FINAL REPORT

# BIOENHANCEMENT OF A RIVER SYSTEM USING A BIOLOGICAL CATALYST

by

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Report to the Water Research Commission on the project entitled

**"BIOREMEDIATION OF A RIVER SYSTEM USING THE ALPHA BIOCATALYST"**

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# EXECUTIVE SUMMARY

**Bioremedi ıtion of a river system using the Alpha Biocatalyst**

by

**MMB Talbot, SW Ascough and A Rankin**

**to the Water Research Commission**

## Motivation and Background.

The rapid urbanisation in South Africa into largely informal settlements together with high population growth and shortage of infrastructural capital is resulting in the pollution of watercourses. As these processes continue more watercourses will become polluted beyond their capacity to assimilate the waste product loading.

In addition the capabilities of man re-engineering natural watercourses in order to satisfy the demand for industrial, commercial land and residentially close to the centres of population and economic activity can have dramatic effects on the functioning of natural aquatic systems. The resultant industrial activities, ordinary domestic growth coupled with inadequate resources and, perhaps, political will to police these activities, invariably leads to pollution of the watercourses.

The combined effect of these events is leading to the destruction of the natural watercourse ecosystem with the resultant loss of the resource to the public at large.

The resultant health hazards, eutrophication problems and oxygen depletion of river systems is particularly evident in the Natal Coastal region. Continued efforts to reduce the volumes of untreated sewage entering the river systems draining informal and semi-formal areas have met with limited success. The control of diffuse source pollution make instream waste treatment one remaining potential option which may ensure the receiving water body is maintained for the recognised water use sectors.

The Alpha biocatalyst technology has been utilised in the effective and efficient bioremediation of many hydrocarbon contaminated sites. It has been successfully applied to the bioremediation of sludge lagoons. The technology has also been highly successful in enhancing the performance of a number of wastewater treatment processes. The condition of receiving water bodies that some of these plants discharge into have been observed to improve. Although this technology had not yet been used specifically for instream bioremediation, existing evidence indicated the potential for success.

There are at least three river systems in the Natal region which usually exceed 10 000 colony forming units of E-coli per 100 ml with concurrent eutrophication and anaerobic sludge build-up indicating excessive pollution. These rivers are the Baynespruit, the Mlazi and the Sipingo. The Sipingo river was considered the most suitable for the investigation for the following reasons:-

1.) There is a relatively large amount of historical water quality data available.

2.) The river is utilised for recreation (contact and fishing) in the semi-tidal lagoon area and is presently considered a health hazard.

3.) The river was considered in the Regional and Town Planning reports of the KZNPA to be the most severely impacted estuary in KwaZulu Natal.

4.) The type of pollution is largely organic (sewage and industrial).

5.) Suitable facilities and security for the reaction units was available at the Mlazi Waste Water Treatment Plant which is the only point source discharge into the river.

**Objectives.**

To evaluate the effects of the Alpha biocatalyst on the assimilative capability of the river segment and to maintain fitness for the recognised water user sectors.

**Major results and conclusions.**

1.) The dissolved oxygen concentration downstream of the biocatalyst addition point trended upwards relative to the upstream concentration. The change took place over an extended period e.g. 4 months for sample point 3 and 7 months for sample point 6. This indicates a substantial improvement in the quality of this stretch of the Sipingo river.

2.) The rate of disappearance of colony forming units of E-coli appears to be quite high given that the residence time from the first sample point to the lagoon is in the region of only two days. The residence time from sample point 4, where the highest concentrations of E-coli were found, is much lower.

3.) Main sources of faecal contamination is from upstream of sewage works and a large inflow somewhere in the canalised section of the industrial area between sample points 3 and 4.

4.) Both ammonia and nitrate concentrations trended downwards the further downstream from the point of the river and the discharge of the sewage works.

5.) The lack of a control against which to compare the measured performance is a limitation in an investigation with so many uncontrolled variables.

# Acknowledgements.

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"Bioremediation of a river system using the Alpha biocatalyst."

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# TABLE OF CONTENTS


| | | |
|---|---|---|
| **Executive Summary** | | i |
| **Acknowledgements** | | iv |
| **Table of Contents** | | 1 |
| **1.** | **Introduction** | 2 |
| 1.1 | Background | 2 |
| 1.2 | Biocatalyst technology | 3 |
| 1.3 | Rationale for river treatment | 5 |
| 1.4 | Project aims | 5 |
| **2.** | **Methodology** | 6 |
| 2.1 | Biocatalyst production | 6 |
| 2.2 | Monitoring | 6 |
| 2.3 | Duration of the investigation | 8 |
| **3.** | **Results and discussion** | 8 |
| 3.1 | Flow | 8 |
| 3.2 | Tidal interchange | 9 |
| 3.3 | Bacteriology | 9 |
| 3.4 | Dissolved oxygen | 11 |
| 3.5 | Ammonia and Nitrate | 12 |
| 3.6 | Organic enrichment | 13 |
| 3.7 | Metals | 14 |
| **4.** | **Summary** | 14 |
| **5.** | **Reference** | 16 |
| **Appendix I: Analytical results** | | 17 |
| a: | Coliforms and E-coli | 18 |
| b: | Dissolved oxygen | 19 |
| c: | Chemical Oxygen Demand (COD) | 20 |
| d: | Oxygen Absorbed (OA) | 21 |
| e: | Ammonia | 22 |
| f: | Nitrate | 23 |
| g: | Total Nitrogen | 24 |
| h: | Fats | 25 |
| i: | Phosphates | 26 |
| j: | Suspended solids | 27 |
| k: | Chloride | 28 |
| l: | Aluminium and Calcium | 29 |
| m: | Magnesium and Sodium | 30 |
| n: | Potassium and Iron | 31 |
| o: | Manganese and Zinc | 32 |
| p: | Copper | 33 |
| q: | Umlazi WWTP final effluent data | 34 |
| r: | Map 1 of the Sipingo River and environs | 35 |

## 1. Introduction.

### 1.1 Background.

The Sipingo River is situated in KwaZulu Natal immediately south of Durban's Louis Botha Airport. ( See map of area in Appendix 1 r).) Over the years man has re-engineered the flow of the Sipingo River and redirected the flow of the Mlazi River which used to enter the sea via the Sipingo Estuary.

Prior to 1952 both the Sipingo River and the Mlazi River entered the Indian Ocean via the Sipingo Estuary. The estuary was normally open to the sea and tidal interchange occurred freely (Ref. 1). Following the diversion of the Mlazi River, for the construction of the airport, the flow of water was insufficient to maintain the estuary open and a sandbar developed. Only in times of heavy storm water run off would this sandbar be breached. In order to partially remedy this situation a steel pipeline was installed through the sandbar to allow some contact with the sea. This pipeline failed and was replaced in 1961 by two concrete pipes each of about 1 metre in diameter (Ref. 2). These pipes are still operational with limited intertidal exchange.

In 1969 the Prospecton industrial area was developed and in order to prevent flooding, part of the flow of the Sipingo River was diverted to the Mbokodweni River some 2 km to the south. Sluice gates were installed at the diversion to allow a certain amount of water to enter the canalised section of the Sipingo River and thus into the estuary. Over time these sluice gates became silted up and a study in 1991 (Ref. 2) concluded that no fresh water from the Sipingo River was flowing through the sluices. A caisson wall was subsequently installed to prevent siltation of the sluice gates and ensure continuous flow of fresh water into the canalised section.

The situation that now exists is that the Sipingo River flows to the canalised section until the flowrate exceeds the capacity of the sluices when the excess flow diverts to the Mbokodweni River. Upstream of the diversion works the river flows through the residential and informal settlement of the Umlazi Township and receives the discharge from the Umlazi Waste Water Treatment Plant.

The reduced flow combined with the sewage infiltration, the discharge from the Umlazi Waste Water Treatment works, industrial pollution (mainly runoff from the Prospecton area) and rubbish infiltration have degraded the riverine and estuary ecosystems to the extent that all recreational activities have largely ceased. The estuary contains a variety of mangrove species and was considered to be the best endowed lagoon system between Durban and Illovo Beach (Ref. 3). It has considerable potential as a recreational area and a nature reserve if the system can be rehabilitated (Ref. 3).

## 1.2 Biocatalyst technology.

The use of biological methods, e.g. addition of enzymes or cultures of bacteria, is well known in waste water treatment. These techniques are usually referred to as biosupplementation or bioaugmentation. Bioenhancement is a term used here to describe the performance enhancement of indigenous micro-organisms by the Alpha biocatalyst.

The Alpha biocatalyst consists of a complex mixture of a very low concentration of by-products from the fermentation of a proprietary, natural substrate. Some of these by-products have dramatic effects on naturally occurring aerobic bacteria. The most significant effects are :-

1. Conference of an ability to function in oxygen deficient environments by using an apparent alternative mechanism to source oxygen.

2. Increased rate of metabolism.

3. Increased growth rate by up to 1000 % in certain circumstances.

4. Conference of an ability to function in rigorous environments such as high salt concentrations, low/high pH and high temperatures.

These effects have enabled the development of a number of application areas around the world including :-

1. Oil well treatment for microbial enhanced oil recovery and paraffin control.

2. In-situ bioremediation of hydrocarbon contamination soil and groundwater.

3. Bioremediation of hazardous waste material by landfarming.

4. Enhancement of waste water treatment plants, (industrial, municipal and agricultural).

5. Remediation of lakes, lagoons and sludge pits.

6. Control of odour caused by anaerobic activity.

The Alpha biocatalyst is being applied to waste water treatment plants and waste water treatment lagoons in South Africa, Central Europe and the Americas with the objectives of improving performance or eliminating odours due to anaerobic activity. It has been found that the rate of organic material breakdown has increased although aeration input has remained the same or even reduced in some cases.

Of significance to the river project are applications where the receiving water bodies have been rehabilitated, for example :-

1) A rendering factory's waste treatment process in Chotycany, Czech Republic did not perform well and was the main source of effluent for a biological pond immediately downstream. In 1992 the ponds water had a very high $BOD_5$ (131 mg/l) and ammonia (376 mg/l) and was devoid of aquatic organisms. The pond and the downstream watercourse was a source of offensive odours due to anaerobic bacterial activity. The treatment of the waste water treatment plant commenced in early 1993, within 30 days the odours from the biological pond were eliminated. By the end of 1993 the quality of the water in the pond had improved to the extent that it was satisfactory for the reintroduction of fish life. Although the pond still receives the bulk of its inflow from the waste treatment plant it assimilates the BOD and nutrient load and maintains satisfactory dissolved oxygen levels.

2) The Mbango Waste Water Treatment Plant situated in Port Shepstone on the KwaZulu Natal South Coast treats a mixture of domestic sewage and industrial effluents. Although the plant has been expanded and in theory has adequate design capacity shock loads from industry caused upsets to the activated sludge process and resulted in massive sludge carryout to the river. Downstream of the treatment plant outfall, the bottom of the river was covered by sludge from the treatment plant. Following the implementation of the Alpha biocatalyst process the incidence of sludge carryout was eliminated. Within two to three months of implementation all sludge deposits in the river bed had disappeared (Ref. 4).

3) In a continuous throughflow treatment of hydrocarbon contaminated sediment and water removed from a lake surrounding the medieval inner city of Telc in the Czech Republic the calculated consumption of oxygen for hydrocarbon degradation amounted to some 350 mt over a five week period. This is equivalent to 10 mt per day. Other than wind action on the treatment lagoons the only other source of aeration was a cascade over which the water was pumped. The input of dissolved oxygen from this source was only 6 kg per day. The apparent consumption of oxygen was some two orders of magnitude above that supplied. Over the same treatment period the dissolved oxygen concentration in the water increased from zero to 4 mg/l (Ref. 5).

## 1.3 Rationale for river treatment.

During a review of applications of the Alpha biocatalyst technology both in South Africa and overseas the idea of treating a polluted river was formulated. During discussions with representatives of the Natal Region of the Department of Water Affairs and Forestry it became apparent that there was a potential need for a low cost, low technology process for the rehabilitation of rivers and estuaries. Current efforts are directed at the identification and elimination of point sources of pollution but do not address the issues of diffuse source pollution nor accumulated organics in the systems.

There are at least three river systems in the KwaZulu Natal Region which already exceed 10 000 colony farming units of E-coli per 100 ml on a virtually continuous basis. Together with eutrophication and anaerobic sludge build up this indicates extensive pollution. The rivers are the Baynespruit, the Mlazi and the Sipingo. The Sipingo river was considered the most suitable for the investigation because :-

1) There is a relatively large amount of historical water quality data available.

2) The river is utilised for recreation (contact and fishing) in the semi-tidal lagoon area and is presently considered a health hazard (Ref. 6).

3) The river is considered to have the most severely impacted estuary system in KwaZulu Natal according to Regional and Town Planning reports.

4) The type of pollution is mainly organic and lends itself to a biological enhancement study.

5) The Mlazi Waste Water Treatment Plant is the only continuous point source discharge into the river system and, therefore, the biocatalyst could be introduced at that point.

6) Suitable facilities and security for the biocatalyst production units are available at the treatment works.

## 1.4 Project Aims.

The aims of the investigation were as follows :-

1) To evaluate the effects of the Alpha biocatalyst on the instream treatment of a segment of the Sipingo river and estuary which is polluted with organic waste of domestic and industrial origin.

