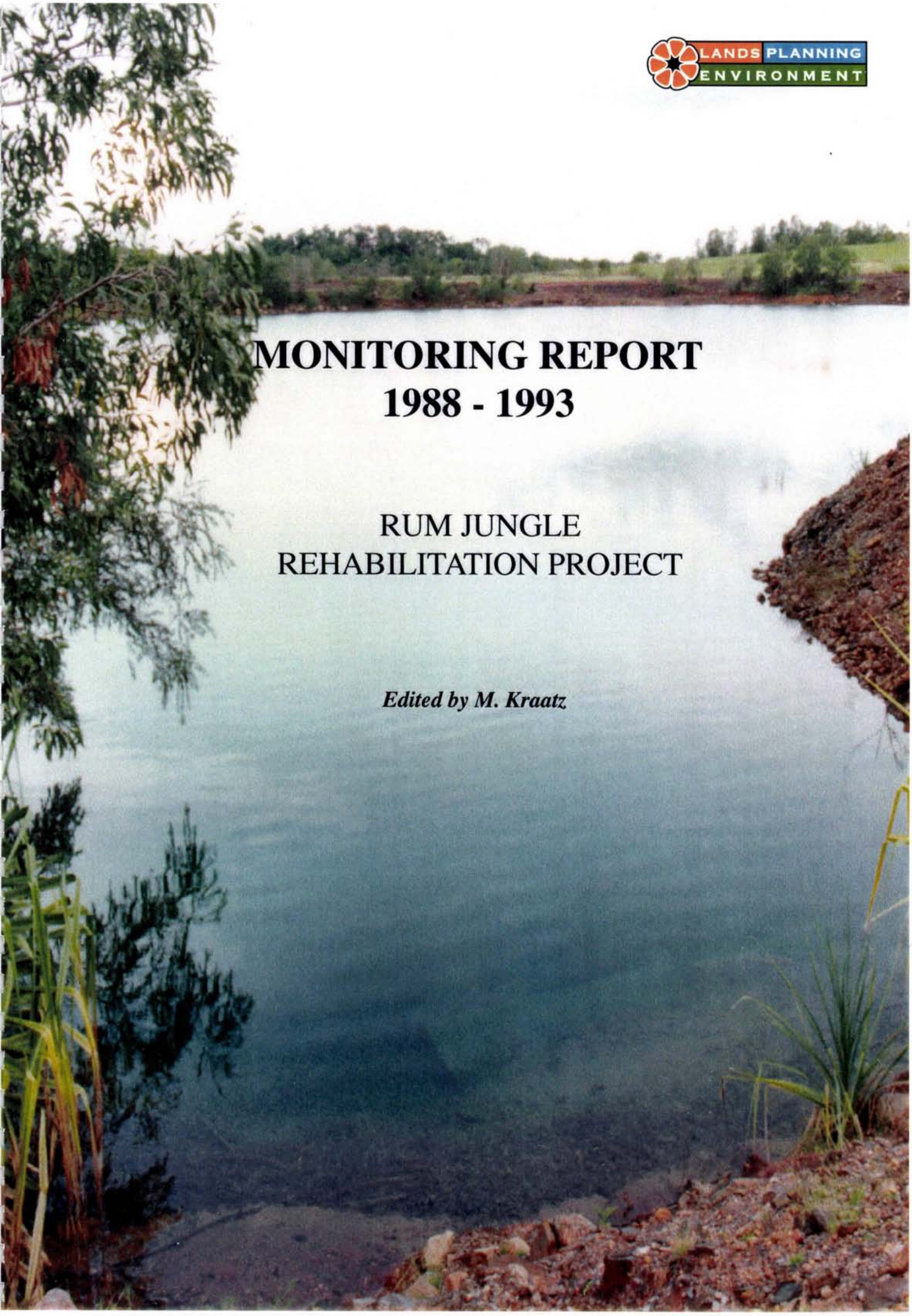

LANDS PLANNING ENVIRONMENT

MONITORING REPORT 1988 - 1993

RUM JUNGLE REHABILITATION PROJECT

Edited by M. Kraatz

MONITORING REPORT
1988 - 1993

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REHABILITATION PROJECT

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Cover: Looking east across Whites Open Cut

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In memory of Dr David Keith Gibson (1939-1995), colleague and friend, whose insights into physical transport processes advanced the study of the Rum Jungle site.

The East Branch of the Finiss River in February 1993 looking downstream from the entrance to the Rum Jungle Rehabilitation Site. GS8150200 can be seen to the left.

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Acknowledgements

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Ms Karen Powell of the Commonwealth Department of Primary Industries and Energy (DPIE) is also owed gratitude for her continuing patience and understanding throughout a long gestation period.

Finally, the editor and authors wish to acknowledge DPIE for providing funds for monitoring and maintenance activities at the Rum Jungle site and for the production of this report.

Abstract

In 1982, a joint Commonwealth and Northern Territory government project was established to rehabilitate the abandoned Rum Jungle mine site. A two year monitoring project undertaken from 1986 to 1988 indicated the short term success of the project as determined by the achievement of objectives established for the original rehabilitation project. The outcomes of this monitoring period are outlined in an earlier report.

In 1988, a site management plan was developed recommending a reduced monitoring program be continued over the next five years to test the longer term environmental response to rehabilitation. Monitoring of the site therefore continued from July 1988 and June 1993 and was funded jointly by the Department of Primary Industries and Energy and the Northern Territory Government.

Monitoring activities throughout the period covered water quality , hydrology and macro-invertebrate ecology of the East Branch of the Finniss River, fish diversity and abundance in the Finniss River, groundwater hydrology, water quality and mixing regimes of the open cuts, chemical activity and water balance of the overburden heaps, and qualitative assessments of surface stability and pasture status.

Monitoring has shown that pollutant concentrations within the East Branch are greatly reduced relative to the pre-rehabilitation regime, but remain sufficiently elevated to impact on this ecosystem. Concentrations of pollutants tend to be highest during the early wet season and late wet season recessional flows when dilution effects are minimal.

A survey of macro-invertebrate populations in the East Branch indicates that macro-invertebrate fauna is still significantly less diverse and less abundant in the lower reach of the East Branch compared with control sites, but that the total number of macro-invertebrate families found in the polluted reach has increased in comparison to a pre-remedial survey. Some degree of recovery is also indicated by the presence of of freshwater Crustacea and Trichopteran larvae within the polluted reach. Fish studies within the main branch of the Finniss River also indicate a degree of ecological improvement in the previously affected region of the river, whereby the numbers of fish species and individuals are similar to or greater than those sampled in the un-impacted region of the river. This improvement is more than likely due to the reduction in acid mine drainage from the East Branch of the river following rehabilitation of the Rum Jungle site.

Groundwater measurements taken in the vicinity of Whites Heap indicate that concentrations of pollutants have not changed significantly over the last five years. This is consistent with the scenario that the time taken for pollutants to be leached from the pore water of the heap is in the order of twenty years. This could also be explained by the presence of a large reservoir of polluted water below the heap, which would respond slowly to changes in pollutant input rates. It is not possible to make reasonable estimates of the pollutant loads in the groundwater at this stage and further work is recommended to resolve this question.

Monitoring showed that Whites Open Cut remains a significant contributor to the total pollution load leaving the site, and studies are continuing to determine the transport mechanisms involved. The mixing zone between the surface layer subject to wet season flushing and the lower polluted waters, narrowed and deepened significantly over the monitoring period.

The cover system on Whites Overburden Heap continued to meet the design specifications in terms of limiting water infiltration to less than five percent of incident rainfall. Temperatures in both Whites and Intermediate Heaps continued to decrease at a rate which seems to be consistent with a large reduction in pollution generation. Pore gas oxygen concentrations in Whites suggest that the cover system may not be as effective in limiting the ingress of oxygen as originally thought, and further investigations are required to assess the impact of this on oxidation rates.

Surface drainage structures and covers remained intact, with only minor repair works required. Pastures generally remained healthy and vigourous, apart from minor areas of die-back and the development of some weed infestations. Fire management required significant resources.

Preface

Throughout the conduct of work described in this Monitoring Report, responsibility for the administration of the Rum Jungle project lay with the Land Conservation Unit of the Conservation Commission of the Northern Territory (CCNT).

In 1995, however, the CCNT was disbanded and the Land Conservation Unit became a part of the newly formed Land Resources Division of the Department of Lands, Planning and Environment (DLPE).

Responsibility for water quality monitoring, previously undertaken by the Water Resources Division of the Power and Water Authority was also transferred with the Division to DLPE in 1996.

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1. SUMMARY

1.1 SITE MANAGEMENT

Management of the Rum Jungle site from July 1988 to June 1993 was carried out in accordance with recommendations from the Site Management Plan (Verhoeven 1988) relating to legislation, administration, land uses and restrictions and monitoring. A five year monitoring and maintenance agreement was made between the Commonwealth and Northern Territory Governments to enable monitoring of:

- surface water quality and hydrology of the East Branch of the Finniss River;
- mine site surface water quality from 1989 to 1991;
- groundwater hydrology;
- water quality and mixing dynamics in Whites and Intermediate Open Cuts;
- chemical activity and water balance of Whites and Intermediate Overburden Heaps;
- fish diversity and abundance in the Finniss River;
- macro-invertebrate ecology of the East Branch of the Finniss River; and
- general site integrity.

A total of $245,800 was expended by both Governments on these activities. Monitoring projects were overseen by the Rum Jungle Monitoring Committee which was comprised of representatives from the Conservation Commission of the NT (CCNT), Power and Water Authority (PAWA), Australian Nuclear Science and Technology Organisation (ANSTO) and the Department of Primary Industries and Energy (DPIE).

The site was declared a Restricted Use Area in 1988 under the *Soil Conservation and Land Utilization Act.* It was excluded from the grant under the Finniss River Land Claim in 1993 following discussions regarding management issues, but remains available for a future grant. Control of access onto the site was difficult due to ongoing vandalism to fencing and gates. Guided access to the site, however, was provided on numerous occasions to educational, scientific and industry groups.

In early 1993, it was concluded that while the rehabilitation had been successful in the short term, it was difficult to predict its medium to long term effectiveness. A further five year monitoring program, designed to improve the ability to predict the future integrity of the site, was thus recommended to the Commonwealth Government.

1.2 WATER QUALITY AND HYDROLOGY OF THE EAST FINNISS RIVER 1988/89 - 1992/93 and MINE SITE SURFACE WATER QUALITY 1989 - 1991

Monitoring the flow and water quality of the East Finniss River continued downstream of the rehabilitation site at gauging station GS8150097. The period covered by this report includes one of the poorest wet seasons recorded since monitoring at the station began in 1965 (1989/90) and one of the wettest in 1988/89. The post rehabilitation relationship between discharge and the pollutant load is emerging, indicating that increased flows lead to increased metal transport from the site.

Although pollutant concentrations measured are at a greatly reduced level relative to the pre-rehabilitation regime, they still remain sufficiently elevated to impact on the freshwater ecosystem of the East Finniss River. The concentration of pollutants tends to be highest during the early wet season flows and the late wet season recessional flows when dilution effects are minimal.

Progressive changes over the study period have been made to the monitoring program to improve the accuracy of pollution load estimates. Programmed data loggers are used to collect flow-weighted composite samples on-site and chemical analysis now takes account of both the dissolved and particulate load. Prior to 1991/92, sampling sites at the mine site were used to help define pollutant sources and major drainage paths to the East Finniss. Spot flow gauging, grab sampling and on-site temperature, pH and conductivity measurements were made as part of the program. This sampling was discontinued, although two of the sites formerly employed (the inflow and outflow of the open cuts) are being established (1993/94 wet season) as continuously gauged stations. Results from the mine site sampling during the period 1989/90 to 1990/91 are presented in Appendix C.

Some preliminary work was undertaken on assessing water, sediment and algal heavy metal contamination along the length of the East Finniss River. Results indicate that although water quality improves significantly as distance downstream increases, levels of contamination in algae and sediment remain elevated along the length of the river. Further studies, in conjunction with ANSTO, are planned to examine in greater detail this aspect of the pollution regime.

1.3 GROUNDWATER HYDROLOGY

The extent of the monitoring has been reduced since 1987 and only six boreholes in the region of Whites Heap have been monitored. Field measurements taken have indicated that the concentrations of pollutants in the groundwater in the vicinity of Whites Heap have not changed significantly in the last five years. This is consistent with the conclusions of the 1986-88 Rum Jungle Monitoring Report edited by Kraatz and Applegate (Gibson and Pantelis 1992) in which it was estimated that the time to leach the pollutants stored in the pore water of the heap was of the order of twenty years. However, the same observations could be explained by the presence of a large reservoir of polluted water below the heap, which would respond slowly to changes in pollutant input rates. Concentrations of pollutants apparently fall with rising water level and rise as the water levels fall, suggesting that there is a layer of comparatively pure water moving over the contaminated water in the wet season and retreating in the dry, with little mixing between the layers.

In the long term, the output of pollutants must be equal to their rates of production, even though the slow response of the system means that at any given time this may not hold true. Therefore any decline in the pollutant load as a result of covering a dump depends on the reduction of oxidation rate.

It is not possible to make reasonable estimates of the pollutant loads in the ground water at this stage.

To pursue the groundwater questions it is further recommended that:

- measurements of the stratification of the water quality be attempted;
- further measurements of the soil conductivity be made, to establish the size and position of the plume of polluted water;
- efforts be made to estimate the water velocity in the plume, possibly taking stratification into account; and
- an attempt be made to measure the pollutant concentrations in the pore water in the heap, to establish the total inventory and its annual rate of release.

1.4 WATER QUALITY AND MIXING REGIMES OF THE OPEN CUTS

Detailed temperature and water quality profiling have been conducted in both the Whites Open Cut and Intermediate Open Cut water bodies over the 1992/93 period. Isopleths of temperature, conductivity, pH and metal concentrations clearly illustrate the flushing of both water bodies during the 1992/93 wet season inflow and the relatively rapid re-establishment of poor water quality in the surface mixed layer of Whites Open Cut.

Over the five year period this report covers, the demarcation between the surface layer subject to the wet season flushing and the dense, polluted lower waters of Whites has changed significantly. The 'mixing zone' has narrowed from some six metres in late 1988 to less than two metres in June 1993 with the pycnocline lowered from about AHD 39 m to AHD 27 m. Estimates of the yearly nett wet season pollution export from the water bodies are presented and related to total loads measured downstream in the East Finniss. These figures reinforce the view that Whites Open Cut remains a significant contributor to the total pollution load leaving the site while on-going studies seek to establish the transport mechanisms involved.

1.5 CHEMICAL ACTIVITY AND WATER BALANCE OF THE OVERBURDEN HEAPS

Monitoring was continued by ANSTO during the period 1988-1993 to determine the longer term effectiveness of the rehabilitation works on Whites and Intermediate Overburden Heaps. Measurements of water balance, temperature profiles and pore gas oxygen concentration profiles were undertaken. The aim of the water balance measurements was to monitor the continued compliance of the cover systems of the heaps with respect to the design specifications. Temperature profiles were measured to demonstrate the cooling of the heaps since rehabilitation. Oxygen profiles were measured to monitor the integrity of the cover system in its capacity to reduce the ingress of oxygen.

Lysimeter measurements demonstrated that the cover system on Whites Overburden Heap continues to meet the design specification that water infiltration be less than 5% of incident rainfall. The cover on Intermediate Heap met the design specifications until 1988. After that time the number of operational lysimeters fell and the data was skewed, apparently indicating that there was a rising trend in infiltration. It is important to note, however, that the design of the cover on Intermediate is the same as the one on Whites Heap and should therefore perform the same. It is very likely that the cover on Intermediate continued to meet the design specification for infiltration throughout the monitoring period.

Temperatures in Whites and Intermediate Heaps have continued to decrease in the long term, at a rate which seems to be consistent with a large reduction in heat generation (and therefore pollution generation) within the heaps.

Pore gas concentration measurements in Whites Heap have indicated a number of time-dependent features which suggest that the cover system may not be as effective in limiting the ingress of oxygen as it could have been. Further investigation to assess the impact of this on oxidation rates is warranted. The oxygen concentration profiles in Intermediate Heap have remained relatively constant and may be due to better cover performance than the one on Whites, or due to different oxidation properties of the underlying waste rock.

Recommended works and options to quantify the pyritic oxidation rates in the waste rock heaps, the effectiveness of the rehabilitation works and the measurement of pollution generation rates may be summarised as follows:

- lysimeters on Whites Heap should continue to be used to quantify water infiltration through the cover system;
- temperature profiles should be analysed to provide values for thermal conductivity of the heaps and to quantify oxidation rates;
- pore gas oxygen concentration profiles should be measured at monthly intervals in Whites and Intermediate Heaps over a period of at least one year;
- a program of work to understand the physical mechanisms of oxygen transport in the heaps and their affect on oxidation rates should be undertaken;
- a quantitative assessment of the effectiveness of the rehabilitation works should be made; and
- an estimate should be made of the current pollution load coming from Dysons Overburden Heap. If it is found to be a significant pollution source, measurements should be made to quantify oxidation rates and pollution generation rates in Dysons and relate these to groundwater pollution loads.

1.6 FISH DIVERSITY AND ABUNDANCE IN THE FINNISS RIVER

Studies of the distribution and abundance of fish in the impacted region of the Finniss River were undertaken in July/August 1992. This was to allow an initial evaluation of the degree of ecological improvement since the reduction in the load of acid mine drainage (AMD) pollution that the river continues to receive.

Investigations to assess the effects of acidic and metallic pollutants originating from the abandoned Rum Jungle mine on the river fauna were first undertaken in 1973/74. These studies indicated that metal concentrations at low pH were responsible for fish kills in the East Branch and side streams. These fish kills extended for up to 15 km downstream of the junction with the East Branch (Jeffree and Williams 1975). Since that time, however, there has been a marked reduction in annual pollution loads in the river, with the most recent results indicating an order of magnitude reduction of Cu and Zn loads with Mn reduced by up to a factor of five.

Results indicate a degree of ecological improvement in the impacted region of the Finniss River. Various sized enmeshing nets were used to sample fish at dusk until midnight at each site. Prior to net-setting or other disturbances at sampling sites, water samples and triplicate depth profiles of temperature, dissolved oxygen (DO), pH, turbidity and conductivities were made to determine any factors affecting the diversity of the species.

