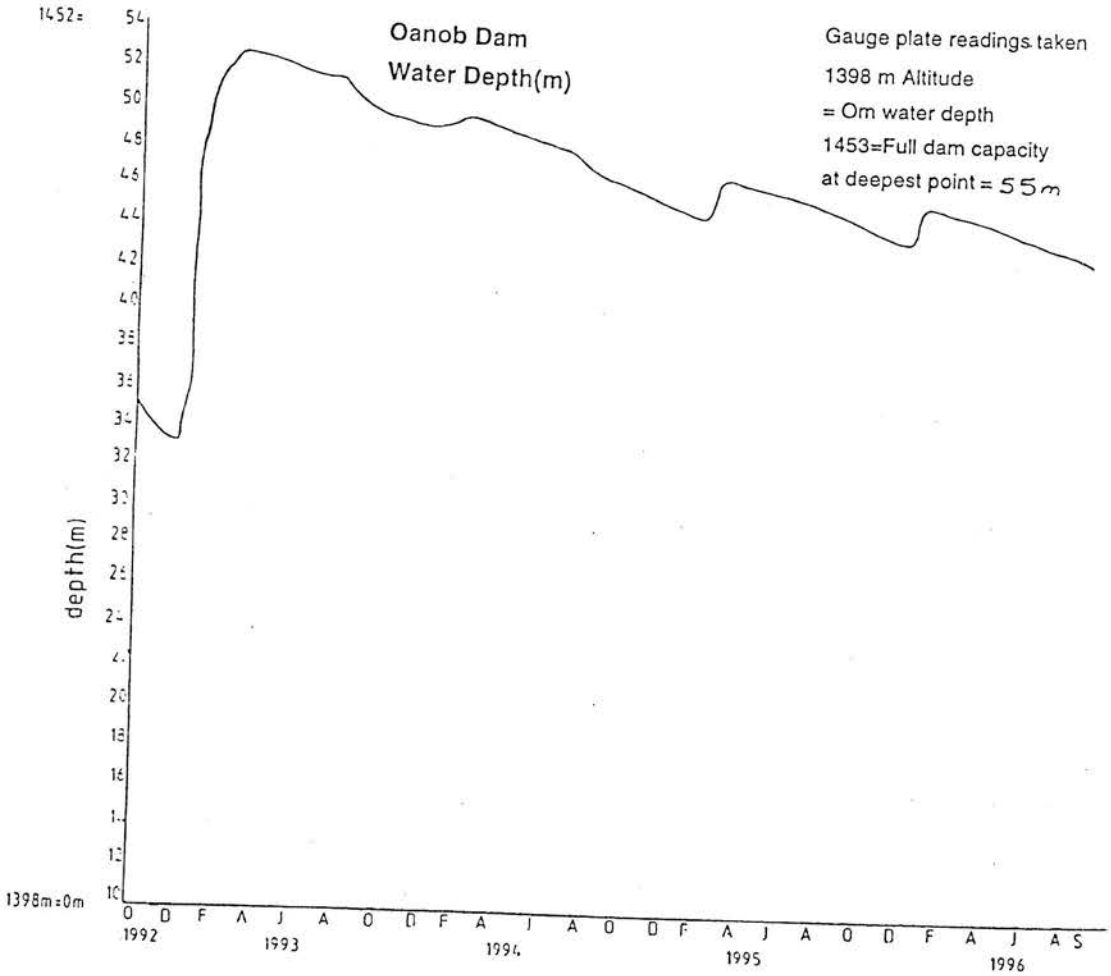
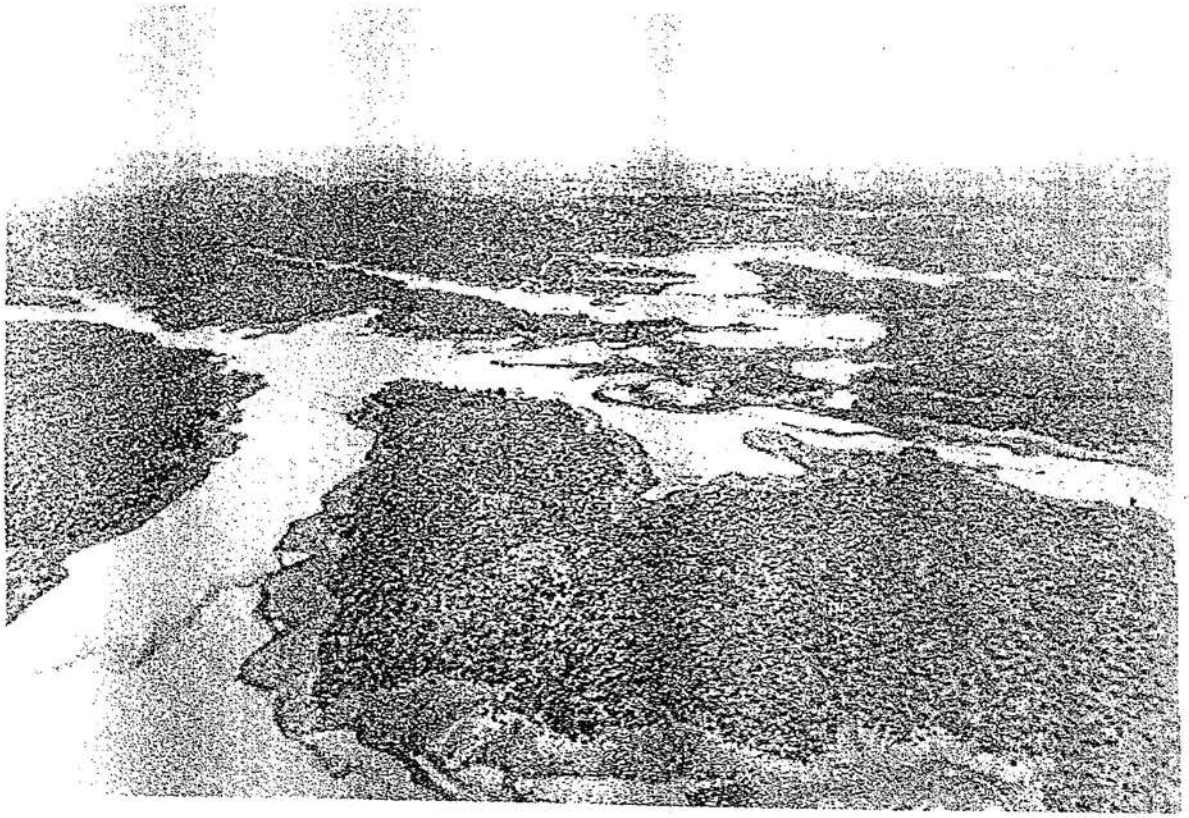



**FIGURE 8 :** INFLOWS, WATERLEVELS AND WITHDRAWALS AT THE OANOB DAM



Photograph of von Bach Dam receiving inflow in rainy season 1997, at about 46 % capacity.

4.1.2. HYDROLOGY

**Von Bach**

From October 1992 to September 1996 water levels fluctuated greatly as shown on the water depth profile figure 6, page 19. Summer rains brought reasonably good inflows at the beginning of 1994 (16,080 $Mm^3$), and 8,683 $Mm^3$ in 1993 however, no inflow occurred in 1995 and minimal inflows in 1996, due to the drought.

Average daily water withdrawal in 1994 was 53499 $m^3$, in 1995 43594 $m^3$ and in 1996 till September it was 31943 $m^3$. The decrease in withdrawal can be attributed to water restrictions imposed on the central areas.

**Swakoppoort Dam**

The depth profile on figure 7, page 21 shows water level fluctuations for Swakoppoort from October '92 to September '96. Summer rains caused inflows at the beginning of each year. In 1993 figure 7 shows that 19,077 $Mm^3$ flowed in, 1994 10,709 $Mm^3$ , 1995 a mere 0,220 $Mm^3$ and in 1996 only 1,633 $Mm^3$. The last two inflows reflect the persisting droughts.

During the 1987-1990 monitoring survey 9900 $m^3$ were pumped from Swakoppoort Dam daily to supply the Navagab mine. In 1994 the amounts have dropped to an average of 4179 $m^3$ a day , rose again in 1995 to 9412 $m^3$/day and finally in 1996 (till September) shot up to 27793 $m^3$/day. Currently Navachab Gold Mine and Karibib receive Swakoppoort water over their purification works, while water is also pumped to the von Bach purification works to meet the Windhoek water demand. This might explain the sudden increase in water withdrawal in 1996. Water quality and productivity changes need to be carefully monitored during and after such transfers to adapt operation procedures where applicable.

**Oanob**

Water level fluctuations of this dam can be seen on the depth profile , figure 8, page 23. It shows that inflows received in 1993 were 26,991 $Mm^3$, the years following '94, '95 and '96 did not provide as much. The amounts were 2,584 $Mm^3$, 3,986 $Mm^3$ and 3,377 $Mm^3$ respectively.

Water was pumped to Rehoboth daily. The amounts increased from 4887,5$m^3$\day in 1992\'93 to 5809$m^3$\day in 1995\'96 .

The floodgates of the dam are opened at intervals in an attempt to save the Camelthorn (*Acacia Erioloba*) forest below the dam by lifting up the groundwater level. In 1993 the gates were open for 4 days beginning of September, releasing 2,526 $Mm^3$. In 1994 2,131$Mm^3$ were released in the beginning of June.

### 4.1.3 TEMPERATURE

The temperature profiles on figure 9 show thermal changes throughout the monitoring time October '92 - September '96. The horizontal isopleths indicate summer stratification while the vertical isopleths show isothermal periods of circulation throughout the water column.

**Von Bach Dam**

Figure 9 shows that the dam stratifies in summer (October-March) with a thermocline varying in depth between 6m and 8m. After overturn, caused by either heavy inflows after summer rains, or autumn temperature decreases and/or wind, the impoundment remained isothermal for about four months (April to August, with a month of variability). During September each year stratification was slowly re-established.

The maximum surface water temperature measured was 28°C. In winter, temperatures declined from 21°C to 12°C. In summer the hypolimnion remained as cold as 12°C.

**Swakoppoort**

The Swakoppoort Dam is monomictic. Stratification occurred from September to March, with the thermocline between 4-8m. Overturn occurred due to summer inflows (March - April), autumn temperature changes and / or wind. The water column remained homogenous from April /May to July, when it slowly commenced stratification again.

During homogeneity, the temperatures ranged from 13-22°C. The highest surface temperature was 29°C and the hypolimnion was never colder than 18°C.

**Oanob**

Oanob dam like the others is monomictic. Stratification occurs from September to April, with a thermocline varying between 4m and 8m. Overturn occurred in April and stratification was re-established by August /September. During this time temperatures ranged between 12-23°C. The highest surface temperature measured was 25°C and the hypolimnion in summer remained at 12°C.

Baseline: From Oct.1992 - Sept. 1993 one proper monomictic cycle occurred with a maximum temperature of 25°C and a minimum temperature of 14°C in winter.

Monitoring: During this time (Oct. 1993 - Sept. 1996) the impoundment showed further signs of a monomictic pattern with 25°C maximum and 12°C minimum.

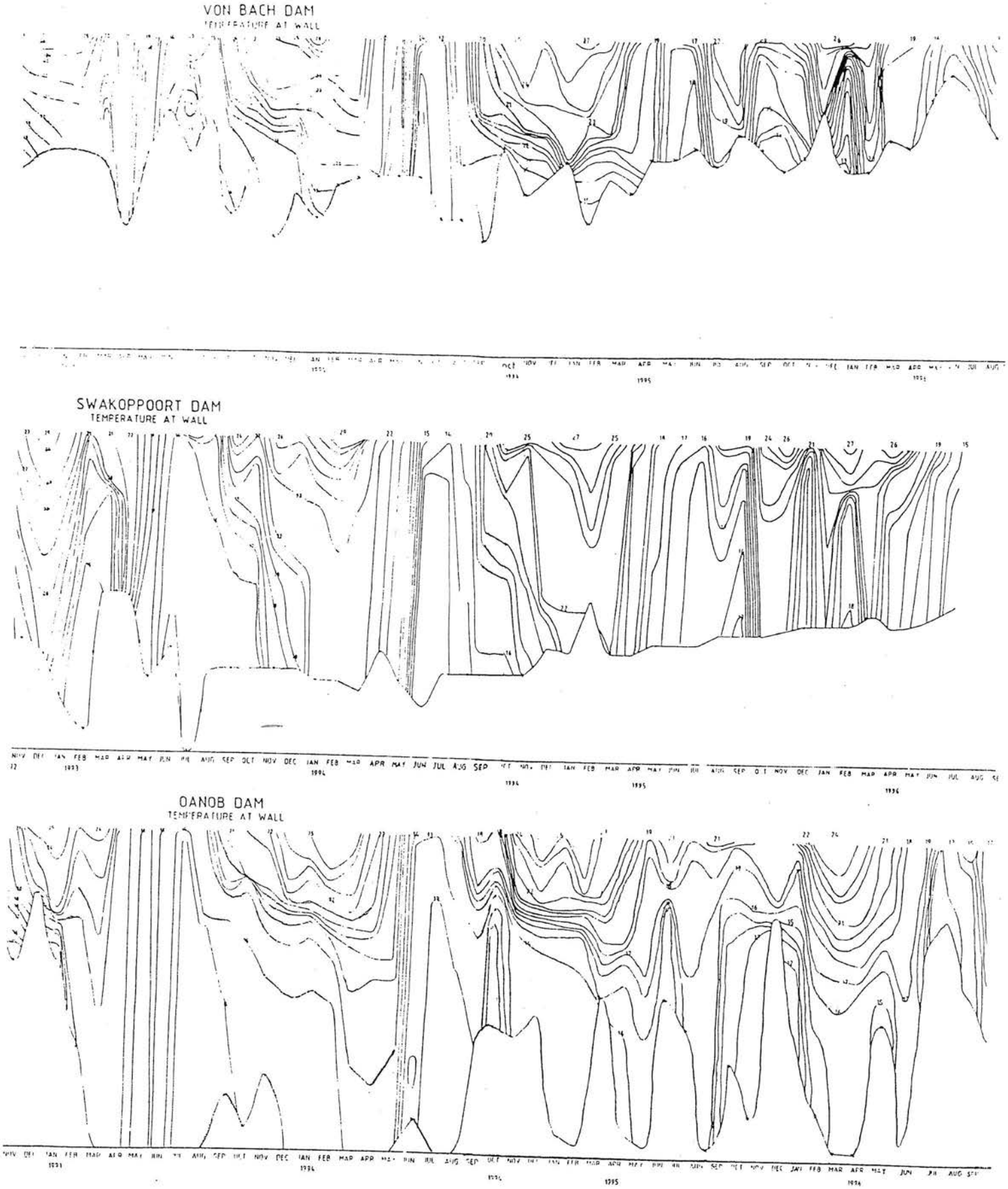



**FIGURE 9 :** TEMPERATURE GRAPHS OF THE THREE DAMS

## 4.2 CHEMICAL CHARACTERISTICS

### 4.2.1 DISSOLVED OXYGEN CONCENTRATIONS

Oxygen is necessary for the respiration of many aquatic organisms and the solubility of chemicals. Figure 10 illustrates the $O_2$ profiles of the three dams for October 1992 -September 1996. Horizontal isopleths indicate summer stratification, where high oxygen levels are found at the surface and low ones in the hypolimnion where oxygen was depleted by oxidative decomposition processes. Vertical isopleths indicate the winter mixing period.

**Von Bach**

In figure 10 the dam showed clear signs of summer stratification and winter mixing. In summer surface waters were very well aerated, while the hypolimnion had minimal oxygen concentrations, often below 1ppm. The oxycline varied annually between 2m and 6m.

**Swakoppoort**

The oxygen profile of this dam is shown in figure 10. Swakoppoort remained stratified in summer from September until March/April. The oxycline during this time was between 2m and 8m. Oxygen levels in the hypolimnion remained very low <1ppm, but did not become anaerobic. Short stratification and appearance of <1ppm conditions were recorded in August /September 1995.

**Oanob**

Oanob is a monomictic dam whose oxygen profile is shown in figure 10. Stratification occurs from September until May. Early overturn occurred during the baseline study in 1993 (April) after heavy inflows during the rainy season. The oxycline remained most constant during stratification and lay between 4-6m. Oxygen levels in the hypolimnion were often low: <1ppm, but conditions did not become anaerobic.

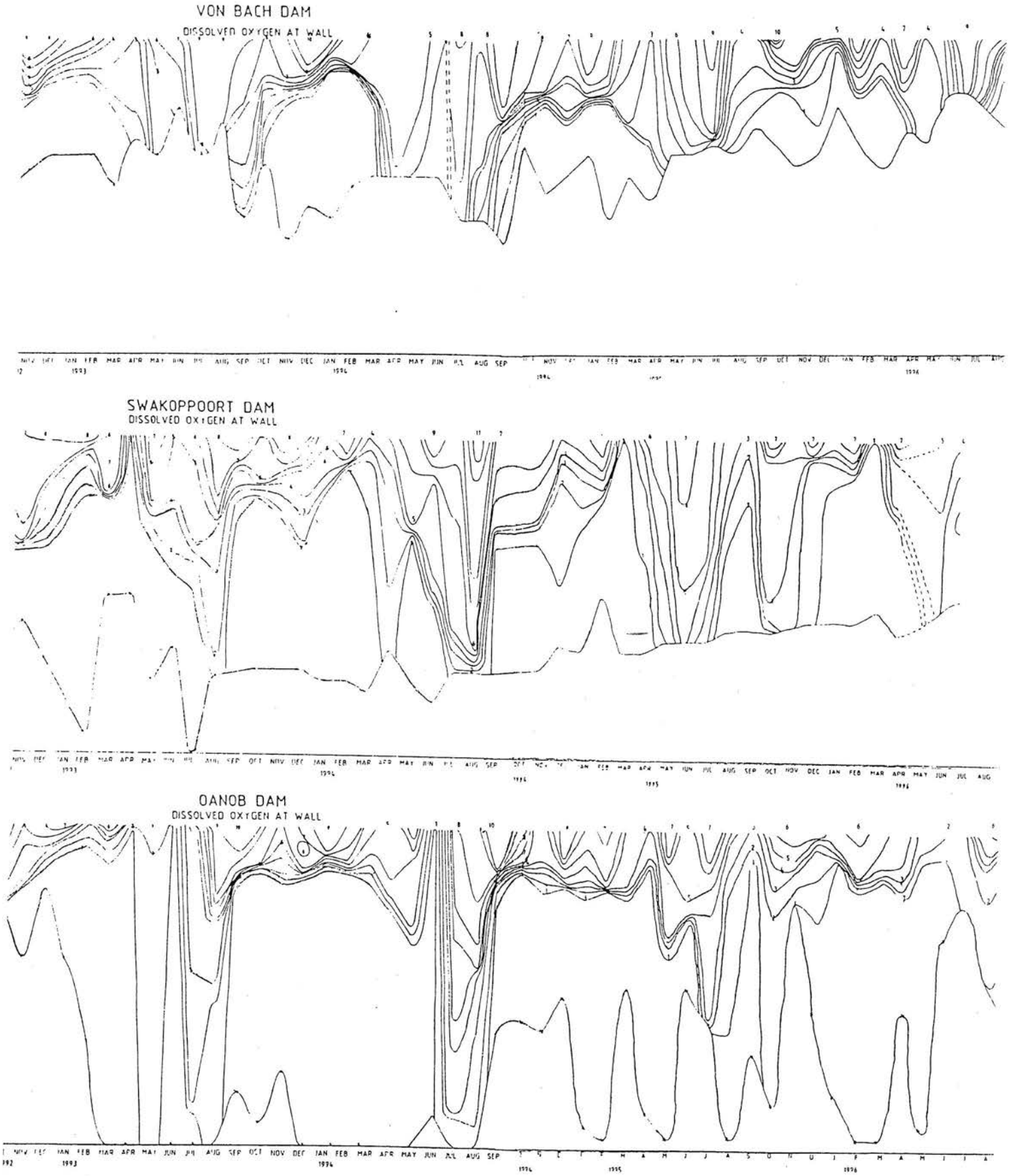



**FIGURE 10** : OXYGEN CONCENTRATIONS OF THE THREE DAMS

### 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 with the dam. Nutrient availability is often linked to stratification patterns and inflows. The relatively low concentrations of the nutrients nitrogen and phosphate are essential to aquatic plant growth and thus the productivity of the impoundment. The results of this survey period reflect the overall trends. Nutrient and $SiO_3$ 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 1-6 at the end of this report.

With the exception of the Oanob baseline period October 1992- September 1993 the results are based on only two samples ( surface and 10 m) at a single site (wall) once a month , therefore no significant mean nor meaningful standard deviation could be established.