2) Should the results permit, to evaluate the effects of the Alpha biocatalyst on the capability of the river segment to assimilate waste and maintain fitness for the recognised water user sectors. (A limiting factor for this evaluation is the lack of control to compare the assimilative capability with the biocatalyst versus normal assimilative capacity).

## 2. Methodology.

### 2.1 Biocatalyst production.

The Alpha biocatalyst is produced on-site for a continuous flow system in specifically designed fermentation vessels called Catalyst Generating Units (CGU's).

During start up the proprietary substrate is pre-processed in the laboratory for two weeks prior to charging into the fermentation vessels which are filled with water. The substrate sinks to the bottom of the vessels and is left for a further period of seven days to establish the fermentation process. A continuous flow of water is introduced part way down the vessel in order to carry out the fermentation products.

After establishing the production process as above the water flow is maintained at a constant rate and the units are fed with additional substrate once per day. No specialised knowledge or skills are needed for routine operation.

For this application the continuous flow of biocatalyst was introduced into the final leg of the maturation pond of the Mlazi Waste Water Treatment Plant and thus into the river. This location was chosen due to the availability of a water source which supplies the chlorination building of the works.

### 2.2 Monitoring.

In order to monitor the effects of the biocatalyst samples of water were taken at random time intervals on a weekly basis. Seven sample points were chosen to be representative of the river and lagoon system as well as taking consideration of previous work, accessibility and safety. The points chosen were :- (See Map 1 Appendix 1 r).).

Point 1 - River opposite Mlazi Waste Water Treatment Plant above discharge point.

Point 2 - Downstream of Mlazi Waste Water Treatment Plant discharge point at pipe bridge.

Point 3 - Artificial lagoon at sluice gates at centre of caisson wall.

Point 4 - The canalised section off Prospecton Road next to railway.

Point 5 - Before the lagoon at bridge crossing the river on Avenue East.

Point 6 - Northern leg of the lagoon north of the Island Hotel.

Point 7 - Southern leg of the lagoon at open park area.

The samples were analysed for the following water quality indicators from January 1994 to September 1994:

a) Chemical Oxygen Demand (COD).

b) Oxygen Absorbed (OA).

c) Free and saline ammonia.

d) Nitrate.

e) Soluble phosphate.

f) pH.

g) Conductivity.

h) Chloride.

i) Soap, oils and grease (ether extractables).

j) Suspended solids.

k) E-coli.

l) Total coliforms.

m) Various metals: Aluminium (Al), Calcium (Ca), Magnesium (Mg), Sodium (Na), Potassium (K), Iron (Fe), Manganese (Mn), Zinc (Zn) and Copper (Pb).

From September 1994 to May 1995 the samples were taken on a less frequent basis, approximately fortnightly and were analysed for :-

a) Oxygen Absorbed.

b) Ammonia.

c) Nitrate.

Dissolved oxygen measurements were made on site at the time of sampling using a portable dissolved oxygen meter.

### 2.3 Duration of the investigation.

The investigation was originally scheduled to take place over a six month period from January 1994 to July 1994 which would have covered both typically wet and dry weather periods. A delay in the manufacture of the fermentation vessels delayed the introduction of the biocatalyst until the second week of February 1994 and civil unrest during the April 1994 National Election restricted access to sampling points. It was decided to extend the fi''^t pha e to September 1994. Preliminary analysis of the results indicated that potentially desirable changes were being seen in the river and it was decided to extend the investigation but on a lower sampling frequency and a reduced range of analyses.

## 3. Results and discussion.

### 3.1 Flow.

Based on observation of the diversion to the Mbokodweni river it is apparent that the majority of the river flow passed through the sluice gates during the period of the investigation. This is quite different to the situation reported in previous studies (Ref 2, Ref 3) where the diversion limited the flow. Grobler (Ref 2) reported that the sluice gates were silted up and no flow was going through the sluices to the lower reaches.

From visual observation the flow of the river upstream of the treatment plant remained relatively constant throughout the investigation period. The contribution of the treatment works was also relatively consistent throughout the period at about 15 to 16 Ml/day (Ref 7). Using the average concentrations nitrate measured in the river upstream of the works, downstream of the works and the final effluent of the works for the six months February to August 1994 the total flow to the sluice gates was in the region of 30 Ml/day or 11 x $10^6$ $m^3$/annum. The nitrate concentration was used from an arbitrary choice, other parameters could have been used, e.g. COD, OA, $PO_4$, in order to calculate and estimate of total flow.

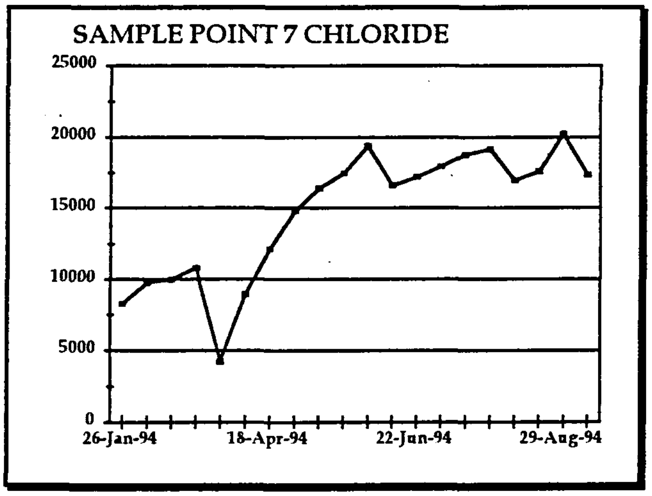
Prior to the installation of the gabion weir the sluice gate inlets were often silted up and a much lower flow to the canalised section occurred (Ref 2). The residence time in the canalised section and the northern leg of the estuary is now much lower than that prevailing up to July 1991.

No major floods were experienced during the study period. The results on suspended solids indicate that there was only one period, during March 1994, where the flow was high enough to suspend solids. This was the only period when significant diversion of the flow occurred due to lack of capacity of the sluice gates.

## 3.2 Tidal interchange.

The chloride and sodium results indicate that there was little sea water ingress to sample point 6 in the northern leg of the estuary. The consistent flow of the fresh water from upstream probably explains this difference to earlier studies. There is, however, some sea water mixing up to that point.

In the southern leg of the estuary the chloride results show appreciable dilution of salt water by fresh water. Within a few weeks the chloride levels had reverted to previous levels and then appeared to stabilise. This suggests there is a reasonably consistent mixing of fresh water and sea water at the sandbar pipelines.




Graph 1: Chloride values (mg/l $Cl^-$) for sample point seven.

## 3.3 Bacteriological.

The results of E-coli indicate (Refer to Graph 2 below) three major sources of raw sewage pollution into the Sipingo river :-

1. The river upstream of the sewage works.

2. Occasionally the sewage works discharge.

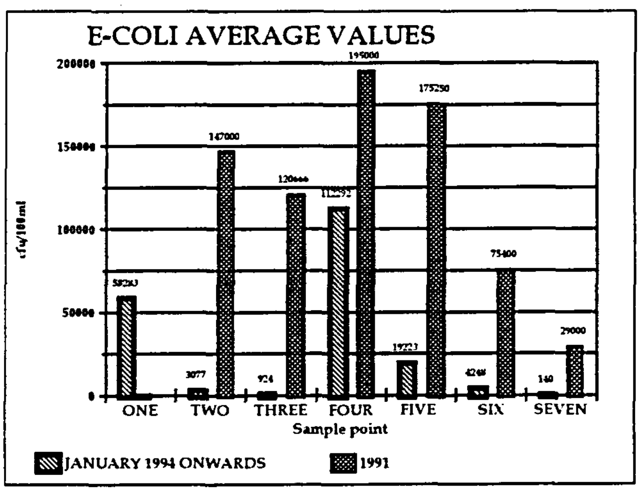
3. An ingress somewhere into the canalised section between the sluice gates and Prospecton Road. This source within the industrial township appears to be the largest source.

1) Compared to the investigation conducted by Grobler in 1991 the degree of sewage pollution from the Mlazi township and industrial area appears to have improved although it is consistently present. It is apparent from flows received by the sewage treatment works that extensive repairs to the sewage reticulation system have been undertaken over the past few years.

2) There are occasional high (>[illegible]000 cfu/100 ml) concentrations of E-coli from the sewage treatment works but generally the works' discharge dilutes the instream faecal contamination levels.

3) The average concentration of E-coli detected at sample point 4 compared to the average at sample point 3 indicates a major sewage leak somewhere in the industrial area. Based on the estimated average flowrate of 30 Ml/day and typical E-coli in domestic sewage of 8 x $10^6$ cfu/100 ml (Ref. 8) this source could be in excess of 50 $m^3$/day.

Graph 2 shows the profile of E-coli down the river from April 1994 to September 1994 compared to the profile measured by Grobler in 1991. It appears that the rate of decline during the biocatalyst investigation is high. The drop in the average concentration from sample point 4 to sample point 5 is quite marked considering that the residence time is only a few hours. The flow in 1991 was lower and thus the residence time was higher.

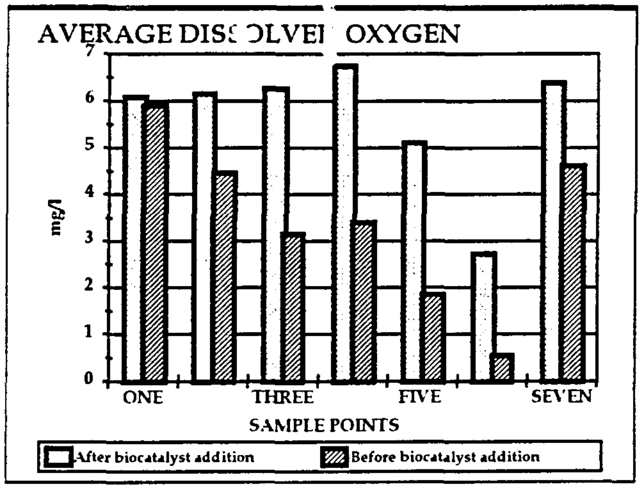



Graph 2: Average E-coli values of the Sipingo River.

## 3.4 Dissolved oxygen.

Dissolved oxygen is an important factor in maintaining the aquatic life. This is particularly so in a heavily polluted system as the Sipingo. The flow of the river is mainly quiescent and the only location where reaeration is likely to occur is after sample point 3 when the river flows over the artificial weir into the sluice gate inlet.

Graph 3 shows the average dissolved oxygen profiles prior to the introduction of biocatalyst and afterwards.

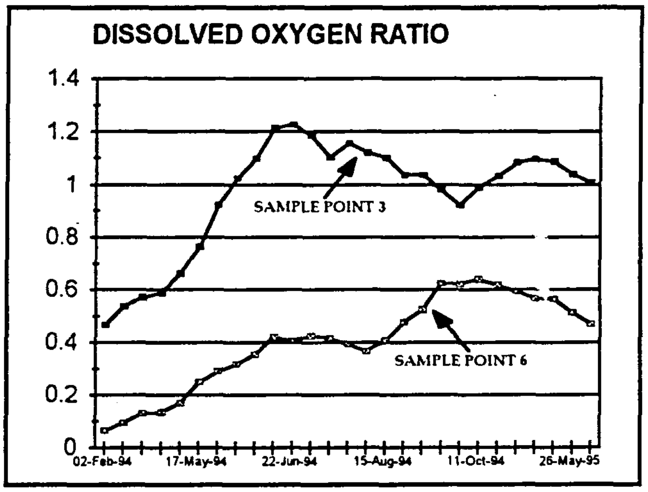



Graph 3: Average dissolved oxygen concentrations.

Initially the dissolved oxygen concentration dropped progressively the further down the river the sample point with the exception of a slight rise between sample point 3 and 4 following reaeration at the weir.

The profile after the introduction of the biocatalyst looks quite different. The dissolved oxygen concentration increases up to sample point 4 and then drops, but remains at higher levels than previously seen. This change did not happen quickly but took a number of months. Graph 4 shows the ratio of the dissolved oxygen concentrations of sample point 3 (the artificial lagoon before the sluice gates) and sample point 6 (the northern leg of the lagoon) to the river upstream of the treatment works. After approximately four months the DO ratio stopped increasing at sample point 3 and after approximately 7 months at sample point 6.

Prolonged exposure to dissolved oxygen concentrations of less than 50% saturation can cause significant changes in biotic community composition, favouring more tolerant species (Draft SA Water Quality Guidelines for Aquatic Ecosystems). Dissolved oxygen reaches saturation at ca. 9mg/l at 20 °C and sea level, which implies that levels of < ca. 4,5 mg/l will cause changes in the biota. The increase in DO brought about by the addition of the biocatalyst raised the level from below 4,5 mg/l at 5 out of 7 stations to being below 4,5 mg/l at only 1 out of 7 stations. This indicates a substantial improvement in the quality of this stretch of the Sipingo River from a condition where it would have been inhabited by biota tolerant of low dissolved oxygen levels to being able to support a much wider range of organisms.