The levels of Cu, Mn, Co and Zn were elevated within the impacted zone compared to other sites. These measured concentrations of trace metals were always highest at the site closest to the East Branch confluence. The water level in the river was low relative to the 1974 dry season.

Previous investigations had shown a reduction in the total numbers of all fish species in the impacted region. The recent study indicated that the numbers of fish species in the previously impacted zone were similar or greater than those sampled in the un-impacted region of the river.

The overall pattern of fish distribution and abundance observed during the 1992 survey suggests a recovery in the fish fauna within the previously impacted region. The improvement is more than likely due to the reduction in AMD from the East Branch of the river following remediation of the Rum Jungle mine site.

1.7 MACRO-INVERTEBRATE ECOLOGY OF THE FINNISS RIVER EAST BRANCH

A survey of macro-invertebrate populations was undertaken in May 1993 in the East Branch of the Finniss River in order to make comparisons with a similar survey undertaken in 1973/74. The findings of this survey show that:

- Concentrations of Cu, Mn and Zn in East Branch waters immediately below the site are two to three orders of magnitude above concentrations measured at control sites upstream of the Rum Jungle mine area and in tributaries of the East Branch. The levels are generally much higher than recommended for drinking water and for the protection of freshwater ecosystems. These metal concentrations decline with distance downstream from the mine site.

- Both univariate and multivariate statistical analyses show that the macro-invertebrate fauna is still significantly less diverse and less abundant in the lower reach of the East Branch compared with control sites. Nevertheless, the total number of macro-invertebrate families found in the polluted reach of the East Branch has increased in comparison with the pre-remedial survey.

- Taxa such as Odonata (eg. dragon and damsel flies), Ephemeroptera (mayflies) and Trichoptera (caddis flies) show, by their extremely low abundances in much of the polluted reach of the East Branch, that they are sensitive indicators of metal pollution, with Coleoptera (beetles) and Diptera (two-winged flies) being more resistant.

- Some degree of recovery is indicated by the presence of freshwater Crustacea and Trichopteran larvae at sites within the polluted reach of the East Branch.

1.8 SITE INTEGRITY

The monitoring and maintenance of rehabilitated surfaces at the Rum Jungle site was continued in order to ensure their ongoing integrity. Major aspects of monitoring were qualitative assessments of surface stability and pasture status including weed presence. Weed and fire management formed a major component of maintenance.

Quantitative assessments of surface stability were not possible given that the instrumentation to undertake such measurements has not been installed. Surface drainage structures and covers were annually inspected following the wet season and in general remained intact. Whilst instances of erosion occurred throughout the site, repair works were primarily conducted in areas where clay covers were under threat or where access across the site was compromised.

No formal, quantitative assessment of the diversity and abundance of pasture species was undertaken throughout the monitoring period, however, pastures generally remained healthy and vigourous, apart from minor areas of die-back. Pastures on all rehabilitated surfaces were slashed and fertilised in 1989 and 1990 in order to encourage growth and development of the A horizon. This activity was subsequently ceased due to prohibitive costs and the judgement that such active encouragement of pastures was no longer required. Maintenance work therefore focussed solely on the control of major weed infestations and the upkeep of firebreaks.

Weeds presented a major problem and were considered to have been introduced through the importation of contaminated borrow material during rehabilitation, and through transport by vehicles, wind and birds. *Hyptis suaveolens* and *Sida acuta* continued to be a problem, however, large infestations of the noxious weed *Themeda quadrivalvis* (Grader Grass) developed and required greater attention. Continuing weed control at the site will be essential to maintaining the value of previous efforts and to containing existing weed infestations within a manageable level. Increased efforts will be required to enable eventual eradication, if that is considered to be a necessary outcome.

A small patch of die-back was identified in 1989 on the northern end of Whites Overburden Heap which did not regenerate or increase in size throughout the remainder of the monitoring period. Patchy growth evident in 1985 on the highest, south-western end of Dysons Open Cut landform remained constant in area until 1988, however by 1990 had increased in size extending down to the first contour bank. An additional area of die-back was also identified in 1990 at the northern end of the open cut. These areas were identified as requiring closer investigation throughout the next monitoring period.

Aspects of the revegetation covered by Ryan in 1992 (Kraatz and Applegate 1992), such as soil fauna and chemistry and tree colonisation, were not addressed in any detail throughout the 1988-93 monitoring period.

2. SITE MANAGEMENT

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2.1 INTRODUCTION

Rum Jungle is an abandoned uranium-copper open cut mine located 85 km south of Darwin in the Northern Territory of Australia (Figure 2.1). Mining was carried out between 1954 and 1965 and operations ceased in 1971. During this time, approximately 3 500 tonnes of uranium and 20 000 tonnes of copper were mined.

The mining operations at Rum Jungle had severe environmental impacts on the Finniss River, the East Branch of which flows through the site. The generation of sulphuric acid and the associated release of heavy metals from the overburden heaps resulted in the destruction of all flora and fauna in the East Branch for 8.5 km downstream of the mine site to the confluence with the Finniss River (Figure 2.2). Reduced bio-diversity was also evident in the Finniss River for a further 15 km. In addition, large quantities of low level radio-nuclides flowed from the tailings dam and were spread down the river system and over 100 km^2 of floodplain. These impacts are described more fully in previous publications (Davy 1975, Department of the Northern Territory 1978).

In 1983, a collaborative agreement was signed between the Australian and Northern Territory Governments which established the Rum Jungle Rehabilitation Project. The agreement extended to 1988, incorporating a four year program of rehabilitation (1982-86) and a two year monitoring program (1986-88). More details on these are provided in Allen and Verhoeven (1986) and Kraatz and Applegate (1992).

In 1988, a Site Management Plan was developed which stated that "to ensure the lasting integrity of the rehabilitation measures it is necessary to properly manage the site and to maintain the rehabilitation" (Verhoeven 1988). Recommendations regarding the nature and extent of ongoing management and monitoring were further described in the Plan which also addressed issues such as legislation and administration, land uses and restrictions. An update on these issues is provided below.

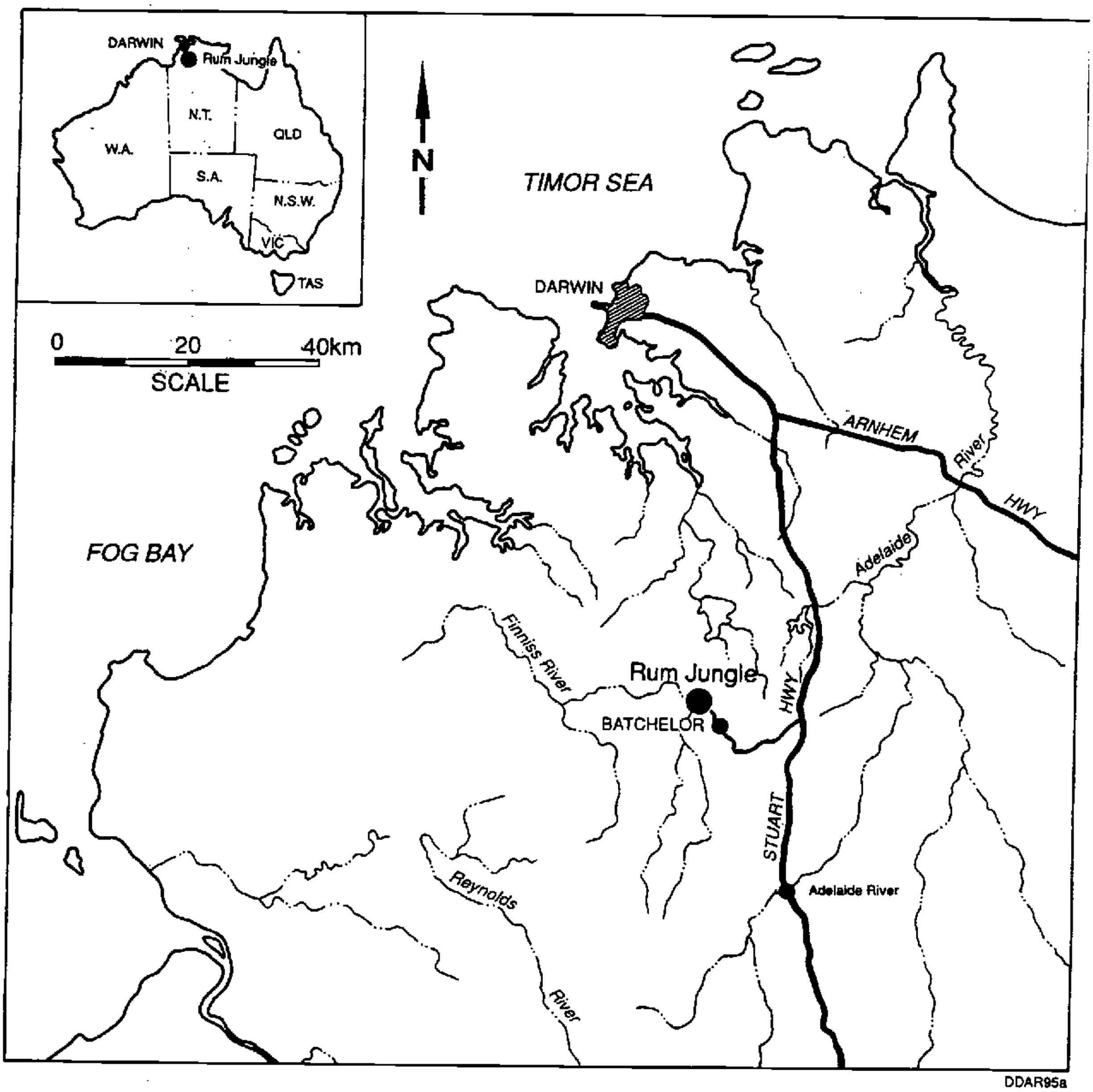


Figure 2.1 Location of the Rum Jungle rehabilitation site.

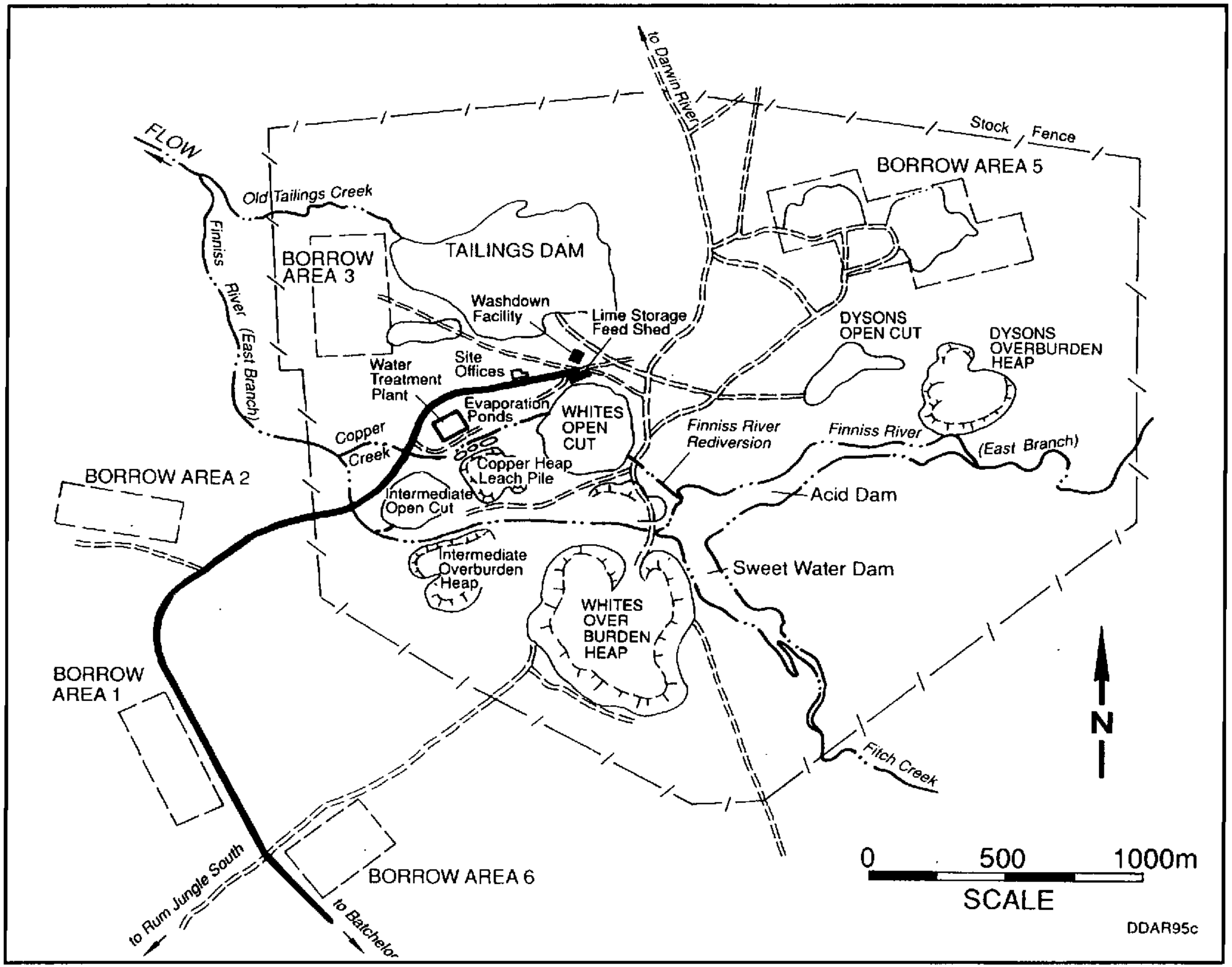


Figure 2.2 Rum Jungle Site Plan.

2.2 MONITORING AND MAINTENANCE AGREEMENT

Recommendations from the Site Management Plan (Verhoeven 1988) formed the basis of a five year cost-sharing agreement with the Commonwealth Government from July 1988 to June 1993.

Total funding of $127 000 was received from the Department of Primary Industries and Energy (DPIE) to match $118 800 contributed by NT Government Agencies and the Australian Nuclear Science and Technology Organisation (ANSTO)(Table 2.1).

The NT Government agencies involved were the Land Conservation Unit of the former Conservation Commission of the NT (CCNT) and the Water Resources Division of the Power and Water Authority (PAWA). Both of these agencies are now incorporated within the Department of Lands, Planning and Environment (DLPE).

2.3 LEGISLATION AND ADMINISTRATION

In 1988, the Rum Jungle rehabilitation site was declared a Restricted Use Area (RUA) under the *Soil Conservation and Land Utilisation Act 1978.* Through this declaration, access to the site is prohibited except in accordance with formal, conditional authorisations from DLPE. This declaration arose out of recommendations from the Site Management Plan that control needed to be exerted which would minimise human impacts on the cover systems employed to prevent the further spread of pollution from the site.

With the employment of this legislation, the CCNT assumed responsibility for the Rum Jungle project including:

- on-ground management and maintenance of the site;
- coordination of the monitoring program through the chairing of the Rum Jungle Monitoring Committee;
- maintenance of written and photographic records of the site beyond mid 1988;
- liaison with DPIE; and
- the production of end of monitoring period reports.

Rum Jungle Monitoring Committee

Liaison, Monitoring and Technical Committees were originally involved in various aspects of the rehabilitation program, but at the commencement of the 1988-93 monitoring period, responsibility for the site was assumed by the Monitoring Committee.

This Committee was initially formed to coordinate the implementation of the monitoring program and was comprised of representatives from the CCNT, PAWA, ANSTO and DPIE. Its objectives and functions were outlined further in the Final Project Report (Allen and Verhoeven 1986). It met on an annual basis between 1988 and 1993 to review the results of previous annual monitoring and reassess future requirements.

Table 2.1 **Cost sharing arrangement for the Rum Jungle Monitoring and Maintenance program 1988/89 - 1992/93.**

ACTIVITY	1988/89	1989/90	1990/91	1991/92	1992/93	TOTAL
MONITORING*						
(I) Water quality, rainfall						
. salaries (PAWA)	12 300	12 300	12 300	12 300	12 300	61 500
. operational (C'wealth)	5 200	5 200	5 200	5 200	5 200	26 000
TOTAL	**17 500**	**17 500**	**17 500**	**17 500**	**17 500**	**87 500**
(ii) Open Cuts						
. salaries (PAWA)	3 400		3 400			6 800
. operational (C'wealth)	3 000		3 000			6 000
TOTAL	**6 400**		**6 400**			**12 800**
(iii)Overburden Heap						
. salaries (ANSTO)	12 000	12 000	6 000	6 000	6 000	42 000
(PAWA)	700	700	700	700	700	3 500
. operational (C'wealth)	12 500	12 500	6 500	6 500	6 500	44 500
TOTAL	**25 200**	**25 200**	**13 200**	**13 200**	**13 200**	**90 000**
(iv)Site integrity						
. salaries (CCNT)	1 000	1 000	1 000	1 000	1 000	5 000
. operational (C'wealth)	500	500	500	500	500	2 500
TOTAL	**1 500**	**1 500**	**1 500**	**1 500**	**1 500**	**7 500**
(v) Flora and Fauna Survey CCNT					To be estimated	
TOTAL MONITORING						
. **Agencies**	**29 400**	**26 000**	**23 400**	**20 000**	**20 000**	**118 800**
. **Commonwealth**	**21 200**	**18 000**	**15 200**	**12 200**	**12 200**	**79 000**
MAINTENANCE**						
(I) Vegetation						
. fertilising	-	25 000	-	-	-	25 000
. slashing	3 000	3 000	3 000	3 000	3 000	15 000
(ii) Rediversion works	-	-	-	-	-	-
(iii) Fencing and fire breaks	500	500	500	500	500	2 500
(iv) Roadworks	1 000	1 000	1 000	1 000	1 000	5 000
(v) Fauna control	-	-	-	-	-	-
(vi) Weeds	500	?	?	?	?	?
TOTAL MAINTENANCE						
. **Agencies**	-	-	-	-	-	-
. **Commonwealth**	**5 000**	**29 500**	**4 500**	**4 500**	**4 500**	**48 000**
TOTAL						
. **Agencies**	**29 400**	**26 000**	**23 400**	**20 000**	**20 000**	**118 800**
. **Commonwealth**	**26 200**	**47 700**	**19 700**	**16 700**	**16 700**	**127 000**

* *Salaries contributed by agencies (PAWA, CCNT, ANSTO). Operational costs funded by Commonwealth.*

** *All maintenance costs funded by Commonwealth.*

Restricted Use Area authorisations

Two authorisations were granted over the RUA at Rum Jungle. These were for exploratory drilling adjacent to Whites and Intermediate Open Cuts, issued in November 1990, and for the pumping of water from Whites Open Cut, issued in October 1992. Conditions under which these authorisations were granted are outlined in Table 2.2.