Graphs 11 - 13 on pages 32 - 39 show the fluctuations in chemicals for the three dams for the period of October 1992 - September 1996.

**Von Bach**

Figure 11 shows the chemical concentrations of von Bach Dam from October 1992 to September 1996. Table 2 overleaf compares the ranges of chemicals found in von Bach and Omatako in the 1987 -'90 survey period to the minimum and maximum concentrations measured in the 1992 -'96 survey period.

Irregularities observed on the graphs might be explained by Omatako inflows, temperature changes and concentrations of ions due to evaporation, resulting from the drought. Further as these results are based largely on only two samples taken from each dam each month, no significant mean could be established and measurements might not display the true conditions for the impoundment.

Compared to the results of the monitoring survey 1987 -'90 (Bethune 1992), most concentrations have increased. The lower ranges remained similar to those of the 87 -90 survey of von Bach while the higher ranges were found consistently higher even than previous concentrations in Omatako water. Two factors could account for this:

1. input from Omatako
2. concentration due to evaporation in the long dry period.

Some trends can be detected which follow water level changes in the impoundment.

During annual dry periods the gradual increase in conductivity, TDS and some major ions indicate concentrations due to evaporation. Rain runoff inputs dilute the concentrations in von Bach, e.g. Jan/ Feb. 94 and Jan/ Feb. 96. Inputs from Omatako are reflected by an increase in ion concentrations and conductivity in the pumping times during the years. Interesting increases in Cl and Mg follow Omatako inputs in Jun./ Jul. 95, resulting in a decrease in conductivity and TDS over August to October as the sediments slowly settled out.

The high concentration of silicates in August 1994 might be caused by a diatom bloom.

**TABLE 2** : A COMPARISON OF GENERAL WATER CHEMISTRY TRENDS IN THE OMATAKO DAM FOR 1987-90 AND VON BACH DAM FOR 1987-90 AS WELL AS 1992-96

| CHEMICAL | VON BACH 87-90 | OMATAKO 87-90 | VON BACH 92-96 |
|---|---|---|---|
| CONDUCTIVITY uS/cm | 123-200 | 139-273 | 117-315 |
| TDS mg/l | 73-125 | 130-158 | 77-209 |
| Total Alkalinity mg/l | 59-96 | 90-134 | 57-139 |
| pH | 7.0 -8.0 | above 8 | 6.9-8.35 |
| Cl mg/l | below 3 | 2 -4.6 | 0.5-15.5 |
| Na mg/l | 1.0 - 3.0 | 5.5-12 | 3-18.5 |
| K mg/l | 5.0- 10.0 | 7.6-13.2 | 6-14.5 |
| SO4 mg/l | below 3,8 | below 5.1 | <1-20 |
| Ca mg/l | 43-68 | 48-80 | 37-76 |
| Mg mg/l | 13-24 | 27-44 | 12.0-39 |
| SiO2 mg/l | below 1,6 | below 4.5 | <0.5-6.5 |

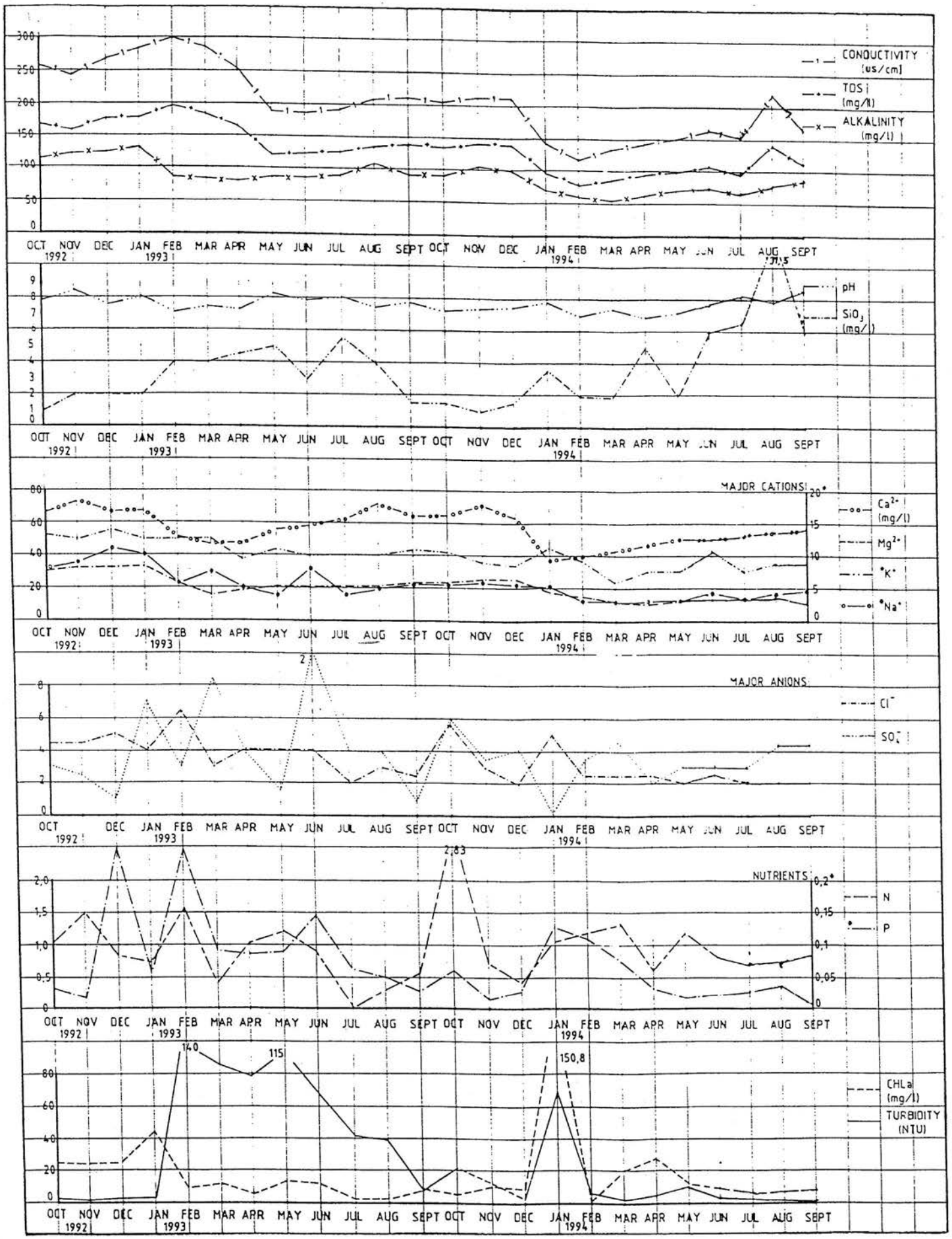



**FIGURE 11 a :** CHEMISTRY TRENDS IN VON BACH OCT. 92 - SEPT. 94

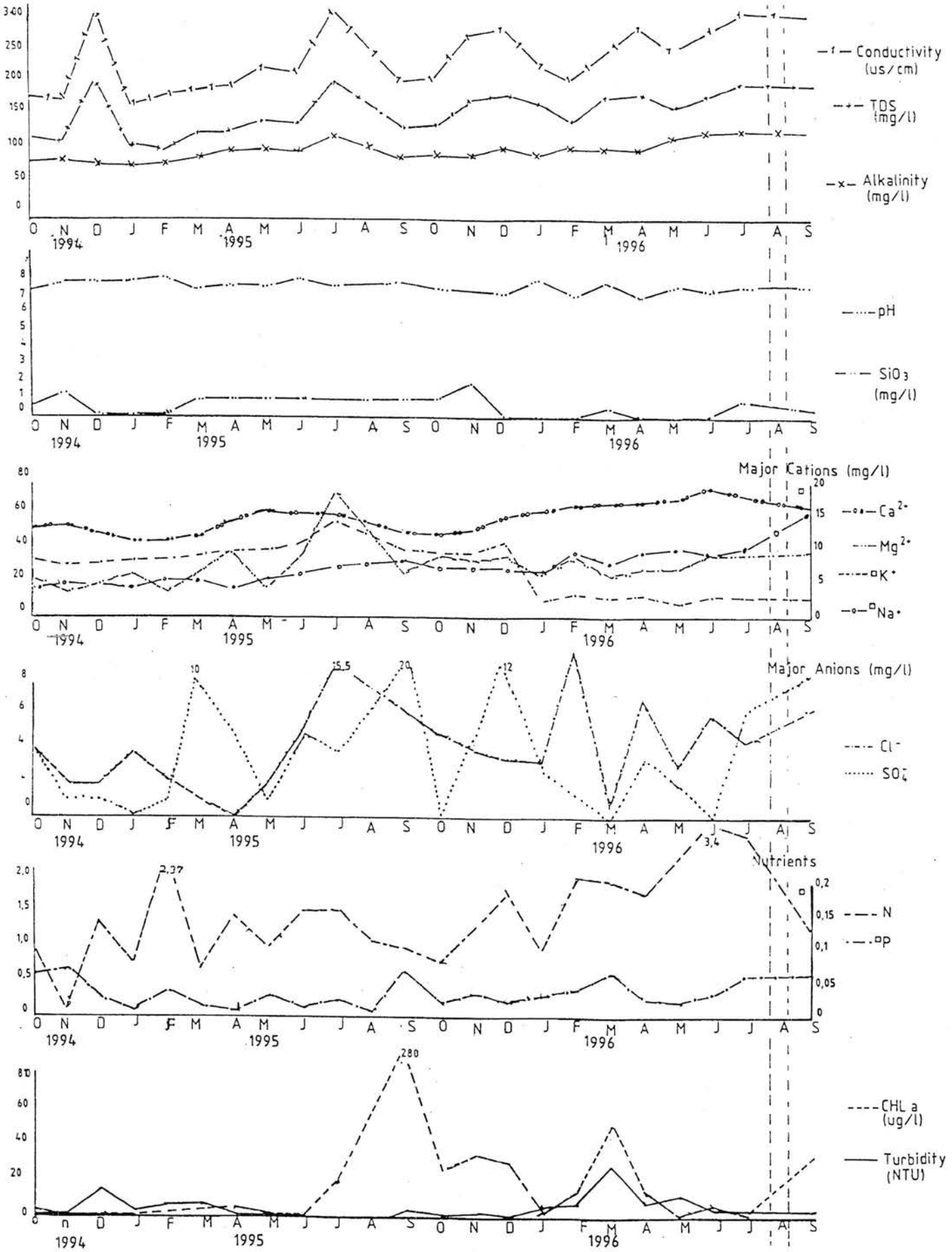



**FIGURE 11 b**: CHEMISTRY TRENDS IN VON BACH OCT. 94 - SEPT. 96

Swakoppoort

Figure 12 shows chemistry trends in this dam for the monitoring time October 1992 to September 1996.

Inflows at the beginning of each year (January to March) had a diluting effect shown by the decrease in conductivity, TDS and alkalinity, except for 1995, when hardly any inflow occurred and concentrations rose. In annual dry periods, concentrations rose slowly. After 1993 anions, most cations, conductivity, TDS and alkalinity showed a steady increase in concentrations over the whole monitoring time, due to a decrease in dam volume caused by evaporation.

In comparison to the other two impoundments, Swakoppoort Dam has the highest chemical concentrations.

**TABLE 3 :** COMPARISONS OF GENERAL CHEMISTRY TRENDS IN SWAKOPPOORT OVER THE THREE BASELINE / MONITORING PERIODS: 1984 - 86, 87 - 90 AND 92 - 96

| CHEMICAL | 1984 -1986 | 1987 - 1990 | 1992 - 1996 |
|---|---|---|---|
| Conductivity uS/cm | 214 - 366 | 202 - 368 | 302 - 580 |
| TDS mg/l | 125 - 326 | 115 - 205 | 199 - 425 |
| Total Alkalinity mg/l | 93 - 232 | 99 - 146 | 129 - 215 |
| pH | 6.9 - 8 | 7.0 - 8.0 | 6.9 - 8.8 |
| $Cl^-$ mg/l | 6.4 - 15.6 | 8.0 - 18.0 | 18 - 46.5 |
| $Na^+$ mg/l | 8.3 - 17.2 | 10.0 - 20.0 | 12.5 - 64 |
| $K^+$ mg/l | 6.8 - 20 | 9.0 - 20.0 | 13 - 31 |
| $SO_4^=$ mg/l | 2.6 - 10.3 | below 7.5 | 7.0 - 35 |
| $Ca^{++}$ mg/l | 65 - 142 | 48 - 99 | 53.5 - 90 |
| $Mg^{++}$ mg/l | 17 - 49 | 15 - 25 | 29 - 59.5 |
| $SiO_2$ mg/l | 6.4 - 15.6 | below 1.7 | < 0.5 - 8 |

The values used in **Table 3** are the minimum and maximum mean monthly concentrations recorded.

Oanob

The concentration of chemicals in Oanob Dam, shown in figure 13, were often not constant over the baseline, as well as the monitoring period. Some chemical fluctuations on the graphs are not easily explained. This could be attributed to the dam still being very young and thus unstable and the fact that during the monthly monitoring period sampling intervals were too long to detect and follow these changes.

However, a few trends could be observed. In the baseline study heavy rainwater inflows beginning of 1993 had a strong diluting effect, shown by the decrease in conductivity, TDS, alkalinity and cation concentrations. During the monitoring period October 1993 - September 1996, little inflow occurred, and due to increased volume loss by evaporation over time the concentrations of cations, alkalinity, TDS and conductivity rose slowly.

The high amount of silicates in October 1994 might be associated with a diatom bloom.

TABLE 4 : GENERAL CHEMISTRY TRENDS IN OANOB FOR 1992 - 96

| CHEMICAL | 1992 - 1996 |
|---|---|
| Conductivity uS/cm | 141 - 264 |
| TDS mg/l | 93 - 174 |
| Total Alkalinity mg/l | 62 - 130 |
| pH | 6.9 - 8.35 |
| $Cl^-$ mg/l | 0.5 - 9 |
| $Na^+$ mg/l | < 1 - 13 |
| $K^+$ mg/l | 5 - 12.8 |
| $SO_4^=$ mg/l | 0.19 - 17.5 |
| $Ca^{++}$ mg/l | 45 - 93.5 |
| $Mg^{++}$ mg/l | 8.9 - 27 |
| $SiO_2$ mg/l | 0.5 - 9 |

The values in **Table 4** are the minimum and maximum mean monthly concentrations recorded.