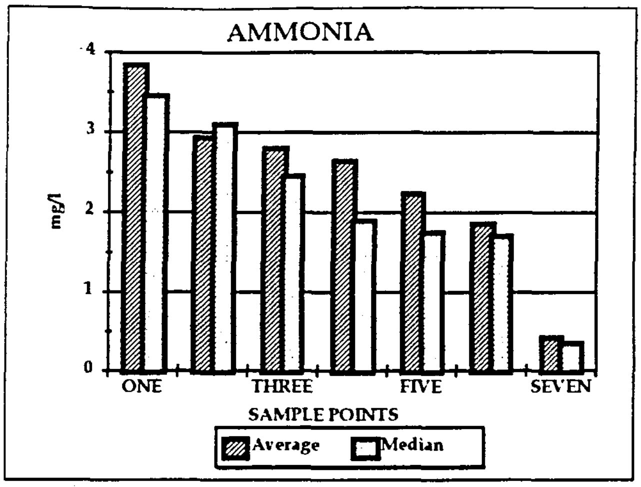



Graph 4: Ratio of sample point 3 and sample point 6 to upstream of the treatment works.

## 3.5 Ammonia and Nitrate.

The average and median ammonia concentration at the various sample points for the duration of the treatment period are shown in graph 5. The main source of ammonia is the river upstream of the Mlazi Waste Water Treatment Plant and on average the concentration is diluted by this discharge.

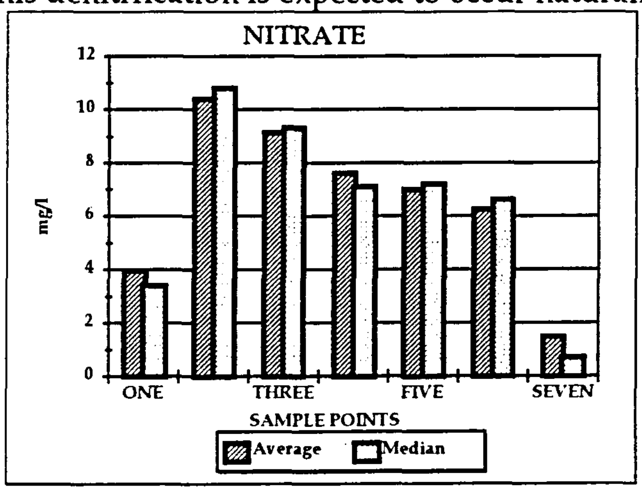
The concentration of ammonia in the river is lower than that measured in 1991 (Ref 2) reflecting the reduction in sewage infiltration above the Mlazi Waste Water Treatment Plant.




Graph 5: Ammonia concentrations of the sample points.

The ammonia concentration progressively reduces as the water flows down the river. The concentration in the northern leg of the lagoon is still marginally high for the maintenance of fish life according to USEPA guidelines (Ref 2).

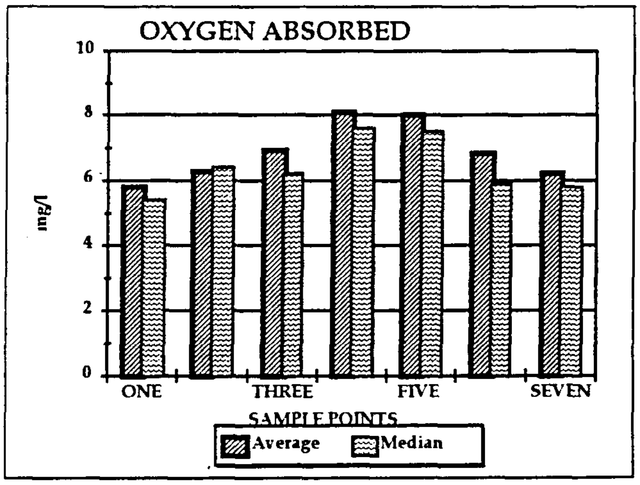
The average and median nitrate concentrations at the various sample points for the period February to September 1994 are shown in graph 6. The major source of nitrate is the Mlazi Waste Water Treatment Plant which, being a trickling filter process has low denitification capabilities. The average nitrate concentration progressively reduces with distance downstream. This denitrfication is expected to occur naturally.




Graph 6: Nitrate concentrations of the sample points.

## 3.6 Organic enrichment.

Graph 7 shows the average and median oxygen absorbed (OA) at each of the sample points for the investigation period. It would appear that the oxygen absorbed increases up to sample point 4 and then decreases. Viewing the data (Appendix) shows that these average values are affected by the frequency of high results measured in the industrial area and immediately downstream thereof. On a number of occasions materials such as oil (diesel) were seen floating on the surface of the water in these areas. It is apparent that considerable amounts of organic materials find their way into the river system from the industrial areas.




Graph 7: Oxygen absorbed concentrations for the review period.

## 3.7 Metals.

Of the metals measured in the investigation there were only a few occasions when zinc and iron were detected at elevated levels. Most of these were at sample point 5 which is after the canalised section of the river. Only dissolved metals were analysed using direct flame atomic absorption spectrophotometry.

## 4. Conclusions.

It appears that the addition of the biocatalyst to the river has generated some desirable effects downstream of the addition point. This is particularly the case for dissolved oxygen. Despite the continuous organic enrichment from sewage contamination upstream of the Mlazi sewage works, the discharge of the works itself (at +/- 50 % of the river flow), sewage contamination from the industrial area and pollution from the industrial area, the dissolved oxygen concentration rose over a number of months. In the lower reaches from upstream of sample point 5 to the mouth, water hyacinth grows which in itself tends to reduce the DO. Experiences from other applications also gives the expectation that deposited sludges would also have contributed to the organic load although this was not monitored in this investigation.

The rate of die-off of colony forming units of E-coli appears to be quite high given that the residence time of the system from the first sample point to the lagoon is in the region of two days. The residence time from sample point 4, where the highest concentrations were found, is much lower.

Both ammonia and nitrate trended downwards from the point sources of the river and the discharge of the sewage works.

The lack of a control against which to compare the measured performance is a limitation in an investigation of a river system with so many uncontrolled variables. In order to scientifically evaluate the biocatalyst further it would be necessary to compare a treated system with a control. Of course it would be impossible to create such a situation within a natural water system where there is no control over any of the many variables. One possibility would be to compare the performance of parallel lagoon systems or wetlands where similar flowrate, loading and environmental conditions could be maintained.

This investigation only focused on the macro-chemical characteristics of the river, while the real impact of pollution is its effect on the biological situation in the receiving water body. The main biological effects are related to the reduction of dissolved oxygen due to microbial degradation of the organic pollution or by degradation of plant debris produced due to excessive nutrification. Therefore future work should also consider effects on the biology of the system.

## References.

1. G. Begg, The estuaries of Natal, Natal Town and Regional Planning Report Volume 41 1978.

2. D.F. Grobler, A water quality investigation of the Isipingo River and estuary, Natal. Department of Water Affairs and Forestry Hydrological Research Institute, June 1992.

3. Rehabilitation of the Isipingo Estuary and Lagoon. Proceedings of a Seminar April 1986. Natal Town and Regional Planning Supplementary Report Volume 25.

4. Private communication G. Purnell, Natal Region of Department of Water Affairs and Forestry.

5. Final Report to Botany Department Czech Institute of Science by J. Skvara, AlphaBio International.

6. Private communication A. Rankin, Natal Region of Department of Water Affairs and Forestry.

7. Private communication D. Luthuli, Umgeni Water Mlazi Waste Water Treatment Plant.

8. Edwin E. Geldrich, Control of Micro-organisms of Public Health Concern in Water. Journal of Environmental Sciences March/April 1986.

9. R.G. Feachem, D.J. Bradley, H. Garelick, D.D. Mara. Sanitation and Disease. Health Aspects of excreta and waste water management.

## Appendix I : a

| DATE SAMPLED | COLIFORM BACTERIA ONE | TWO | THREE | FOUR | FIVE | SIX | SEVEN | E. COLI ONE | TWO | THREE | FOUR | FIVE | SIX | SEVEN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 02-Feb-94 | PP | PP | PP | PP | PP | PP | PP | | | | >500 | | >500 | >500 |
| 14-Feb-94 | TN | TN | TN | TN | TN | TN | TN | 200 | 200 | 500 | 0 | 400 | 0 | 800 |
| 04-Mar-94 | TN | 0 | TN | TN | PP | TN | 0 | TN | 0 | 0 | TN | PP | TN | 0 |
| 10-Mar-94 | 10000 | 25000 | 0 | TN | PP | PP | 15000 | 10000 | 25000 | 0 | TN | 0 | 0 | 0 |
| 25-Mar-94 | 180 | 300 | 70 | 20 | TN | TN | 0 | 0 | 120 | 30 | 0 | TN | TN | 0 |
| 18-Apr-94 | 1300 | 500 | TN | TN | TN | TN | 300 | 200 | 0 | TN | TN | TN | TN | 30 |
| 17-May-94 | 540000 | 0 | 4000 | 1000 | 3600 | 0 | 0 | 540000 | 0 | 500 | 0 | 2000 | 0 | 0 |
| 25-May-94 | 340 | 490 | 410 | 261000 | 98000 | 54000 | 40 | 190 | 138 | 280 | 87000 | 43000 | 1100 | 14 |
| 01-Jun-94 | 108000 | 10 | 1500 | 164000 | 46000 | 1200 | 330 | 53000 | 0 | 300 | 74000 | 23000 | 470 | 330 |
| 09-Jun-94 | 13600 | 490 | 1250 | 114000 | 38000 | 14000 | 90 | 7800 | 230 | 640 | 58000 | 9700 | 290 | 0 |
| 14-Jun-94 | 96000 | 15000 | 7100 | 10200 | 51000 | 4600 | 4 | 12000 | 4200 | 1400 | 7800 | 15000 | 2300 | 4 |
| 22-Jun-94 | 6900 | 74 | 2600 | 1440000 | 9200 | 5700 | 1060 | 4800 | 0 | 2400 | 219000 | 25000 | 2600 | 70 |
| 05-Jul-94 | 20000 | 0 | 500 | 880000 | 97000 | 9700 | 340 | 70 | 0 | 174 | 200000 | 30000 | 6000 | 98 |
| 15-Jul-94 | 23000 | 3000 | 2600 | 570000 | 71000 | 79000 | 20 | 32000 | 160 | 1080 | 96000 | 48000 | 22000 | 14 |
| 22-Jul-94 | 37000 | 18600 | 4500 | | | | | 9000 | 2900 | 750 | 300000 | 11000 | 11200 | |
| 02-Aug-94 | 47000 | | | 95000 | 68000 | 77000 | 1030 | 39000 | | | 21000 | 16000 | 3600 | 760 |
| 15-Aug-94 | 28000 | 2600 | 4500 | 250000 | 94000 | 51000 | 340 | 8600 | 100 | 200 | 31000 | 8000 | 1100 | 50 |
| 29-Aug-94 | 99000 | 79000 | 22000 | 640000 | 320000 | 5700 | 174 | 51000 | 16000 | 960 | 360000 | 14000 | 314 | 36 |
| 02-Sep-94 | 20200 | 36000 | 20000 | 36000 | 60000 | | 2800 | 220 | 13200 | 2400 | 6000 | 5200 | | 300 |