Table 2.2 Conditions under which authorisations were granted for activities at the Rum Jungle Restricted Use Area.

Exploratory Drilling
• Drilling rigs, vehicles and any associated disturbance will not encroach upon any rehabilitated area within the RUA. • Drilling in the vicinity of the rehabilitated Copper Heap Leach area will not penetrate either the cover system or the sub-surface drainage system. • The upper one metre of the drill holes will be capped with concrete. • Sumps will be backfilled and contoured to prevent water ponding upon completion of the drilling program. • Soil Conservation Officers will inspect the site during and after completion of the drilling to ensure that the site has been rehabilitated to a satisfactory standard.
Whites Open Cut Water Pumping
• Extraction of water from Whites Open Cut will not exceed a maximum rate of 4.0 litres/second. • Water pumped from the Open Cut will be transmitted by continuous pipeline placed to the approval of the Commissioner for Soil Conservation. The pipeline shall be laid above the ground, but buried and/or encased for protection from vehicular traffic across roadways, within the RUA from Whites Open Cut to the southern toe of Whites Overburden Heap, whereafter the pipe may be buried in a shallow trench. All leaks in the pipeline will be rectified within one day of detection or notification. • The pump inlet will be placed on a pontoon to the satisfaction of the Controller of Water Resources. Pumping shall cease immediately the pump inlet is more than one metre below the surface water level in Whites Open Cut. • Pumping will cease on or before 31 December 1992 and the pump, pontoon and all pipe removed from the area. • The final disposal of water pumped from Whites Open Cut will be as directed by the Controller of Water Resources and will be by return to Whites Open Cut and/or release to natural receiving waters. • Soil Conservation Officers will inspect all areas of work at the start of the wet season and will identify any areas requiring soil conservation treatment. • These areas will be treated immediately according to specifications provided by the Commissioner for Soil Conservation or his delegate.

Finniss River Land Claim

Title to the Rum Jungle rehabilitation site was vested in the Northern Territory following self government in 1978. In 1981, however, the site was recommended for grant to an Aboriginal Land Trust as part of Area 4 of the Finniss River Land Claim.

Management and monitoring issues associated with Rum Jungle were outlined in various detriment submissions developed by the NT Government and included those described in the 1988 Site Management Plan (Verhoeven 1988).

In general, there was concern whether Commonwealth and NT Government interests in the Rum Jungle project could be sufficiently protected. The NT Government thus recommended that before any grant of land was made over the site, a **prior** formal agreement should be made with the Land Trust protecting "...Territory and Commonwealth rights to gain access to the Rum Jungle area for maintenance and monitoring and restricting land usage by traditional owners in accordance with recommendations made in the Plan" (NT Government 1988). A proposal for a draft agreement with the Finniss River Land Claimants was developed along these lines in 1992, but was not further pursued. Title to the majority of Area 4 was transferred to the Traditional Owners in 1993 but this excluded the Rum Jungle site which was set aside at the wish of the Traditional Owners but is still subject to future claim.

2.4 LAND USES AND RESTRICTIONS

In general, the potential land uses and restrictions outlined in the Site Management Plan remained relevant at the end of the 1988-93 monitoring period. The following provides an update on issues associated with access, tourism and research, mining and grazing.

Access

Whilst activity was legally restricted under the *Soil Conservation and Land Utilization Act*, continuing vandalism to fences and gates meant that access was not satisfactorily restricted. The extent to which this occurred and its subsequent impacts on the site can only be assessed in a qualitative manner as part of the annual site integrity assessments described in Chapter 9 of this report. The issue of vandalism, however, will need to be addressed in any considerations of future site management.

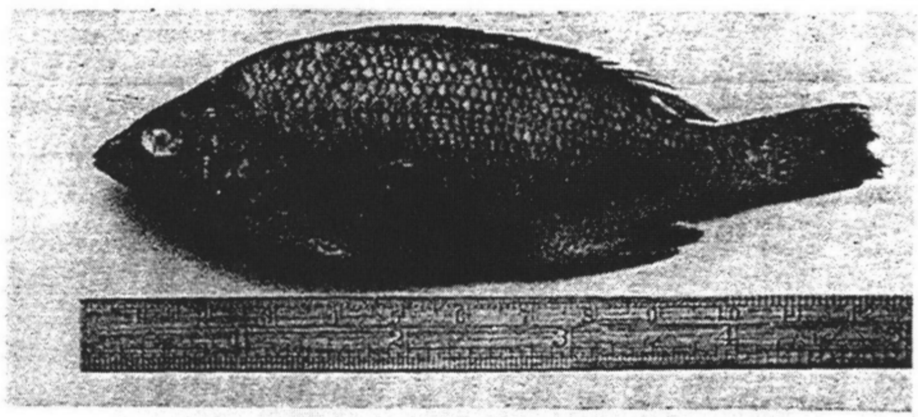
Tourism and research

The site continued to attract interest as a scientific, educational and tourism destination and guided access was provided on many occasions over the monitoring period. Groups included students from local Darwin primary and high schools and the Northern Territory University and personnel from national and international research and industry organisations.

Funding for the construction of an interpretation display was not available from either the Commonwealth or Territory Governments. The concept was still considered to be worth pursuing, however, given future availability of funds. No formal arrangement was developed regarding organised tour operations.

The discovery of a new species of fish in the Finniss River in the course of ecological monitoring attracted media attention throughout Australia and an example is provided in Plate 2.1.

NEWS Northern Territory News, Wednesday, February 3, 1993



The newly discovered grunter fish ... a significant find.

New grunter good news

The Conservation Commission has welcomed the discovery of a new species of fish found in a once-heavily polluted Top End river.

The new species of grunter was found by scientists doing a biological study of the Finniss River, Federal Science Minister Ross Free said yesterday.

The federally funded study was done on behalf of the Rum Jungle Monitoring Committee, a Territory body formed in 1986.

Committee chairman Rod Applegate said the new grunter, named because of the noise it makes when landed, was part of a large grunter family common in NT fresh waters.

It was very small — not a table fish, nor one with commercial possibilities, he said.

But the find was significant.

The discovery of the new species and the abundance of other fish and marine creatures in the Finniss found in the survey showed rehabilitiation had worked, Mr Applegate said.

The river, which carried large amounts of dissolved copper and zinc from the former Rum Jungle uranium mine, underwent $20 million of clean-up work 10 years ago.

Plate 2.1 A Northern Territory News article on the discovery of a new fish species in the Finniss River.

Mining

An Exploration Licence (EL 4880) was granted by the Department of Mines and Energy to Compass Resources P/L in 1989. Exploratory drilling was undertaken as outlined previously, but no further activity had been foreshadowed at the completion of the monitoring period.

Grazing

No significant impacts occurred on the site as a result of feral buffalo, despite difficulties in maintaining a stock proof fence. Feral pigs were more prevalent, but impacts were restricted to the wetter areas within the Sweetwater and Acid Dams.

2.5 MONITORING

This report provides the results of monitoring on:

- surface water quality and hydrology of the East Branch of the Finniss River;
- minesite surface water quality from 1989 to 1991;
- groundwater hydrology;
- water quality and mixing dynamics in Whites and Intermediate Open Cuts;

- chemical activity and water balance of Whites and Intermediate Overburden Heaps;
- fish diversity and abundance in the Finniss River;
- macro-invertebrate ecology of the East Branch of the Finniss River; and
- general site integrity.

Overall, the results indicate that the objectives of the original rehabilitation project continue to be met. It needs to be stressed, however, that the rehabilitation works were "never intended or expected to eliminate all of the pollution sources" but that the effects of pollution would be small compared with that prior to rehabilitation (Verhoeven 1988).

Rainfall throughout the monitoring period was mainly average and below, varying from a high of 1600 mm in 1988/89 to a low in the following year of 900 mm. This compares with an average rainfall in the Rum Jungle area of 1500 mm as reported by Davy (1975). The rehabilitation works have therefore still not been significantly tested by above average rainfalls.

Monitoring beyond June 1993

In February 1993, the Monitoring Committee assessed the results from the previous five years and concluded that while the rehabilitation had been successful in the short term, it was difficult to predict its medium to long term effectiveness. Through the previous monitoring and an improved understanding of acid mine drainage mechanisms, shortcomings in the original monitoring program had become obvious and needed to be remedied. The main areas of concern about long term effectiveness related to:

- the effectiveness of the cover seal on Whites and Intermediate Overburden Heaps in inhibiting pollution generation within these heaps;
- long term time dependent changes in the pollution loads exiting the base of Whites and Intermediate Overburden Heaps;
- the contribution of pollution loads in the East Finniss River from Whites and Intermediate Open Cuts and how this may change with time;
- the contributions of Dysons Overburden Heap and the effectiveness of its modified cover system;
- the water quality in both the East Branch and the Finniss River downstream of its confluence; and
- the ecological effects of the pollutants downstream of the mine and the response to rehabilitation.

The Rum Jungle Monitoring Committee subsequently recommended that a further period of at least five years monitoring was required in order to develop the ability to predict the future integrity of the site and an extended monitoring program was designed specifically for this purpose. Total funding sought from the Commonwealth amounted to $927 250, with NT Government support of $390 000 in salary and operational costs. Although, the program had not been finalised by June 1993, the Federal Government had indicated its strong support for the extended program.

3. SURFACE WATER QUALITY AND HYDROLOGY
East Finniss River - 1988/89 to 1992/93
MINE SITE SURFACE WATER QUALITY - 1989 to 1991

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3.1 INTRODUCTION

Post rehabilitation monitoring of surface water quality at the Rum Jungle mine site and the East Branch of the Finniss River continued over the period 1988/89 through 1992/93. This period included one of the poorest wet seasons recorded since monitoring at the station began in 1965 and one of the wettest in 1988/89.

Collection of data on water quality and hydrology in the East Finniss at gauging station GS8150097, and to a lesser extent GS8150200 (Figure 3.1), was a particular focus for the monitoring activity reported in this chapter. In addition, data collected from both mine site surface waters (other than the open cuts) and from a preliminary survey of water, benthic algae and sediment downstream of the rehabilitation site along the East Branch, is presented.

3.2 MONITORING PROGRAM

Modifications to the program

The focus of surface water monitoring since 1986-88 (Kraatz and Applegate 1992) and over the period 1988/89 through 1992/93 has undergone significant change. A brief summary of those changes are as follows:

- Radium 226 monitoring at all surface water sites was discontinued following the 1987/88 wet season.
- Gauging and sampling at the station downstream of the confluence of the East Finniss and Finniss River (GS8150204) was discontinued following the 1987/88 wet season.
- Gauging and sampling at sites draining Dysons Overburden and Open Cut landform were discontinued following the 1987/88 wet season.
- Spot sampling and gauging from selected sites within the mine precinct was discontinued following the 1990/91 wet season.
- Estimation of both the filtrable and total heavy metal loads began in the 1990/91 wet season. Prior to this, only *dissolved* metal concentrations were reported.
- Real time flow weighting of samples collected at gauging stations GS8150097 and GS8150200 using programmable data loggers has occurred since 1991/92.

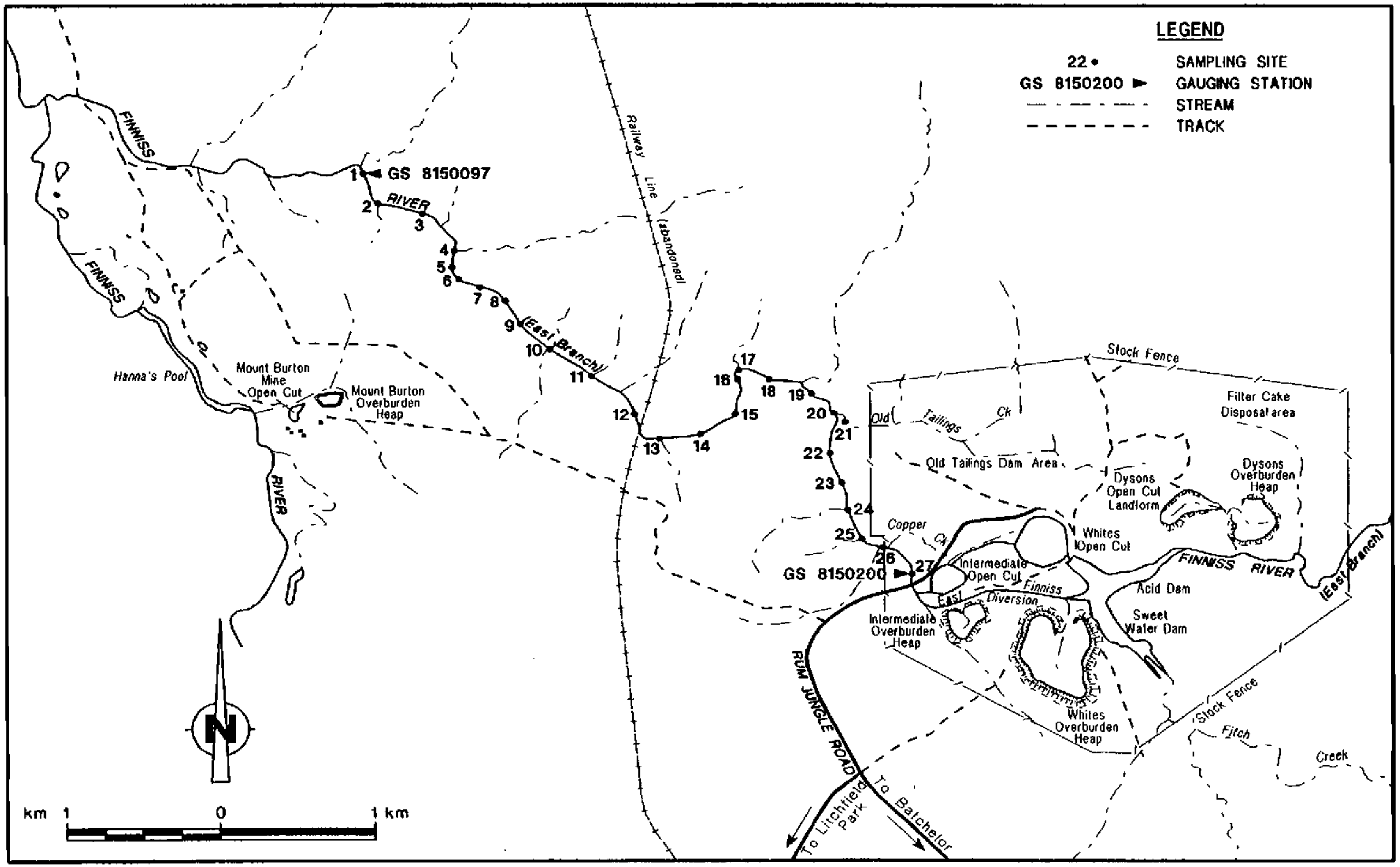

Figure 3.1 Sampling sites and gauging stations on the East Branch of the Finniss River.

- Flow weighted samples collected from GS8150097 in 1992/93, in addition to being analysed using standard Atomic Absorption Spectrometry (AAS) methodology, were analysed using a semi quantitative Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) multi-element scan to assess contaminant concentrations other than those targeted on a routine basis.
- A survey of heavy metal partitioning between the sediment, benthic algae and water was made along the East Finniss during late recessionary flow in April 1993.

East Finniss River

The focus of surface water quality monitoring activity downstream of the mine site continued to be at gauging station GS8150097. Continuous streamflow data, together with daily composite water quality data, were collected over the period 1988-1993. Flow weighted composites were also collected over wet seasons 1991/92 and 1992/93. Annual metal loads exiting the mine site were computed from data collected at this gauging station. The flow weighted composite samples collected in 1992/93 were analysed using a semi-quantitative multi-element ICP-MS scan in addition to the standard flame AAS technique for priority metal pollutants. A comparison of load estimates from the ICP scans, the daily composite samples and the flow weighted AAS analysed samples is made in the discussion section of this report.

With the closure of the Copper Creek overflow (Figure 3.2) in 1991 the bulk of mine site runoff and through-flow passed GS8150200. Due to concern (Henkel 1991Appendix C: 112) regarding the sedimentation of heavy metals along the length of the East Finniss, especially upstream of GS8150097, GS8150200 was equipped for continuous gauging and the collection of flow weighted composites over wet seasons 1991/92 and 1992/93. This data allowed comparisons to be made with loads estimated at the downstream station GS8150097 for 1991/92. Frequent instrument malfunctions at GS8150200 prevented a repeat of the comparison in 1992/93.

To complement the pollutant load checking undertaken at GS8150200, a survey of the sediments, benthic algae and water at selected sites (27 in total) between the two stations was undertaken (Figure 3.1). Selected heavy metals concentrations were determined on water, sediment and benthic algae samples, with additional general parameters being analysed on the water samples. This survey was conducted on 22/4/93 when the East Finniss was approaching cease-to-flow.