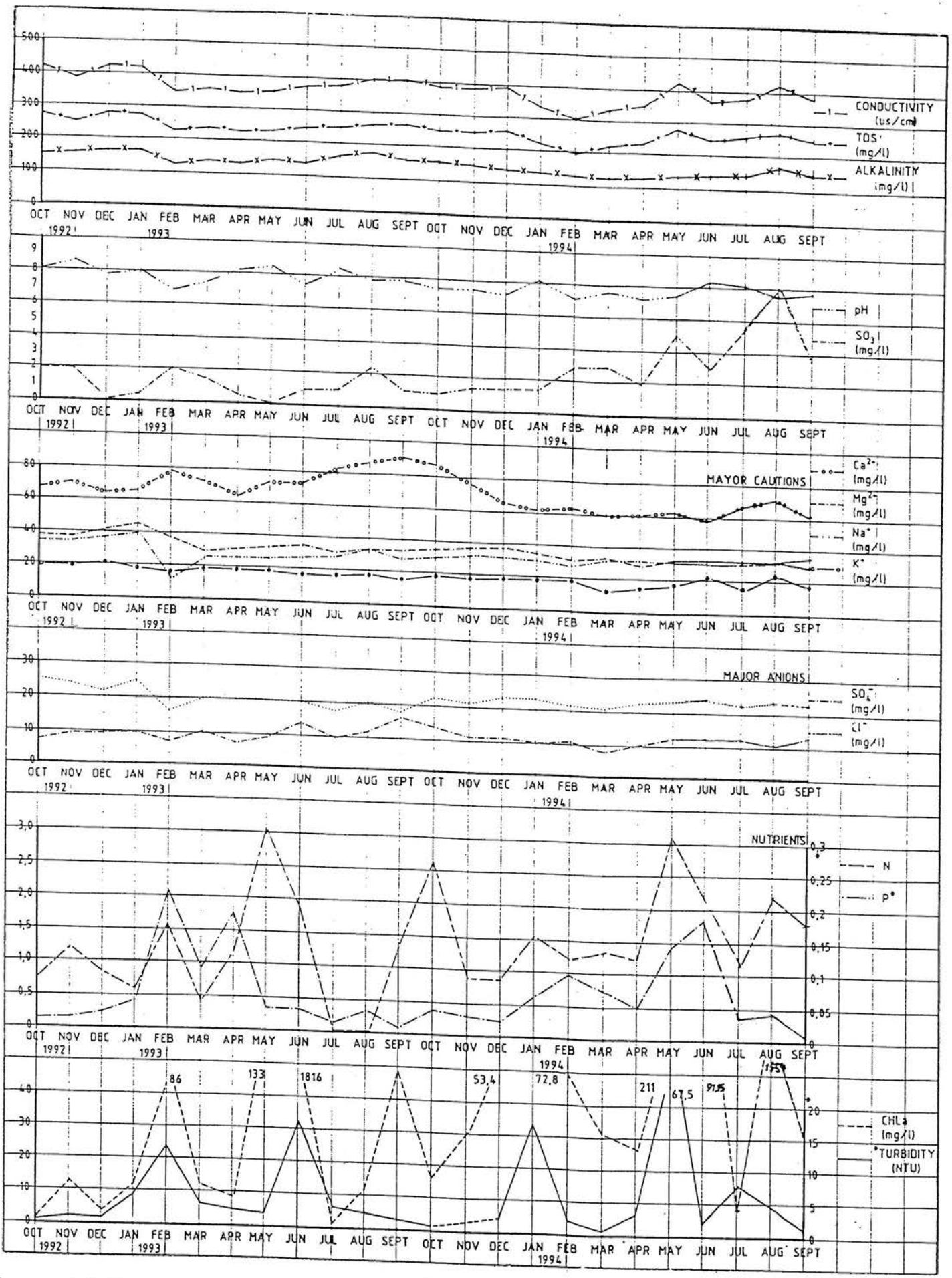



**FIGURE 12 a:** CHEMISTRY TRENDS IN SWAKOPPOORT, OCT. 92 -SEP.94

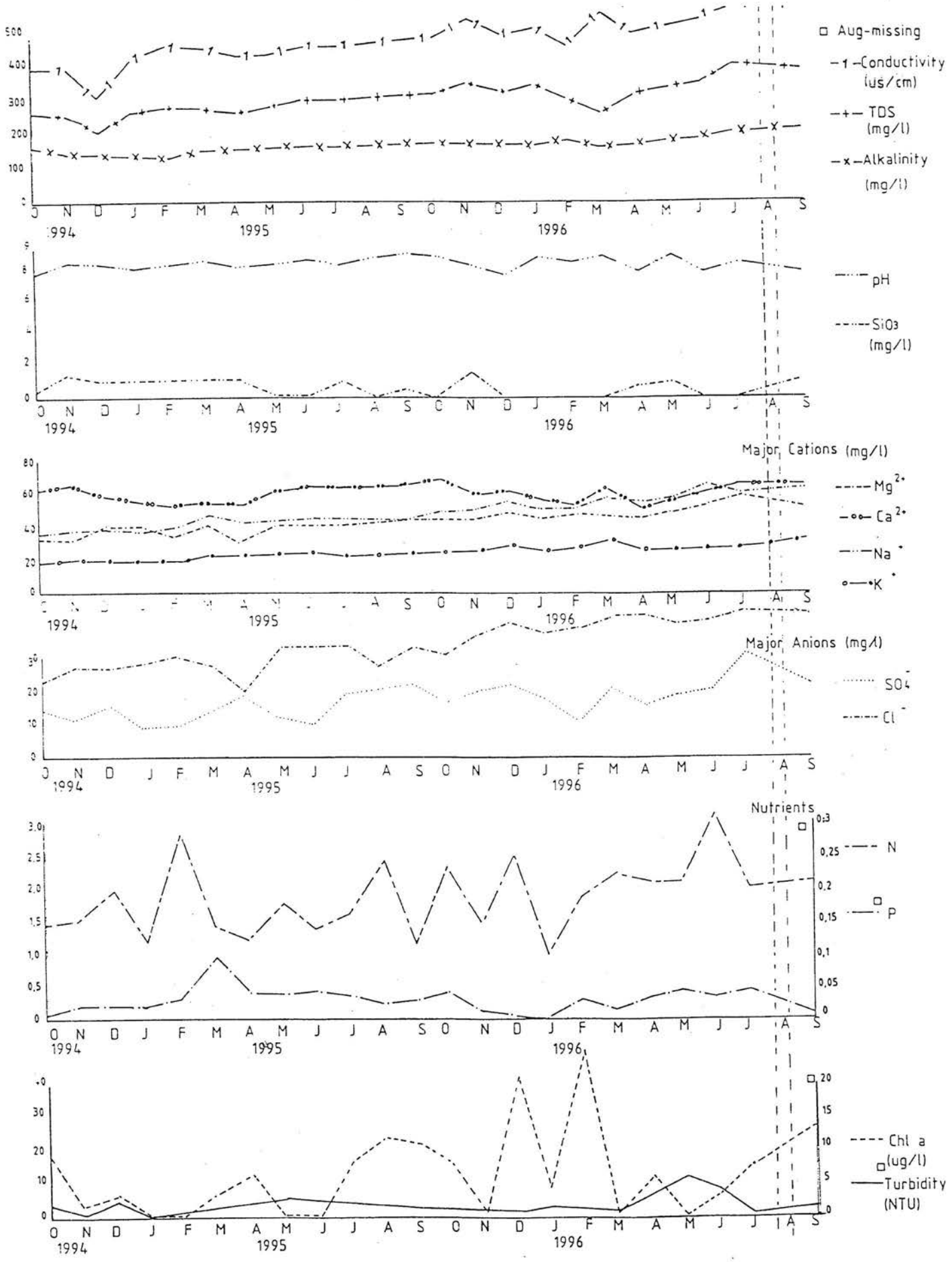



**FIGURE 12b**: CHEMISTRY TRENDS IN SWAKOPPOORT, OCT. 94- SEP. 96

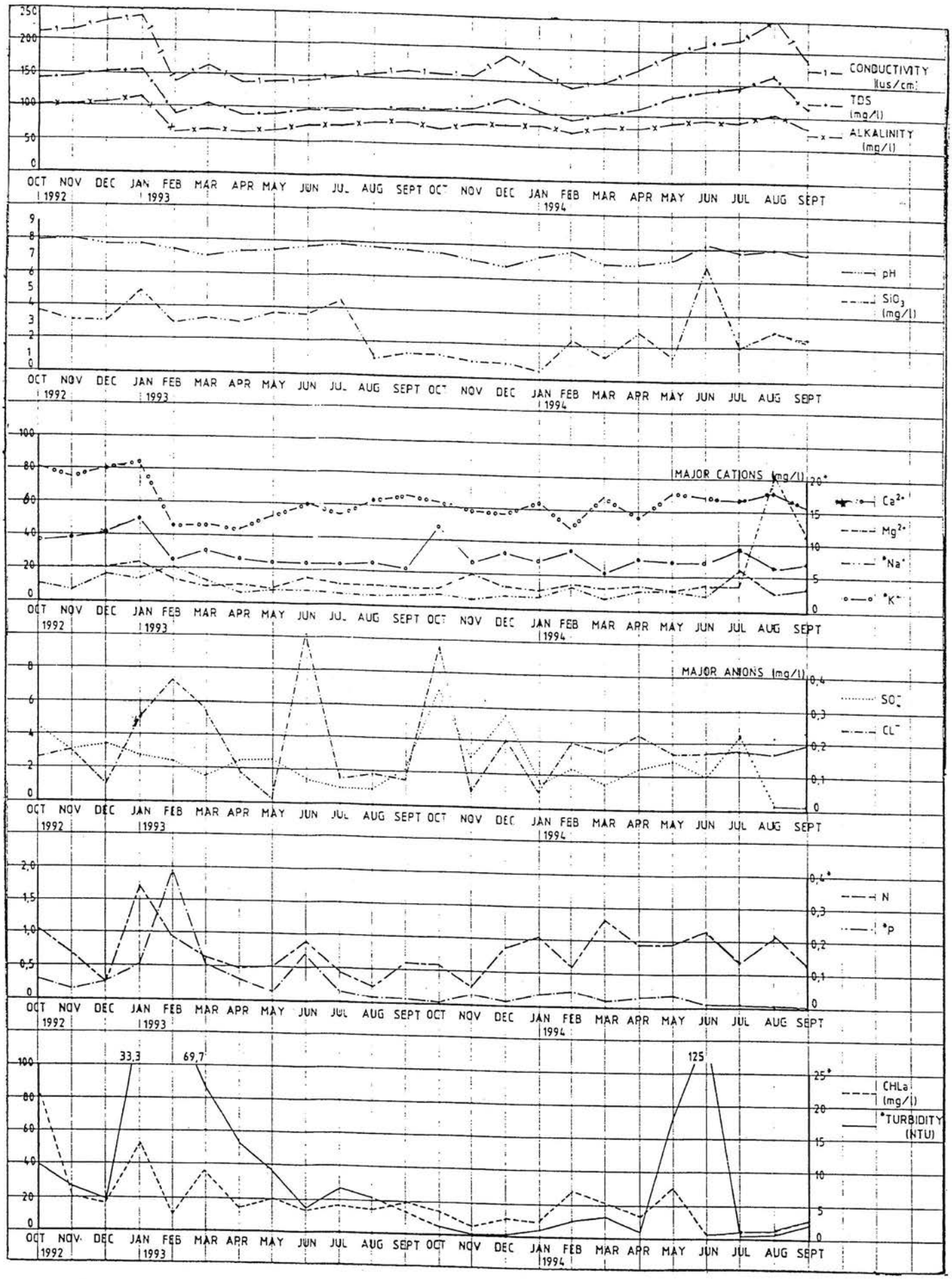



**FIGURE 13 a:** CHEMISTRY TRENDS IN OANOB, OCT. 92 - SEP. 94

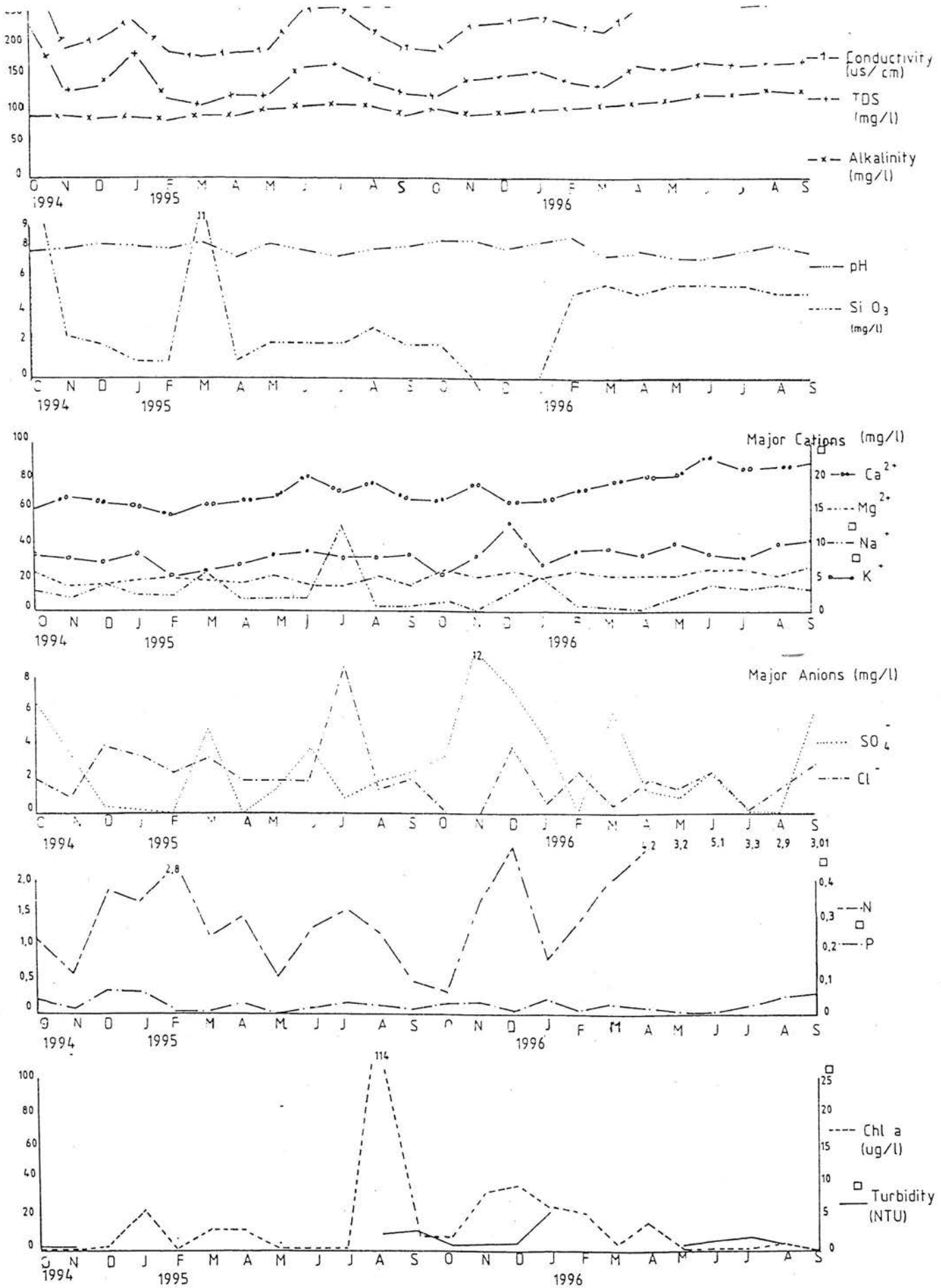
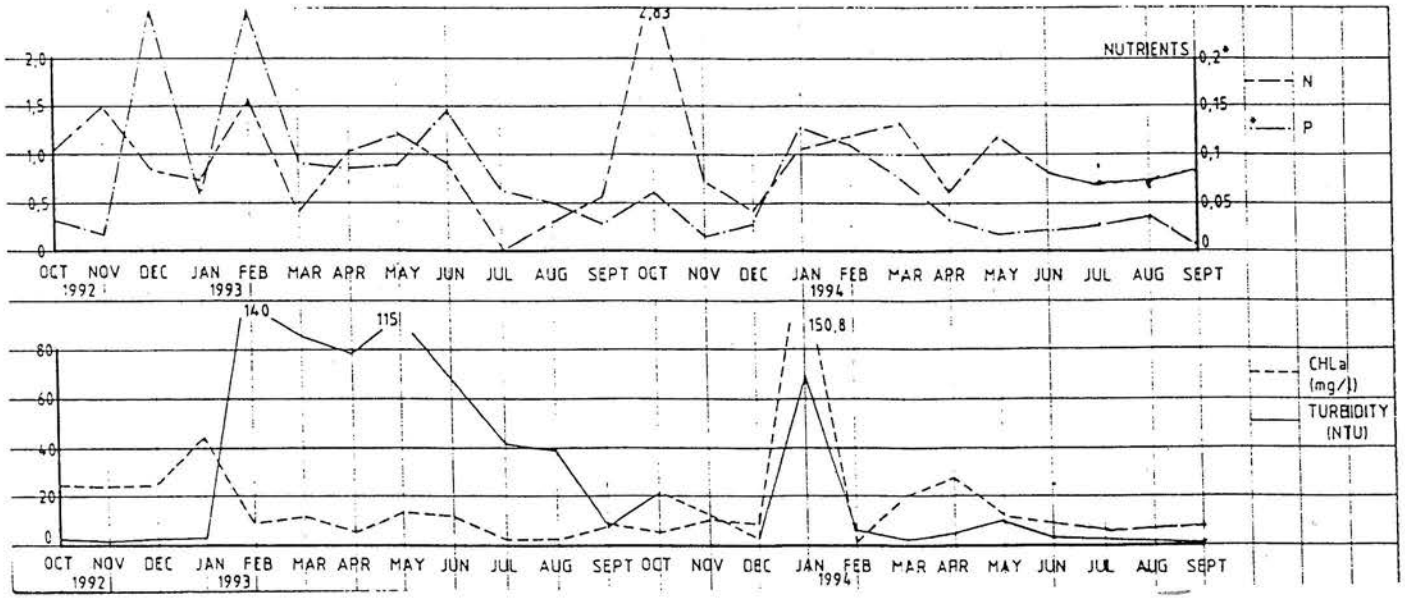
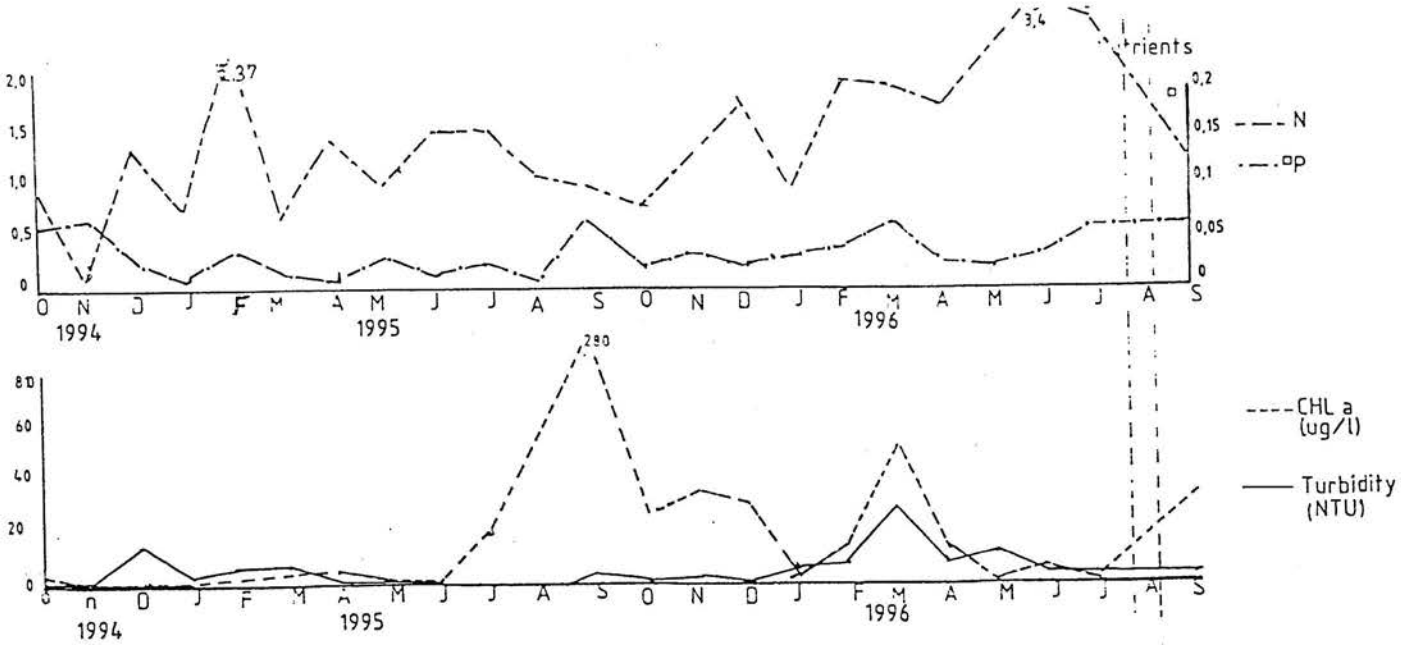



**FIGURE 13 b**: CHEMISTRY TRENDS IN OANOB, OCT 94 - SEP. 96

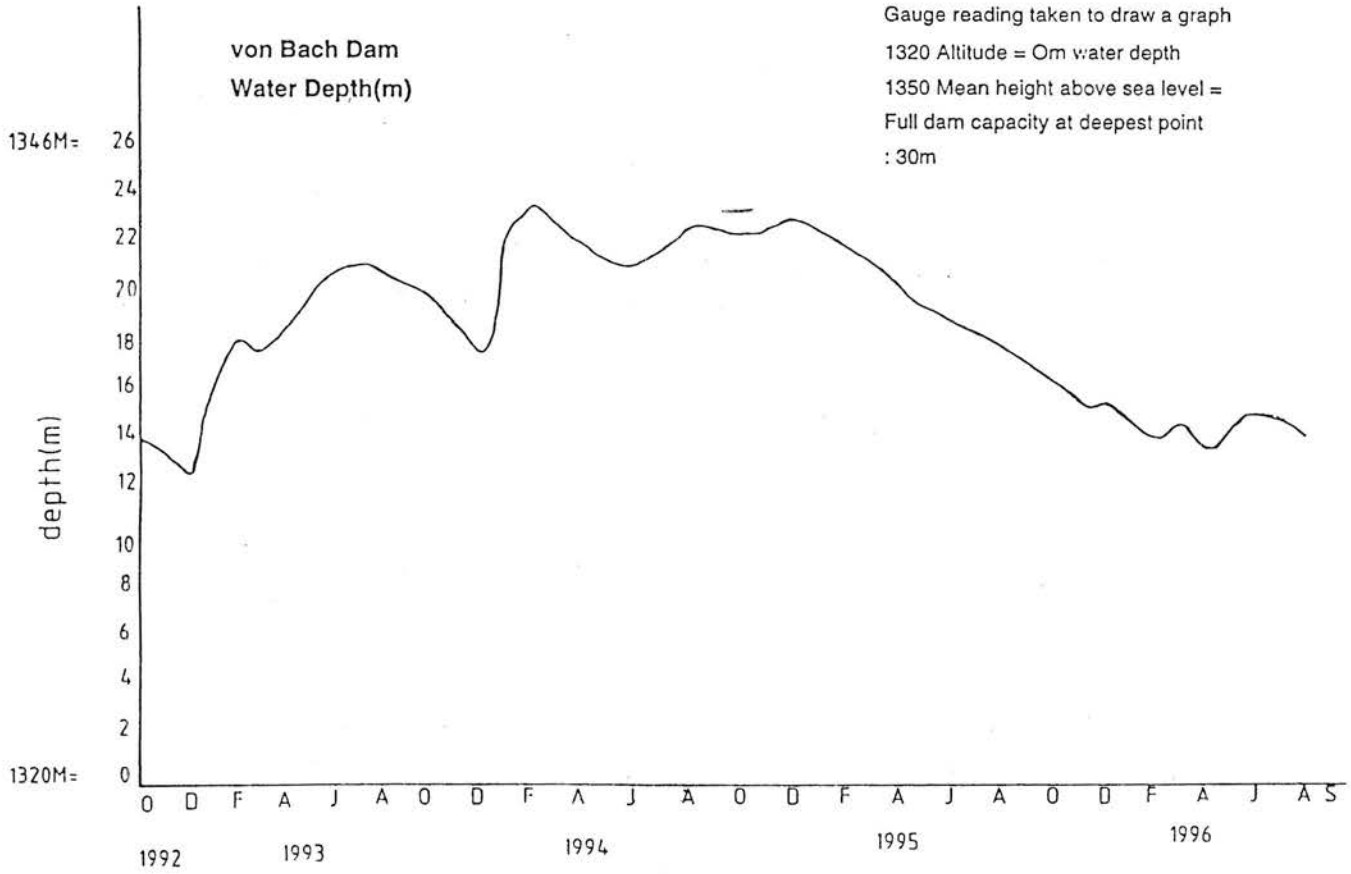
## 4.2.2.1 NUTRIENT DISCUSSION OF VON BACH DAM WITH REPEATED FIGURES OF WATERLEVELS AND CHEMISTRY TRENDS