**TN = Too numerous to count**
**PP = Probably present**

Appendix I : b

| DATE SAMPLED | DISSOLVED OXYGEN BEFORE CHLOR | BEFORE DISCH | ONE | TWO | THREE | FOUR | FIVE | SIX | SEVEN | RATIO ONE | TWO | THREE | FOUR | FIVE | SIX | SEVEN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 02-Feb-94 | | | 6.2 | 4.3 | 2.9 | 3.6 | 1.4 | 0.4 | 5.2 | 1.000 | 0.694 | 0.468 | 0.581 | 0.226 | 0.065 | 0.839 |
| 14-Feb-94 | | | 5.6 | 4.6 | 3.4 | 3.2 | 2.3 | 0.7 | 4 | 1.000 | 0.821 | 0.607 | 0.571 | 0.411 | 0.125 | 0.714 |
| 04-Mar-94 | | | 5.5 | 4.7 | 3.5 | 4 | 1 | 1.1 | 3 | 1.000 | 0.855 | 0.636 | 0.727 | 0.182 | 0.200 | 0.545 |
| 10-Mar-94 | | | 6 | 4.8 | 3.8 | 4 | 5.1 | 0.9 | 6 | 1.000 | 0.800 | 0.633 | 0.667 | 0.850 | 0.150 | 1.000 |
| 25-Mar-94 | | | 4.8 | 5.1 | 4.6 | 5.3 | 5.6 | 1.5 | 4 | 1.000 | 1.063 | 0.958 | 1.104 | 1.167 | 0.313 | 0.833 |
| 17-May-94 | | | 4.8 | 4.7 | 4.7 | 4.5 | 3.6 | 2.2 | 2.3 | 1.000 | 0.979 | 0.979 | 0.938 | 0.750 | 0.458 | 0.479 |
| 25-May-94 | | | 6 | 6.4 | 8.4 | 7.5 | 3.1 | 2 | 3 | 1.000 | 1.067 | 1.400 | 1.250 | 0.517 | 0.333 | 0.500 |
| 01-Jun-94 | | | 5.4 | 5.9 | 6.2 | 6.2 | 4.8 | 1.8 | 5.2 | 1.000 | 1.093 | 1.148 | 1.148 | 0.889 | 0.333 | 0.963 |
| 09-Jun-94 | | | 5.9 | 6 | 5.9 | 5.6 | 5.7 | 2 | 5.7 | 1.000 | 1.017 | 1.000 | 0.949 | 0.966 | 0.339 | 0.966 |
| 14-Jun-94 | | | 4.4 | 6.8 | 6.8 | 7.3 | 7.3 | 2.8 | 9.5 | 1.000 | 1.545 | 1.545 | 1.659 | 1.659 | 0.636 | 2.159 |
| 22-Jun-94 | | | 9 | 8 | 9.4 | 10.4 | 7 | 3.5 | 7.4 | 1.000 | 0.889 | 1.044 | 1.156 | 0.778 | 0.389 | 0.822 |
| 05-Jul-94 | | | 5.2 | 6.1 | 6.2 | | 0.9 | 2.2 | 12 | 1.000 | 1.173 | 1.192 | 0.000 | 0.173 | 0.423 | 2.308 |
| 15-Jul-94 | | | 8.2 | 5.8 | 6 | 8.5 | | 2.4 | 9.5 | 1.000 | 0.707 | 0.732 | 1.037 | 0.000 | 0.293 | 1.159 |
| 27-Jul-94 | | | 4.5 | 5 | 5.7 | 7.4 | 4.4 | 1 | 6.1 | 1.000 | 1.111 | 1.267 | 1.644 | 0.978 | 0.222 | 1.356 |
| 08-Aug-94 | | | 7 | 8.4 | 9.6 | 10.2 | 10 | 3.6 | 5.2 | 1.000 | 1.200 | 1.371 | 1.457 | 1.429 | 0.514 | 0.743 |
| 15-Aug-94 | | | 6.5 | 6.5 | 6.1 | 8.8 | 6.5 | 3.8 | 3.8 | 1.000 | 1.000 | 0.938 | 1.354 | 1.000 | 0.585 | 0.585 |
| 29-Aug-94 | | | 4 | 4.4 | 3.5 | 3.3 | 0.8 | 3.1 | 3.6 | 1.000 | 1.100 | 0.875 | 0.825 | 0.200 | 0.775 | 0.900 |
| 19-Sep-94 | | | 4.75 | 5.3 | 3.5 | 1.5 | 0.5 | 2.5 | 4 | 1.000 | 1.116 | 0.737 | 0.316 | 0.105 | 0.526 | 0.842 |
| 26-Sep-94 | | | 4.2 | 4.2 | 4.1 | 6.5 | 3 | 3 | 10 | 1.000 | 1.000 | 0.976 | 1.548 | 0.714 | 0.714 | 2.381 |
| 06-Oct-94 | | | 6 | 5 | 6.5 | 6.5 | 7 | 3 | 8 | 1.000 | 0.833 | 1.083 | 1.083 | 1.167 | 0.500 | 1.333 |
| 11-Oct-94 | | | 5.6 | 6.2 | 7.1 | 7 | 5.8 | 3.8 | 9 | 1.000 | 1.107 | 1.268 | 1.250 | 1.036 | 0.679 | 1.607 |
| 17-Oct-94 | | | 6 | 6 | 6.6 | 6.6 | 5.2 | 4 | 3.5 | 1.000 | 1.000 | 1.100 | 1.100 | 0.867 | 0.667 | 0.583 |
| 02-May-95 | 6.2 | 1.8 | 6.9 | 7.1 | 6.8 | 7.6 | 6.3 | 2.8 | 4.6 | 1.000 | 1.029 | 0.986 | 1.101 | 0.913 | 0.406 | 0.667 |
| 12-May-95 | 5.2 | 3.6 | 7.2 | 7.4 | 7.5 | 8.1 | 6.8 | 4.2 | 7.2 | 1.000 | 1.028 | 1.042 | 1.125 | 0.944 | 0.583 | 1.000 |
| 16-May-95 | 9 | 3.9 | 8 | 8.4 | 8.3 | 10 | 7.9 | 3.9 | 11 | 1.000 | 1.050 | 1.038 | 1.250 | 0.988 | 0.488 | 1.375 |
| 26-May-95 | 4.2 | 1.1 | 7.33 | 7.2 | 7.6 | 7.1 | 7.6 | 3.1 | 7.6 | 1.000 | 0.982 | 1.037 | 0.969 | 1.037 | 0.423 | 1.037 |
| 20-Jun-95 | 7.5 | 5.8 | 8.7 | 8.4 | 8.1 | 7.8 | 6.6 | 3.9 | 8.2 | 1.000 | 0.966 | 0.931 | 0.897 | 0.759 | 0.448 | 0.943 |

Appendix I : c

| DATE SAMPLED | CHEMICAL OXYGEN DEMAND ONE | TWO | THREE | FOUR | FIVE | SIX | SEVEN |
|---|---|---|---|---|---|---|---|
| 26-Jan-94 | 11 | 11 | 19 | 19 | 344 | 20 | 240 |
| 02-Feb-94 | 33 | 37 | 37 | 48 | 55 | 26 | 177 |
| 14-Feb-94 | 37 | 149 | 111 | 223 | 149 | 186 | 446 |
| 04-Mar-94 | 34 | 18 | 30 | 383 | 22 | 41 | 297 |
| 10-Mar-94 | 45 | 47 | 24 | 26 | 992 | 39 | 173 |
| 25-Mar-94 | 39 | 24 | 28 | 35 | 47 | 51 | 630 |
| 18-Apr-94 | 31 | 39 | 44 | 28 | 44 | 40 | 320 |
| 17-May-94 | 31 | 35 | 27 | 39 | 47 | 55 | 118 |
| 25-May-94 | 480 | 400 | 880 | 68 | 20 | 35 | 1071 |
| 01-Jun-94 | 24 | 28 | 20 | 28 | 48 | 40 | 964 |
| 09-Jun-94 | 385 | 12 | 4 | 71 | 28 | 20 | 79 |
| 14-Jun-94 | 38 | 34 | 27 | 42 | 42 | 34 | 153 |
| 22-Jun-94 | 20 | 36 | 32 | 48 | 40 | 32 | 121 |
| 05-Jul-94 | 16 | 37 | 41 | 77 | 53 | 41 | 2032 |
| 15-Jul-94 | 40 | 51 | 32 | 60 | 56 | 48 | 201 |
| 22-Jul-94 | 36 | 83 | 44 | 67 | 52 | 44 | 159 |
| 02-Aug-94 | 12 | 36 | 48 | 52 | 40 | 68 | 3680 |
| 15-Aug-94 | 51 | 47 | 28 | 32 | 32 | 44 | |
| 29-Aug-94 | 56 | 64 | 87 | 87 | 127 | 182 | |
| 02-Sep-94 | 16 | 48 | 44 | 48 | 104 | 167 | |

**Appendix I : d**

| DATE SAMPLED | OXYGEN ABSORBED | | | | | | |
|---|---|---|---|---|---|---|---|
| | ONE | TWO | THREE | FOUR | FIVE | SIX | SEVEN |
| 26-Jan-94 | 5.4 | 7.2 | 7.4 | 6.4 | 5.6 | 6 | 6.2 |
| 02-Feb-94 | 6.6 | 8 | 8.4 | 7.8 | 9.8 | 7.4 | 10 |
| 14-Feb-94 | 8.4 | 9 | 7.8 | 9.6 | 9 | 8.4 | 7.6 |
| 04-Mar-94 | 6.2 | 6.6 | 5.4 | 18.6 | 7.6 | 8 | 5.8 |
| 10-Mar-94 | 10 | 9.6 | 9.6 | 8 | 9.6 | 11.2 | 5.4 |
| 25-Mar-94 | 9.6 | 7.6 | 7.2 | 7.2 | 7.4 | 6.8 | 4.6 |
| 18-Apr-94 | 5.4 | 3.8 | 7.2 | 8.2 | 7.4 | 6.2 | 6.4 |
| 17-May-94 | 5.2 | 4.6 | 5 | 5.6 | 6.8 | 9.8 | 4.4 |
| 25-May-94 | 4.8 | 4.2 | 5 | 12.4 | 5.4 | 5.6 | 6 |
| 01-Jun-94 | 4.4 | 3.8 | 4.2 | 5 | 8.8 | 5.6 | 2.8 |
| 09-Jun-94 | 3.6 | 3.8 | 3.8 | 11 | 5.2 | 4.4 | 3.6 |
| 14-Jun-94 | 4.2 | 4 | 2.8 | 3.4 | 4.2 | 5.2 | 4.8 |
| 22-Jun-94 | 5 | 4.8 | 4.4 | 5.8 | 13.6 | 3.4 | 5.2 |
| 05-Jul-94 | 4.6 | 5.8 | 6 | 8.4 | 6.8 | 5.8 | 6.2 |
| 15-Jul-94 | 4 | 6.6 | 6 | 10.8 | 6.8 | 6.8 | 3.4 |
| 22-Jul-94 | 3.2 | 5 | 8.2 | 11.4 | 4.2 | 6.8 | 3.4 |
| 02-Aug-94 | 5.2 | 6.4 | 6.4 | 6.8 | 5.8 | 5.4 | 4 |
| 15-Aug-94 | 6.6 | 6.8 | 7 | 7.8 | 6.4 | 5.8 | 4 |
| 29-Aug-94 | 6.6 | 7.6 | 5.8 | 5.6 | | 2.2 | 8 |
| 02-Sep-94 | 5.6 | 7 | 6.8 | 5.2 | 10.8 | 5.4 | 4.4 |
| 19-Sep-94 | 7.8 | 11.4 | 14 | 11.6 | 12.8 | 21.2 | 10.2 |
| 26-Sep-94 | 7.4 | 7 | 8.6 | 11.4 | 8.2 | 8.4 | 6 |
| 06-Oct-94 | 6 | 5.8 | 8.6 | 7.2 | 6.2 | 5.2 | 4.4 |
| 11-Oct-94 | 9.4 | 5 | 5.4 | 6 | 6.4 | 5.8 | 4.2 |
| 17-Oct-94 | 4.8 | 6.6 | 5.8 | 6.6 | 8.4 | 5.6 | 17.2 |
| 10-Feb-95 | 7.6 | 7.6 | 7.8 | 8.4 | 8 | 8.8 | 10 |
| 27-Feb-95 | 5.6 | 5 | 5.8 | 9.4 | 10.4 | 7.8 | 7.4 |
| 17-Mar-95 | 5.4 | 4.8 | 5 | 5.4 | 7.4 | 5.2 | 7.8 |
| 30-Mar-95 | 7.6 | 6.8 | 6.6 | 6.8 | 7.6 | 4.8 | 6.2 |
| 07-Apr-95 | 5.4 | 8.2 | 6.2 | 8.4 | 6.4 | 10.4 | 5.6 |
| 13-Apr-95 | 6.6 | 6.4 | 21.6 | 10.6 | 13 | 6 | 6.6 |
| 20-Apr-95 | 4 | 6.8 | 7.4 | 6.8 | 9 | 7 | 8.6 |
| 26-Apr-95 | 5.4 | 5.2 | 6.2 | 7.2 | 9.6 | 6.8 | 7.2 |
| 03-May-95 | 4.4 | 5 | 5.6 | 5.2 | 11.6 | 5.8 | 3.6 |
| 13-May-95 | 4.8 | 5.2 | 5.2 | 9 | 7.6 | 5.2 | 6.8 |
| 17-May-95 | 3.6 | 5.4 | 5.2 | 5.2 | 5.6 | 3.4 | 5.8 |
| 27-May-95 | 3.6 | 8.6 | 7.6 | 7.4 | 6.6 | 8.2 | 5.6 |
| **AVERAGE** | **5.8** | **6.3** | **6.9** | **8.1** | **8.0** | **6.8** | **6.2** |
| **MEDIAN** | **5.4** | **6.4** | **6.2** | **7.6** | **7.6** | **5.9** | **5.8** |
| **MEDIAN JAN-FEB 94** | **6.6** | **8.0** | **7.8** | **7.8** | **9.0** | **7.4** | **7.6** |
| **AVERAGE JAN-FEB 94** | **6.8** | **8.1** | **7.9** | **7.9** | **8.1** | **7.3** | **7.9** |
| **MEDIAN MAR 94 ....** | **5.4** | **6.1** | **6.1** | **7.3** | **7.4** | **5.8** | **5.7** |
| **AVERAGE MAR 94 ....** | **5.7** | **6.1** | **6.9** | **8.1** | **7.9** | **6.8** | **6.0** |