3.3 METHODS

Chemical analysis

Earlier Power and Water Authority (PAWA) reports on Rum Jungle surface water monitoring presented heavy metal data that referred to *dissolved* concentrations and *dissolved* loads of Cu, Zn and Mn rather than to total concentrations and loads. Prior to rehabilitation, when pH levels in the East Finniss were low (pH's of four to five common), the dissolved metal concentrations measured at GS8150097, some 5.6 km downstream of the mine site would have approximated total metal concentrations. Since rehabilitation, the trend in pH and alkalinity in the East Finniss has been to increase and this trend has a significant influence on metal speciation. Copper begins to precipitate from solution at pH's less than five while Zn, Ni and Mn follow at higher pH's. Co-precipitation of these metals with Al and Fe flocs at lower pH's enhance this process in the East Finniss River. The bulk of heavy metal data reported prior to the 1990/91 wet season was from

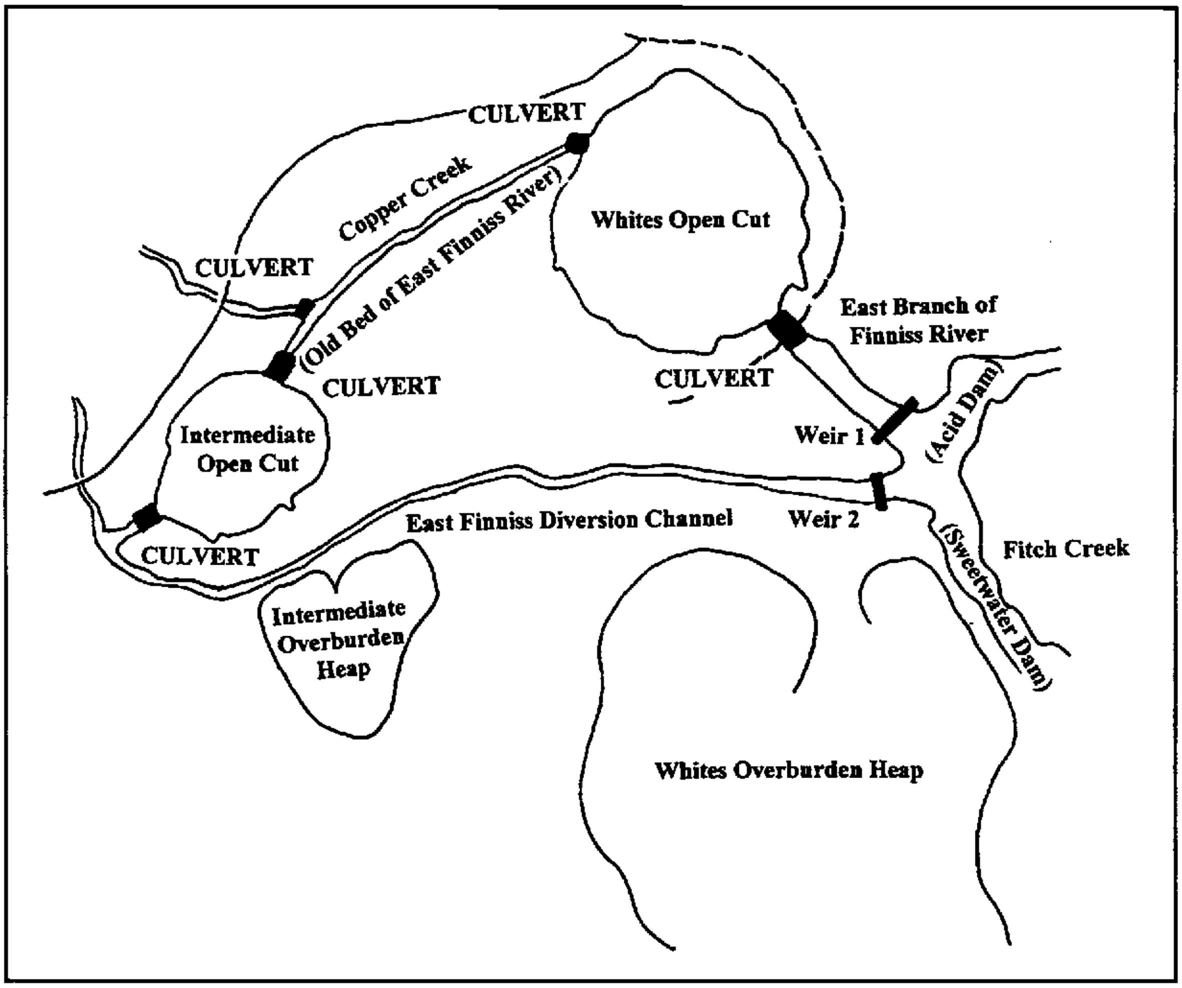

Figure 3.2 Rediversion of the East Branch of the Finniss River.

analysis of samples where there was no filtration and no acidification of samples.

In 1990/91 and 1991/92, individual samples of both daily composites and flow-weighted composites were divided in two with one half being acidified prior to heavy metal analysis (flame AAS) and the other analysed as before (ie. flame AAS analysis on an *as received* basis). These two sets of results for heavy metals have been designated the *total* and *dissolved* fractions in tables and graphs.

In 1992/93 a revised wet season analysis protocol included filtration, in the laboratory, of individual sample aliquot through a 0.45 μm membrane to give a *filtrable* heavy metal fraction for each sample and acidification of a separate aliquot to give a *total* heavy metal result. The analyses were conducted in the NATA registered PAWA water laboratory in Darwin. In addition, in 1992/93 sub-samples of the flow weighted composites collected from GS8150097 (unfiltered) were dispatched to the State Chemistry Laboratory in Adelaide for a 63 element, semi quantitative ICP-MS analysis. The analysis report received from this laboratory is reproduced in full at Appendix A.

Heavy metal analysis of sediment and benthic algal samples collected from the East Finniss on 22/4/93 was performed by the Northern Territory University (NTU) (see Appendix B for details).

Mine site sampling

Prior to 1991/92, sampling sites at the mine site were used to help define pollutant sources and major drainage paths to the East Finniss. Spot flow gauging, grab sampling and on-site temperature, pH and conductivity measurements were made as part of this program. This sampling was discontinued, although two of the sites formerly employed (the inflow and outflow of the open cuts) are being established (1993/94 wet season) as continuously gauged stations. Results from the mine site sampling during the period 1989/90 to 1990/91 are presented at Appendix A.

East Finniss guaging stations

GS8150097 continued as the key gauging/sampling station on the East Finniss River, it being the designated site for annual pollutant load estimates from the Rum Jungle mine site. Gauging station GS8150097 was initially equipped by Water Resources in 1965 and has been operating as a continuous recording station since that time. The gauging station control is a shallow concrete v-notch weir downstream of the recorder. The catchment area is 71 km^2.

A similar gauging/sampling regime is used upstream at gauging station GS8150200. This station was commenced in December 1981 and recording was continuous to August 1988. The station re-opened in November 1991 and is currently scheduled to remain open through to 1998. The control structure is a gravel bar at the site of an old road crossing 20 m downstream of the tower. The cease-to-flow level has varied from a Water Resources Division (WRD) datum of 1.477 m (1981) to 1.436 m (1987) and 1.402 m (1993). The catchment area of 52 km^2 includes most of the Rum Jungle mine site (in total approximately 0.6 km^2). Runoff from the rehabilitated tailings dump area discharges downstream of this station through Old Tailings Creek.

The two gauging stations, GS8150097 and GS8150200 have instrumentation consisting of a stilling well, float tape, shaft encoder, data logger and automatic sampler(s). The stilling wells are of concrete pipe construction and are connected to the river via 70 mm galvanised pipe, placed at different levels to avoid loss of data quality due to silt blockages.

The data loggers (SDS *Torrens* - Adelaide) are programmed and interrogated via laptop computer. Stage data is collected by programming the logger to 'wake up' every five minutes and read the shaft encoder. If the reading has changed from the preset five millimetre range of the previous reading then that stage height and time is logged onto the data storage module.

The daily composite samples of some 500 mL are collected using a Sigma autosampler with a 24 bottle carousel and comprise three individual aliquot taken at eight hourly intervals.

Flow weighted samples are collected from an 80 L plastic bin that has received pumped aliquots (500 mL using a Sigma pump) from the river at intervals determined by river flow. This process is achieved by programming the previously determined stage/discharge relationship, converted to the form of exponential equations, into the logger. The logger, in 'wake up' mode, calculates the total volume of water that has passed the station since the previous reading. Once the preset volume of water has been calculated to have passed, the logger sends a contact closure signal to the sampler which then pumps the designated aliquot and the logger writes the time, date, sequential number, stage, flow and cumulative volume to the data storage module. The bin contents are sub-sampled at approximately weekly intervals with two one litre representative samples being taken after thorough mixing of the water and sediment.

East Finniss - survey of stream

On 22/4/93 samples of sediment, benthic algae and water were collected at sites on the East Finniss between GS8150097 and GS8150200 (Figure 3.1). These samples give a snapshot of the prevailing heavy metal dispersion along the length of the river at a time of late 92/93 wet season recessional flow. There was difficulty in taking representative samples in that the benthic algal mat entrained varying amounts of sediment and flocculant material. This *floc* is most probably an iron oxyhydroxysulfate (Bigham et al. 1990) with adsorbed heavy metal contamination and washing it from the algal filaments was done with variable success. At each location the least *floc*-contaminated algae was sampled and given a gentle washing in the river flow to remove the bulk of entrained *floc* and stored (in river water) in 50 mL specimen containers. These samples were rinsed again with distilled water on return to the laboratory then dispatched for heavy metal analysis to the NTU.

Representative sampling of the sediments also presented a problem in that the river currents and stream bed morphology have given rise to significant differentiation and dispersion of gravels, sand, silt and clay material. A 50 mL volume of sediment was sampled using a specimen container to scoop sediment from the stream bed where there was minimum gravel and pebble cover. Sites close to where the corresponding algal specimen had been collected were selected. Water samples were taken as dip samples from flowing water at the site. Sampling was conducted in a downstream to upstream direction using quad-runners for access to the sites along the river. The survey was completed over a period of some five hours.

3.4 RESULTS AND DISCUSSION

Pollutant loads - as measured at GS8150097

Annual loads of selected heavy metals being discharged from the Rum Jungle mine site have been computed from data collected at gauging station GS8150097. Results covering all years when comprehensive data have been collected are presented in Table 3.1.

This data is presented graphically in Figures D.1-3 (Appendix D) to illustrate the relationships between discharge and heavy metal loads both pre- and post-rehabilitation. A plot of total flow in the East Finniss (as recorded at GS8150097) versus rainfall (as recorded at R815205-Whites Overburden Heap) is included (Figure D.4).

Some alternative load estimates for 1992/93, supplementary to those presented above, were made. The first estimate alternative used daily composite sample analyses and daily discharge means in a manner similar to that used for load computation prior to 1991/92. The second used the flow weighted samples but analytical data generated by ICP-MS rather than the flame-AAS data. A comparison of the load estimates so determined is presented in Table 3.2.

Table 3.1 Historical load data (in tonnes) from GS8150097* together with a record of flow and rainfall.

Year	Flow (m^3*10^6)	Rainfall (mm)	Cu (total)	Cu (dissolved)	Zn (total)	Zn (dissolved)	Mn (total)	Mn (dissolved)	SO_4 (tonnes)
1969/70	7	896	44				46		3 300
1970/71	33	1 611	77		24		110		12 000
1971/72	31	1 542	77		24		84		6 600
1972/73	22	1 545	67		22		77		5 500
1973/74	69	2 000	106		30		87		13 000
1982/83	9.5	1 121	23		5		6		1 520
1983/84	48	1 704	28		9		21		3 600
1984/85	11.7	1 136	9.1		4.1		7.2		1 600
1985/86	11.4	1 185	3.7		2.7		8.2		4 400
1986/87	13.2	1 222	5.6		2.7		8.6		2 870
1987/88	6.3	1 064	3.2		2		5.4		1 230
1988/89	35	1 600	5.4		4.4		19.2		3 940
1989/90	3.1	900	1.8		1.6		3.9		760
1990/91	40.5	1 590	14.9	3	7.4	6	30.5	24.1	4 000
1991/92	7.1	1 002	3.8	2.8	2.7	2.6	9.1	8.9	1 260
1992/93	29.9	1 421	11.9	5	3.9	3.9	24.7	21.8	2 696

* *Data sourced from Davy (1975) and annual PAWA/WRD surface water monitoring reports 1983-1991.*

Table 3.2 Load estimates 1992/93 at GS8150097.

Method	Cu (tonnes)	Zn (tonnes)	Mn (tonnes)	SO_4 (tonnes)
AAS-real time flow weighted	11.9	3.8	24.7	2 696
ICP-MS real time flow weighted	14.4	4	22.8	-
AAS-daily mean conc./ discharge	17.8	4.9	26.8	2 209

These figures indicate a discrepancy of up to 50% in the case of Cu loads using different computational approaches and highlight the sensitivity of the final estimates to the initial analytical data. The flow-weighted/flame AAS figure has been chosen as the most appropriate to use as it is perceived to be the most accurate. However, it should be noted that some load estimates prior to flow-weighted sampling being introduced were generated using mean daily discharge and daily composite concentration data.

East Finniss - 1991/92 cumulative heavy metal loads at GS8150097 and GS8150200

In 1991/92, flow weighted composite samples were collected at the two gauging stations GS8150200 and GS8150097. This data was collected to assess whether heavy metals were precipitating along the 5.6 km of river between the two stations. The hypothesis put forward was that loads computed at GS8150097 were an underestimate of the pollution leaving the mine site due to precipitation between the two stations. Table 3.3 presents heavy metal load estimates computed for each station for wet season 1991/92 together with mean concentrations.

Although these estimates indicate good agreement with the Cu and Zn loads, there is sufficient discrepancy in the Mn and SO_4 loads to suggest that there is an accrual of Mn and SO_4 downstream of the gauging station GS8150200 from spring or surface waters discharging to the East Branch between the two stations.

Table 3.3 Discharge and pollutant load estimates for 1991/92 at GS8150097 and GS8150200.

	Discharge (m^3*10^6)	Cu (t)	Cu mean conc. (mg/L)	Zn (t)	Zn mean conc. (mg/L)	Mn (t)	Mn mean conc. (mg/L)	SO_4 (t)
GS8150097	7.12	3.75	0.53	2.65	0.37	8.9	1.29	12 600
GS8150200	5.21	3.86	0.74	2.50	0.48	6.5	1.25	9 160

Figures D.5 and D.6 plot the cumulative discharge and Cu, Zn and Mn loads for 1991/92 at GS8150097 and GS8150200 respectively. From these figures it can be seen that the first 20% of flow, as gauged at GS8150097, carried 25% of the total Mn load whereas at GS8150200 the first 20% of flow carried 30% of the total Mn load, as measured at the respective stations. This bias is consistent with first flush and wash-off effects associated with early wet season runoff. Similar trends can be seen with the other pollutant loads.

In 1992/93, malfunctioning of data loggers and batteries prevented comprehensive data being recorded at GS8150200 and no follow up comparison in load estimates was possible with the downstream station.

East Finniss - sediment, benthic algae and water quality survey of the river (22/4/93)

As described above, a survey of the sediments, benthic algae and water of the East Finniss River was conducted on 22/4/93 to assess heavy metal contamination downstream of the mine site. In addition, the survey sought to locate groundwater discharge between GS8150097 and GS8150200 that could account for the Mn and SO_4 load discrepancies outlined in Table 3.3.

Sample site locations are shown in Figure 3.1 and numbered 1-27. It should be noted that Site 21 is some 100 m upstream in the Old Tailings Creek and not in the bed of the East Finniss. Figure D.7 illustrates the recessional flow in the East Finniss, as measured at each gauging station, over the period leading up to and including the sampling date ; surface flow at the upstream station was approximately 1 L/s while at the gauging weir GS8150097 flow was in the order of 15 L/s on 22/3/93. Figures D.8 and D.9 plot water quality parameters determined for each site (except Site 21) and show dilution of all parameters under the possible influence of groundwater discharging to the river between the stations. No surface water inflows to the East Finniss were detected (including Site 21) between the two stations on the day of sampling. Due to difficulty of access to certain reaches of the river, however, the survey was not comprehensive in this regard. The apparent dilution ratio of parameters between the upstream and downstream sites are presented in Table 3.4.

Table 3.4 Chemical analyses and conductivities of water samples taken at GS8150200 and GS8150097 on 22/4/93 and the dilution ratios between them.

	Cu (mg/L)	Zn (mg/L)	Mn (mg/L)	Ni (mg/L)	Ca (mg/L)	Mg (mg/L)	SO_4 (mg/L)	Conductivity (μS/cm)
Site 27	3.65	7.75	7.2	3.85	78	239	922	2 070
Site 1	0.56	0.87	1.5	0.56	34	74	401	786
Ratio 27:1	**6.5**	**8.9**	**4.8**	**6.9**	**2.3**	**3.2**	**2.3**	**2.6**

These dilution ratios must be treated conservatively given that they are based on spot samples. The results, however, support an hypothesis that dilution waters enter downstream of Site 27 and have, on average, elevated Ca, Mg and SO_4 concentrations and quite likely significant Mn concentrations as well.

Based on a total flow at Site 27 of 1.5 L/s and flow at Site 1 of 15 L/s (ie. a ten fold increase) and the hypothesis that additional salts can be attributed to spring water only and not dissolution of stream bed deposits, the mean concentrations of these parameters in groundwater in-flow between sites are estimated to be (approximately) 29, 56, 343 and 0.86 mg/L respectively (with no allowance for evaporation).

Water of this quality is consistent with an hypothesis that contaminated groundwater from the rehabilitation site has moved through a dolomitic aquifer and in the process had acidity neutralised. Cu, Zn and Ni may have precipitated preferentially from solution relative to Mn. If this hypothesis is valid, the groundwater flow would assist in explaining the discrepancies in loads between the two gauging stations as outlined in 3.3 above. A further possibility, given that GS8150200 does not gauge/sample runoff from the rehabilitated tailings area (see 3.2 above), is that the Mn is sourced from this area. The results of benthic algae and sediment heavy metal analyses in the Old Tailings Creek (see Site 21 results below) indicate that the creek is subject to significant contamination. However, there is no indication from Figures D.8 or D.9 that the Mn or SO_4 concentrations change significantly downstream of this tributary of the East Finniss. A repeat of the snapshot survey is programmed in 1993/94 and a regular (six weekly) sample collection by the Australian Nuclear Science and Technology Organisation (ANSTO) along the East Branch during 1994/5, in conjunction with a macro-invertebrate study, should provide further data to assist understanding of surface and groundwater hydrology and water chemistry during late wet season recessional flow.

Sediment and benthic algae heavy metal concentrations at the sites sampled are presented in Figures D.10/14 as a series of bar graphs for individual metals. No algae samples were collected at Sites 1-10 and no control samples were taken at un-impacted sites on the day of sampling. Site 21 is included although situated on a small tributary to the East Finniss. Results from an ANSTO survey conducted in May/June 1993 provide background heavy metal concentrations for both algae and sediment at un-impacted sites in the area. These results, together with mean concentrations of pollutants from the impacted sites, are summarised in Table 3.5.

The bar graphs (Figures D.10/14) give no indication of obvious attenuation in heavy metal concentrations of either sediment (over 5.6 km) or algae (over 3.3 km) as distance from the rehabilitation site increases. Levels of contamination, on a dry weight basis at least, are far higher in the benthic algae than in the sediment. Similar partitioning of heavy metals between sediment and algae has been recorded in a study from the Tambo River in Victoria (Hart et al. 1992).