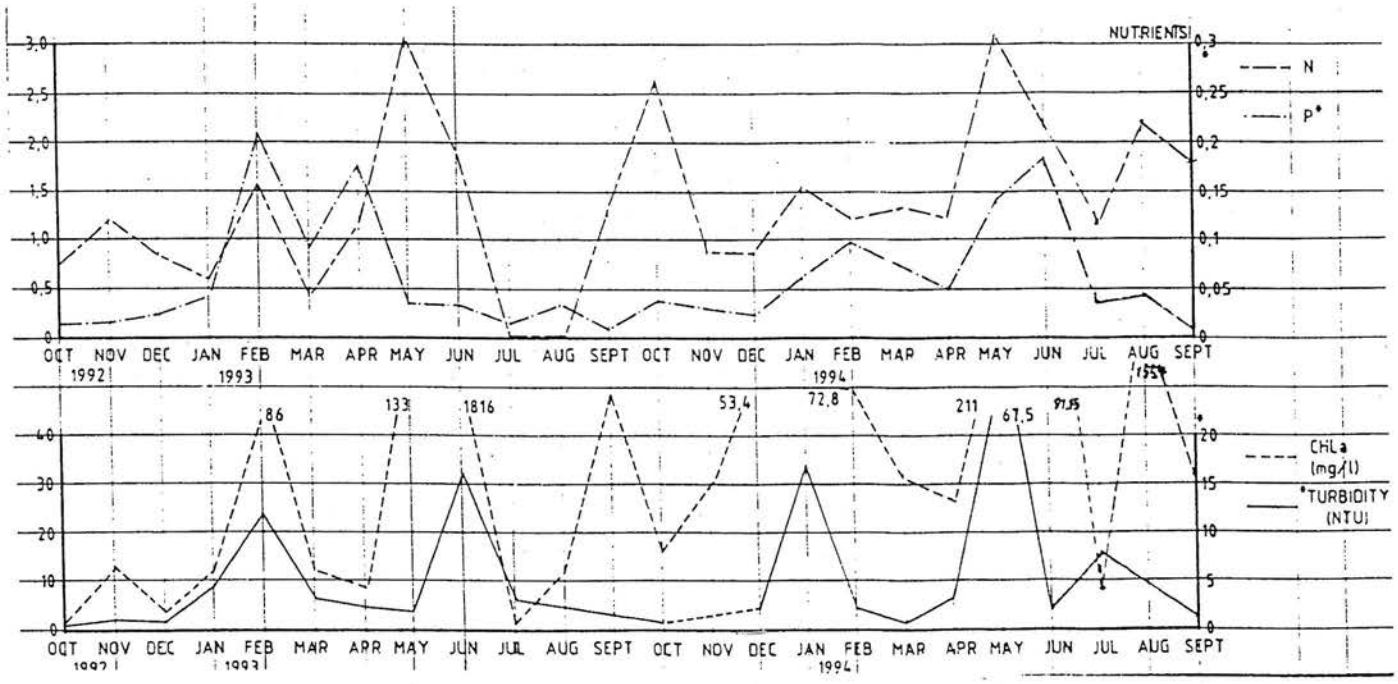



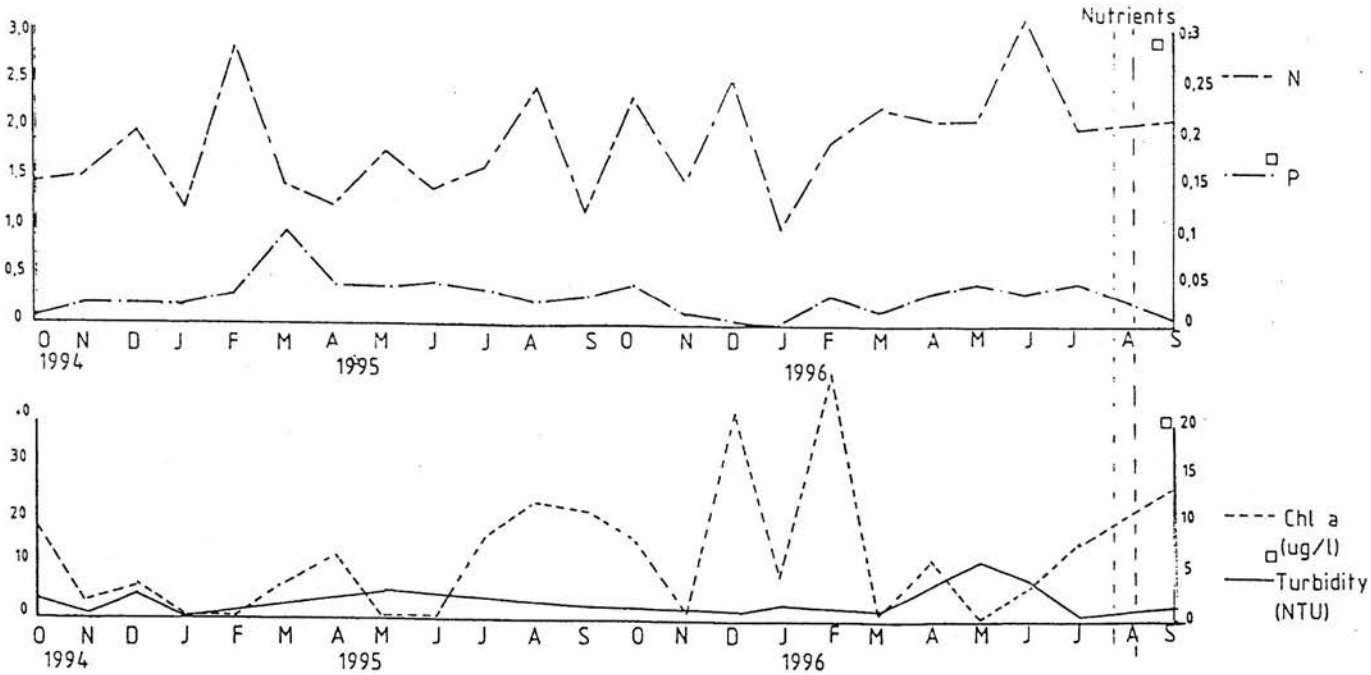
Increases in nutrients and resultant algal blooms were detected in different situations:

With natural inflow nutrients were washed into the impoundment, causing increases in nutrients, turbidity and Chl *a*. This happened in December '92, February '93, January '94 and March '96. No inflows were received in '95, and thus no nutrient increase occurred. An increase in nutrients and turbidity were observed when water was pumped from Omatako,as seen in May '93. Also, algal blooms at the end of winter occurred when temperatures and light increased in spring and stratification commenced. Nutrients were still plentiful at this stage due to former mixing of the water column.



## 4.2.2.2 NUTRIENT DISCUSSION OF SWAKOPPOORT DAM WITH REPEATED FIGURES OF WATERLEVELS AND CHEMISTRY TRENDS

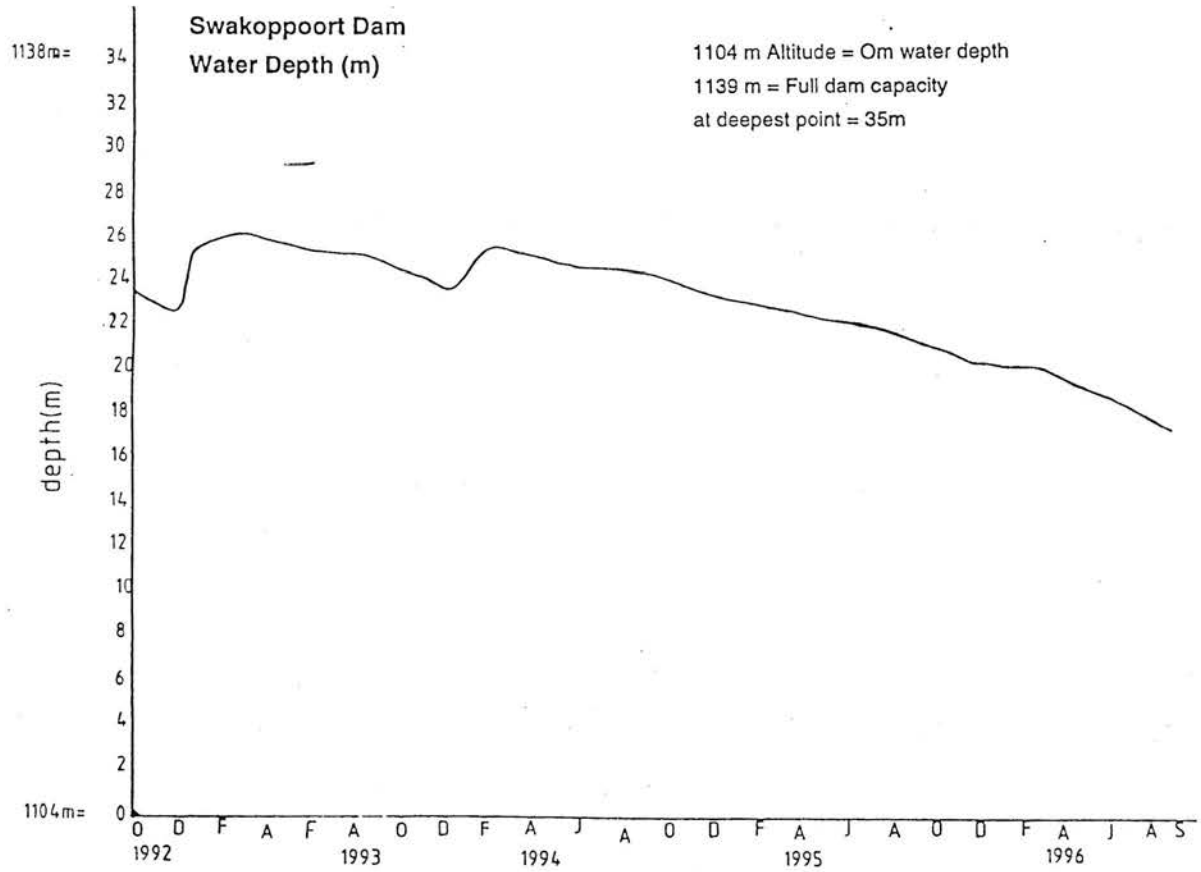


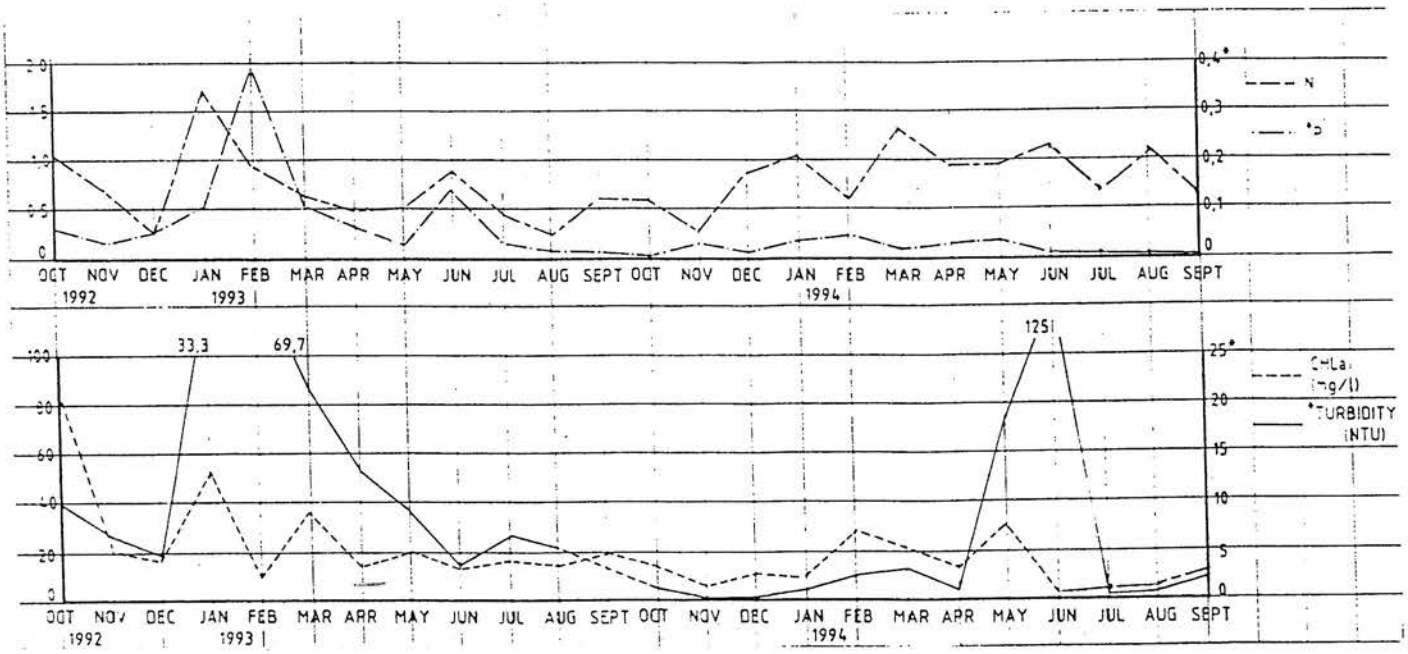
Similar to the von Bach Dam, the Swakoppoort impoundment showed nutrient and Chl *a* fluctuations at different times of the year.

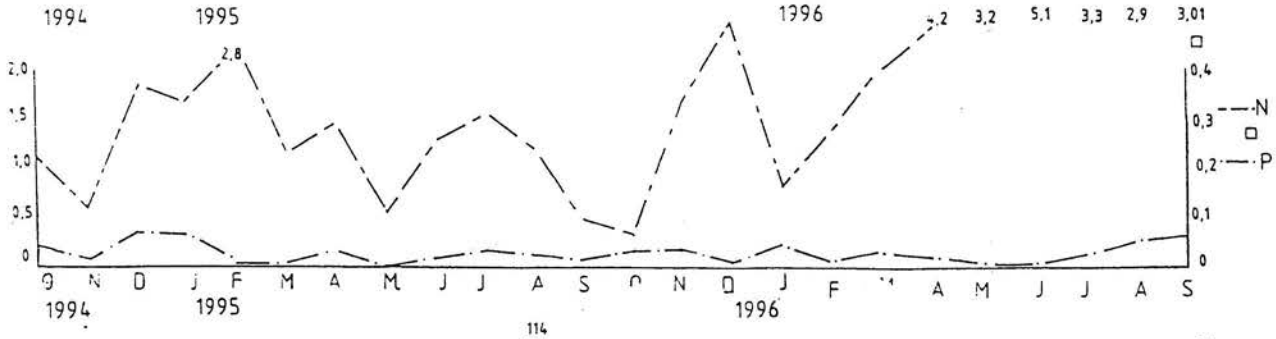
Nutrient increases due to inflows occurred in January/ February '93 and '96. These patterns were not clearly observable in '94, due to too long time intervals between samples taken. In '95 hardly any inflow occurred, explaining no increases in nutrients. In May 1993 and '94 blooms resulted from the mixing of the impoundment and thus the available nutrients. In August /September of 1993 and '94, increasing light and temperature caused blooms.

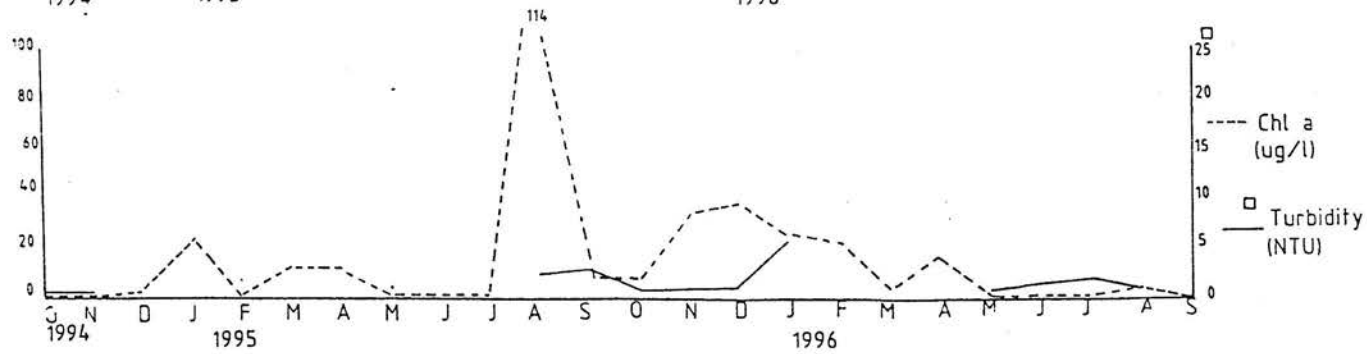
There are no clear explanations for several irregularities which occur from the end of '94 to '96, these could be due to increasing eutrophication, the lack of inflows and resultant long retention time.



## 4.2.2.3 NUTRIENT DISCUSSION OF OANOB DAM WITH REPEATED FIGURES OF WATERLEVELS AND CHEMISTRY TRENDS



In Oanob Dam nutrients increased with inflows between December and April of 1993, '94 and '95. Breakdown of stratification caused nutrients to well up from the bottom in May/ June 1993. In August 1995 warming spring conditions and the still freely available nutrients gave rise to another algal bloom.

Here it was also difficult to explain certain fluctuations, like the constantly high nutrient values after March 1996 and the turbidity value in June 1994. This high turbidity reading is most probably a laboratory error as the Secchi reading for the same day is 1,2 m indicating clear conditions and no turbidity.

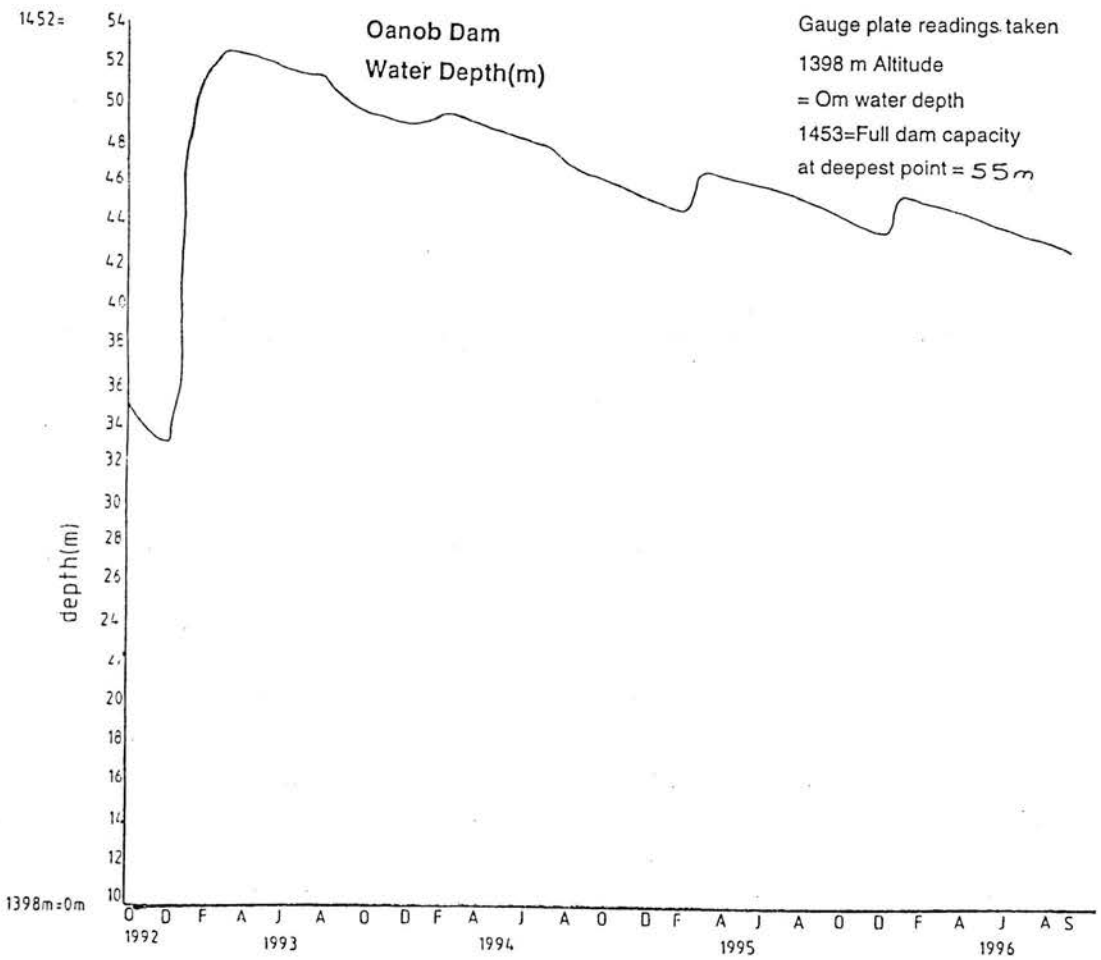


TABLE 5 : A COMPARISON OF GENERAL WATER CHEMISTRY TRENDS IN THE THREE DAMS FROM 1992 - 1996

| CHEMICAL | VON BACH | SWAKOPPOORT | OANOB |
|---|---|---|---|
| Conductivity uS/cm | 117 -315 | 302 -580 | 141 -264 |
| TDS mg/l | 77 -209 | 199.5 -425 | 93 - 174 |
| Total Alkalinity mg/l | 57 -139 | 129- 215 | 62 - 130 |
| pH | 6.9 -8.35 | 6.9 - 8.8 | 6.9 - 8.35 |
| Cl mg/l | 0.5 - 15.5 | 18 - 46.5 | 0.5 - 9 |
| Na mg/l | 3 -18.5 | 12.5 - 64 | <1 -13 |
| K mg/l | 6 - 14.5 | 13 - 31 | 5 - 12.8 |
| SO4 mg/l | <1 -20 | 7.0 - 35 | 0.19 -17.5 |
| Ca mg/l | 37 - 76 | 53.5 - 90 | 45 -93.5 |
| Mg mg/l | 12.0 - 39 | 29 - 59.5 | 8.9 - 27 |
| SiO2 mg/l | <0.5 -6.5 | <.5 - 8 | 0.5 - 9 |

The values of Table 5 are the minimum and maximum monthly concentrations recorded.