**Appendix I : e**

| DATE SAMPLED | AMMONIA ONE | TWO | THREE | FOUR | FIVE | SIX | SEVEN |
|---|---|---|---|---|---|---|---|
| 26-Jan-94 | 0 | 3 | 2.3 | 1.05 | 1.6 | 1.4 | 0.06 |
| 02-Feb-94 | 0 | 3.3 | 3.6 | 15 | 1.2 | 1.1 | 0 |
| 14-Feb-94 | 0.1 | 2.7 | 1.8 | 1.5 | 0.7 | 0.6 | 0 |
| 04-Mar-94 | 0.6 | 0.9 | 0.6 | 0 | 0 | 1.1 | 0 |
| 10-Mar-94 | 0.07 | 0.1 | 0.6 | 0 | 0 | 0.4 | 0.4 |
| 25-Mar-94 | 0.5 | 0 | 0 | 0 | 1.9 | 1.4 | 0.3 |
| 18-Apr-94 | 2.9 | 1.87 | 6 | 1.7 | 0.9 | 1.7 | 0.3 |
| 17-May-94 | 7.2 | 3.2 | 2.3 | 2.6 | 2.2 | 2.3 | 0 |
| 25-May-94 | 3.1 | 2.3 | 3.1 | 0.7 | 2.9 | 1.3 | 0.4 |
| 01-Jun-94 | 0.6 | 0.4 | 0.5 | 0.2 | 0.2 | 0.2 | 0.2 |
| 09-Jun-94 | 6.4 | 3.1 | [illegible].3 | 1.5 | 2 | 2.2 | 0.4 |
| 14-Jun-94 | 6.5 | 2.2 | [illegible].5 | 1.3 | 1.3 | 1.9 | 0.1 |
| 22-Jun-94 | 6.1 | 3.7 | 4.1 | 2.6 | 5.6 | 2.6 | 0.7 |
| 05-Jul-94 | 5.7 | 3.5 | 3.6 | 1.7 | 3.9 | 3.9 | 0.6 |
| 15-Jul-94 | 7.2 | 5.5 | 4.3 | 3.1 | 3.9 | 1.9 | 0 |
| 22-Jul-94 | 7.2 | 4.3 | 5.7 | 5.1 | 5.9 | 5.9 | 0.6 |
| 02-Aug-94 | 8.3 | 6.6 | 6.4 | 6.7 | 6.5 | 4.1 | 0.9 |
| 15-Aug-94 | 5.3 | 3.1 | 2.6 | 3.4 | 3.2 | 1.7 | 0.5 |
| 29-Aug-94 | 8 | 4.4 | 4.5 | 2.4 | 0.9 | 1.1 | 0 |
| 02-Sep-94 | 5.9 | 5 | 5.3 | 1.1 | 1.6 | 1.5 | 0.7 |
| 19-Sep-94 | 6.1 | 3.6 | 4.2 | 6.1 | 4.7 | 0.1 | 0.2 |
| 26-Sep-94 | 7.7 | 3.5 | 4.5 | 3 | 4.2 | 3.3 | 0.7 |
| 06-Oct-94 | 2.7 | 4.1 | 2.8 | 3.4 | 0 | 1.6 | 2.1 |
| 11-Oct-94 | 3.3 | 1.7 | 2 | 2.4 | 4.2 | 1.4 | 0.5 |
| 17-Oct-94 | 3.5 | 2.6 | 2 | 1.9 | 2.2 | 1.9 | 0.9 |
| 10-Feb-95 | 4.1 | 2.7 | 2.1 | 1.1 | 1.4 | 1.7 | 0.3 |
| 27-Feb-95 | 1.3 | 1.2 | 0.6 | 7.4 | 0.1 | 0.1 | 0.9 |
| 17-Mar-95 | 1 | 0.6 | 0.1 | 0.1 | 0.3 | 0.5 | 0.2 |
| 30-Mar-95 | 3.4 | 1.4 | 0.6 | 0.4 | 0.4 | 0.6 | 0.5 |
| 07-Apr-95 | 1.8 | 0.6 | 0.3 | 0.1 | 0.6 | 0.8 | 0.1 |
| 20-Apr-95 | 4.9 | 5.2 | 5.5 | 4.8 | 4.2 | 3.4 | 0.5 |
| 26-Apr-95 | 2.1 | 3.2 | 2.7 | 2.1 | 2.5 | 3.6 | 0.6 |
| 03-May-95 | 4.1 | 3.2 | 2.4 | 1.9 | 0.1 | 1.8 | 0.1 |
| 13-May-95 | 2.3 | 1.3 | 0.6 | 1 | 1.6 | 2.2 | 0.3 |
| 17-May-95 | 6.2 | 3.5 | 2.5 | 2.7 | 3.2 | 2.2 | 0.2 |
| 27-May-95 | 2.1 | 8 | 6.8 | 5.2 | 4.3 | 3.4 | 0.7 |

**Appendix I : f**

| DATE SAMPLED | NITRATE ONE | TWO | THREE | FOUR | FIVE | SIX | SEVEN |
|---|---|---|---|---|---|---|---|
| 26-Jan-94 | 3.4 | 3.6 | 3.6 | 3.6 | 3.4 | 3.5 | 0.08 |
| 02-Feb-94 | 5 | 7.9 | 10 | 8.5 | 7.4 | 6.7 | 0 |
| 14-Feb-94 | 4.7 | 11.5 | 9.3 | 8.1 | 10.1 | 8.4 | 6.8 |
| 04-Mar-94 | 3.5 | 12.8 | 11.9 | 0 | 10.2 | 2 | 0.4 |
| 10-Mar-94 | 5.2 | 8.8 | 6.4 | 3.9 | 6.6 | 0.4 | 2 |
| 25-Mar-94 | 13.6 | 12.6 | 3.4 | 6.8 | 0 | 0 | 7.4 |
| 18-Apr-94 | 1.7 | 6.4 | 1.3 | 1.1 | 1.1 | 1 | 0.6 |
| 17-May-94 | 4 | 10.8 | 10.6 | 8.9 | 7.2 | 6.1 | 0.5 |
| 25-May-94 | 2.5 | 11.7 | 12.4 | 5.3 | 12.6 | 9.5 | 1.7 |
| 01-Jun-94 | 0 | 0.5 | 0.5 | 0.2 | 0.2 | 0.2 | 0.2 |
| 09-Jun-94 | 0.8 | 7.2 | 6.4 | 5.9 | 6.5 | 5.1 | 0.8 |
| 14-Jun-94 | 2.1 | 7.4 | 6.3 | 5.3 | 5.6 | 12.7 | 0.4 |
| 22-Jun-94 | 1 | 12.2 | 11.4 | 10.9 | 11.4 | 10 | 2 |
| 05-Jul-94 | 1.1 | 10.9 | 10.9 | 10.5 | 10.6 | 10.7 | 1.3 |
| 15-Jul-94 | 1.1 | 16.3 | 16.4 | 13.8 | 14.4 | 10.7 | 0.2 |
| 22-Jul-94 | 0.8 | 17.9 | 13.2 | 9.8 | 11.9 | 8.3 | 0.9 |
| 02-Aug-94 | 2.7 | 13.9 | 13.3 | 11.3 | 12.1 | 10.4 | 1.4 |
| 15-Aug-94 | 2.7 | 11.5 | 12.2 | 9.7 | 10.2 | 8.4 | 0.7 |
| 29-Aug-94 | 11.5 | 11.2 | 10.6 | 22.2 | 0.2 | 0.1 | 0 |
| 02-Sep-94 | 4.3 | 10.7 | 12.4 | 3.5 | 2.1 | 1.3 | 0 |
| 19-Sep-94 | 1.7 | 8.1 | 8.3 | 0.6 | 0.04 | 0.6 | 0 |
| 26-Sep-94 | 0.7 | 12.1 | 10.4 | 7.5 | 7.8 | 9.2 | 0.5 |
| 06-Oct-94 | 0.2 | 13.8 | 9 | 10.4 | 11.2 | 0 | 2 |
| 11-Oct-94 | 3.6 | 14.3 | 12.6 | 9.7 | 9.4 | 9.1 | 0.5 |
| 17-Oct-94 | 1.5 | 9.8 | 7.1 | 5.2 | 4.4 | 7.8 | 0 |
| 10-Feb-95 | 7.2 | 8.1 | 4.8 | 4.8 | 6.6 | 5.4 | 0.5 |
| 27-Feb-95 | 1.7 | 6.3 | 5.7 | 3.2 | 5.3 | 6.6 | 0.21 |
| 17-Mar-95 | 5.2 | 13 | 12.5 | 11.4 | 12.4 | 9.2 | 0.8 |
| 30-Mar-95 | 4.5 | 6.3 | 6.7 | 6.9 | <0.1 | 4.7 | 2.4 |
| 07-Apr-95 | 7.5 | 12.9 | 12.33 | 11.5 | 10 | 6.4 | 0.9 |
| 13-Apr-95 | 14.5 | 15.4 | 14.3 | 12.1 | 12.5 | 7.4 | 2.5 |
| 20-Apr-95 | 2.7 | 6.8 | 6.4 | 6.1 | 5.7 | 4.7 | 0.2 |
| 26-Apr-95 | 4.1 | 7.5 | 7.4 | 7.1 | 5.33 | 4.5 | 1.3 |
| 03-May-95 | 3.1 | 7.7 | 6.5 | 5.7 | 0.2 | 7.5 | 11.2 |
| 13-May-95 | 6.7 | 13 | 7.8 | 4.3 | 4.1 | 15.2 | 1.3 |
| 17-May-95 | 5.7 | 8.2 | 9.4 | 12.4 | 9.2 | 6 | 0.7 |
| 27-May-95 | 3.9 | 8.5 | 9 | 9.6 | 7.3 | 8.4 | 1 |

**Appendix I : g**

| DATE | TOTAL NITROGEN | | | | | | |
|---|---|---|---|---|---|---|---|
| SAMPLED | ONE | TWO | THREE | FOUR | FIVE | SIX | SEVEN |
| 26-Jan-94 | 3.4 | 6.6 | 5.9 | 4.65 | 5 | 4.9 | 0.14 |
| 02-Feb-94 | 5 | 11.2 | 13.6 | 23.5 | 8.6 | 7.8 | 0 |
| 14-Feb-94 | 4.8 | 14.2 | 11.1 | 9.6 | 10.8 | 9 | 6.8 |
| 04-Mar-94 | 4.1 | 13.7 | 12.5 | 0 | 10.2 | 3.1 | 0.4 |
| 10-Mar-94 | 5.27 | 8.9 | 7 | 3.9 | 6.6 | 0.8 | 2.4 |
| 25-Mar-94 | 14.1 | 12.6 | 3.4 | 6.8 | 1.9 | 1.4 | 7.7 |
| 18-Apr-94 | 4.6 | 8.27 | 7.3 | 2.8 | 2 | 2.7 | 0.9 |
| 17-May-94 | 11.2 | 14 | 12.9 | 11.5 | 9.4 | 8.4 | 0.5 |
| 25-May-94 | 5.6 | 14 | 15.5 | 6 | 15.5 | 10.8 | 2.1 |
| 01-Jun-94 | 0.6 | 0.9 | 1 | 0.4 | 0.4 | 0.4 | 0.4 |
| 09-Jun-94 | 7.2 | 10.3 | 8.7 | 7.4 | 8.5 | 7.3 | 1.2 |
| 14-Jun-94 | 8.6 | 9.6 | 7.8 | 6.6 | 5.9 | 14.6 | 0.5 |
| 22-Jun-94 | 7.1 | 15.9 | 15.5 | 13.5 | 17 | 12.6 | 2.7 |
| 05-Jul-94 | 6.8 | 14.4 | 14.5 | 12.2 | 14.5 | 14.6 | 1.9 |
| 15-Jul-94 | 8.3 | 21.8 | 20.7 | 16.9 | 18.3 | 12.6 | 0.2 |
| 22-Jul-94 | 8 | 22.2 | 18.9 | 14.9 | 17.8 | 14.2 | 1.5 |
| 02-Aug-94 | 11 | 20.5 | 19.7 | 18 | 18.6 | 14.5 | 2.3 |
| 15-Aug-94 | 8 | 14.6 | 14.8 | 13.1 | 13.4 | 10.1 | 1.2 |
| 29-Aug-94 | 19.5 | 15.6 | 15.1 | 24.6 | 1.1 | 1.2 | 0 |
| 02-Sep-94 | 10.2 | 15.7 | 17.7 | 4.6 | 3.7 | 2.8 | 0.7 |
| 19-Sep-94 | 7.8 | 11.7 | 12.5 | 6.7 | 4.74 | 0.7 | 0.2 |
| 26-Sep-94 | 8.4 | 15.6 | 14.9 | 10.5 | 12 | 12.5 | 1.2 |
| 06-Oct-94 | 2.9 | 17.9 | 11.8 | 13.8 | 11.2 | 1.6 | 4.1 |
| 11-Oct-94 | 6.9 | 16 | 14.6 | 12.1 | 13.6 | 10.5 | 1 |
| 17-Oct-94 | 5 | 12.4 | 9.1 | 7.1 | 6.6 | 9.7 | 0.9 |
| 10-Feb-95 | 11.3 | 10.8 | 6.9 | 5.9 | 8 | 7.1 | 0.8 |
| 27-Feb-95 | 3 | 7.5 | 6.3 | 10.6 | 5.4 | 6.7 | 1.11 |
| 17-Mar-95 | 6.2 | 13.6 | 12.6 | 11.5 | 12.7 | 9.7 | 1 |
| 30-Mar-95 | 7.9 | 7.7 | 7.3 | 7.3 | 0.4 | 5.3 | 2.9 |
| 07-Apr-95 | 9.3 | 13.5 | 12.63 | 11.6 | 10.6 | 7.2 | 1 |
| 20-Apr-95 | 7.6 | 12 | 11.9 | 10.9 | 9.9 | 10.8 | 3 |
| 26-Apr-95 | 6.2 | 10.7 | 10.1 | 9.2 | 7.83 | 8.3 | 0.8 |
| 03-May-95 | 7.2 | 10.9 | 8.9 | 7.6 | 0.3 | 6.3 | 1.4 |
| 13-May-95 | 9 | 14.3 | 8.4 | 5.3 | 5.7 | 9.7 | 11.5 |
| 17-May-95 | 11.9 | 11.7 | 11.9 | 15.1 | 12.4 | 17.4 | 1.5 |
| 27-May-95 | 6 | 16.5 | 15.8 | 14.8 | 11.6 | 9.4 | 1.4 |