Table 3.5 Comparison of heavy metal contamination in sediment and benthic algae at polluted and control sites on the East Finniss River (1993).

	Cu (mg/kg)	Zn (mg/kg)	Mn (mg/kg)	Ni (mg/kg)
Sediment - contaminated	695	95	240	80
Sediment - control	16	3.5	3.9	3.9
Benthic algae - contaminated	8 500	950	590	515
Benthic algae - control	134	39	54	20

** Data used for control sites taken May/June 1993 (courtesy J. Ferris ANSTO). Expressed as mean (dry weight) concentrations.*

East Finniss - daily trends in water quality at GS8150097 from 1988/89 to 1992/93

Trends in the pH, conductivity, SO_4 concentration and the metal concentrations of Cu, Zn and Mn in daily composite water samples collected at GS8150097, together with the GS8150097 hydrograph for the particular wet season are shown in Figures D.15 to D.44 for the period 1988/89 to 1992/93 (detailed presentation of data for 1988/89-1990/91 appears in completed PAWA Reports 43/89, 22/91and 59/91). Some hydrographic and chemical data are missing due to equipment and/or battery failure but an overall trend for each wet season is apparent. The variation in total annual discharge over this five year period and the temporal distribution of each wet seasons flow is evident from the hydrographs. In general, high flows dilute pollutants whereas the early and late wet season flows, with their respective first flush and low dilution effects carry higher concentrations of pollutants. This is clearly illustrated for 1988/89 when Cu concentrations at the onset and end of the wet season were of the order of 2 mg/L but during high flows were generally less than 0.1 mg/L (Figure D.18.)

East Finniss River - 1992/93 ICP-MS multi-element scan

Aliquots of the 16 flow-weighted composites collected at GS8150097 during 1992/93 were analysed using ICP-MS to give a semi-quantitative 63 element scan for each. The only prior comprehensive element scan on waters in the Rum Jungle mine site had been conducted in July 1984 (Cook 1985) on Whites Open Cut prior to rehabilitation. The results for the 1992/93 survey are presented in Appendix A.

The results, where duplication exists, are in good agreement with the PAWA laboratory analyses, although load computations using the different sets of results give rise to significantly different estimates (see Table 3.2 above). For the range of elements not routinely monitored and which are considered environmentally toxic (ANZECC 1992), only Al, Pb and possibly U appear to be at sufficiently elevated concentrations to be of concern. Given the relatively high concentrations of Cu, Zn, Ni and acid that are discharged to the East Finniss, it is unlikely and probably unnecessary, that additional toxicity or synergistic effects could be ascribed to these additional pollutants.

3.5 CONCLUSION

Monitoring of the pollution regime at the Rum Jungle mine site has continued over the five year period 1988-1993. Elements of the program have changed but load estimates of the priority heavy metals discharged to the East Finniss River from the mine site and the detailing of daily trends in water quality have continued in a systematic fashion. A post-rehabilitation relationship between annual discharge and pollutant load is emerging that confirms the success of the project in its own terms (70% reduction in Cu and Zn loads) but highlights the situation of an on-going pollution discharge from the site to the East Finniss River.

A survey of the pollution plume down the East Finniss River between GS8150097 and GS8150200, as expressed by heavy metal concentrations in sediment, benthic algae and water samples, was made in April 1993.

The results indicate appreciable heavy metal contamination in the reach of river impacted by mine site effluent. Preliminary water analyses also suggest that groundwater discharge to the East

Branch between the two principal gauging stations is a hydrological feature that may be an important element in determining the water chemistry of recessional flows and residual water holes in this section of the river. This groundwater discharge to the East Finniss appears to have a broad spatial distribution along that length of river surveyed rather than being a specific point source. Follow-up work planned for 1994 will help clarify this dilution influence, if any occurs. The issue of contamination of sediment and algae by heavy metals will be pursued further by specialised ANSTO limnological surveys.

ICP-MS multi-element scans of composite samples collected at the downstream gauging station GS8150097 during the 1992/93 wet season has provided a valuable supplement to defining the chemical matrix of the river water at this site. In general, the results, where there was duplication between ICP-MS and the conventional flame AAS and wet chemical analyses, were in good agreement. The comprehensive multi-element scans confirm that the key contaminants discharged to the East Finniss are the heavy metals Cu, Zn, Mn and Ni. These have been targeted by the monitoring program since rehabilitation. Other contaminants present, apart from Al, are in relatively low concentrations.

Overall, the results from the wet season monitoring over the five year period 1988-93 confirm the persistence of pollutant transport from the mine site to the East Finniss River and help define its occurrence, distribution and source from within the rehabilitated site. A special focus of the on-going surface water monitoring program, in addition to the overall load computations, will be to examine in more detail the early and late wet season flow and contaminant regime in the East Finniss River. In addition, there has been no systematic analysis to date of the temporal variability in pollutant concentrations on a year by year basis. The development of a frequency distribution analysis of pollutant concentrations for each year, both pre- and post-rehabilitation where sufficient data is available, is a high priority for improved interpretation of the collected data.

4. GROUNDWATER HYDROLOGY

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4.1 INTRODUCTION

An interpretation of groundwater data at Rum Jungle up to 1989 was presented in the Rum Jungle Monitoring Report 1986-88 edited by Kraatz and Applegate (Gibson and Pantelis 1992). This chapter presents an interpretation of field data collected at Rum Jungle from 1988 to 1993. The extent of the monitoring has been reduced since 1987 and only six boreholes in the region of Whites Heap have been monitored. Questions that arise are:

- has there been any change in groundwater quality over the last five years?
- can any estimate be made of the pollutant loads from the heap?

Gibson and Pantelis (1992) concluded, on the basis of mathematical modelling of water and pollutant transport through the waste, that the time scale for leaching the soluble contaminants already generated within Whites Overburden Heap would be about twenty years, assuming that pollution generation was effectively stopped by the exclusion of oxygen. On this basis one would not expect to see significant change in the concentrations of pollutants draining from the dump over a five year period. As the infiltration rate through the dump has been reduced by the cover, the pollutant load would decline. If the cover reduced the water infiltration through the dump but left the oxidation rate unaffected, this load reduction would be temporary, as ultimately the average load is equal to the pollution production rate.

In the long term, the output of pollutants must ultimately be equal to their rates of production. However at any given time, the balance will not necessarily hold true, due to the slow response time of the system. It is also possible for precipitation and resolubilisation of a pollutant to produce a delay in its appearance in the groundwater. Therefore, any decline in the pollutant load as a result of covering a dump depends on the reduction in oxidation rate. On the other hand, the concentration of pollutants may rise or fall, depending on whether the fractional change in the infiltration rate is greater or smaller than the fractional change in the oxidation rate.

4.2 DISTRIBUTION OF POLLUTED GROUNDWATER

Figure 4.1 shows the disposition of the five boreholes which have been monitored from 1984 till the end of 1992. The circles drawn around the positions of the boreholes represent the average concentration of Cu in the water in the borehole, the areas of the circles being proportional to the concentrations. The period of averaging is from 1988 till 1992. The highest Cu concentration

[1] *Dr David Gibson was tragically killed following the preparation of this chapter.*

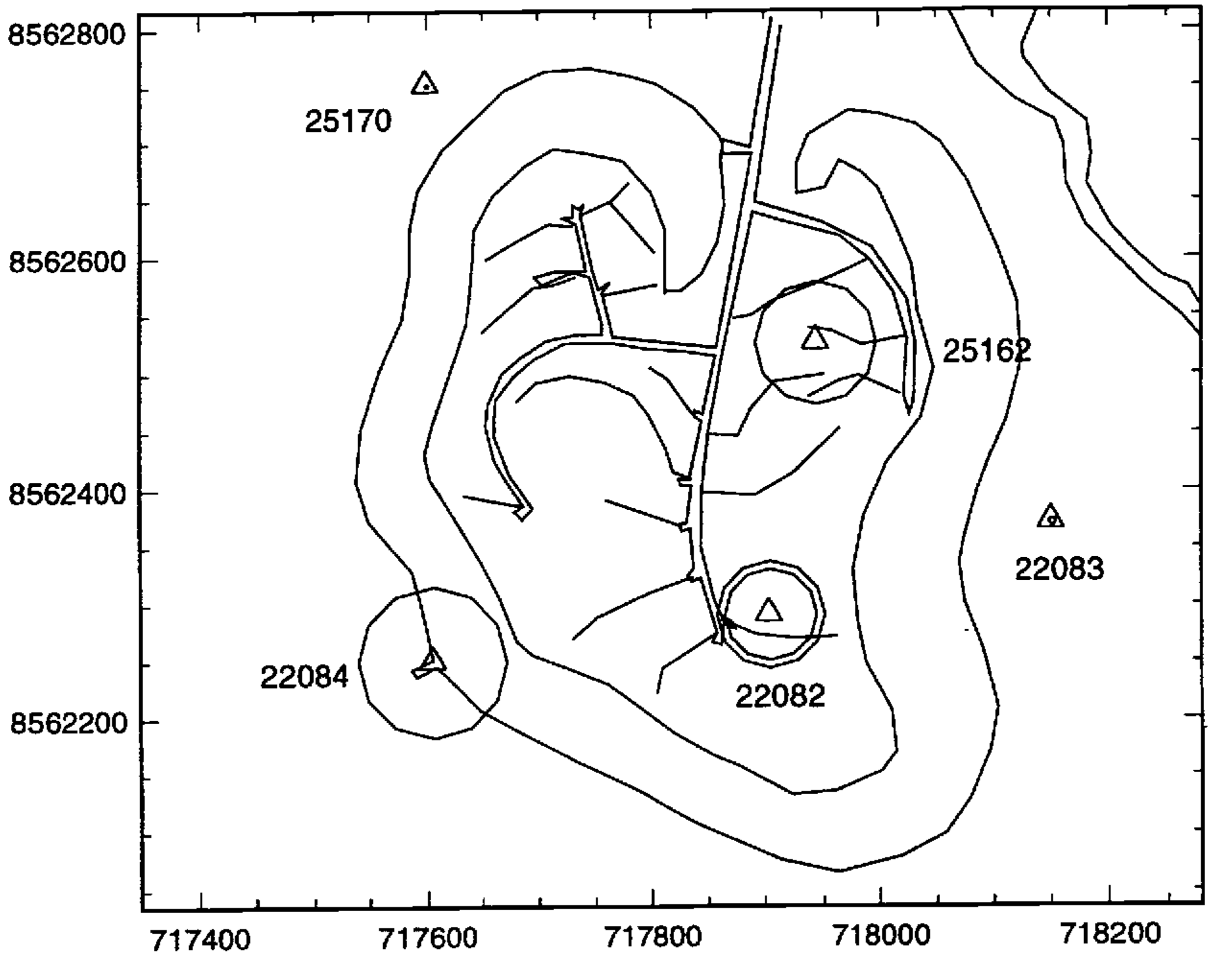

Figure 4.1 **Map of Whites Heap showing positions of the five boreholes monitored up till 1994. The areas of the circles drawn around the borehole positions are proportional to the Cu concentrations, averaged over the period from 1988 till 1994. In the cases of 22083 and 25170, the comparatively low concentrations appear as very small circles within the triangles that mark the position of the holes. The borehole 22082 has an upper and lower screen, hence two (rather similar) concentrations.**

appears at RN22084, on the south-west edge of the heap. There is evidence that there is an aquifer passing below the heap in a north-east, south-west orientation (the Giants Reef fault). The borehole RN25164, installed in 1987 about 150 m to the south of RN22084 revealed a deep wet clay layer in this area. It appeared likely that there would be considerable water movement in this aquifer. A preliminary electro-magnetic conductivity measurement made by K. Martin (private communication) demonstrated a high conductivity region in the area south-west of Whites Heap, which can be interpreted as a plume of high conductivity water that has emanated from beneath the dump.

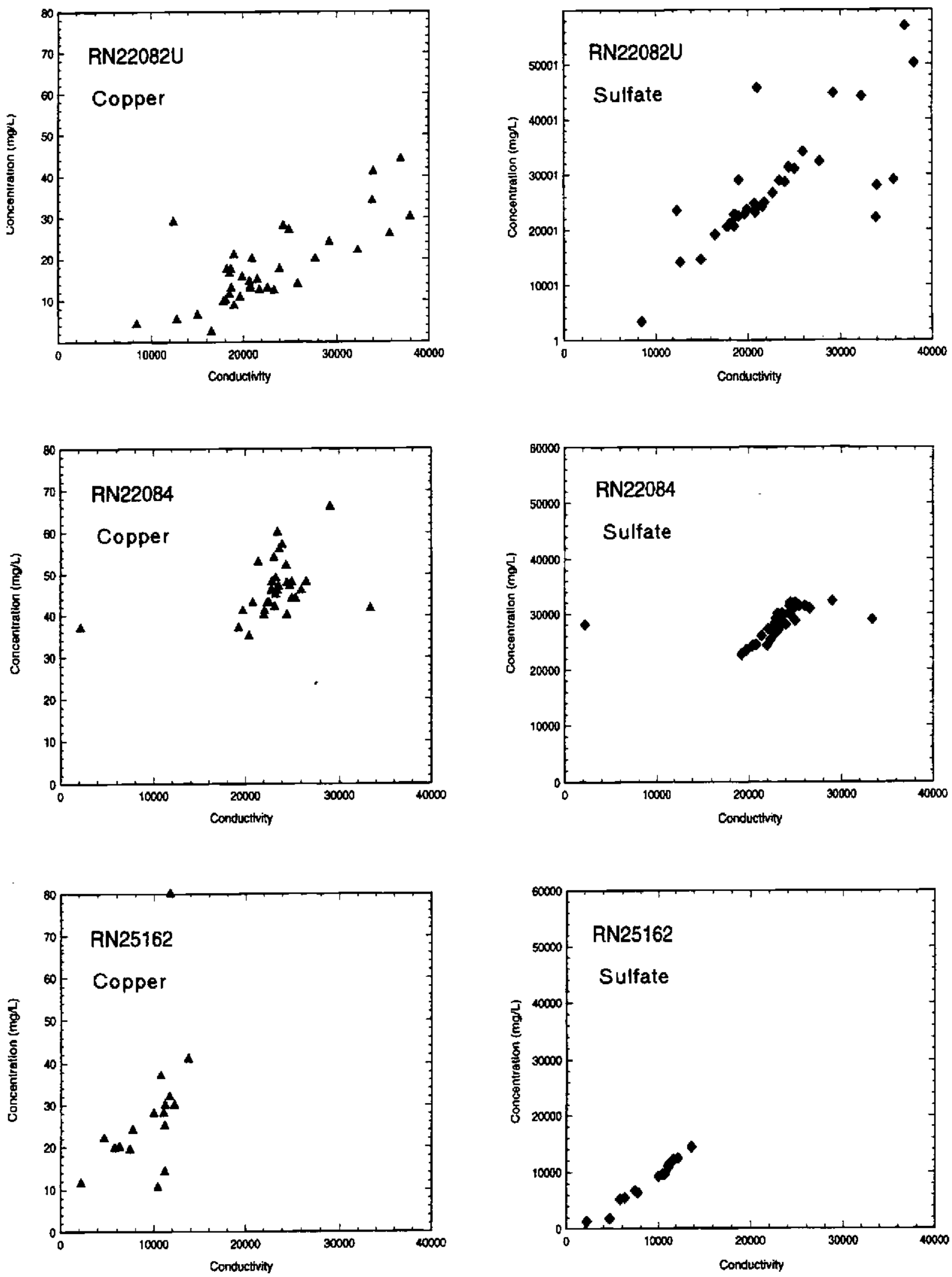

Figure 4.2 Copper and sulfate concentrations plotted against electrical conductivity for three boreholes.

4.3 RATIO OF POLLUTANTS

It can be instructive to look at the variation of one measure of pollutant concentration versus another. This has been done in Figure 4.2, where two sets of such relationships, one Cu the other SO_4, both plotted against electrical conductivity, are shown for the three boreholes with high pollution levels illustrated in Figure 4.1.

The Cu and SO_4 sets are similar for each hole, except that the scatter on the SO_4 is considerably less. The Cu concentration is much more influenced by chemical conditions, such as pH, than SO_4. Copper is also much more likely to be adsorbed onto the soil which could also lead to variation in the concentration in the soil water.

The spread of points on any one plot is interpreted as follows. When a water sample is collected from a borehole the hole is pumped for a while, and then a 'fresh' sample is taken from water that is drawn into the borehole through the slotted screen. If there is stratification of water quality the composition of the sample is a weighted average of the concentrations of the various levels. As has been shown previously (Gibson and Pantelis 1992), the concentrations of the pollutants apparently fall with rising water level and rise as the water level falls. When the measurement protocol is taken into account, this observation shows that the rise in water level comes from a layer of comparatively pure water moving over the contaminated water in the wet season and retreating in the dry. The varying degree of dilution is responsible for the spread of the points, roughly along a straight line.

The pattern of points is different for each of the three holes. As the spread of points depends on the variation in dilution brought about by the clean water layer forming and draining away, it is not altogether surprising that this variation occurs, as there is a strong element of chance in the ratio of clean to contaminated water that will be drawn into the hole during the sampling process. The two holes that sample water below the heap (RN22082U and RN25162) differ in their spread of points, which shows that being below the dump is not the determining factor. The positions of the holes with respect to hydrogeological features, such as an aquifer associated with a geological fault, may be responsible for the different patterns.

4.4 GROUNDWATER LEVELS

The water level is another area in which the pattern of behaviour when comparing boreholes is not clear. Figure 4.3 shows that the water levels of the three boreholes RN22084, RN25162 and RN22083 rise and fall in phase. This contrasts with the phase lag of about two weeks shown in RN22082U as can be seen in Figure 4.4. It might be thought that the two week lag could be due to the time for water to travel approximately 100 m from the edge of the dump to the site of RN22082. The picture here is that the groundwater level rises everywhere as rain infiltrates the soil, except under the dump, where the infiltration is reduced to five per cent by the cover. But in this case the changes in levels in RN25162 would also be retarded. Figure 4.3, however, shows that this is not the case. Another picture of water level change, in which water level changes propagate as a wave from high in a catchment, is also not consistent with the data. In this scenario, a progression of time delays across a sequence of boreholes would be expected. Examination of water level changes leads us to believe that the behaviour of the boreholes is affected by their chance positions with respect to hydrogeological structures.