## 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. Figures 11 -13 reflect the Chl *a* concentrations recorded in the three dams during the survey time.

**Von Bach**

The dam showed clear signs of algal blooms in January 1992, January '93 and December '95. Both blooms in January correspond with nutrient increases, but the December bloom in 1995 corresponds 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 Chl *a* value recorded at Von Bach for the monitoring period was ± 280 µg\ℓ. Some recordings were above 20µg\ℓ. However, almost 80% of the values were lower than 10µg\ℓ, indicating a possible decrease in productivity, compared to the last survey, where half the values were above 20µg\ℓ (Bethune '92). This can be attributed to the impact of increased turbidity as a result of water inputs from Omatako Dam.

**Swakoppoort**

The dam showed regular algal blooms, the worst ones being in February '93, June '93, September '93, January '94, May '94 and July '94. All blooms showed a positive correlation with increasing nutrient concentrations, except for the worst one in June '93, where values exceeded 1800µg\ℓ and nutrients dropped low that month.

Regular occurrences of values exceeding 30µg\ℓ indicate that this dam is by far the most productive of the three impoundments and that the values have increased greatly since the last monitoring period.

**Oanob**

Chl *a* values were not stable in this dam. They varied almost monthly from high to low Chl *a* concentrations. The worst bloom occurred in August '95 with values of just under 120µg\ℓ. Nutrient values (Nitrogen) were dropping at time. Just under half of the values exceed 20µg\ℓ, making it a fairly productive impoundment.

### 4.3.2 HIGHER PLANTS

Due to their steep draw-down zones and irregular water fluctuations, none of the three impoundments have any established marginal vegetation and with the exception of floating *Spirodela* plants, which are once again evident on Swakoppoort dam, following the 1992-96 dry periods. There are no floating macrophytes either.

### 4.3.3 FISH

According to the Ministry of Fisheries and Marine Resources at Mariental there are six different fish species presently occurring in the three impoundments. Of these six species, four occur in von Bach, five in Swakoppoort and three in Oanob.

**Von Bach**

This dam supports four fish species, namely *Oreochromis mossambicus, Clarias gariepinus, Cyprinus carpio* and *Micropterus salmoides. Tilapia sparmanii* and *Barbus paludinosus*, found in the 1987 -1990 monitoring survey were not included on the recent list from the Freshwater Research Institute at Hardap (January 1997).

**Swakoppoort**

The five fish species found here are: *O. mossambicus, C. gariepinus, C. carpio, B. Paludinosus* and *T. sparmanii. C. carpio* was not observed in the former surveys, however two species, *T. rendalli* and *O. macrochir* were found during the survey periods of 1984 -1990 and were not on the recent list. The impoundment was stocked with these species earlier, but they may not have survived the predatory *Clarias gariepinus*, which dominate.

**Oanob**

According to the Ministry of Fisheries and Marine Resources this young dam already hosts three different fish species : *O. mossambicus, C. carpio* and *B. paludinosus.*

### 4.3.4 BIRDS

All available data on the bird counts from 1992 to 1996 are included in Table 4 at the bottom of the page. This comprises seven bird counts for the Von Bach and Swakoppoort Dams, as well as five for Oanob. The counts were conducted in co-operation with the Ministry of Wildlife, Conservation and Tourism as part of an International Wetland Bird Program (IWBP).

**Von Bach**

Of the three dams the von Bach Dam has the lowest counts in species as well as numbers (an average of 15 species and 330 birds ). The high boat traffic on von Bach Dam is undoubtedly a factor for the low numbers of water birds inhabiting this dam.

**Swakoppoort**

Swakoppoort Dam has both the greatest wetland bird diversity as well as the greatest numbers ( a mean of 23 species and 1900 birds). The richness of this dam is probably due to it's prolific fish fauna, undisturbed shoreline and larger shallow areas at the inlet, which supports some of the smaller wading birds.

**Oanob**

Unfortunately no data was found for the 1996 counts on this dam.
The species diversity, as well as the bird abundance of Oanob Dam lies between those of von Bach and Swakoppoort with, on average 16 species and 400 birds. There is a reasonably low amount of boat traffic on this dam, which might have contributed to the fast colonisation of the young dam by wetland birds.

**TABLE 6:** DATA ON BIRD COUNTS FROM 1992 TO 1996

| | | Jan-92 | Jul-92 | Jan-94 | Apr-94 | Jan-95 | Jan-96 | Apr-96 |
|---|---|---|---|---|---|---|---|---|
| VON BACH | NO.SPECIES | 22 | 16 | 12 | 9 | 19 | 12 | 14 |
| | NO. BIRDS | 440 | 724 | 193 | 131 | 418 | 272 | 135 |
| SWAKOPPOORT | NO.SPECIES | 21 | 25 | 21 | 23 | 31 | 22 | 22 |
| | NO.BIRDS | 2105 | 3243 | 1791 | 1795 | 1691 | 1346 | 1236 |
| OANOB | NO.SPECIES | 14 | 17 | 13 | 12 | 25 | no | readings |
| | NO. BIRDS | 101 | 205 | 833 | 493 | 436 | | |

In Table 6 the 1992 bird count results were included,
to give a better view of possible patterns.

## 5. CONCLUSIONS

During this monitoring period it became evident that the impoundments underwent changes and instabilities. However, it was sometimes difficult to draw the correct conclusions about these occurrences as: monitoring only once a month at one site is not always sufficient to detect and follow chemical and biological changes within the whole impoundment.

### Von Bach

Von Bach Dam remained a typically monomictic impoundment with increasing chemical concentrations and turbidity. Increasing turbidity caused by the Omatako inflows could be causing the decrease in productivity noted in this last survey. Turbidity decreases the productive euphotic zone in an impoundment. The second explanation for the decreased productivity might be a lack of nutrient rich natural inflows since 1994. Von Bach receives water inputs from Omatako Dam. The water chemistry of Omatako is very different to the von Bach's and the influence of this difference can be observed when pumpings take place, as the chemistry trends in the von Bach impoundment change in these times. To establish the extent of the chemical changes occurring in the von Bach Dam water, caused by these pumpings, it might be important to include the Omatako Dam into the monitoring programme once again. Additionally, a site on von Bach near to the Omatako inflow should be monitored.

### Swakoppoort

This dam is monomictic, chemically stable and becoming increasingly eutrophic. The chemical concentrations are the highest of the three dams. It is the most productive impoundment, and of medium transparency. *Spirodela* which was once a problem on this dam has recently reappeared after having been washed over the wall in 1989. Swakoppoort Dam has lost a lot of its volume especially in the last year due to increased evaporation during the drought and increased water withdrawal to supply Windhoek and Navagab Mine, as well as Karibib.

### Oanob

A baseline was established for this dam and regular monthly monitoring commenced. The impoundment is monomictic and the water is clear. The chemistry is still unstable and further fortnightly monitoring is recommended .

## 6. RECOMMENDATIONS

6.1 That this report be accepted as the update of the limnological monitoring of the von Bach and Swakoppoort Dams, as well as the limnological baseline and monitoring report on Oanob Dam for the period 1992 -1996.

6.2 That monitoring should be done on a more regular basis and at more sites to allow more accurate observations, especially in times of overturn and inflow, as the chance of water quality changes in these times is very high.

6.3 That the responsibility of limnological monitoring of state impoundments be handed over to Namwater as from October 1996 .

Compiled by: K. Schachtschneider
Student Research Assistant
( University of Cape Town)
Date: July 1997

## 7. APPROVAL OF RECOMMENDATIONS

This progress report is approved for submission to the Director : Resource Management.

DEPUTY DIRECTOR : WATER ENVIRONMENT DATE 10/7/97

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

DIRECTOR : RESOURCE MANAGEMENT DATE 14/07/97

The recommendations in this report have been decided as follows:

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UNDER SECRETARY FOR WATER AFFAIRS DATE:

## 8. ACKNOWLEDGMENTS

I would like to thank all who assisted with this monitoring (and baseline for Oanob) programme. Filemon and Matheus Gariseb, Ellis Ekanjo, George Diergaardt, Freddy Koujo and Manfredt Katjitae assisted with fieldwork. Water analyses were done by the chemical and biochemical laboratories at Aigams. Elna Almirall and Roland Roeis assisted with data analysis. Kevin Roberts was responsible for the bird counts on the dams, as well as the comments on the bird abundance at the three dams.. Manfredt Katjitae assisted with report preparation.
I would also like to thank the people who provided information and material to make this report possible. Dr. Rob Simmons for the bird count data, Mr. Strauss for the provision of fish data, NP du Plessis for information on Oanob water releases, the Hydrology Division, the Drawing Office, as well as Operations Central and South. Pauline van Wyk typed the draft report. Shirley Bethune guided and critically evaluated the report.

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## 10. ADDENDUM

**TABLE 1:** MEAN MONTHLY VALUES AND STANDARD DEVIATIONS OF SOME CHEMICAL CHARACTERISTICS OF WATER FROM VON BACH DAM. OCTOBER 1992 - SEPTEMBER 1996

**TABLE 2** : MEAN MONTHLY VALUES AND STANDARD DEVIATIONS OF SOME BIOCHEMICAL CHARACTERISTICS OF WATER FROM VON BACH DAM. OCTOBER 1992 - SEPTEMBER 1996

**TABLE 3:** MEAN MONTHLY VALUES AND STANDARD DEVIATIONS OF SOME CHEMICAL CHARACTERISTICS OF WATER FROM SWAKOPPOORT DAM. OCTOBER 1992 - SEPTEMBER 1996

**TABLE 4** : MEAN MONTHLY VALUES AND STANDARD DEVIATIONS OF SOME BIOCHEMICAL CHARACTERISTICS OF WATER FROM SWAKOPPOORT DAM. OCTOBER 1992 - SEPTEMBER 1996

**TABLE 5:** MEAN MONTHLY VALUES AND STANDARD DEVIATIONS OF SOME CHEMICAL CHARACTERISTICS OF WATER FROM OANOB DAM. OCTOBER 1992 - SEPTEMBER 1996

**TABLE 6** : MEAN MONTHLY VALUES AND STANDARD DEVIATIONS OF SOME BIOCHEMICAL CHARACTERISTICS OF WATER FROM OANOB DAM. OCTOBER 1992 - SEPTEMBER 1996

**GRAPH 1** : ORIGINAL, COMPUTERISED GRAPHS OF WATER CHEMISTRY TRENDS IN VON BACH DAM

**GRAPH 2** : ORIGINAL, COMPUTERISED GRAPHS OF WATER CHEMISTRY TRENDS IN SWAKOPPOORT DAM

**GRAPH 3** : ORIGINAL, COMPUTERISED GRAPHS OF WATER CHEMISTRY TRENDS IN OANOB DAM

TABLE 1

Von Bach Dam (some monthly means and standard deviations of chemical characteristics)

| Chemical Unit | Apr-93 n=2 | Sep-93 n=2 | Jan-94 n=2 | Apr-94 n=2 | Sep-94 n=2 | Jan-95 n=2 | Apr-95 n=2 | Sep-95 n=2 | Jan-96 n=2 | Apr-96 n=2 | Sep-96 n=2 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total Alkalinity | | 94 | 73 | 66 | 84 | 80 | 103 | 94 | 99 | 111 | 134 |
| as CaCO3 mg\l | | 0 | 1.41 | 0 | 0 | 0 | 1.41 | 0 | 7.07 | 7.07 | 2.82 |
| Conductivity | | 212 | 146 | 145 | 164.5 | 171.5 | 200 | 209 | 246 | 276.2 | 306.5 |
| us/cm | | 2.83 | 1.41 | 1.41 | 2.12 | 0.71 | 1.41 | 1.41 | 11.3 | 21.9 | 17.67 |
| pH | | 7.8 | 7.85 | 6.85 | 8.2 | 8.2 | 7.9 | 8.15 | 8.25 | 7.25 | 7.9 |
| (Laboratory) | | 0 | 0.21 | 0.21 | 0 | 0 | 0.14 | 0.07 | 0.07 | 0.07 | 0.21 |
| TDS | | 140 | 96.5 | 95.5 | 109 | 113.5 | 132 | 138 | 162.5 | 182.5 | 202.5 |
| mg/l | | 1.41 | 0.71 | 0.71 | 1.41 | 0.71 | 1.41 | 1.41 | 7.78 | 14.85 | 12.02 |
| Na | | 5.5 | 5 | 3 | 4 | 4 | 9 | 7 | 6.5 | 9.5 | 15.5 |
| mg/l | | 0.71 | 0 | 0 | 0 | 0 | 0 | 0 | 0.71 | 0.71 | 3.53 |
| K | | 11 | 11 | 75 | 8 | 8.5 | 9 | 10 | 10 | 11 | 12 |
| mg/l | | 0 | 0 | 0.71 | 0 | 0.71 | 0 | 0 | 0 | 1.41 | 1.41 |
| SO4 | | 1 | * | 2 | 4.5 | * | 5 | 20 | 3.5 | 3.5 | 8.5 |
| mg/l | | 0 | 0 | 0 | 2.2 | 0 | 0 | 0 | 3.54 | 0.71 | 2.12 |
| Ca as CaCO3 | | 64.5 | 37 | 47 | 55 | 45 | 57 | 50 | 61 | 68.5 | 64.5 |
| mg/l | | 3.54 | 0 | 0 | 0 | 0 | 0 | 0 | 1.41 | 2.12 | 3.53 |
| Mg asCaCO3 | | 23 | 18.5 | 10 | 14 | 25 | 21 | 33 | 27 | 29 | 39 |
| mg/l | | 2.83 | 3.54 | 2.83 | 2.83 | 0 | 0 | 0 | 2.83 | 0 | 2.82 |
| SiO3 | | 1.5 | 3.5 | 5 | 6 | * | 1 | 1 | * | * | 0.5 |
| mg/l | | 0.71 | 0.71 | 4.24 | 7.07 | 0 | 0 | 0 | 0 | 0 | 0.7 |
| Cl | | 2.5 | 5 | 2.5 | 2 | 4 | 1 | * | 3.5 | 3 | 6.5 |
| mg/l | | 0.71 | 1.41 | 0.71 | 0 | 0 | 0 | 0 | 2.12 | 0 | 0.7 |

TABLE 2 **Von Bach Dam** (some monthly means and standard deviations of biochemical characteristics)

| biochemical unit | Oct-92 n=2 | Jan-93 n=2 | Apr-93 n=2 | Sep-93 n=2 | Jan-94 n=2 | Apr-94 n=2 | Sep-94 n=2 | Jan-95 n=2 | Apr-95 n=2 | Sep-95 n=2 | Jan-96 n=2 | Apr-96 n=2 | Sep-96 n=2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tot.unfil. | 0.032 | 0.058 | 0.087 | 0.03 | 0.125 | 0.034 | 0.011 | 0.012 | 0.008 | 0.067 | 0.006 | 0.027 | 0.065 |
| Phosphate | 0.008 | 0.032 | 0.033 | 0.011 | 0.021 | 0.004 | 0.004 | 0.005 | 0.001 | 0.03 | 0 | 0.018 | 0.007 |
| Tot.fil. | 0.012 | 0.037 | 0.064 | 0.017 | 0.027 | 0.007 | 0.003 | 0.003 | * | 0.028 | 0.001 | 0.006 | 0.045 |
| Phosphate | 0.006 | 0.022 | 0.028 | 0.008 | 0.005 | 0 | 0.004 | 0.001 | 0 | 0.003 | 0 | 0.006 | 0.007 |
| Ortho Phos- | 0.008 | 0.012 | 0.034 | 0.007 | 0.019 | 0.001 | 0.002 | 0.001 | * | 0.005 | 0.001 | 0.002 | 0.01 |
| phate fil. | 0 | 0.006 | 0.001 | 0.009 | 0.006 | 0 | 0.003 | 0.002 | 0 | 0.006 | 0 | 0.001 | 0 |
| NO3 | 1 | 0.5 | 1.83 | * | * | 0.5 | * | * | * | * | 0.68 | * | * |
| | 0 | 0 | 0.52 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.25 | 0 | 0 |
| NO2 | * | * | * | 1 | * | * | * | * | * | * | 0.075 | 0.35 | * |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.11 | 0.07 | 0 |
| Total N | 1.05 | 0.73 | 1.04 | 0.59 | 1.05 | 0.66 | 0.085 | 0.79 | 1.54 | 1.01 | 1 | 1.77 | 1.4 |
| | 0.64 | 0.62 | 0.27 | 0 | 0.21 | 0.47 | 0.4 | 0.1 | 0.57 | 0 | 0 | 0.42 | 0.72 |
| NH4 | 15 | 0.15 | 0.42 | 0.145 | 0.15 | 0.33 | 0.21 | 0.14 | 0.57 | 0.33 | 0.5 | 0.89 | 0.13 |
| | 0.21 | 0.21 | 0.48 | 0.21 | 0.21 | 0.47 | 0.1 | 0 | 0.35 | 0 | 0.24 | 0.42 | 0 |
| CHL a | 25.8 | 45.86 | 5.77 | 9.7 | 150.8 | 28.65 | 6.88 | 2.87 | 6.31 | 280.3 | 3.44 | 16.05 | 35.5 |
| ug/l | 4.1 | 6.48 | 6.62 | 8.91 | 26.77 | 8.13 | 3.24 | 0.81 | 4.05 | 184 | 1.63 | 1.63 | 21.07 |
| Turbidity | 0.9 | 2.9 | 79.17 | 8.6 | 68 | 4.75 | 1.4 | 0.35 | 5.15 | 3.5 | 3.65 | 6.45 | 4.15 |
| | 0.14 | 0 | 18.48 | 0.57 | 0 | 0.35 | 0.28 | 0.071 | 0.07 | 2.12 | 0.21 | 4.17 | 2.62 |

TABLE 3

**Swakoppoort Dam** (some means and standard deviations of chemical characteristics)

| Chemical Unit | Oct-92 n=2 | Jan-93 n=2 | Apr-93 n=2 | Sep-93 n=2 | Jan-94 n=2 | Apr-94 n=2 | Sep-94 n=2 | Jan-95 n=2 | Apr-95 n=2 | Sep-95 n=2 | Jan-96 n=2 | Apr-96 n=2 | Sep-96 n=2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total Alkalinity as CaCO3 mg\l | 154<br>0 | 169<br>1.41 | 136<br>11.31 | 156<br>2.83 | 134<br>14.14 | 136<br>0 | 149<br>1.41 | 144<br>2.83 | 158<br>8.49 | 176<br>2.83 | 170<br>8.49 | 188<br>0 | 215<br>1.41 |
| Conductivity us/cm | 412.5<br>2.12 | 420.5<br>0.71 | 351<br>9.9 | 408.2<br>3.54 | 338<br>21.21 | 357<br>7.07 | 394.5<br>7.78 | 420<br>12.73 | 422<br>9.9 | 490.5<br>0.71 | 543<br>32.6 | 517<br>16.97 | 634.5<br>13.44 |
| pH (Laboratory) | 8.15<br>0.07 | 8.05<br>0.07 | 8.3<br>0 | 7.9<br>0 | 8.2<br>0.57 | 7.35<br>0.21 | 7.65<br>0.35 | 7.9<br>0.14 | 7.9<br>0.14 | 8.8<br>0 | 8.55<br>0.21 | 7.8<br>0.28 | 7.8<br>0.28 |
| TDS mg/l | 272<br>1.41 | 277.5<br>0.71 | 231.5<br>6.36 | 269.5<br>2.12 | 223<br>14.14 | 235.5<br>4.95 | 260.5<br>4.95 | 277<br>8.49 | 278.5<br>6.36 | 323.5<br>0.71 | 358.5<br>21.92 | 341<br>11.31 | 419<br>8.49 |
| Na mg/l | 34<br>0 | 39.5<br>0.71 | 26<br>0 | 28<br>0 | 30<br>0 | 31<br>0 | 35<br>0 | 37.5<br>0.71 | 42<br>1.41 | 45<br>0 | 51.5<br>0.71 | 57<br>0 | 64<br>1.41 |
| K mg/l | 19<br>0 | 18.5<br>0.71 | 18<br>0 | 16<br>0 | 18.5<br>0.71 | 16<br>0 | 17.5<br>0.71 | 19<br>0 | 23<br>0 | 24<br>0 | 26.5<br>0.71 | 26<br>0 | 30.5<br>0.71 |
| SO4 mg/l | 7<br>0 | 9.5<br>0.71 | 7<br>0 | 16<br>5.66 | 10<br>0 | 10<br>0 | 13<br>0 | 9.5<br>0.71 | 18.5<br>3.54 | 22.5<br>3.54 | 17.5<br>0.71 | 16.5<br>0.71 | 24.5<br>3.54 |
| Ca as CaCO3 mg/l | 67<br>0 | 65<br>0 | 63.5<br>12.02 | 90<br>0 | 61<br>19.8 | 60<br>0 | 63.5<br>2.12 | 55<br>0 | 53.5<br>2.12 | 66<br>1.41 | 57<br>0 | 55<br>0 | 67<br>0 |
| Mg asCaCO3 mg/l | 37<br>0 | 45<br>0 | 31<br>2.83 | 33<br>0 | 35<br>2.83 | 29<br>0 | 31<br>2.83 | 41<br>0 | 31<br>2.83 | 45<br>0 | 45<br>0 | 47<br>0 | 54<br>0 |
| SiO3 mg/l | 2<br>0 | 0.5<br>0.71 | 0.5<br>0.71 | 1<br>0 | 1.5<br>0.71 | 2<br>0 | *<br>0 | 1<br>0 | 1<br>0 | 0.5<br>0.71 | *<br>0 | 0.5<br>0.71 | 1<br>0 |
| Cl mg/l | 25<br>0 | 25<br>0 | 20<br>0 | 18<br>0 | 23.5<br>3.54 | 22.5<br>0.71 | 23<br>0 | 28.5<br>2.12 | 20<br>0 | 33.5<br>0.71 | 37<br>4.24 | 46<br>0 | 46.5<br>0.71 |