**Appendix I : h**

| DATE SAMPLED | ONE | TWO | THREE | FATS FOUR | FIVE | mg/l SIX | SEVEN |
|---|---|---|---|---|---|---|---|
| 26-Jan-94 | 120 | 40 | 40 | 400 | 1720 | 100 | 100 |
| 02-Feb-94 | 160 | 120 | 100 | 60 | 60 | 80 | 60 |
| 14-Feb-94 | 80 | 80 | 100 | 260 | 4040 | 1680 | 380 |
| 04-Mar-94 | 820 | 340 | 340 | 1720 | 1000 | 880 | 80 |
| 10-Mar-94 | 40 | 40 | 60 | 60 | 1080 | 40 | 3920 |
| 25-Mar-94 | 60 | 60 | 60 | 80 | 200 | 400 | 60 |
| 18-Apr-94 | 0 | 0 | 60 | 60 | 140 | 240 | 40 |
| 17-May-94 | 0 | 2560 | 160 | 0 | 0 | 3100 | 1660 |
| 25-May-94 | 340 | 580 | 240 | 880 | 100 | 460 | 420 |
| 01-Jun-94 | 200 | 260 | 40 | 0 | 200 | 400 | 1160 |
| 09-Jun-94 | 0 | 0 | 500 | 40 | 80 | 540 | 140 |
| 14-Jun-94 | 0 | 420 | 260 | 40 | 0 | 760 | 100 |
| 22-Jun-94 | 1620 | 0 | 0 | 0 | 0 | 340 | 180 |
| 05-Jul-94 | 4260 | 1260 | 40 | 280 | 120 | 1000 | 700 |
| 15-Jul-94 | 200 | 180 | 0 | 320 | 460 | 340 | 0 |
| 22-Jul-94 | 100 | 260 | 420 | 220 | 520 | 180 | 240 |
| 02-Aug-94 | 400 | 0 | 0 | 60 | 0 | 0 | 80 |
| 15-Aug-94 | 140 | 180 | 140 | 240 | 180 | 420 | 0 |
| 29-Aug-94 | 360 | 120 | 40 | 140 | 380 | 300 | 40 |
| 02-Sep-94 | 0 | 380 | 0 | 0 | 0 | 120 | 80 |

## Appendix I : i

| DATE SAMPLED | PHOSPHATES ONE | TWO | THREE | FOUR | FIVE | SIX | SEVEN |
|---|---|---|---|---|---|---|---|
| 26-Jan-94 | 1 | 2.9 | 2.9 | 2.1 | 1.9 | 1.5 | 0.6 |
| 02-Feb-94 | 1.1 | 3.7 | 3.5 | 3.3 | 2.2 | 2.4 | 1 |
| 14-Feb-94 | 0.3 | 3.6 | 3.2 | 2.7 | 2.6 | 2.3 | 0.1 |
| 04-Mar-94 | 1.2 | 4.3 | 3.9 | 5.9 | 4.9 | 2.8 | 0.2 |
| 10-Mar-94 | 0.1 | 0.9 | 1.6 | 0.5 | 0.2 | 1.1 | 0.8 |
| 25-Mar-94 | 1.4 | 3.2 | 4.3 | 2.3 | 2.5 | 2.8 | 0.4 |
| 18-Apr-94 | 0.6 | 3.3 | 4.2 | 2.7 | 3 | 2.5 | 0.8 |
| 17-May-94 | 1.5 | 3.6 | 3.4 | 2.8 | 3.2 | 3.3 | 0.2 |
| 25-May-94 | 0.8 | 0 | 0 | 0 | 0 | 2.9 | 0 |
| 01-Jun-94 | 1 | 3.7 | 3.4 | 2.9 | 2.9 | 2.9 | 1.5 |
| 09-Jun-94 | 0.4 | 2.7 | 2.5 | 2.5 | 4.1 | 3.3 | 2.5 |
| 14-Jun-94 | 1.3 | 2.5 | 2 | 0.5 | 1.8 | 3.7 | 0.2 |
| 22-Jun-94 | 1.4 | 4.2 | 3.4 | 3.2 | 3.6 | 3.3 | 0.7 |
| 05-Jul-94 | 0.8 | 3.6 | 3.4 | 2.9 | 3.1 | 3.1 | 0.3 |
| 15-Jul-94 | 1.3 | 4.1 | 3.6 | 3.6 | 2.7 | 4.8 | 0 |
| 22-Jul-94 | 0 | 2.7 | 1.8 | 2.5 | 1.9 | 2.2 | 0 |
| 02-Aug-94 | 1.9 | 3.9 | 3.6 | 3 | 2.8 | 2.1 | 0.7 |
| 15-Aug-94 | 1.1 | 3.2 | 3.4 | 2.5 | 2.3 | 2 | |
| 29-Aug-94 | 1.1 | 2.9 | 2.5 | | | | |
| 02-Sep-94 | 2 | 3.6 | 3.3 | 0.9 | 1.1 | 0.7 | 0.3 |

**Appendix I : j**

| DATE SAMPLED | SUSPENDED SOLIDS ONE | TWO | THREE | FOUR | FIVE | SIX | SEVEN |
|---|---|---|---|---|---|---|---|
| 26-Jan-94 | 15 | 33 | 41 | 41 | 35 | 10 | 82 |
| 02-Feb-94 | 16 | 21 | 26 | 52 | 41 | 24 | 12 |
| 14-Feb-94 | 20 | 61 | 27 | 32 | 36 | 34 | 100 |
| 04-Mar-94 | 23 | 23 | 28 | 97 | 24 | 36 | 126 |
| 10-Mar-94 | 291 | 269 | 172 | 260 | 267 | 283 | 84 |
| 25-Mar-94 | 16 | 24 | 28 | 42 | 29 | 25 | 72 |
| 18-Apr-94 | 13 | 13 | 8 | 43 | 37 | 24 | 103 |
| 17-May-94 | 10 | 6 | 7 | 24 | 30 | 12 | 118 |
| 25-May-94 | 10 | 14 | 19 | 16 | 19 | 30 | 177 |
| 01-Jun-94 | 16 | 6 | 10 | 31 | 26 | 20 | 120 |
| 09-Jun-94 | 5 | 4 | 8 | 37 | 15 | 20 | 122 |
| 14-Jun-94 | 4 | 24 | 16 | 16 | 25 | 13 | 29 |
| 22-Jun-94 | 5 | 9 | 11 | 16 | 27 | 8 | 145 |
| 05-Jul-94 | 7 | 6 | 17 | 22 | 21 | 12 | 143 |
| 15-Jul-94 | 11 | 10 | 11 | 31 | 18 | 23 | 118 |
| 22-Jul-94 | 6 | 17 | 19 | 28 | 17 | 30 | 141 |
| 02-Aug-94 | 5 | 15 | 13 | 24 | 15 | 20 | 117 |
| 15-Aug-94 | 66 | 10 | 18 | 32 | 21 | 23 | 149 |
| 29-Aug-94 | 113 | 30 | 49 | 92 | 108 | 30 | 170 |
| 02-Sep-94 | 17 | 18 | 13 | 25 | 44 | 22 | 155 |

Appendix I : k

| DATE SAMPLED | CHLORIDE ONE | TWO | THREE | FOUR | FIVE | SIX | SEVEN |
|---|---|---|---|---|---|---|---|
| 26-Jan-94 | 73 | 90 | 84 | 187 | 85 | 144 | 8280 |
| 02-Feb-94 | 84 | 100 | 94 | 93 | 102 | 306 | 9750 |
| 14-Feb-94 | 79 | 87 | 85 | 94 | 90 | 352 | 10000 |
| 04-Mar-94 | 77 | 81 | 77 | 81 | 88 | 278 | 10800 |
| 10-Mar-94 | 55 | 54 | 51 | 50 | 50 | 67 | 4250 |
| 25-Mar-94 | 81 | 75 | 75 | 84 | 117 | 241 | 8950 |
| 18-Apr-94 | 73 | 75 | 116 | 118 | 129 | 215 | 12150 |
| 17-May-94 | 65 | 60 | 60 | 70 | 80 | 198 | 14800 |
| 25-May-94 | 71 | 70 | 74 | 77 | 291 | 800 | 16400 |
| 01-Jun-94 | 67 | 59 | 61 | 70 | 92 | 30 | 17450 |
| 09-Jun-94 | 47 | 55 | 52 | 64 | 65 | 328 | 19400 |
| 14-Jun-94 | 70 | 55 | 46 | 52 | 52 | 250 | 16600 |
| 22-Jun-94 | 69 | 60 | 61 | 66 | 65 | 432 | 17200 |
| 05-Jul-94 | 70 | 72 | 70 | 77 | 88 | 146 | 17950 |
| 15-Jul-94 | 65 | 88 | 86 | 92 | 95 | 305 | 18750 |
| 22-Jul-94 | 70 | 85 | 82 | 97 | 102 | 179 | 19150 |
| 02-Aug-94 | 74 | 84 | 81 | 99 | 99 | 155 | 16950 |
| 15-Aug-94 | 72 | 77 | 76 | 84 | 82 | 250 | 17600 |
| 29-Aug-94 | 71 | 89 | 81 | 166 | 304 | 1300 | 20250 |
| 02-Sep-94 | 68 | 90 | 90 | 150 | 243 | 1650 | 17350 |

Appendix I : 1

| DATE | ALUMINIUM | | | | | | | CALCIUM | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SAMPLED | ONE | TWO | THREE | FOUR | FIVE | SIX | SEVEN | ONE | TWO | THREE | FOUR | FIVE | SIX | SEVEN |
| 26-Jan-94 | 0.1 | 0.16 | 0.16 | 0.13 | 0.09 | 0.1 | 0.13 | 20.4 | 22.4 | 23 | 23.3 | 23.2 | 25.5 | 170 |
| 02-Feb-94 | 0.3 | 0.2 | 0.6 | 0.4 | 0.66 | 0.2 | 0.4 | 20.8 | 21.1 | 22 | 24 | 23.7 | 28.4 | 222 |
| 14-Feb-94 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 18 | 20.3 | 21.1 | 23.5 | 23 | 31 | 200 |
| 04-Mar-94 | 0.1 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 19.3 | 24.4 | 23.5 | 28 | 25.8 | 30 | 200 |
| 10-Mar-94 | 0.7 | 1.2 | 0.7 | 1 | 0.4 | 0.8 | 0.3 | 16 | 16.8 | 17 | 16.8 | 16 | 16 | 88 |
| 25-Mar-94 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 18.3 | 18.4 | 18.5 | 19.6 | 23.4 | 28.3 | 23.4 |
| 18-Apr-94 | | | 0.1 | 0.2 | 0.1 | 0.1 | 0.1 | | | 22.2 | 26.6 | 27 | 30 | 280 |
| 17-May-94 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 19.6 | 20.5 | 19 | 19.5 | 22 | 24 | 320 |
| 25-May-94 | 0.1 | 0.1 | 0.14 | 0.1 | 0.1 | 0.18 | 0.18 | 18.5 | 17.5 | 17.7 | 19.7 | 23 | 31.8 | 290 |
| 01-Jun-94 | 0.1 | 0.1 | 0.12 | 0.1 | 0.1 | 0.14 | 0.14 | 18.3 | 17.2 | 17 | 19.1 | 20 | 24 | 350 |
| 09-Jun-94 | 0.15 | 0.15 | 0.2 | 0.3 | 0.3 | 0.1 | 0.1 | 16 | 19 | 17 | 18.5 | 19.2 | 22 | 380 |
| 14-Jun-94 | 0.1 | 0.3 | 0.35 | 0.35 | 0.34 | 0.15 | 0.15 | 19.8 | 15.9 | 15 | 16 | 16.1 | 20.8 | 400 |
| 22-Jun-94 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.14 | 18 | 17.8 | 18 | 19 | 18.4 | 23 | 330 |
| 05-Jul-94 | 0.1 | 0.1 | 0.1 | 0.15 | 0.12 | 0.1 | 0.1 | 18.5 | 16.1 | 16.8 | 17.5 | 17.3 | 20.3 | 350 |
| 15-Jul-94 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 19.6 | 19 | 19.2 | 20.1 | 20.8 | 25 | 520 |
| 22-Jul-94 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 19.9 | 17.3 | 17.9 | 19.3 | 20.7 | 22.8 | 380 |
| 02-Aug-94 | 0.1 | 0.12 | 0.1 | 0.1 | 0.13 | 0.1 | 0.1 | 22.8 | 21.54 | 22.8 | 24.9 | 25.9 | 29.4 | 60 |
| 15-Aug-94 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 22.5 | 21.1 | 20.3 | 2.3 | 22.7 | 28.9 | 374 |
| 29-Aug-94 | 0.1 | 0.12 | 0.14 | 0.14 | 0.1 | 0.1 | 0.2 | 22.8 | 23 | 23 | 41.8 | 60 | 92 | 420 |
| 02-Sep-94 | 0.1 | 0.12 | 0.14 | 0.1 | 0.1 | 0.1 | 0.1 | 18.5 | 25.9 | 19.5 | 35.8 | 42.8 | 73 | 340 |