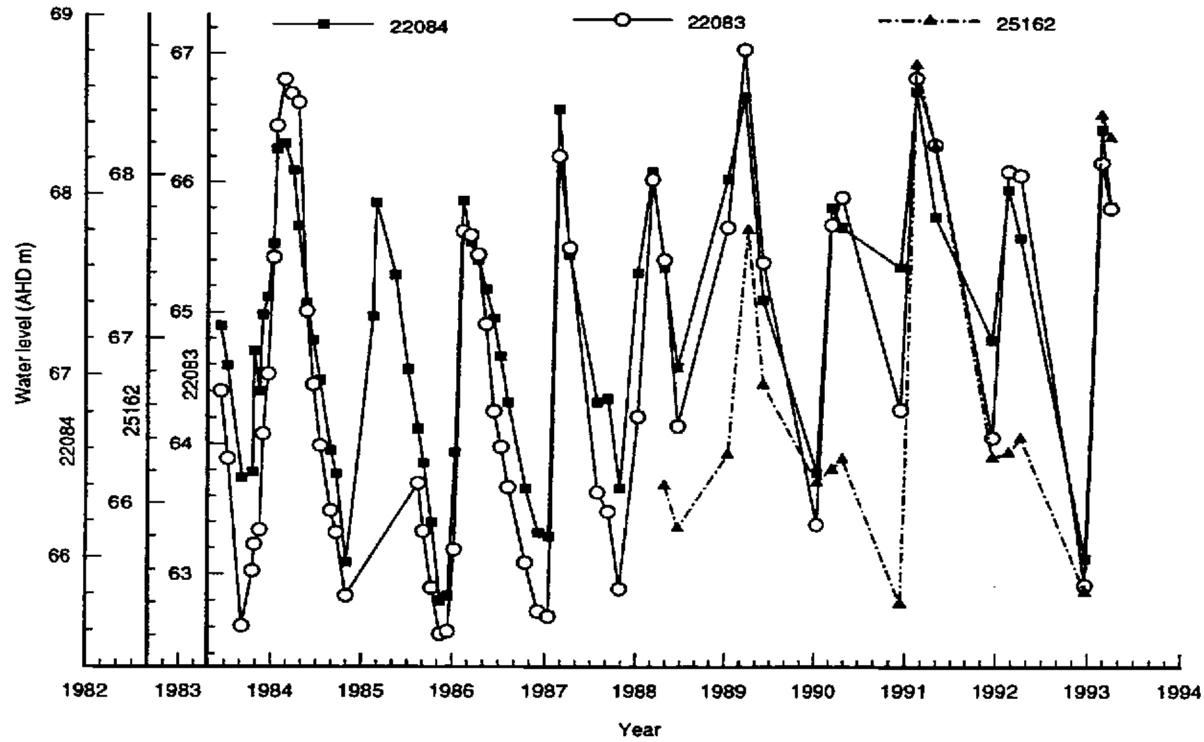

Figure 4.3 Water levels in the three bore holes RN22084, RN25161 and RN22083 rise and fall in phase.

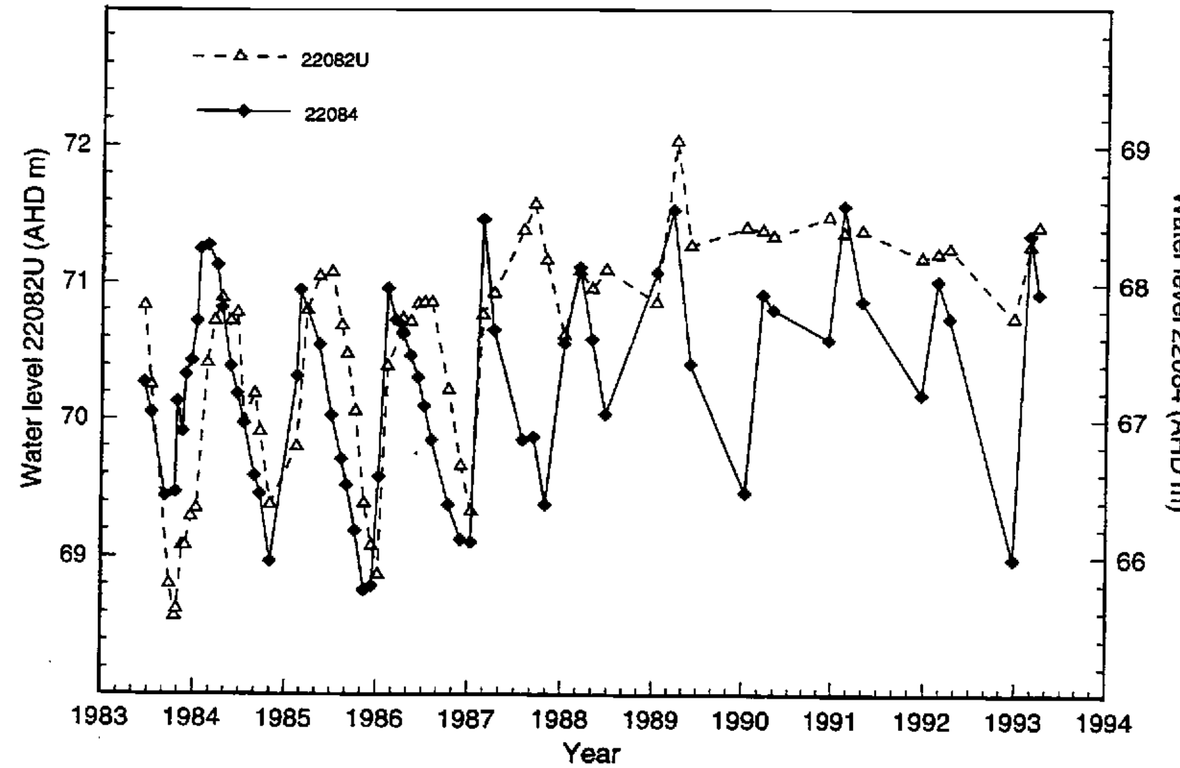

Figure 4.4 A phase lag of about two weeks is evident in water levels in RN22082U.

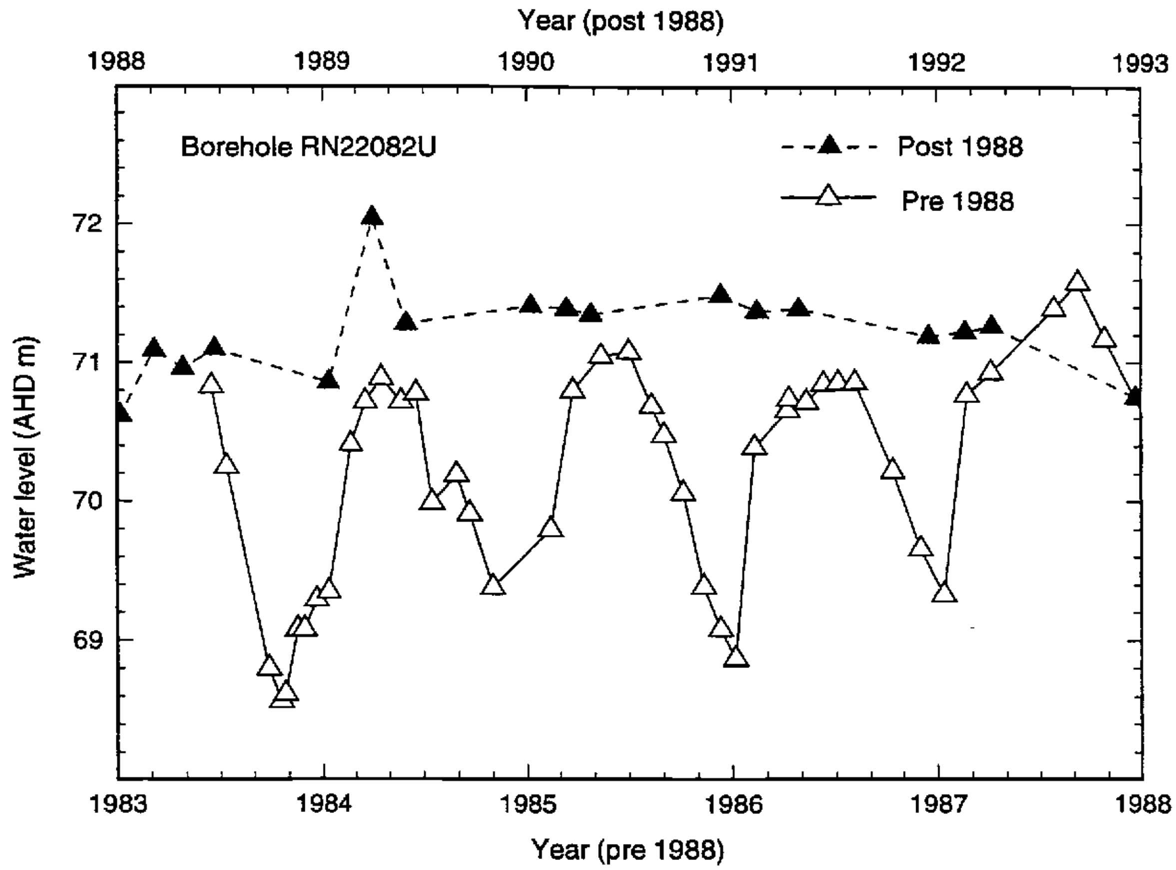

Figure 4.5 **Ground water levels below Whites Heap at borehole RN22082U, showing the dearth of measurements in the dry season (note the upper and lower time axis).**

4.5 WATER QUALITY UNDERNEATH WHITES HEAP

It is very important to take account of the times that the measurements were made when looking at the water quality below the heap. It was shown in Gibson and Pantelis (1992) that the apparent concentrations of pollutants in the water below the heap were cyclic, falling as the water level rose and increasing again as the level fell. This was taken as evidence that a layer of fresh water flowed over the top of a deeper polluted layer each wet season and flowed out again at the end of the wet, with little mixing between the two. The additional data since 1988 are compared with the pre-1988 data in Figure 4.6.

If the timing of the post-1988 measurements were to be ignored it would appear that the SO_4 concentration had fallen since 1988. It is clear, however, from the figure that the measurements have been made during the wet season, when the concentrations are lower.

The conclusion is that the pollutant concentrations below Whites Heap are unchanged since monitoring began in 1983. It therefore appears that a layer of fresh water forms over the pool of polluted water each year and that the degree of mixing is insufficient to cause observable change in SO_4 concentration below the dump. It might be concluded from the essentially unchanging

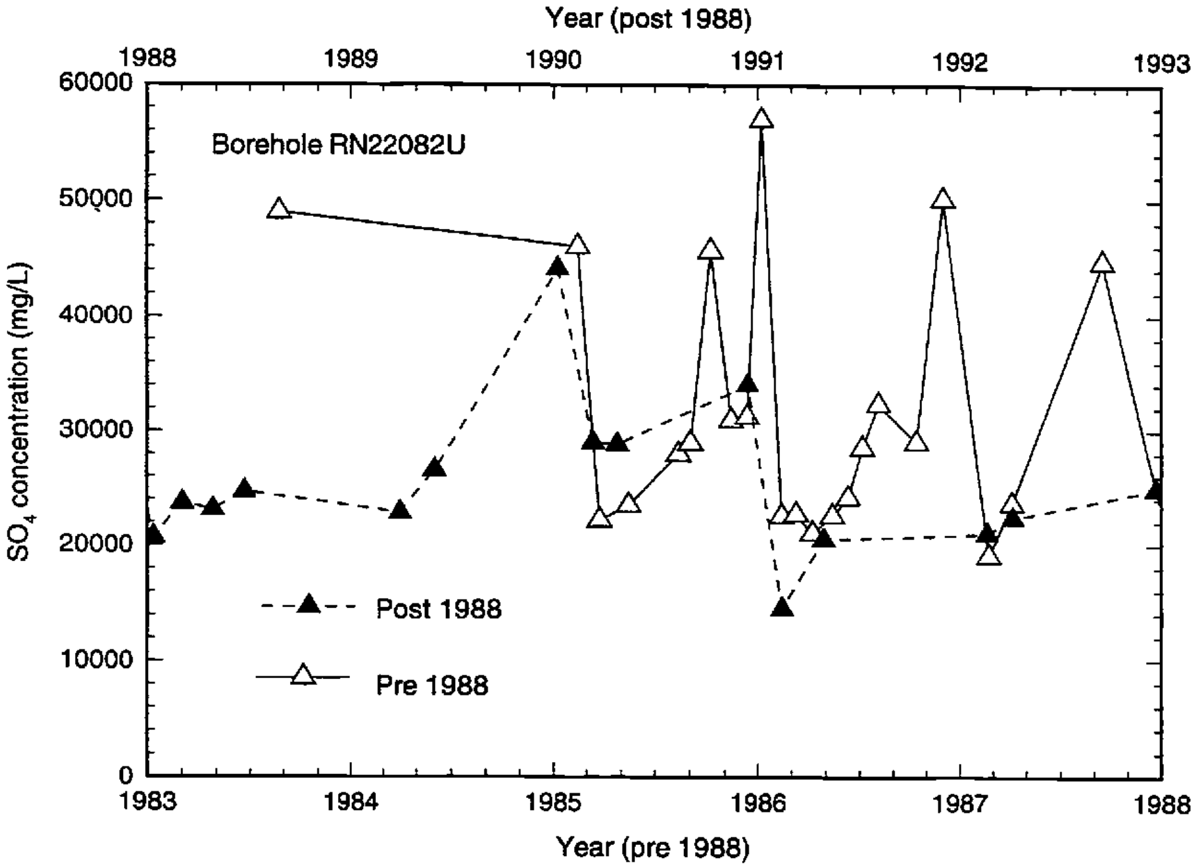

Figure 4.6 Sulfate concentration beneath Whites Heap before and after 1988.

concentrations below the heap that the pollutant load leaving the reservoir below the heap each year is equal to the load entering the groundwater from the base of the heap. However, until some estimate of the volume of polluted water below the heap can be made, allowing an estimate of the sensitivity of the concentrations to discrepancies in pollution production rates and rates of output to the groundwater (loads), the conclusion suggested above is not justified.

4.6 CONCENTRATIONS OUTSIDE HEAP

The SO_4 concentration in the borehole on the south-west edge of the heap is also shown in two time zones, divided into pre- and post- 1988 (Figure 4.7). In this case, the measurements appear to show some indication of a small drop in SO_4 levels. However, any conclusion that the water quality is showing even small improvement in the groundwater outside the heap is dispelled by examination of the Cu concentrations, displayed for RN22084 in two time zones in Figure 4.8.

4.7 POLLUTANT LOAD TO GROUNDWATER

With the data to hand it is not really possible to give any reliable estimate of pollutant loads from the heap. There is certainly a reserve of polluted water lying below the heap, but the water velocity may be low in the lower part of the aquifer, the site of the polluted layer, if the hydraulic conductivity is low here compared with the surface layer, where the fresh water flows.

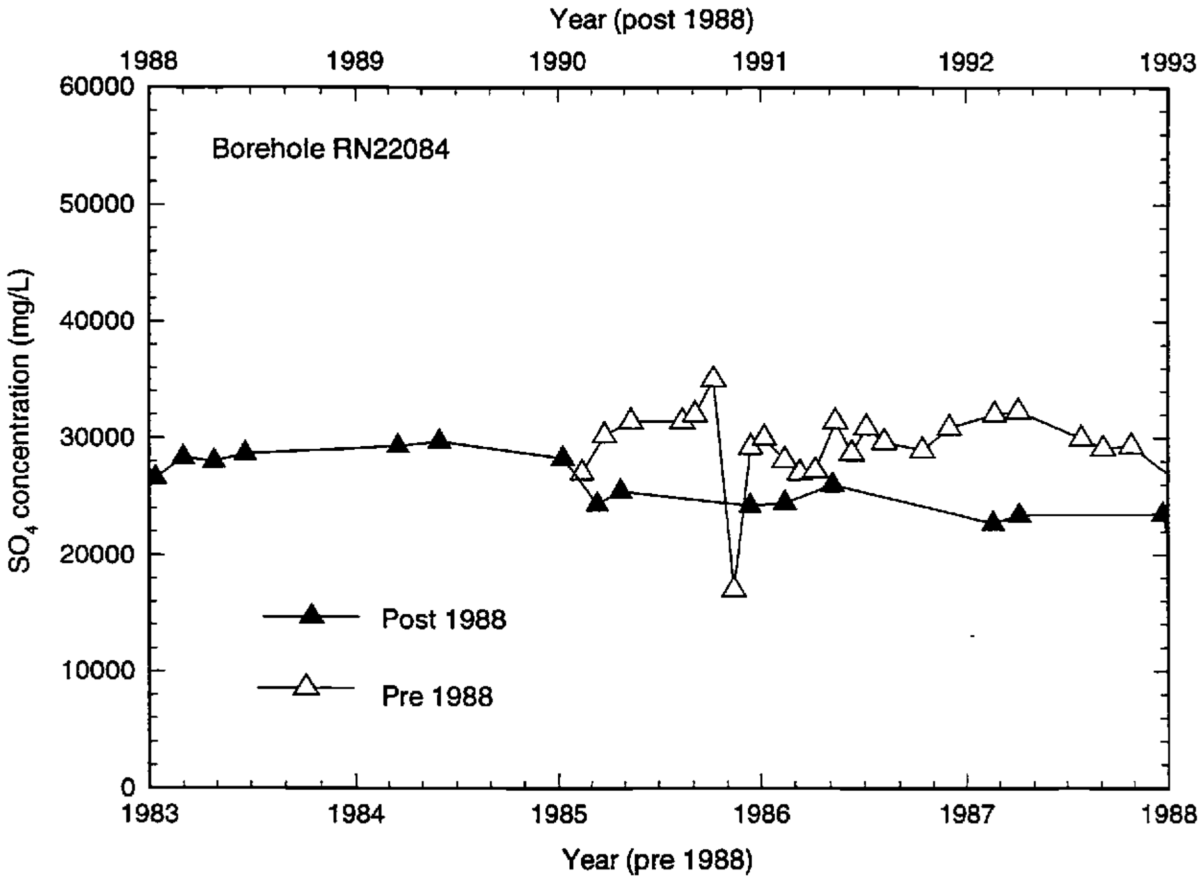

Figure 4.7 Sulfate concentration in RN22084 before and after 1988.