TABLE 4 **Swakoppoort Dam** (some monthly means and standard deviations of biochemical characteristics)

| biochemical unit | Oct-92 n=2 | Jan-93 n=2 | Apr-93 n=2 | Sep-93 n=2 | Jan-94 n=2 | Apr-94 n=2 | Sep-94 n=2 | Jan-95 n=2 | Apr-95 n=2 | Sep-95 n=2 | Jan-96 n=2 | Apr-96 n=2 | Sep-96 n=2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tot.unfil. | 0.012 | 0.04 | 0.127 | 0.01 | 0.064 | 0.049 | 0.015 | 0.016 | 0.04 | 0.03 | 0.004 | 0.039 | 0.1 |
| Phosphate | 0.004 | 0.026 | 0.017 | 0.001 | 0.018 | 0.006 | 0.008 | 0.007 | 0.019 | 0.02 | 0.001 | 0.03 | 0.014 |
| Tot.fil. | 0.006 | 0.039 | 0.1 | * | 0.014 | 0.015 | 0.011 | 0.011 | 0.011 | 0.022 | 0.001 | 0.012 | 0.075 |
| Phosphate | 0.003 | 0.027 | 0.006 | 0 | 0.006 | 0 | 0.011 | 0.007 | 0.004 | 0.02 | 0 | 0.016 | 0.0071 |
| Ortho Phos- | 0.004 | 0.012 | 0.092 | * | 0.01 | 0.008 | 0.009 | 0.008 | 0.004 | 0.011 | 0.001 | 0.007 | 0.025 |
| phate fil. | 0.004 | 0.006 | 0.007 | 0 | 0.005 | 0.001 | 0.011 | 0.006 | 0.004 | 0.002 | 0 | 0.008 | 0.007 |
| NO3 | * | 0.25 | 0.5 | 0.25 | * | 0.75 | * | * | * | 0.5 | * | * | * |
| | 0 | 0.35 | 0 | 0.35 | 0 | 0.35 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NO2 | * | * | * | 0.1 | * | * | 0.175 | 0.1 | * | * | * | * | * |
| | 0 | 0 | 0 | 0.14 | 0 | 0 | 0.247 | 0.14 | 0 | 0 | 0 | 0 | 0 |
| Total N | 0.75 | 0.58 | 1.11 | 1.34 | 1.51 | 1.155 | 1.77 | 1.24 | 1.21 | 1.18 | 1 | 2.05 | 2.55 |
| | 0.21 | 0 | 0.4 | 0.21 | 0.43 | 0.23 | 0.7 | 0.44 | 1.03 | 0.23 | 0 | 0.017 | 0.219 |
| NH4 | 0.45 | 0.44 | 0 | 0.29 | 0.15 | 0.83 | 0.57 | 1.01 | 0.4 | 0.34 | 0.5 | 0.88 | 0.04 |
| | 0.64 | 0.21 | 0 | 0 | 0.21 | 0.23 | 0 | 0.54 | 0.11 | 0.007 | 0.24 | 0 | 0.014 |
| CHL a | 2.87 | 12.04 | 8.59 | 48.7 | 72.8 | 26.35 | 31.75 | * | 12.6 | 22.78 | 9.18 | 14.3 | 26.95 |
| ug/l | 4.05 | 5.67 | 2.42 | 2.4 | 64.01 | 1.63 | 18.96 | 0 | 3.25 | 19.24 | 6.48 | 5.66 | 4.031 |
| Turbidity | 0.5 | 4.75 | 2.45 | 2.05 | 33 | 3.25 | 1.7 | 0.35 | | 2.4 | 2.65 | 7.35 | 3.5 |
| | 0 | 3.18 | 0.35 | 1.48 | 4.24 | 0.35 | 0.14 | 0.07 | | 0.14 | 0.21 | 2.33 | 3.25 |

TABLE 5 **Oanob Dam** (some monthly means and standard deviations of chemical characteristics)

| Chemical<br>Unit | Oct-92<br>n=8 | Jan-93<br>n=8 | Apr-93<br>n=16 | Sep-93<br>n=15 | Jan-94<br>n=2 | Apr-94<br>n=2 | Sep-94<br>n=2 | Jan-95<br>n=2 | Apr-95<br>n=2 | Sep-95<br>n=2 | Jan-96<br>n=2 | Apr-96<br>n=2 | Sep-96<br>n=2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total Alkalinity | 101.25 | 118.25 | 62.25 | 86.27 | 85 | 82 | 88 | 90 | 90 | 92 | 102 | 110 | 129 |
| as CaCO3 mg\l | 13.39 | 17.52 | 5.83 | 9.68 | 7.07 | 8.49 | 11.31 | 0 | 0 | 5.66 | 19.8 | 2.83 | 7.071 |
| Conductivity | 213.88 | 239.88 | 141.25 | 164.6 | 165.5 | 175 | 181 | 234 | 184 | 192 | 240.5 | 254 | 263.5 |
| us/cm | 25.22 | 23.11 | 6.33 | 15.26 | 13.44 | 4.24 | 15.56 | 64.3 | 11.31 | 7.07 | 14.85 | 18.4 | 9.192 |
| pH | 7.89 | 7.86 | 7.42 | 7.69 | 7.6 | 7.15 | 7.7 | 7.9 | 7.3 | 7.9 | 8.05 | 7.65 | 7.6 |
| (Laboratory) | 0.17 | 0.17 | 0.58 | 0.18 | 0.85 | 0.21 | 0.57 | 0.21 | 0.28 | 0 | 0.49 | 0.071 | 0 |
| TDS | 141.25 | 158.25 | 93.31 | 108.87 | 109.5 | 115.5 | 119.5 | | 121.5 | 126.5 | 159 | 167.5 | 174 |
| mg/l | 16.51 | 15.03 | 4.27 | 10.03 | 9.19 | 2.12 | 10.61 | | 7.78 | 4.95 | 9.9 | 12.03 | 5.66 |
| Na | 2.75 | 3.5 | 1.5 | 1.67 | 2 | 3 | 3.5 | 2.5 | 2 | 1 | 5.5 | 1 | 3.5 |
| mg/l | 1.98 | 1.69 | 0.52 | 0.49 | 0 | 1.41 | 0.71 | 0.71 | 0 | 0 | 0.71 | 0 | 0.71 |
| K | 9.25 | 12.75 | 6.56 | 5.87 | 7.5 | 8 | 7.5 | 8.5 | 7 | 8.5 | 7 | 8.5 | 10.5 |
| mg/l | 0.46 | 1.16 | 0.63 | 1.25 | 0.71 | 0 | 0.71 | 0.71 | 0 | 0.71 | 0 | 0.71 | 0.71 |
| SO4 | 2.63 | 5 | 1.81 | 1.47 | 1 | 4.5 | 3 | 0.5 | * | 2.5 | 4.5 | 1.5 | 6 |
| mg/l | 1.77 | 3.37 | 2.07 | 0.52 | 0 | 2.12 | 0 | 0.71 | 0 | 0.71 | 0.71 | 0.71 | 0 |
| Ca as CaCO3 | 80.63 | 85.75 | 45.75 | 66.6 | 65 | 57.5 | 62.5 | 63.5 | 65 | 67.5 | 66 | 80 | 88.5 |
| mg/l | 14.79 | 16.42 | 4.2 | 9.1 | 7.07 | 10.61 | 10.61 | 4.95 | 7.07 | 3.54 | 12.73 | 0 | 9.192 |
| Mg asCaCO3 | 20.38 | 24 | 11.75 | 12 | 12 | 16 | 12 | 18.5 | 16.5 | 16 | 21 | 21 | 27 |
| mg/l | 1.77 | 2.83 | 1.77 | 0 | 0 | 0 | 0 | 0.53 | 6.36 | 0 | 0 | 0 | 2.828 |
| SiO3 | 3.75 | 5 | 3.19 | 1.5 | 0.5 | 3 | 2.5 | 1 | 1 | 2 | * | 5 | 5 |
| mg/l | 0.71 | 2.27 | 0.4 | 0.52 | 0.71 | 0 | 0.71 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cl | 4.57 | 2.88 | 2.38 | 2.2 | 1.5 | 2.5 | 2 | 3.5 | 2 | 2 | 0.5 | 2 | 3 |
| mg/l | 2.32 | 0.83 | 2.09 | 1.47 | 0.71 | 2.12 | 0 | 2.12 | 0 | 0 | 0.71 | 0 | 0 |

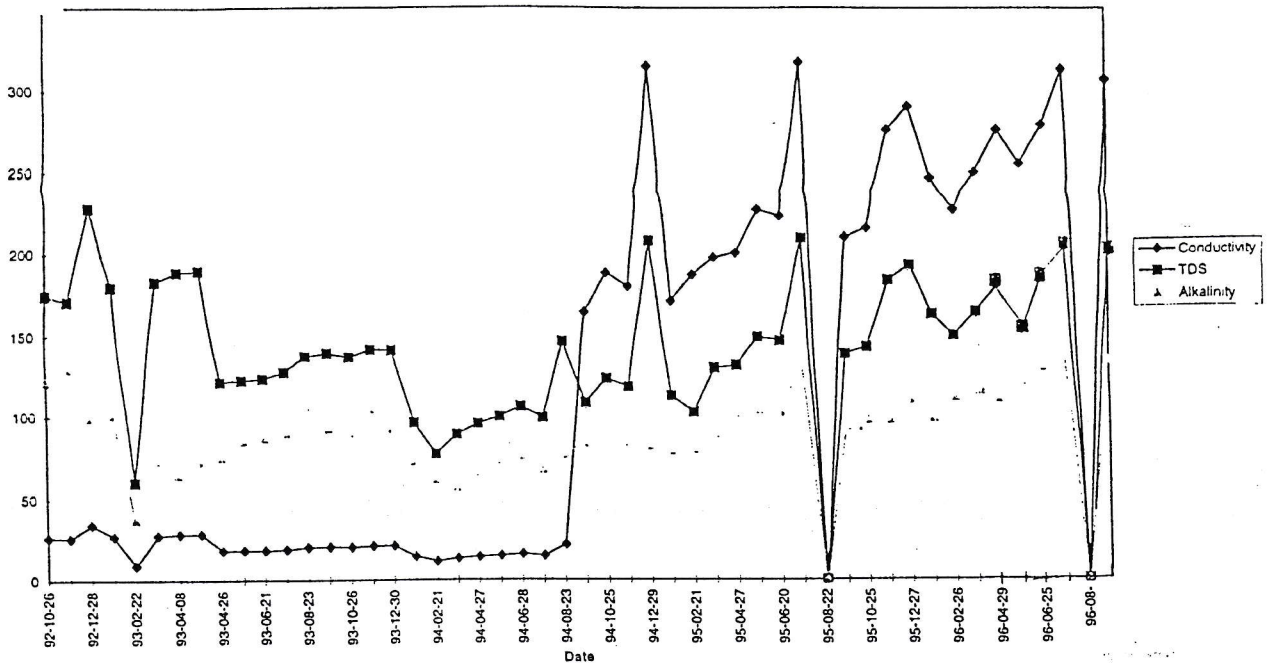
TABLE 6 **Oanob Dam** (some monthly means and standard deviations of biochemical characteristics)

FromOct.92 -Sep93 samples taken twice monthly,below latest sample of each month given

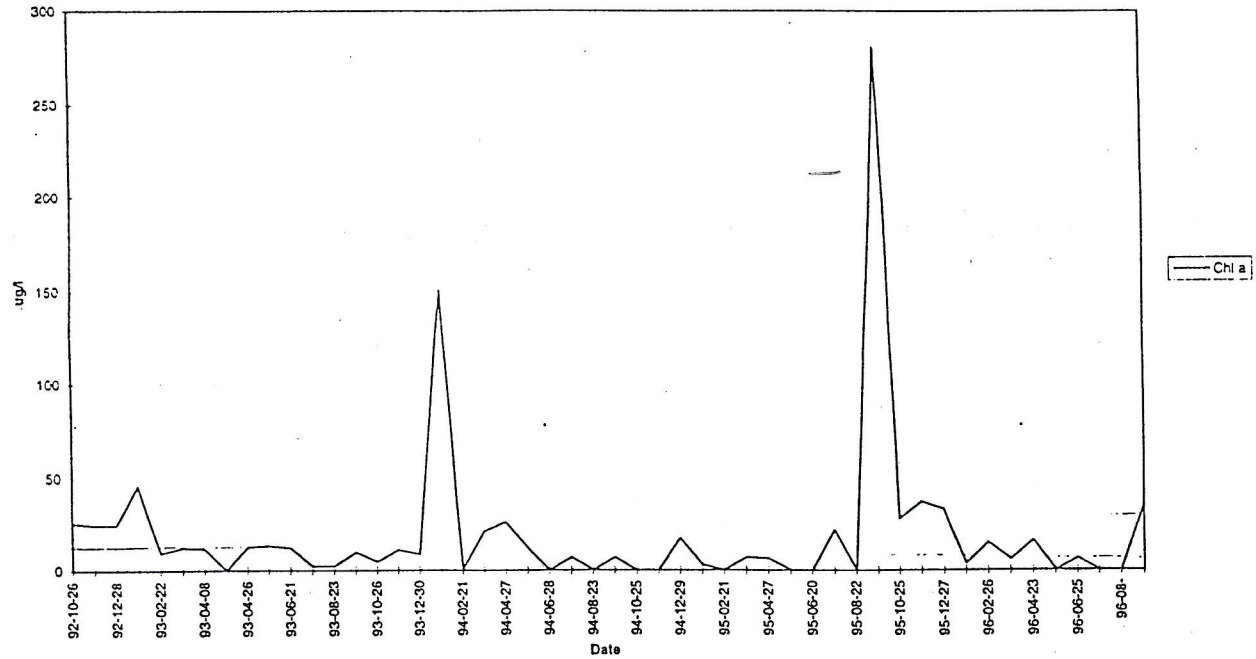
| biochemical unit | Oct-92 n=4 | Jan-93 n=4 | Apr-93 n=8 | Sep-93 n=7 | Jan-94 n=2 | Apr-94 n=2 | Sep-94 n=2 | Jan-95 n=2 | Apr-95 n=2 | Sep-95 n=2 | Jan-96 n=2 | Apr-96 n=2 | Sep-96 n=2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tot.unfil. | 0.018 | 0.187 | 0.1 | 0.014 | 0.018 | 0.015 | 0.007 | 0.007 | 0.039 | 0.015 | 0.041 | 0.02 | 0.06 |
| Phosphate | 0.072 | 0.177 | 0.035 | 0.003 | 0.004 | 0.011 | 0.001 | 0.003 | 0.033 | 0.011 | 0.01 | 0.01 | 0 |
| Tot.fil. | 0.003 | 0.024 | 0.019 | 0.007 | 0.006 | 0.002 | 0.005 | 0.005 | 0.016 | 0.013 | 0.001 | 0.001 | 0.05 |
| Phosphate | 0.003 | 0.014 | 0.01 | 0.005 | 0.002 | 0.003 | 0.001 | 0.001 | 0.008 | 0.008 | 0 | 0 | 0 |
| Ortho Phos- | * | 0.006 | 0.011 | 0.003 | 0.001 | * | 0.003 | 0.002 | 0.028 | 0.012 | * | 0.001 | 0.03 |
| phate fil. | 0 | 0.007 | 0.006 | 0.004 | 0 | 0 | 0.001 | 0.003 | 0.018 | 0.006 | 0 | 0 | 0 |
| NO3 | 0.75 | 0.875 | 0.25 | * | * | * | 0.5 | * | 0.5 | 0.015 | * | * | * |
| | 0.957 | 0.854 | 0.27 | 0 | 0 | 0 | 0 | 0 | 0.71 | 0.07 | 0 | 0 | 0 |
| NO2 | * | * | * | * | * | * | * | * | * | * | * | * | * |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total N | 0.189 | 2.19 | 0.55 | 0.59 | 1.06 | 0.99 | 0.57 | 1.54 | 1.49 | 0.5 | 0.83 | 4.23 | 3.015 |
| | 0.241 | 1.917 | 0 | 0 | 0.64 | 0.47 | 0 | 0.44 | 1.17 | 0.24 | 0.71 | 2.84 | 0.799 |
| NH4 | 0.126 | 0.803 | 0.243 | * | 0.45 | 0.165 | 0.29 | 0.93 | 0.66 | 0.34 | 0.83 | 0.83 | 0.6 |
| | 0.252 | 0.69 | 0.23 | 0 | 0.64 | 0.23 | 0 | 0.87 | 11.9 | 0.47 | 0.71 | 0.4 | 0.4525 |
| CHL a | 34.4 | 39.85 | 19.92 | 17.68 | 8.6 | 13.16 | 12.6 | | 0.99 | 8.03 | 26.94 | 17.22 | |
| ug/l | 33.03 | 26.19 | 9.6 | 11.5 | 5.66 | 10.16 | 3.25 | 23.5 | | 11.35 | 25.13 | 16.24 | |
| Turbidity | 14.38 | 64.48 | 2.24 | 1.59 | 1.05 | 1.25 | 1.75 | 33.2 | | 2.9 | 5.9 | | |
| | 15.66 | 83.89 | 0.66 | 1.31 | 0.07 | 1.06 | 1.63 | no read. | | 0.42 | 2.26 | | |