Appendix I : m

| DATE | MAGNESIUM | | | | | | | SODIUM | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SAMPLED | ONE | TWO | THREE | FOUR | FIVE | SIX | SEVEN | ONE | TWO | THREE | FOUR | FIVE | SIX | SEVEN |
| 26-Jan-94 | 15.5 | 13.2 | 13.6 | 14.8 | 14.6 | 17.7 | 530 | 62.9 | 72 | 70 | 70.7 | 72 | 108 | 3600 |
| 02-Feb-94 | 15 | 11.8 | 11.7 | 13 | 13.5 | 20 | 730 | 72 | 79 | 85 | 74 | 72 | 124 | 5240 |
| 14-Feb-94 | 14.1 | 10.1 | 11.4 | 12.8 | 11.9 | 24.5 | 640 | 70 | 71 | 73 | 78 | 78 | 185 | 4900 |
| 04-Mar-94 | 14 | 9.8 | 10.7 | 12.3 | 11.7 | 23.6 | 710 | 64 | 65 | 66 | 70 | 71 | 175 | 4800 |
| 10-Mar-94 | 12.3 | 12 | 11.8 | 11.4 | 10.7 | 10.8 | 266 | 44 | 46 | 41 | 41.5 | 42 | 70 | 1900 |
| 25-Mar-94 | 14.5 | 10.5 | 111.4 | 13 | 15.6 | 23.3 | 15.6 | 55 | 54 | 56 | 53 | 74 | 140 | 4300 |
| 18-Apr-94 | | | 10 | 13.5 | 14.6 | 21 | 940 | | | 100 | 103 | 109 | 160 | 6600 |
| 17-May-94 | 11.2 | 8.5 | 8.8 | 10.7 | 14.2 | 18.2 | 1120 | 55 | 61 | 56 | 56 | 103 | 134 | 7300 |
| 25-May-94 | 14 | 10 | 11.2 | 12.5 | 26 | 65 | 1170 | 55 | 60 | 57 | 68 | 190 | 456 | 8000 |
| 01-Jun-94 | 13 | 9.7 | 9.7 | 11.8 | 13 | 24 | 1250 | 55 | 51 | 52 | 63 | 65 | 184 | 8300 |
| 09-Jun-94 | 10.5 | 9.6 | 10 | 10.7 | 10.7 | 18.2 | 1430 | 38.3 | 44.5 | 44.8 | 63 | 68 | 130 | 10800 |
| 14-Jun-94 | 13.6 | 8.4 | 8.4 | 8.7 | 9.3 | 20.8 | 1290 | 54 | 51 | 43 | 43 | 44 | 145 | 9500 |
| 22-Jun-94 | 13.4 | 9.5 | 10 | 10.6 | 10 | 17 | 1190 | 52 | 43 | 50 | 52 | 54 | 100 | 7400 |
| 05-Jul-94 | 13.2 | 9.6 | 10.2 | 11.2 | 10.6 | 13.5 | 1200 | 60 | 73 | 68 | 75 | 75 | 125 | 1090 |
| 15-Jul-94 | 11.8 | 10.2 | 10.4 | 11.4 | 11 | 25.6 | 1380 | 5 | 80 | 72 | 95 | 84 | 200 | 1140 |
| 22-Jul-94 | 13.2 | 10.4 | 11.3 | 12 | 12.3 | 17.2 | 1260 | 53 | 74 | 63 | 78 | 82 | 123 | 9000 |
| 02-Aug-94 | 14.6 | 10.9 | 12.5 | 14 | 13.8 | 18.3 | 1220 | 60 | 68 | 68 | 79 | 75 | 99 | 8600 |
| 15-Aug-94 | 14.3 | 11 | 11.2 | 13.2 | 12.1 | 22 | 1300 | 74 | 64 | 63 | 66 | 67 | 147 | 9000 |
| 29-Aug-94 | 14 | 11 | 11.5 | 21.1 | 32.2 | 101 | 1200 | 58 | 66 | 62 | 102 | 200 | 680 | 8400 |
| 02-Sep-94 | 14 | 11.4 | 11.9 | 21.8 | 31 | 126 | 1340 | 58 | 69 | 73 | 106 | 183 | 880 | 8800 |

**Appendix I : n**

| DATE SAMPLED | POTASSIUM ONE | TWO | THREE | FOUR | FIVE | SIX | SEVEN | IRON ONE | TWO | THREE | FOUR | FIVE | SIX | SEVEN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 26-Jan-94 | 5 | 14 | 12.2 | 10.6 | 11.7 | 11.7 | 195 | 0.52 | 0.61 | 0.71 | 0.63 | 0.65 | 0.43 | 0.27 |
| 02-Feb-94 | 5 | 14.3 | 13.6 | 122 | 9.9 | 13 | 215 | 0.89 | 0.54 | 0.93 | 1.14 | 2.4 | 0.99 | 0.3 |
| 14-Feb-94 | 5.4 | 14.8 | 12.5 | 13.3 | 13 | 15.5 | 218 | 0.3 | 0.1 | 0.18 | 0.09 | 0.11 | 0.07 | 0.22 |
| 04-Mar-94 | 5.8 | 13.8 | 12.6 | 15.5 | 12.8 | 19.5 | 250 | 1.42 | 0.2 | 0.36 | 0.73 | 0.31 | 0.4 | 0.22 |
| 10-Mar-94 | 4.4 | 6.8 | 7.2 | 6.2 | 7 | 8.4 | 89 | 1.2 | 1.4 | 1.5 | 2.2 | 5 | 1.6 | 0.6 |
| 25-Mar-94 | 6 | 13.2 | 10.2 | 10.6 | 12.8 | 18.1 | 200 | 0.95 | 0.43 | 0.62 | 0.8 | 1.1 | 0.51 | 0.2 |
| 18-Apr-94 | | | 24.3 | 16.7 | 18.9 | 19.5 | 300 | | | 0.08 | 0.35 | 0.31 | 0.3 | 0.18 |
| 17-May-94 | 6 | 9.3 | 10.2 | 9.3 | 11.6 | 15.4 | 400 | 0.87 | 0.38 | 0.49 | 0.69 | 0.58 | 0.53 | 0.31 |
| 25-May-94 | 4.7 | 9 | 8 | 8 | 14 | 24.5 | 320 | 0.46 | 0.37 | 0.44 | 0.34 | 0.54 | 0.5 | 0.48 |
| 01-Jun-94 | 6 | 8.6 | 8.6 | 7.7 | 9 | 13.5 | 398 | 0.6 | 0.32 | 0.39 | 0.64 | 1.24 | 0.53 | 0.46 |
| 09-Jun-94 | 4.6 | 7.4 | 6.6 | 8 | 7.8 | 11 | 410 | 0.55 | 0.49 | 0.47 | 0.57 | 0.47 | 0.4 | 0.53 |
| 14-Jun-94 | 6.3 | 7.1 | 6.7 | 5.8 | 6 | 13.7 | 370 | 1 | 0.4 | 0.44 | 0.5 | 0.48 | 0.35 | 0.36 |
| 22-Jun-94 | 6.1 | 9.8 | | 9.3 | 10 | 13 | 350 | 1.07 | 0.46 | 0.57 | 0.6 | 0.47 | 0.45 | 0.65 |
| 05-Jul-94 | 7.6 | 12.5 | 12.4 | 12.6 | 13.4 | 11.5 | 330 | 1.03 | 0.57 | 0.78 | 0.72 | 0.69 | 0.65 | 0.4 |
| 15-Jul-94 | 5.7 | 15 | 14.4 | 13 | 13.6 | 17 | 416 | 0.73 | 0.23 | 0.44 | 0.4 | 0.48 | 0.38 | 0.35 |
| 22-Jul-94 | 5.9 | 13.7 | 12.6 | 14.8 | 16.7 | 17.1 | 260 | 1.36 | 0.49 | 0.8 | 0.9 | 0.9 | 1.35 | 0.5 |
| 02-Aug-94 | 6.1 | 13 | 11.4 | 13.1 | 12.6 | 13.4 | 380 | 1.59 | 0.58 | 0.84 | 1.14 | 1.11 | 0.88 | 0.37 |
| 15-Aug-94 | 6.5 | 11.5 | 11.4 | 12.5 | 11.9 | 14.4 | 388 | 1.4 | 0.6 | 0.88 | 1.33 | 0.98 | 1 | 0.45 |
| 29-Aug-94 | 7.5 | 14.1 | 12 | 16 | 24.6 | 38.4 | 375 | 1.6 | 0.69 | 0.64 | 2.9 | 1.81 | 0.55 | 0.54 |
| 02-Sep-94 | 6.5 | 15 | 14.8 | 12.2 | 24.3 | 45 | 370 | 1.57 | 0.85 | 0.69 | 2 | 1.56 | 0.8 | 0.54 |

Appendix I : o

| DATE | MANGANESE | | | | | | | ZINC | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SAMPLED | ONE | TWO | THREE | FOUR | FIVE | SIX | SEVEN | ONE | TWO | THREE | FOUR | FIVE | SIX | SEVEN |
| 26-Jan-94 | 0.1 | 0.11 | 0.15 | 0.13 | 0.12 | 0.07 | 0.1 | 0.02 | 0.02 | 0.03 | 0.05 | 0.04 | 0.04 | 0.06 |
| 02-Feb-94 | 0.18 | 0.14 | 0.14 | 0.16 | 0.22 | 0.12 | 0.11 | 0.01 | 0.01 | 0.02 | 0.03 | 1.37 | 0.05 | 0.05 |
| 14-Feb-94 | 0.13 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.07 | 0.04 | 0.04 | 0.06 | 0.05 | 0.06 | 0.08 | 0.13 |
| 04-Mar-94 | 0.09 | 0.04 | 0.04 | 0.15 | 0.05 | 0.07 | 0.05 | 0.07 | 0.07 | 0.04 | 0.06 | 0.2 | 0.29 | 0.08 |
| 10-Mar-94 | 0.07 | 0.14 | 0.22 | 0.15 | 0.04 | 0.13 | 0.17 | 0.03 | 0.06 | 0.1 | 0.06 | 0.05 | 0.12 | 0.06 |
| 25-Mar-94 | 0.18 | 0.08 | 0.13 | 0.17 | 0.26 | 0.12 | 0.07 | 0.01 | 0.02 | 0.03 | 0.03 | 0.05 | 0.03 | 0.05 |
| 18-Apr-94 | | | 0.02 | 0.01 | 0.01 | 0.02 | 0.11 | | | 0.04 | 0.02 | 0.05 | 0.05 | 0.09 |
| 17-May-94 | 0.05 | 0.04 | 0.02 | 0.08 | 0.12 | 0.11 | 0.13 | 0.01 | 0.01 | 0.01 | 0.02 | 0.01 | 0.03 | 0.05 |
| 25-May-94 | 0.1 | 0.11 | 0.11 | 0.13 | 0.13 | 0.1 | 0.25 | 0.01 | 0.02 | 0.02 | 0.02 | 0.05 | 0.05 | 0.06 |
| 01-Jun-94 | 0.08 | 0.08 | 0.09 | 0.1 | 0.15 | 0.13 | 0.16 | 0.01 | 0.03 | 0.03 | 0.04 | 1.96 | 0.44 | 0.08 |
| 09-Jun-94 | 0.06 | 0.06 | 0.07 | 0.07 | 0.07 | 0.05 | 0.16 | 0.02 | 0.03 | 0.03 | 0.04 | 0.05 | 0.04 | 0.1 |
| 14-Jun-94 | 0.09 | 0.06 | 0.06 | 0.07 | 0.09 | 0.08 | 0.17 | 0.01 | 0.01 | 0.02 | 0.02 | 0.05 | 0.08 | 0.07 |
| 22-Jun-94 | 0.17 | 0.11 | 0.11 | 0.09 | 0.09 | 0.05 | 0.14 | 0.01 | 0.03 | 0.02 | 0.03 | 0.04 | 0.1 | 0.11 |
| 05-Jul-94 | 0.12 | 0.1 | 0.11 | 0.12 | 0.12 | 0.1 | 0.12 | 0.02 | 0.03 | 0.03 | 0.03 | 0.1 | 0.08 | 0.1 |
| 15-Jul-94 | 0.09 | 0.06 | 0.1 | 0.1 | 0.1 | 0.09 | 0.12 | 0.02 | 0.02 | 0.03 | 0.02 | 0.56 | 0.16 | 0.08 |
| 22-Jul-94 | 0.22 | 0.1 | 0.12 | 0.13 | 0.15 | 0.19 | 0.13 | 0.01 | 0.02 | 0.02 | 0.05 | 0.3 | 0.46 | 0.09 |
| 02-Aug-94 | 0.35 | 0.2 | 0.28 | 0.3 | 0.3 | 0.21 | 0.19 | 0.01 | 0.03 | 0.02 | 0.18 | 1 | 0.07 | 0.08 |
| 15-Aug-94 | 0.18 | 0.12 | 0.15 | 0.17 | 0.16 | 0.11 | 0.12 | 0.02 | 0.03 | 0.03 | 0.05 | 0.09 | 0.12 | 0.09 |
| 29-Aug-94 | 0.1 | 0.11 | 0.14 | 0.38 | 0.37 | 0.3 | 0.12 | 0.01 | 0.03 | 0.03 | 2.8 | 0.18 | 0.06 | 0.08 |
| 02-Sep-94 | 0.17 | 0.2 | 0.15 | 0.35 | 0.39 | 0.21 | 0.14 | 0.04 | 0.07 | 0.05 | 0.13 | 0.24 | 0.08 | 0.11 |