4.8 CONCLUSION

The field measurements show that the concentrations of pollutants in the groundwater in the vicinity of Whites Heap have not changed significantly in the last five years. This is consistent with the conclusions of the earlier report (Gibson and Pantelis 1992) in which it was estimated that the time to leach the pollutants stored in the pore water of the heap was of the order of 20 years. However, the same observations could also be explained by the presence of a large reservoir of polluted water below the heap, which would respond slowly to changes in pollutant input rates.

It is not possible to make reasonable estimates of the pollutant loads in the groundwater at this stage. To pursue the groundwater questions further it is recommended that:

- measurements of the stratification of water quality be attempted;
- further measurements of soil conductivity be made, to establish the size and position of the plume of polluted water;efforts be made to estimate the water velocity in the plume, possibly taking stratification into account; and
- an attempt be made to measure the pollutant concentrations in the pore water in the heap, to establish the total inventory and its annual rate of release.

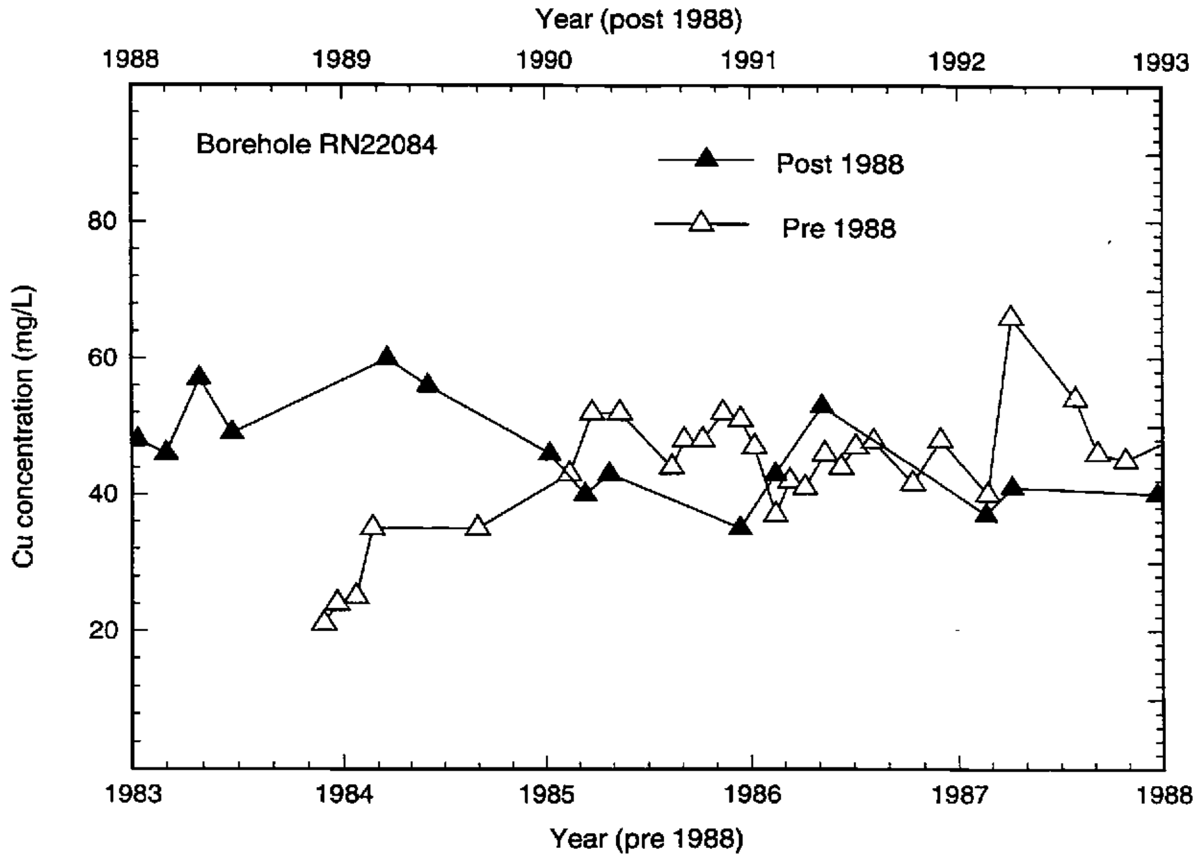

Figure 4.8 **Copper concentration in RN22084, comparison of pre- and post- 1988 trends.**

5. WATER QUALITY AND MIXING DYNAMICS WHITES AND INTERMEDIATE OPEN CUTS

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5.1 INTRODUCTION

Whites and Intermediate water bodies represent the flooded, partially backfilled open cuts developed during the mining operation at Rum Jungle prior to 1971. Whites, although reaching a maximum depth of some 110 m as an open cut is currently only about 50 m deep with a surface diameter of approximately 360 m. The Intermediate water body, although of a similar depth is significantly smaller in volume, with an approximate diameter of 210-270 m. The hypsographic relationships for each water body are shown in Figure 5.1 along with the regression equations that were used to generate estimates of Cu inventories in each (see 5.3 below).

Detailed physico-chemical measurements of the water column in both Whites and Intermediate Open Cuts were made prior to rehabilitation and these profiles have continued as an important element of the monitoring program since rehabilitation. Data from these profiles have allowed the initial water treatment process to be closely monitored and the effectiveness of annual flushing of the open cuts during wet season flows to be determined (Kraatz and Applegate 1992: 98-102). In addition, these investigations led to the development of hypotheses concerning the source of pollutants exiting the open cuts and their relative contribution to the overall pollutant loads discharged from the mine site. Inflow of contaminated groundwater, diffusion across concentration boundaries, pyritic oxidation on the pit walls and vertical turbulence were put forward as feasible mechanisms for pollutant transport. A detailed and systematic monitoring program was implemented in March 1992 to evaluate these propositions.

5.2 MONITORING PROGRAM

Sampling

Intensive physico-chemical profiling in these water bodies was re-implemented in 1992. Prior to March 1992, a scaled back work program had reduced profiling over the period 1988-91 to twice yearly, scheduled for pre- and post-wet season in October and May of each year.

The re-invigorated program involved monthly profiling using a Hydrolab Surveyor II multi-parameter probe (measuring depth, pH, temperature, conductivity, dissolved oxygen and oxidation reduction potential) coupled with a submersible pump and discharge hose to the surface which allowed for collection of samples for later chemical analysis. Probe data were collected

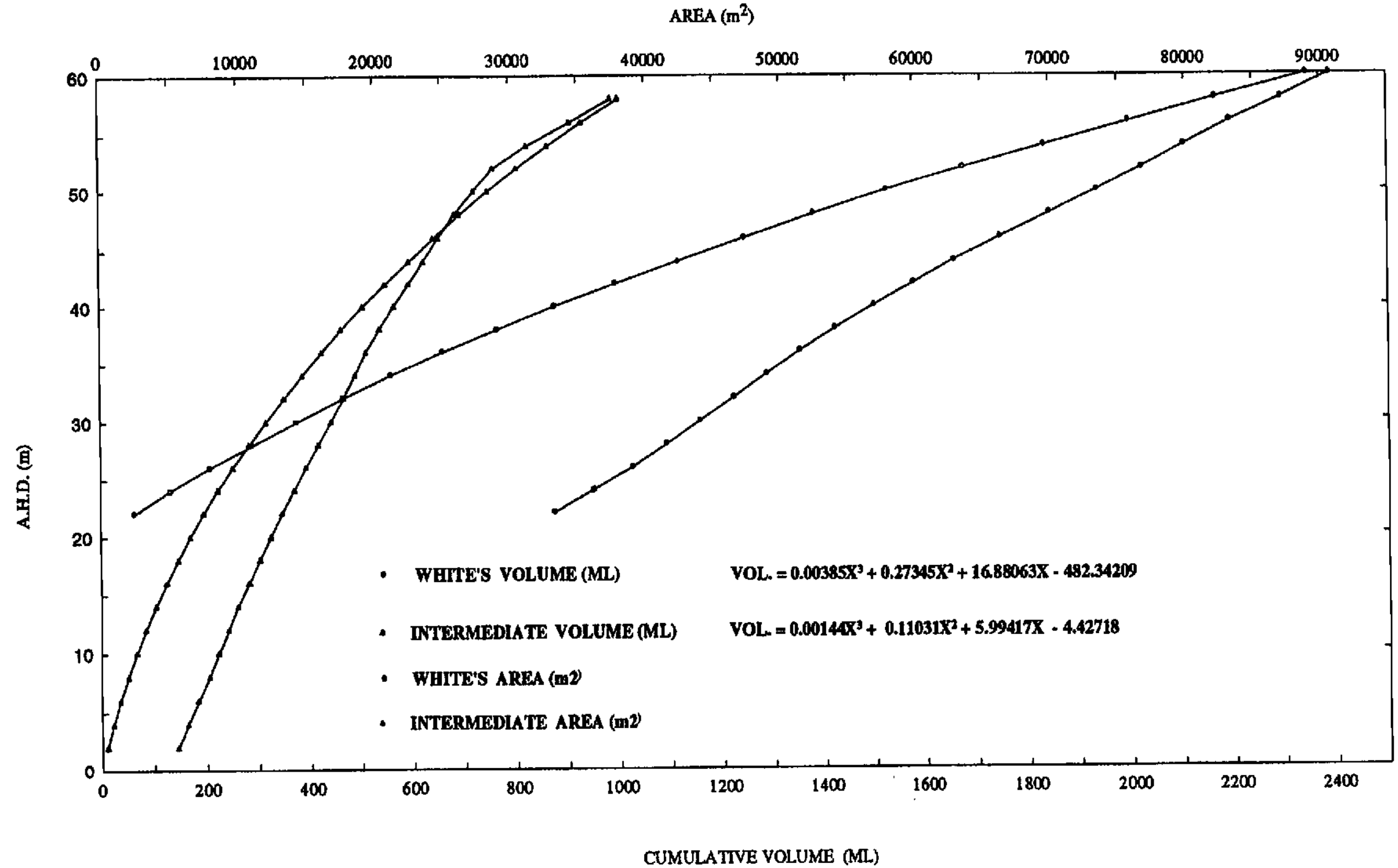


Figure 5.1 Hysographic plots for Whites and Intermediate Open Cut water bodies.

at metre intervals down to a depth of 35 m and pumped samples were taken at five metre intervals for heavy metals and at ten metre intervals for general parameter analysis. Additional samples from each water body were collected from just above the pycnocline in the transition zone to give improved definition to the pollutant dispersion pattern in this region of the water column. During periods of inflow to the open cuts, fortnightly profiling was programmed.

5.3 RESULTS AND DISCUSSION

Results are presented in the form of isopleth diagrams detailing temperature, pH, conductivity, Cu and Mn profiles above 34 m AHD (Australian Height Datum) in Whites, and 25 m AHD in Intermediate over a period spanning the 1992/93 wet season (Figures 5.2 to 5.6). These diagrams highlight the influence of wet season inflow to the water bodies where mixing/flushing extended to depths of 30 m. The conductivity and Cu isopleths for Whites in particular illustrate the flushing process of the turbulent inflowing water from the upper East Finniss River. The conductivity of the surface waters decreased from approximately 500 μS/cm at the end of the 1992 dry season to approximately 150 μS/cm as wet season inflow subsided in March 1993. The Cu concentrations of the surface waters were diluted from one milligram per litre to 0.1 mg/L over the same period.

In addition to the isopleths, Cu inventories in both Whites (above 32 m AHD) and Intermediate (above 30 m AHD) are plotted against time from October 1986 to November 1993 (Figure 5.7). In Whites, the Cu inventory above 32 m AHD on 13/1/93 was 6.1 t (prior to wet season inflow). The subsequent flushing by relatively pollutant free water from the upper East Finniss River, however, reduced this inventory to 2.1 t by 13/2/93 and to 0.41 t by 1/4/93. (This estimate presumes negligible settlement of Cu containing Fe/Al flocs that form under the influence of rising pH in the water column). That is, a minimum of approximately 5.7 t of Cu was moved from Whites (or strictly from above 32 m AHD in Whites) to the East Finniss River, while the total Cu transport estimate from the mine site, as measured at GS8150097, was 11.9 t. That is, Whites Open Cut was the source of approximately 48% of the total load in the 1992/93 wet season. Given the vertical turbulence during the period of inflow, this estimate must be seen as conservative. This figure is based on the nett difference in Cu inventories from the end of the dry season to the end of the wet season above 32 m AHD in Whites and does not account for any dynamic Cu flux established from below 32 m AHD to the East Finniss during flushing of the open cuts. The Cu flushed from Whites has a low residence time in the Intermediate as evidenced by the corresponding Cu inventories estimates for the Intermediate being substantially lower (eg. 0.376 t on 13/1/93, 0.727 t on 3/2/93 and 0.161 t on 1/4/93). The Cu isopleths for the Intermediate water body (Figure 5.5) indicate minor and transient increases in Cu concentration during the period of wet season through-flow.

In Whites, an estimated Cu inventory of 407 kg (above 32m AHD) on 1/4/93 increased to 1019 kg on 21/7/93 with a corresponding drop in surface water pH from 6.7 to 4.5. During this period there was no surface water inflow to the water body. The change in pH and Cu concentration represents a relatively rapid and serious degradation of water quality in the surface waters of Whites and is an outcome that is at odds with the original rehabilitation objective of sustaining good water quality in the surface waters of the open cuts throughout the dry season. In contrast, the water quality in the surface waters of the Intermediate water body was maintained at a level appropriate for recreational use.

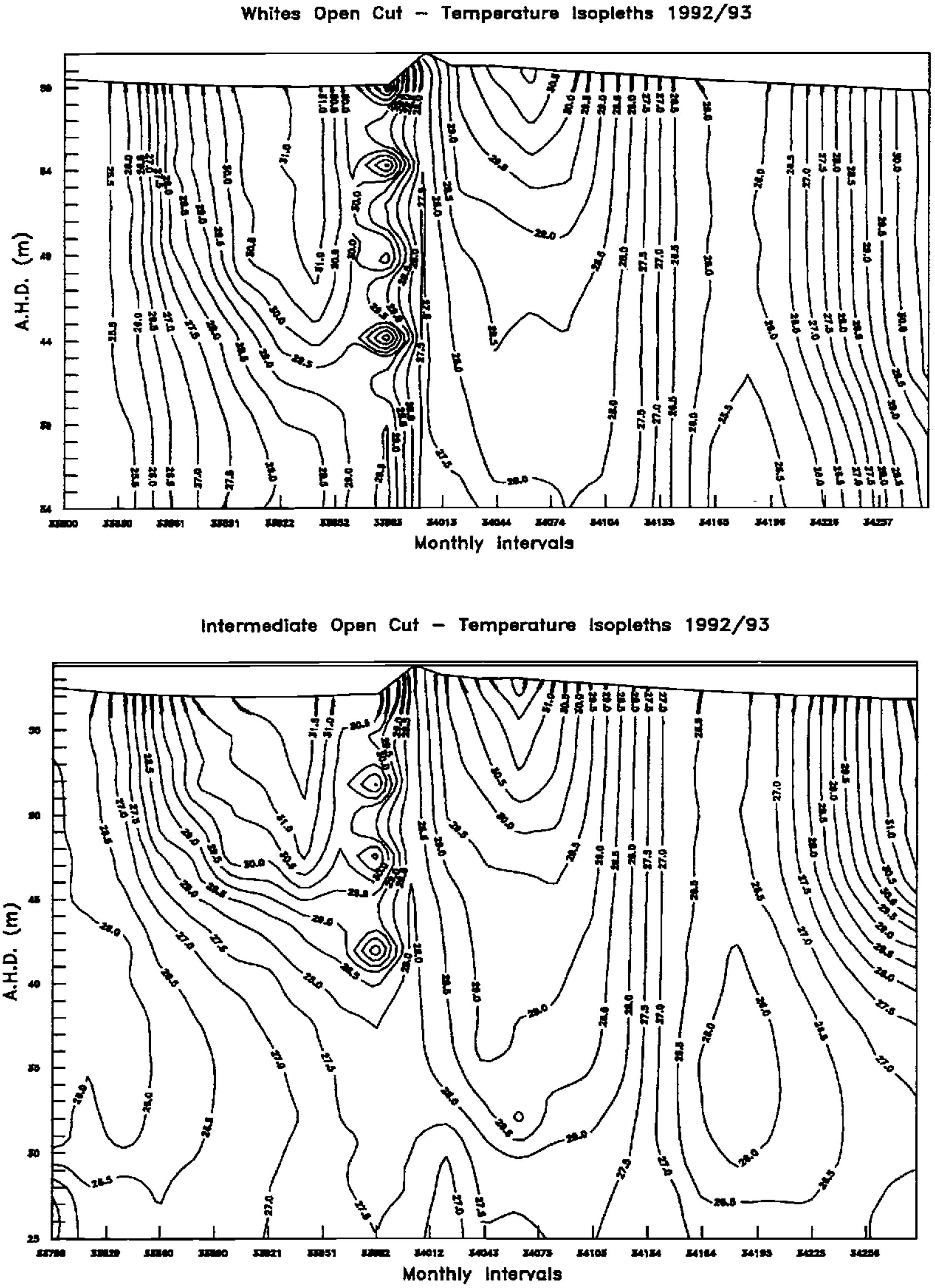
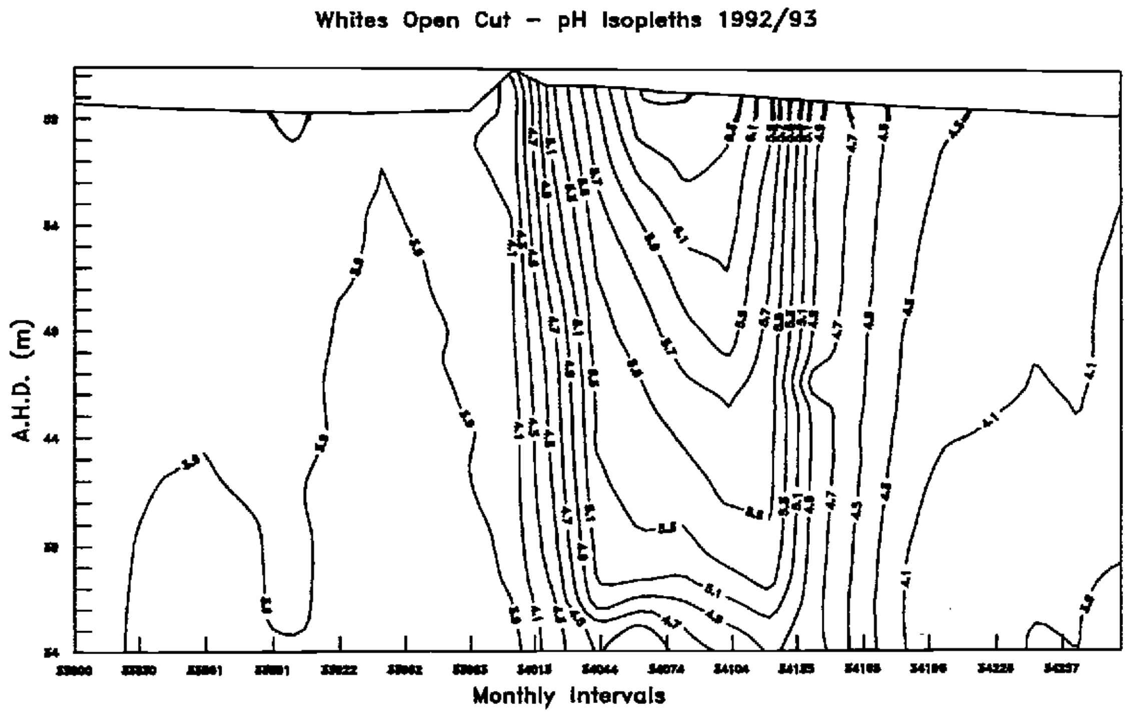


Figure 5.2 Temperature (°C) isopleths in Whites (to 34 m AHD) over wet season 1992/93 (note: monthly ticks at *Lotus 123* day intervals of 30.45).