RAPH 1

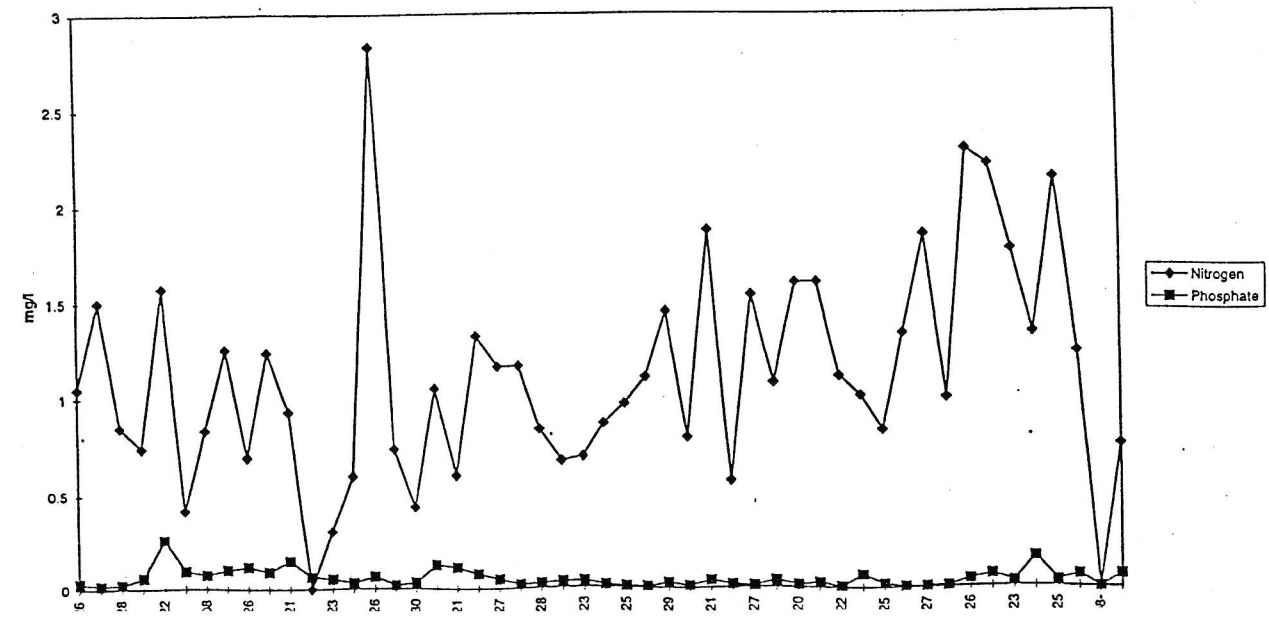
von Bach Dam



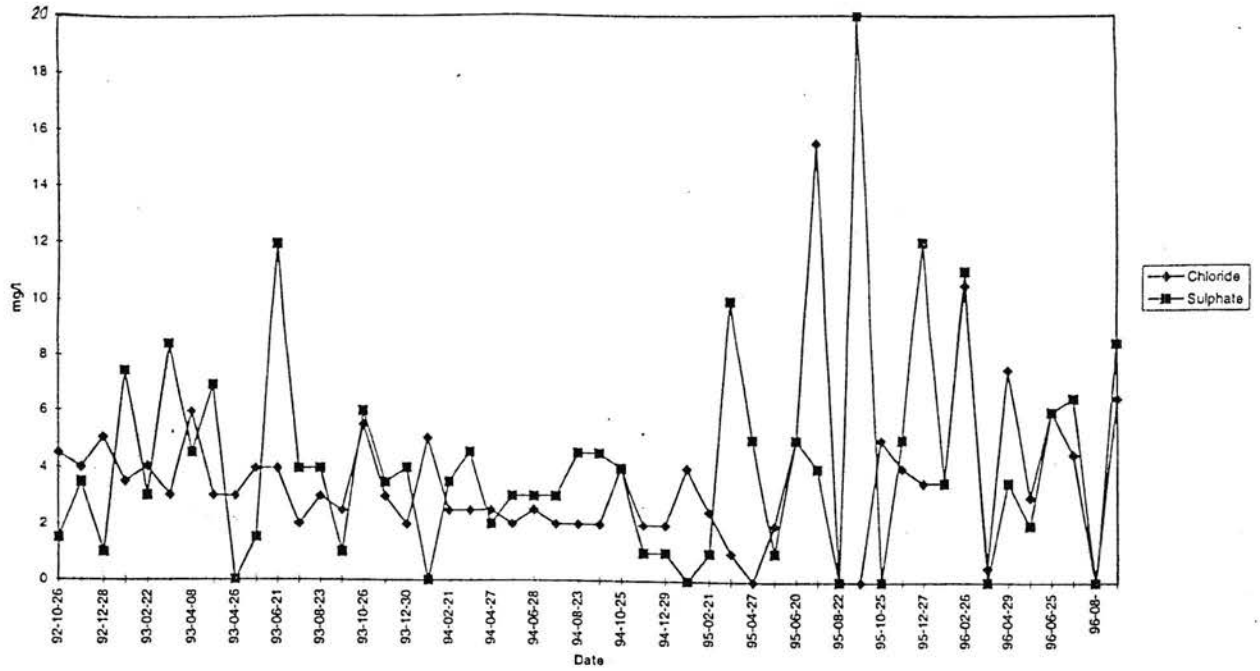

Chl a



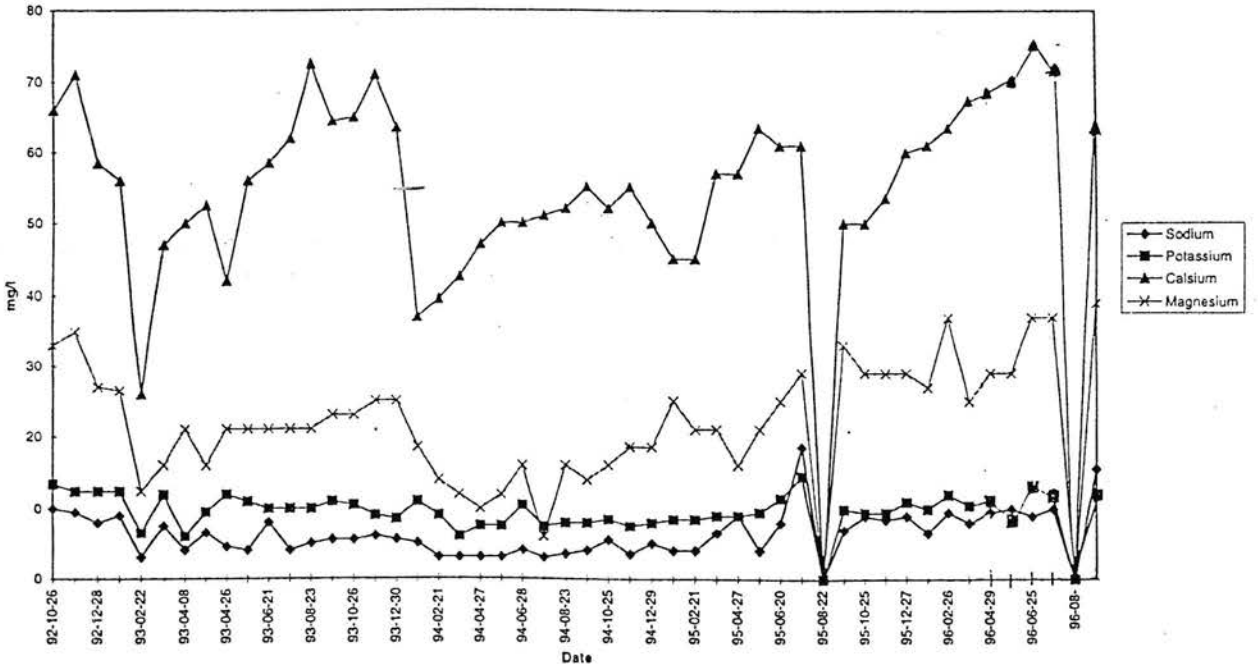

Nutrients in von Bach Dam



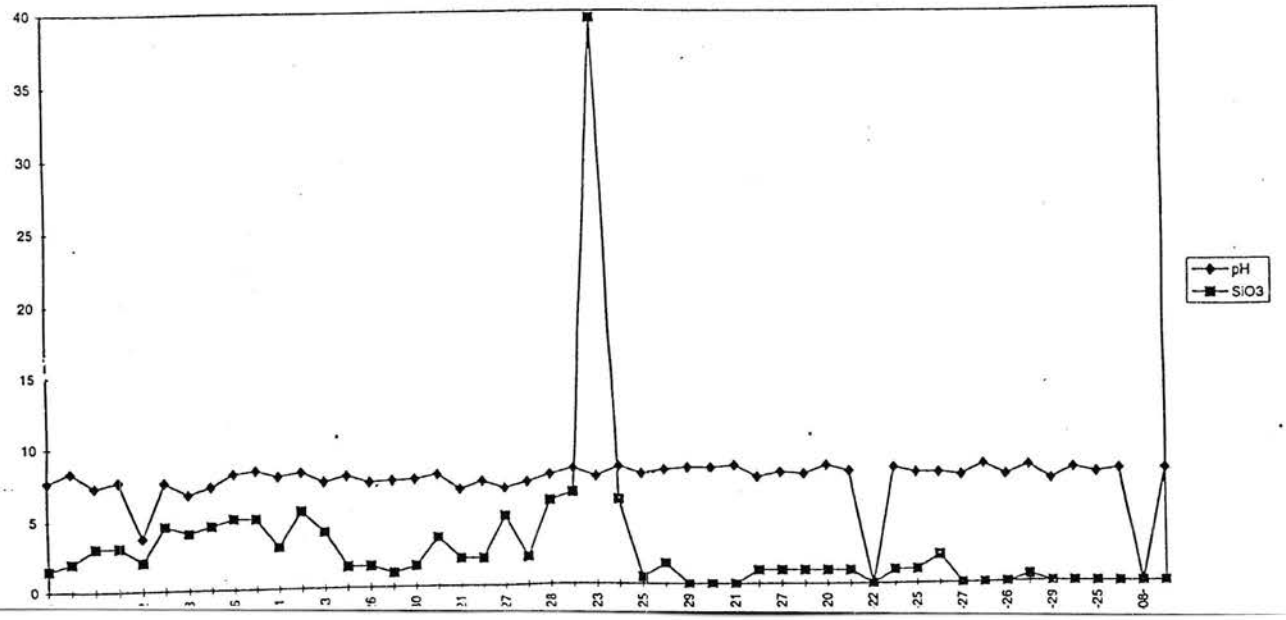
Anions in von Bach Dam




Cations in von Bach Dam

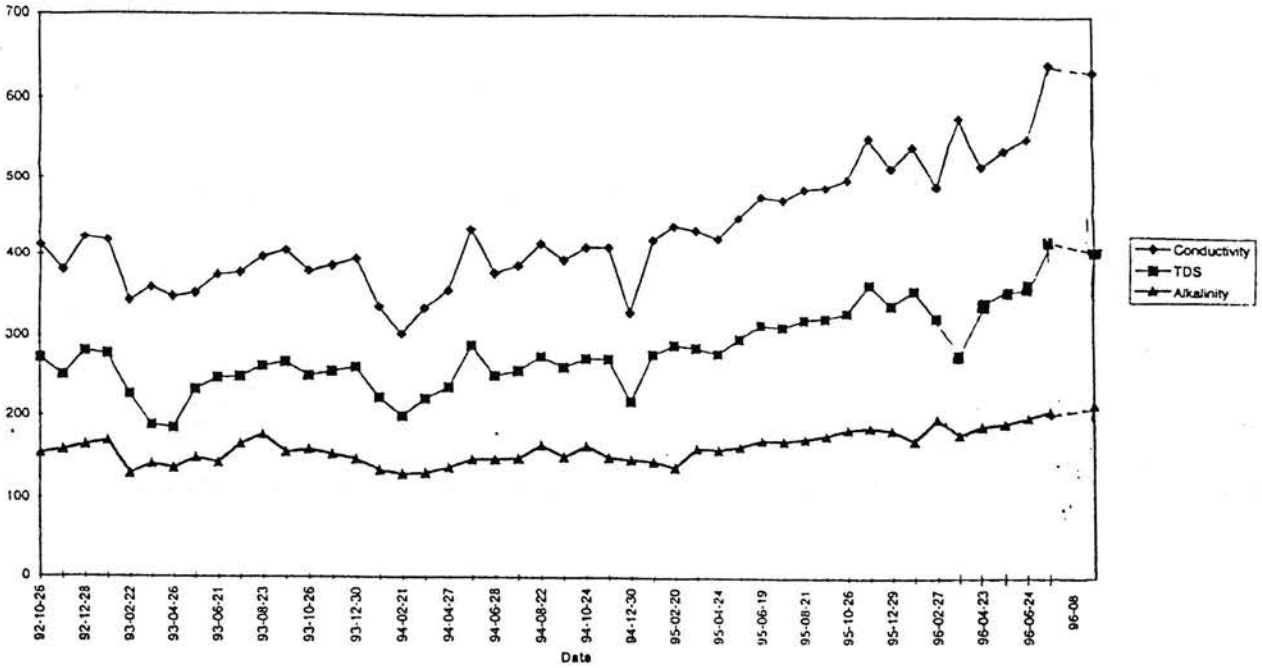



pH,SiO3 in von Bach Dam

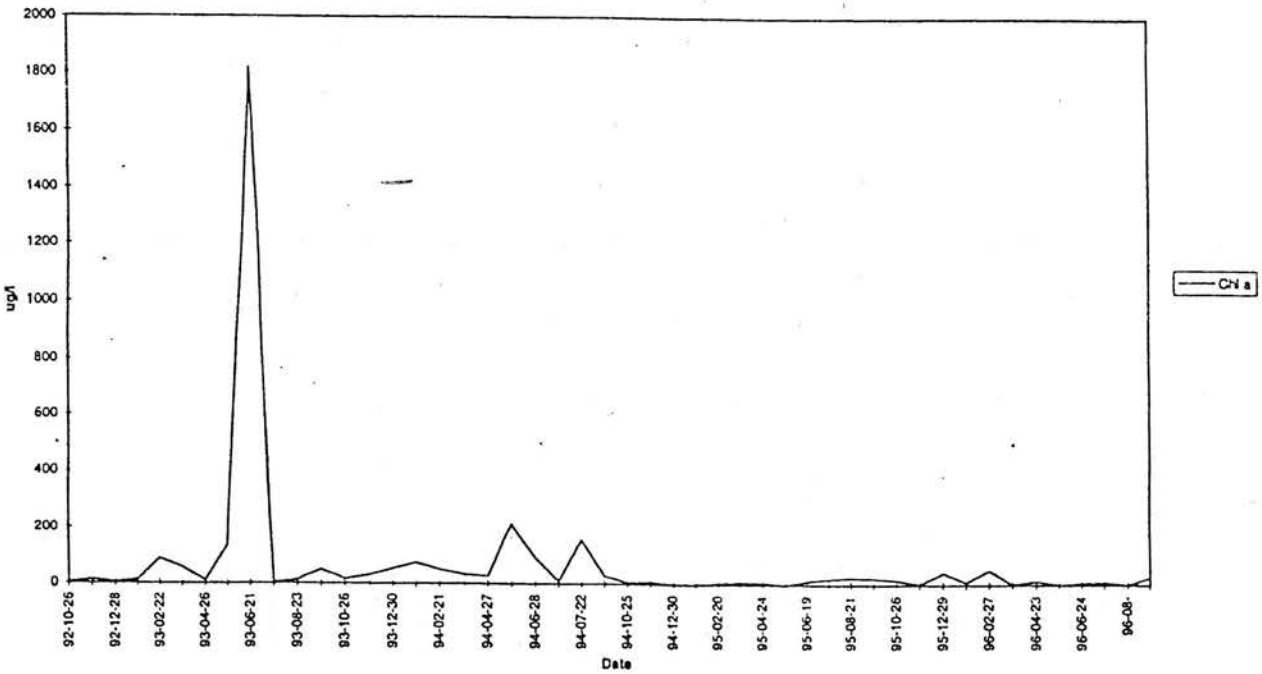


RAPH 2

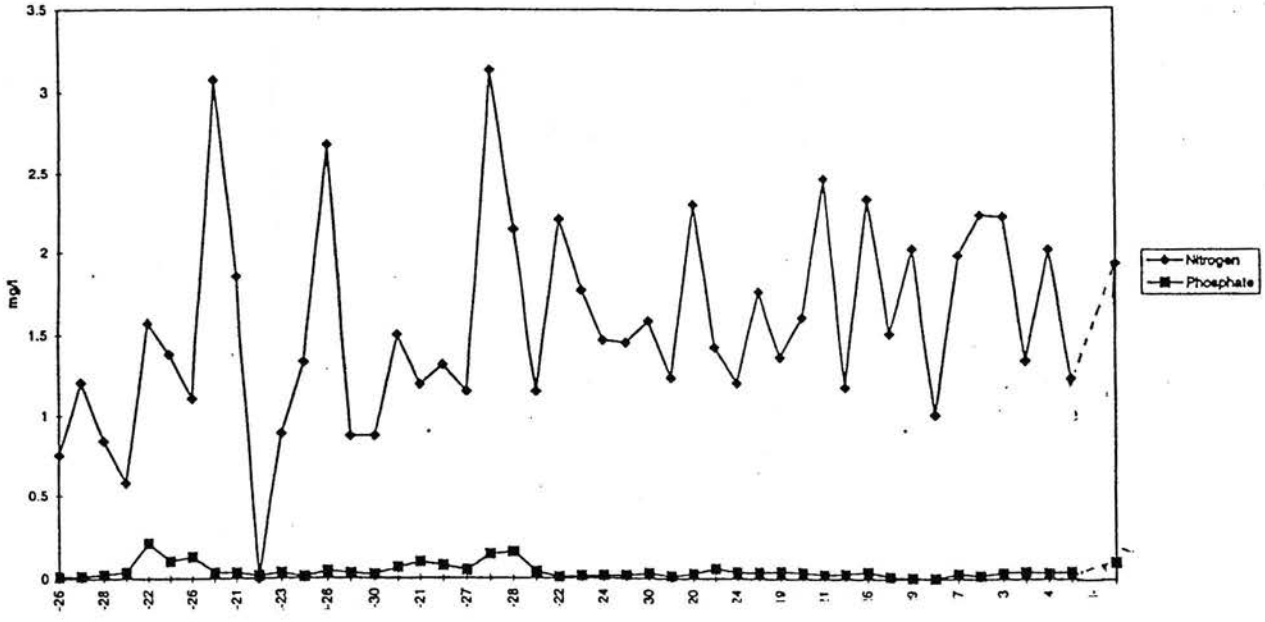
Swakoppoort Dam



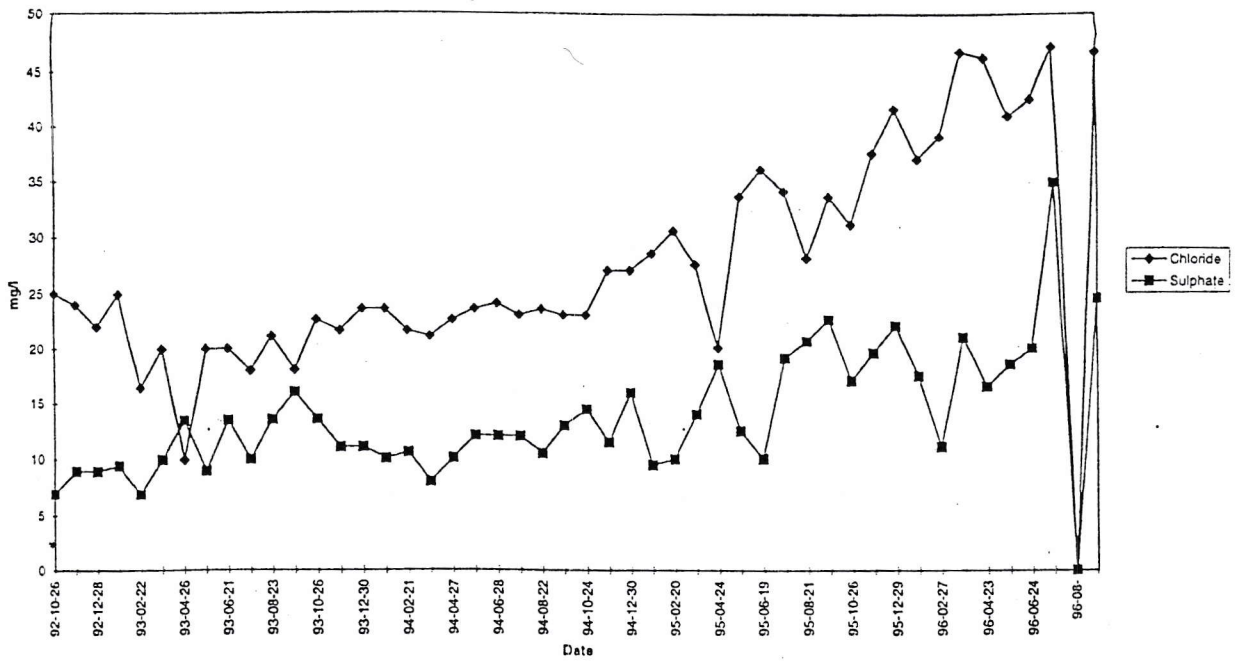

Chl a in Swakoppoort Dam