Appendix I : p

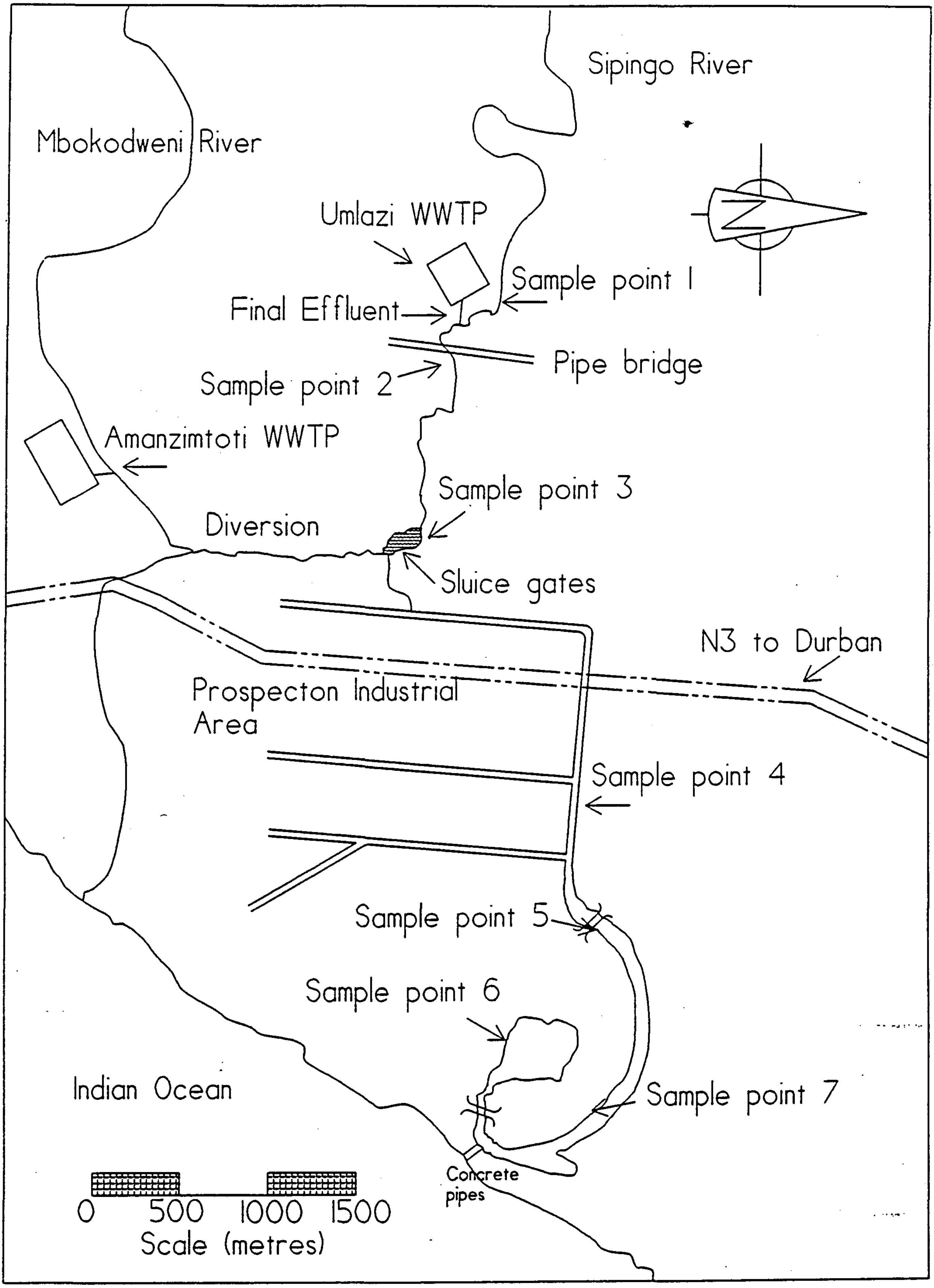
| DATE | COPPER | | | | | | |
|---|---|---|---|---|---|---|---|
| SAMPLED | ONE | TWO | THREE | FOUR | FIVE | SIX | SEVEN |
| 26-Jan-94 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.03 |
| 02-Feb-94 | 0.06 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.05 |
| 14-Feb-94 | 0.14 | 0.02 | 0.03 | 0.02 | 0.02 | 0.01 | 0.08 |
| 04-Mar-94 | 0.01 | 0.01 | 0.01 | 0.04 | 0.03 | 0.02 | 0.04 |
| 10-Mar-94 | 0.01 | 0.01 | 0.01 | 0.022 | 0.01 | 0.01 | 0.02 |
| 25-Mar-94 | 0.03 | 0.02 | 0.08 | 0.03 | 0.03 | 0.03 | 0.06 |
| 18-Apr-94 | | | 0.02 | 0.03 | 0.01 | 0.06 | 0.06 |
| 17-May-94 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.03 |
| 25-May-94 | 0.01 | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 | 0.08 |
| 01-Jun-94 | 0.01 | 0.03 | 0.03 | 0.1 | 0.1 | 0.01 | 0.09 |
| 09-Jun-94 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.08 |
| 14-Jun-94 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.05 |
| 22-Jun-94 | 0.02 | 0.01 | 0.04 | 0.04 | 0.01 | 0.03 | 0.09 |
| 05-Jul-94 | 0.1 | 0.1 | 0.1 | 0.01 | 0.02 | 0.02 | 0.06 |
| 15-Jul-94 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.09 |
| 22-Jul-94 | 0.01 | 0.02 | 0.02 | 0.05 | 0.03 | 0.03 | 0.12 |
| 02-Aug-94 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.09 |
| 15-Aug-94 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.06 |
| 29-Aug-94 | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 0.01 | 0.08 |
| 02-Sep-94 | 0.01 | 0.01 | 0.01 | 0.01 | 0.09 | 0.03 | 0.08 |

Appendix I : q

# UMLAZI WASTE WATER TREAMENT PLANT FINAL EFFLUENT

| DATE | E. COLI. FINAL | OA FINAL | NH3 FINAL | NO3 FINAL | DATE | E. COLI. FINAL | OA FINAL | NH3 FINAL | NO3 FINAL |
|---|---|---|---|---|---|---|---|---|---|
| 18-Jan-94 | 640 | 4.34 | 2.61 | 10.3 | 19-Dec-94 | 2 | 3.60 | 3.22 | 11.6 |
| 02-Feb-94 | 40 | 3.86 | 2.19 | 7.94 | 27-Dec-94 | 38 | 4.32 | 2.01 | 16.2 |
| 09-Feb-94 | 1040 | 4.12 | 4.71 | 11.4 | 06-Jan-95 | 14 | 5.08 | 2.09 | 15.1 |
| 16-Feb-94 | 14 | 5.12 | 3.74 | 11.4 | 10-Jan-95 | 0 | 3.38 | 1.35 | 15.6 |
| 23-Feb-94 | 46 | 5.22 | 1.35 | 15.6 | 17-Jan-95 | | 3.40 | 1.64 | 14 |
| 03-Mar-94 | 8 | 4.34 | 2.91 | 8.84 | 24-Jan-95 | 20 | 7.06 | 2.61 | 9.91 |
| 09-Mar-94 | 22 | 4.2 | 1.06 | 18.2 | 31-Jan-95 | 302 | 4.06 | 0.85 | 10.9 |
| 16-Mar-94 | 76 | 4 | 1.33 | 11.7 | 07-Feb-95 | 1520 | 5.02 | 1.81 | 7.96 |
| 24-Mar-94 | 10 | 4.42 | 2.02 | 11.9 | 14-Feb-95 | 0 | 2.80 | 0.50 | 7.94 |
| 30-Mar-94 | 4 | 5.2 | 6 | 13.1 | 21-Feb-95 | 22 | 3.98 | 2.33 | 10.4 |
| 05-Apr-94 | 20 | 9.32 | 5.15 | 8.16 | 28-Feb-95 | 12 | 2.66 | 1.09 | 7.92 |
| 13-Apr-94 | 960 | 5.2 | 3.29 | 13.5 | 08-Mar-95 | 42 | 7.44 | 2.85 | 5.85 |
| 20-Apr-94 | 4 | 5.22 | 4.28 | 9.08 | 15-Mar-95 | 120 | 5.38 | 1.26 | 12.9 |
| 26-Apr-94 | 0 | 3.84 | 2.41 | 8.75 | 22-Mar-95 | 98 | 3.42 | 1.32 | 13.6 |
| 05-May-94 | 4000 | 6.58 | 5.38 | 9.21 | 29-Mar-95 | 28 | 4.60 | 2.00 | 14.7 |
| 19-May-94 | 14 | 3.18 | 2.23 | 15.5 | 05-Apr-95 | 124 | 5.52 | 4.74 | 18.8 |
| 26-May-94 | 1360 | 4.3 | 2.34 | 15.1 | 12-Apr-95 | 6 | 3.58 | 0.50 | 20.6 |
| 02-Jun-94 | 28 | 4.28 | 4.08 | 17.5 | 19-Apr-95 | 20400 | 11.10 | 6.18 | 11.5 |
| 09-Jun-94 | 16 | 3.66 | 2.87 | 19.2 | 26-Apr-95 | 22 | 5.26 | 3.84 | 12 |
| 16-Jun-94 | 11000 | 5.36 | 6.17 | 16.9 | 03-May-95 | 6 | 6.74 | 2.14 | 7.35 |
| 30-Jun-94 | 6 | 4.88 | 6.71 | 23.5 | 10-May-95 | 18 | 7.12 | 1.60 | 11.61 |
| 07-Jul-94 | 64 | 8.04 | 4.56 | <0.5 | 18-May-95 | 14 | 6.52 | 2.08 | 17.5 |
| 29-Jul-94 | 880 | 5.82 | 1.62 | 3.7 | 25-May-95 | 10100 | 12.30 | 6.62 | 15.1 |
| 05-Aug-94 | 1100 | 4.96 | 3.77 | 10.7 | 01-Jun-95 | 42 | 7.24 | 4.52 | 17.7 |
| 12-Aug-94 | 10 | 5.98 | 3.22 | 21.6 | 08-Jun-95 | 42 | 11.30 | 9.10 | 21.1 |
| 19-Aug-94 | 24 | 5.70 | 2.25 | 20.3 | 15-Jun-95 | 66 | 5.60 | 3.21 | 18.8 |
| 26-Aug-94 | 1200 | 9.72 | 12.90 | 4.92 | 22-Jun-95 | 20 | 6.32 | 3.98 | 18.1 |
| 02-Sep-94 | 2000 | 7.68 | 3.49 | 16.3 | 29-Jun-95 | 4 | 7.32 | 4.84 | 17.3 |
| 09-Sep-94 | 4 | 7.78 | 3.07 | 18.1 | 06-Jul-95 | 12 | 7.32 | 1.96 | 16.4 |
| 16-Sep-94 | 38 | 9.42 | 5.60 | 15.1 | 13-Jul-95 | 30 | 5.68 | 4.46 | 21.7 |
| 23-Sep-94 | 6 | 8.46 | 3.69 | 13.6 | 20-Jul-95 | 10 | 6.18 | 2.98 | 30.7 |
| 30-Sep-94 | 80 | 6.10 | 3.33 | 13.2 | 28-Jul-95 | 0 | 6.16 | 3.56 | 19.7 |
| 03-Oct-94 | 0 | 6.18 | 1.54 | 13.4 | 04-Aug-95 | 2000 | 12.70 | 7.84 | 14.3 |
| 13-Oct-94 | 12 | 4.30 | 3.88 | 18 | 11-Aug-95 | 18 | 5.28 | 4.28 | 17.6 |
| 20-Oct-94 | 4 | 5.34 | 3.20 | 9.38 | 18-Aug-95 | 0 | 4.02 | 2.68 | 20.4 |
| 24-Oct-94 | 22400 | 5.96 | 2.96 | 21.8 | 25-Aug-95 | 0 | 3.02 | 2.40 | 21.3 |
| 31-Oct-94 | 158 | 8.08 | 5.24 | 6.98 | 01-Sep-95 | 8 | 3.80 | 1.70 | 21.8 |
| 07-Nov-94 | 600 | 5.33 | 1.29 | 3.97 | 08-Sep-95 | 212 | 9.58 | 3.90 | 19.9 |
| 14-Nov-94 | 58 | 8.14 | 4.08 | 8.55 | 15-Sep-95 | 2 | 5.12 | 3.22 | 16.5 |
| 21-Nov-94 | 0 | 6.58 | 5.42 | 11.9 | 22-Sep-95 | 0 | 7.34 | 5.68 | 14.5 |
| 05-Dec-94 | 11400 | 4.76 | 3.25 | 13.6 | 29-Sep-95 | 0 | 3.96 | | |
| 12-Dec-94 | 14 | 5.58 | 2.84 | 3.24 | AVERAGE | 1141.37 | 5.82 | 3.40 | 13.93 |

MAP I


Sipingo River
Mbokodweni River
Umlazi WWTP
Sample point 1
Final Effluent
Pipe bridge
Sample point 2
Amanzimtoti WWTP
Sample point 3
Diversion
Sluice gates
N3 to Durban
Prospecton Industrial Area
Sample point 4
Sample point 5
Sample point 6
Indian Ocean
Sample point 7
Concrete pipes
0 500 1000 1500
Scale (metres)