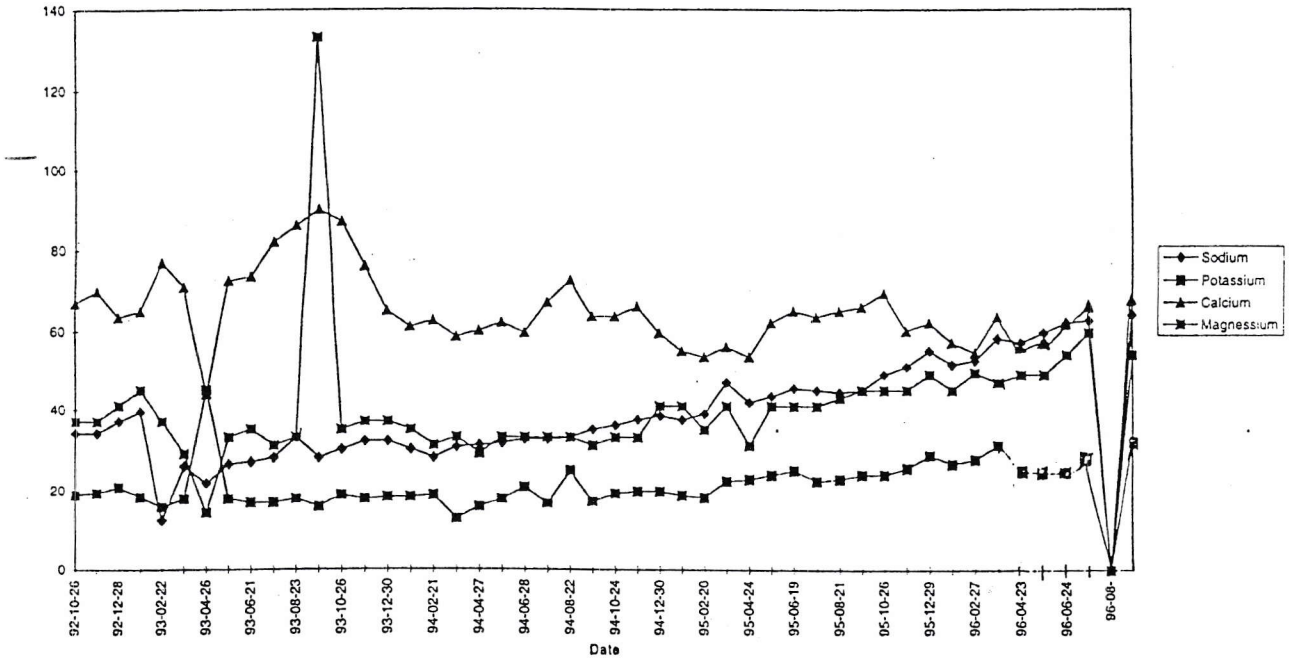

Nutrients in Swakoppoort



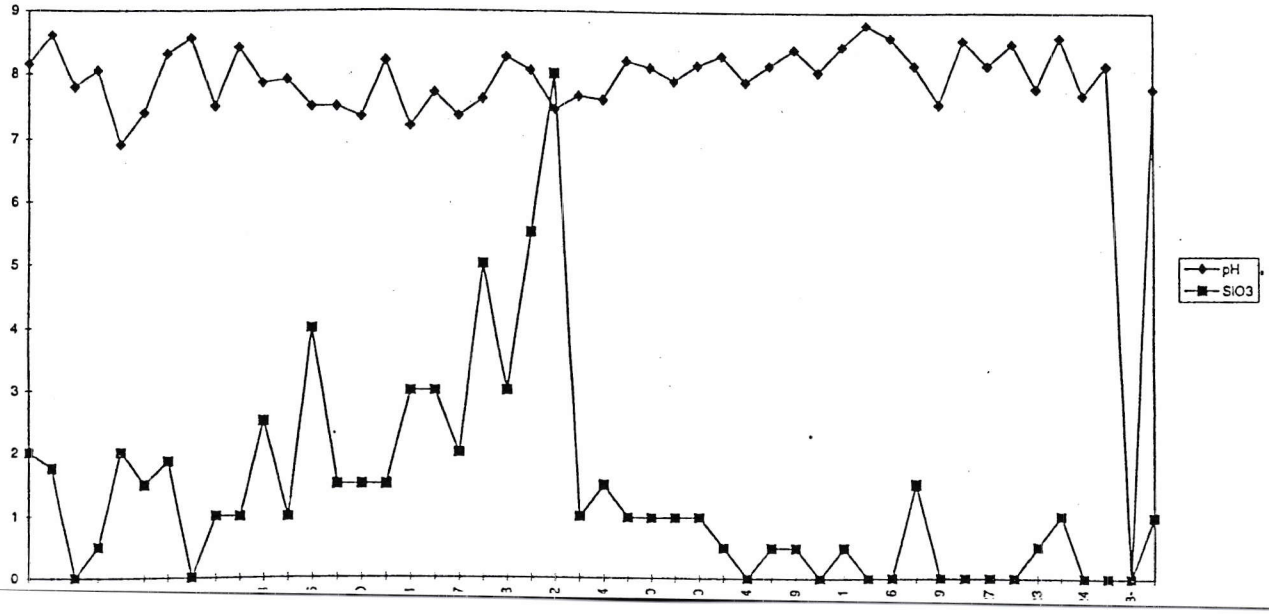
anions



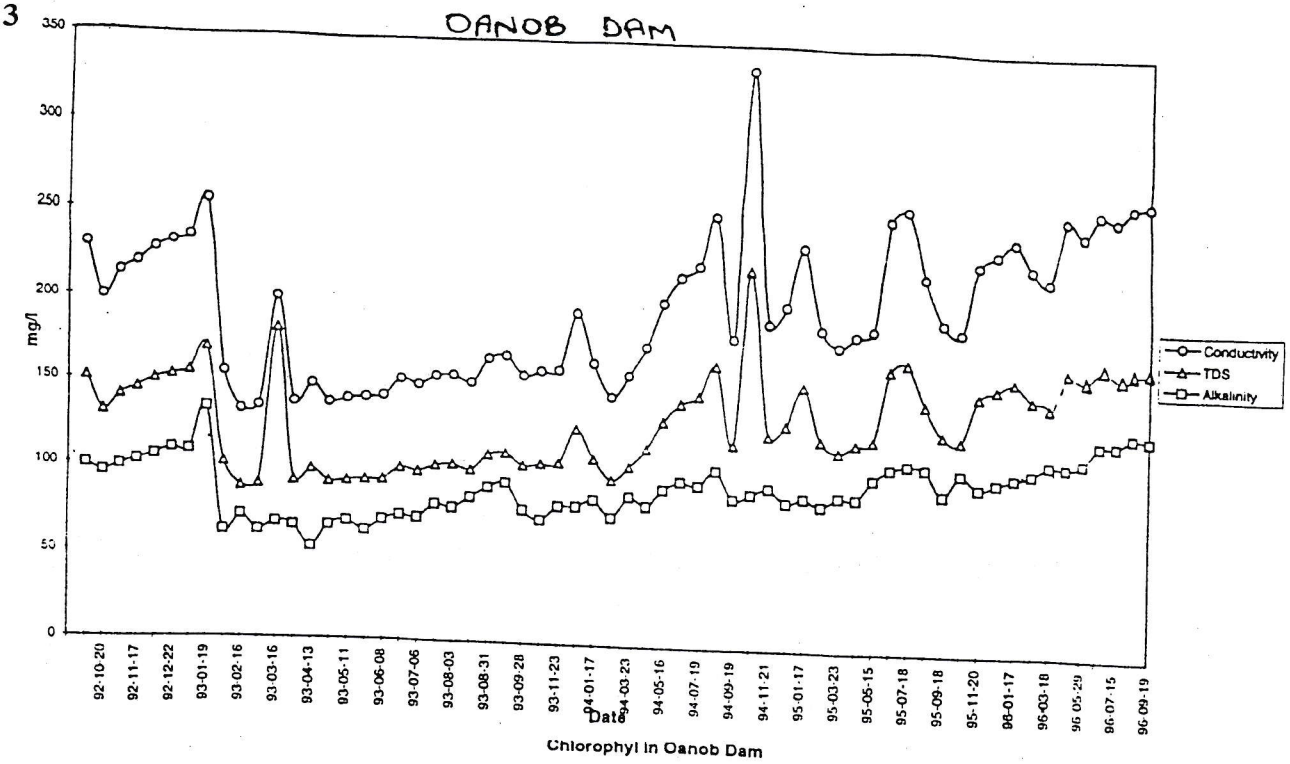

Cations in Swakoppoort Dam



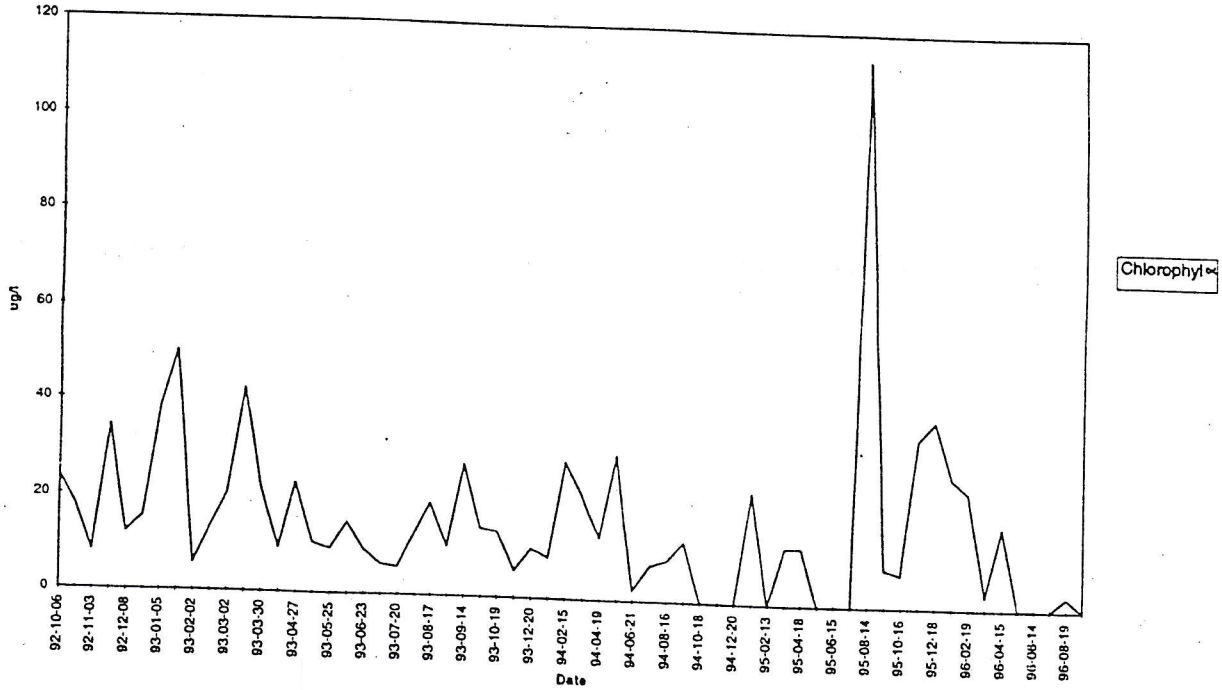

pH,SiO3 in Swakoppoort



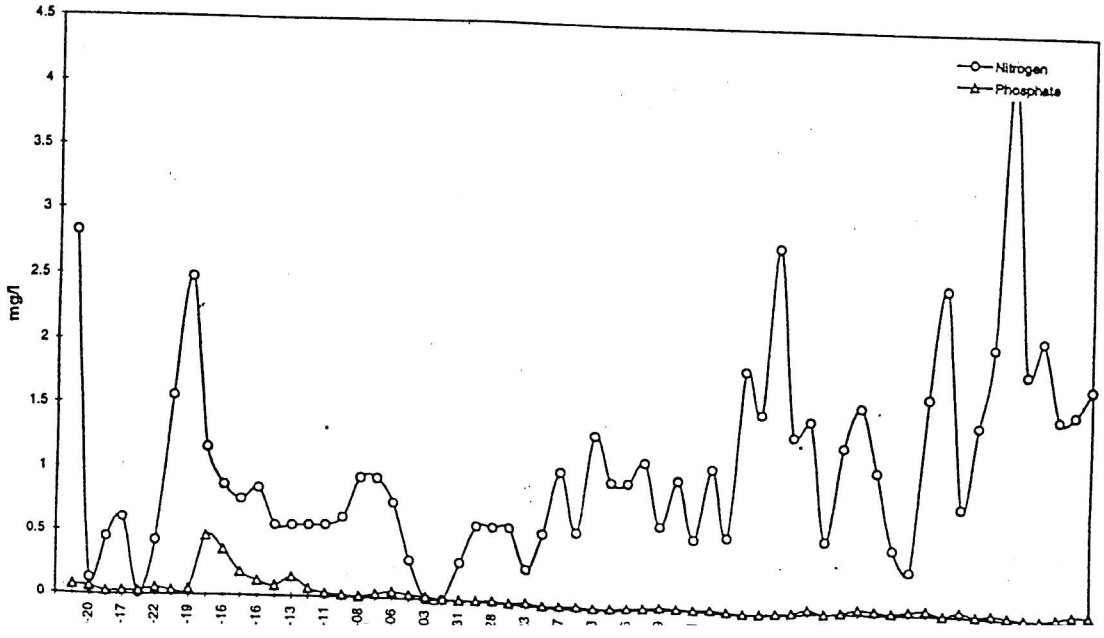
RAPH 3



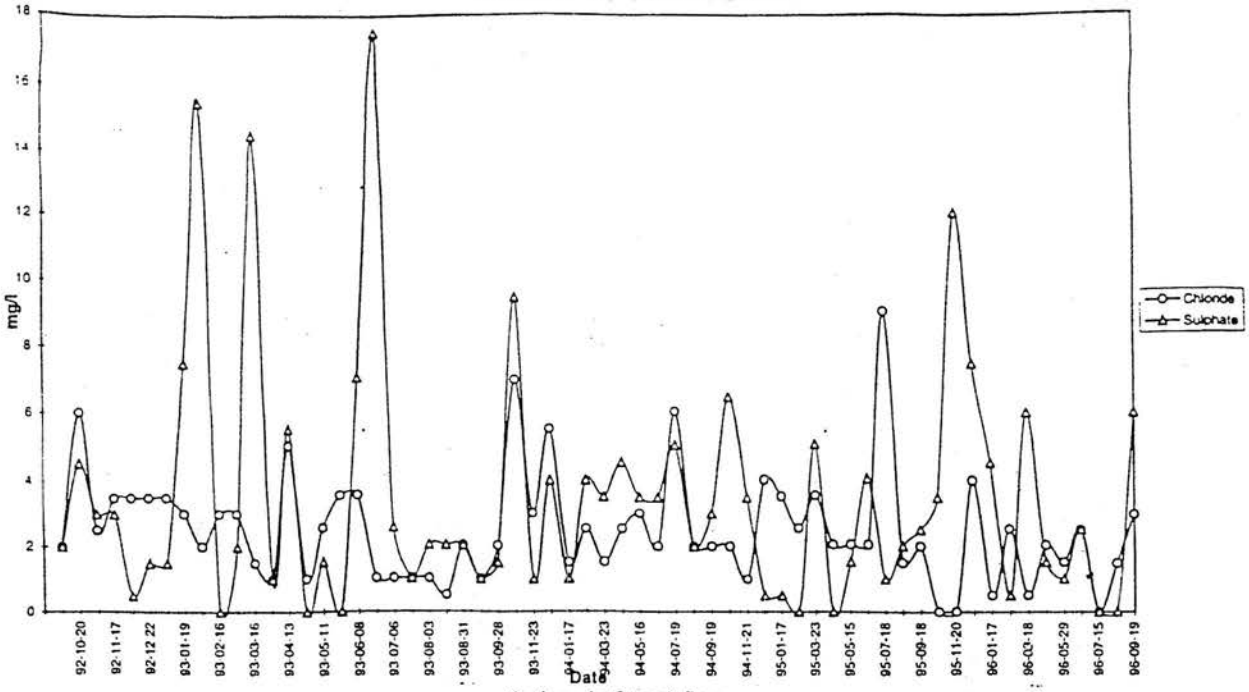

Chlorophyl in Oanob Dam



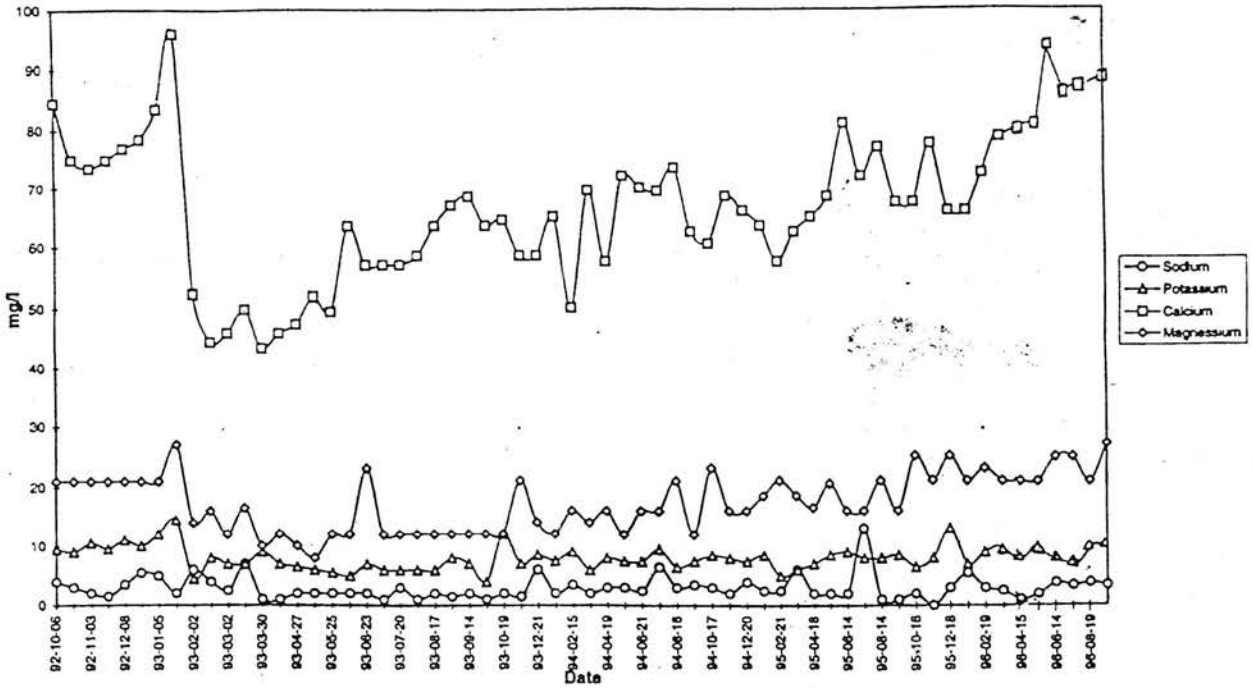

Nutrients in Oanob Dam

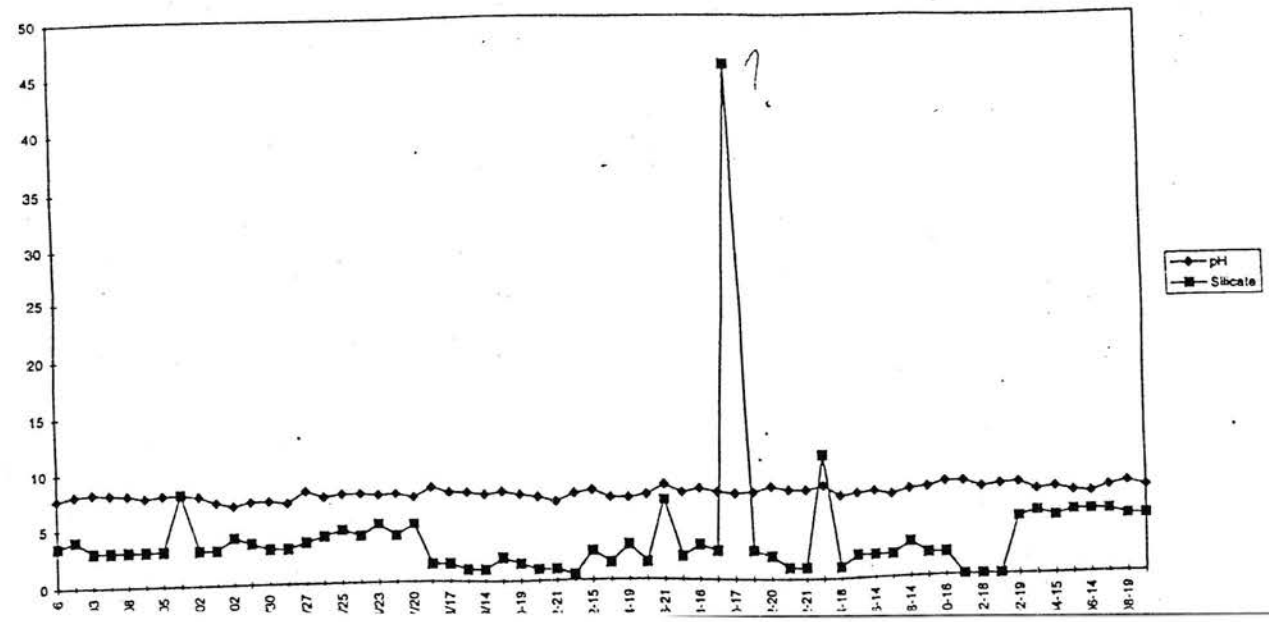


Anions in Oanob Dam




Cations in Oanob Dam




pH, SIO3 In Oanob Dam