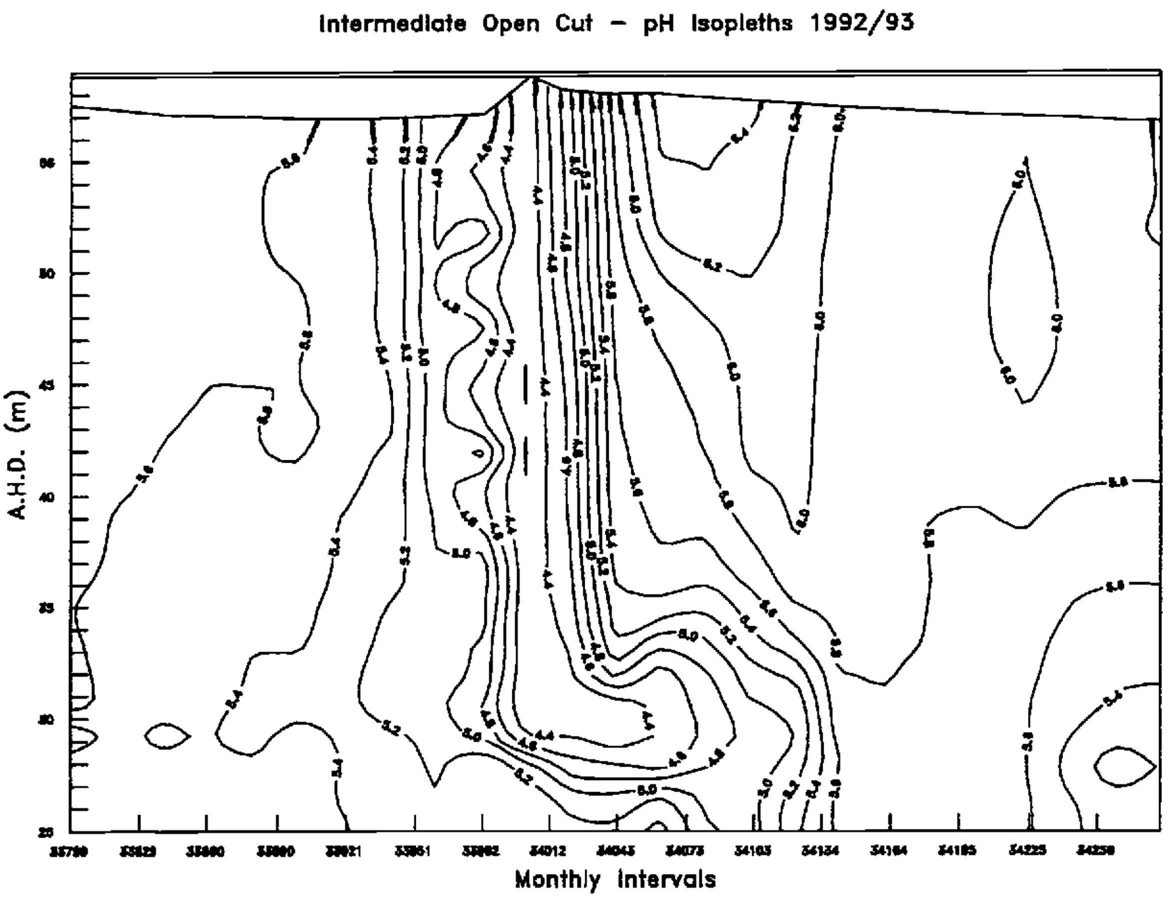
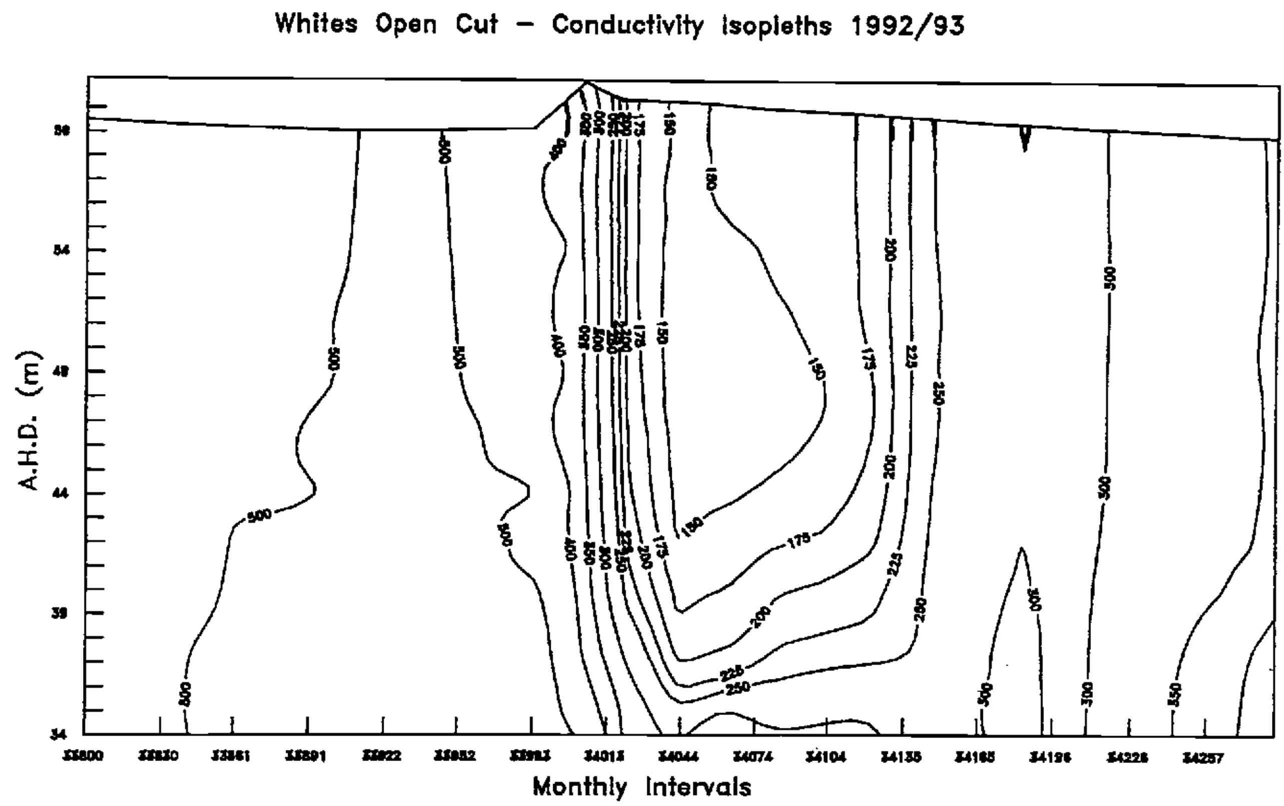


Figure 5.3 pH isopleths in Whites (to 34 m AHD) and Intermediate (to 25 m AHD) over wet season 1992/93 (note: monthly ticks at *Lotus 123* day intervals of 30.45).



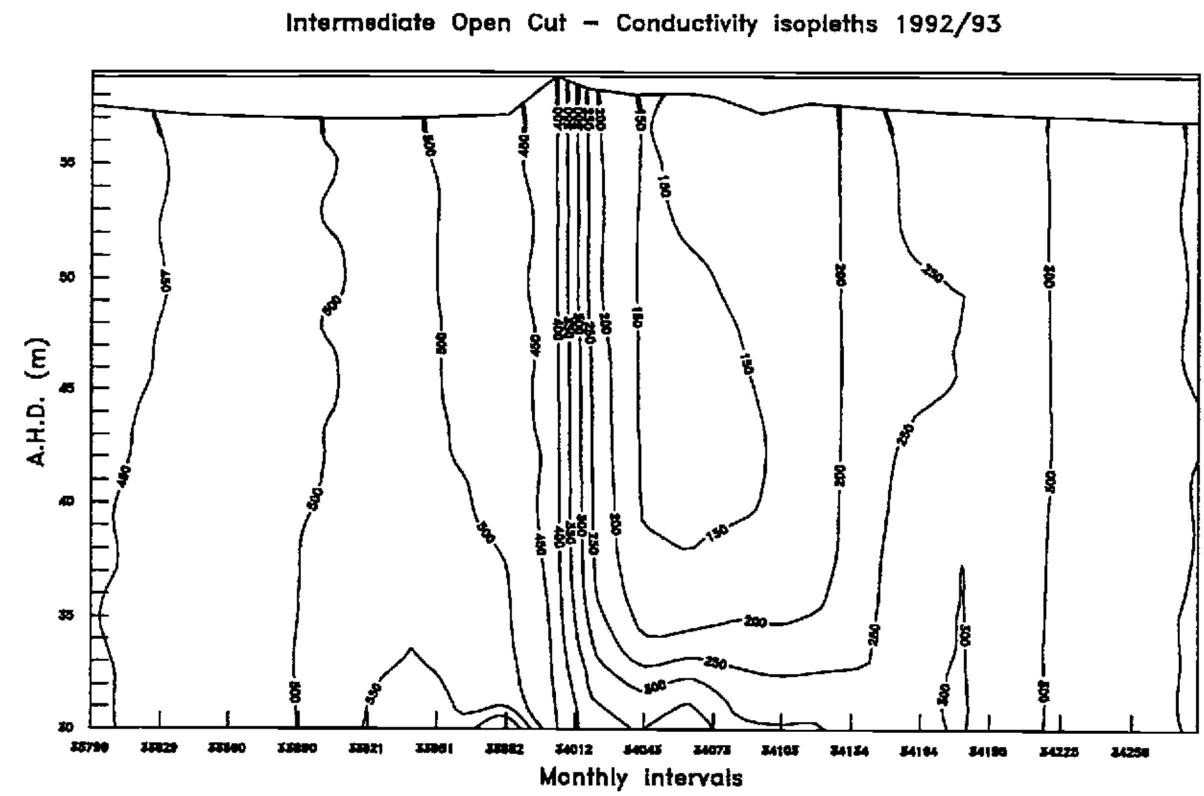
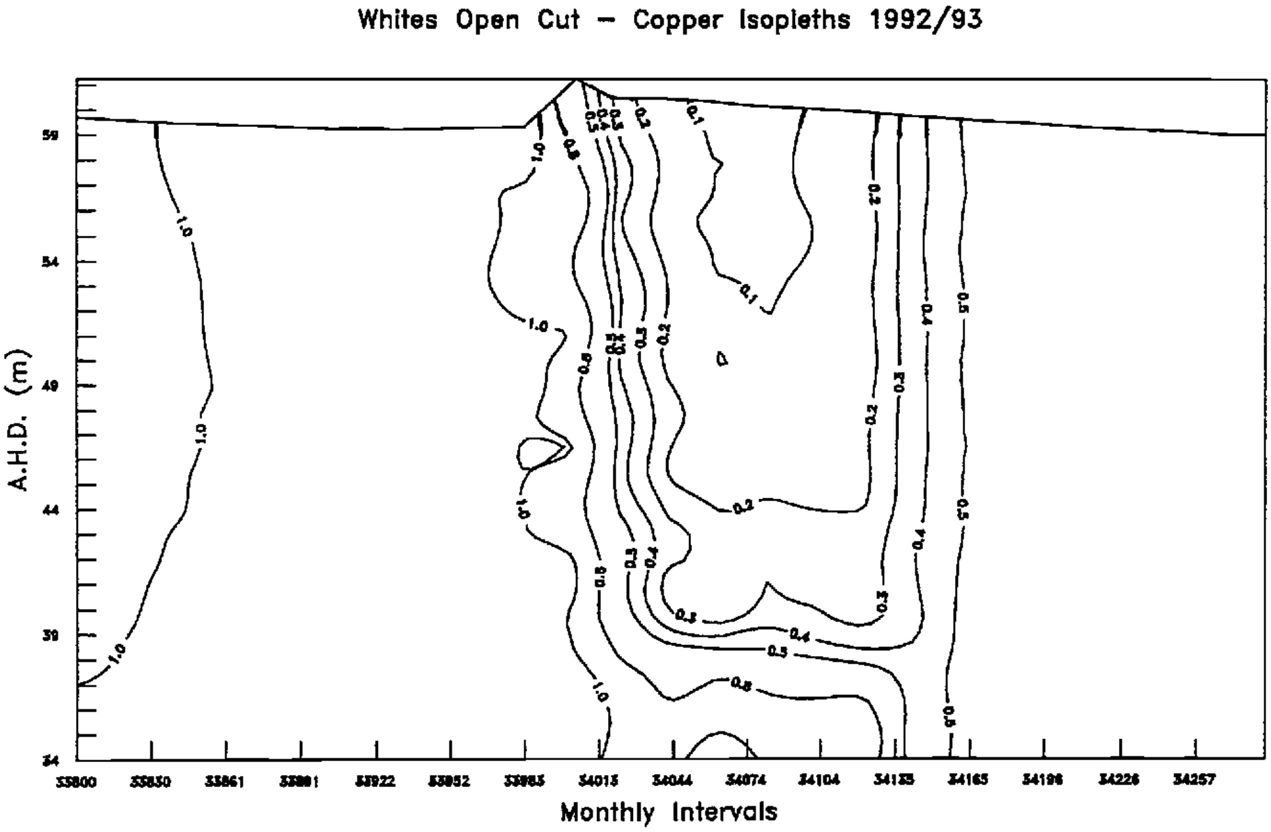


Figure 5.4 Conductivity (μS/cm) isopleths in Whites (to 34 m AHD) over wet season 1992/93 (note: monthly ticks at *Lotus 123* day intervals of 30.45).



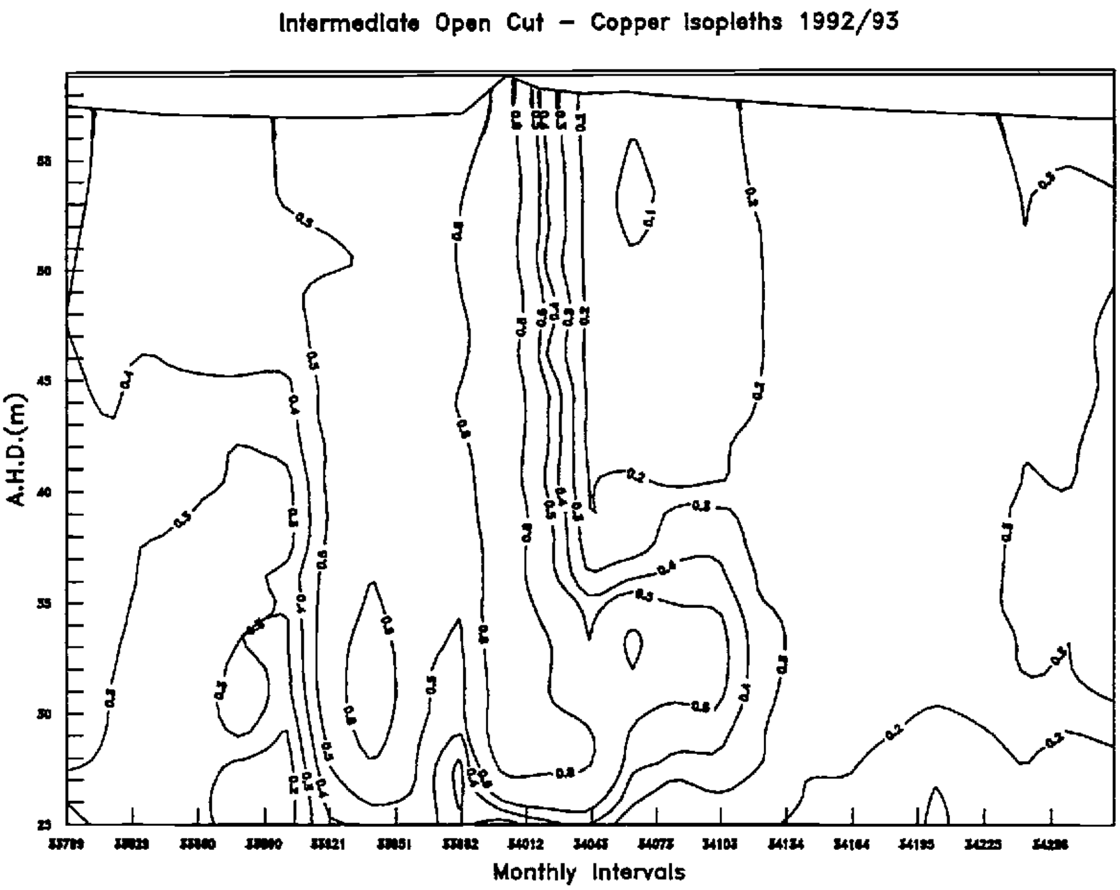


Figure 5.5 Copper (mg/L) isopleths in Whites (to 34 m AHD) and Intermediate (to 25 m AHD) over wet season 1992/93 (note: monthly ticks at *Lotus 123* day intervals of 30.45).

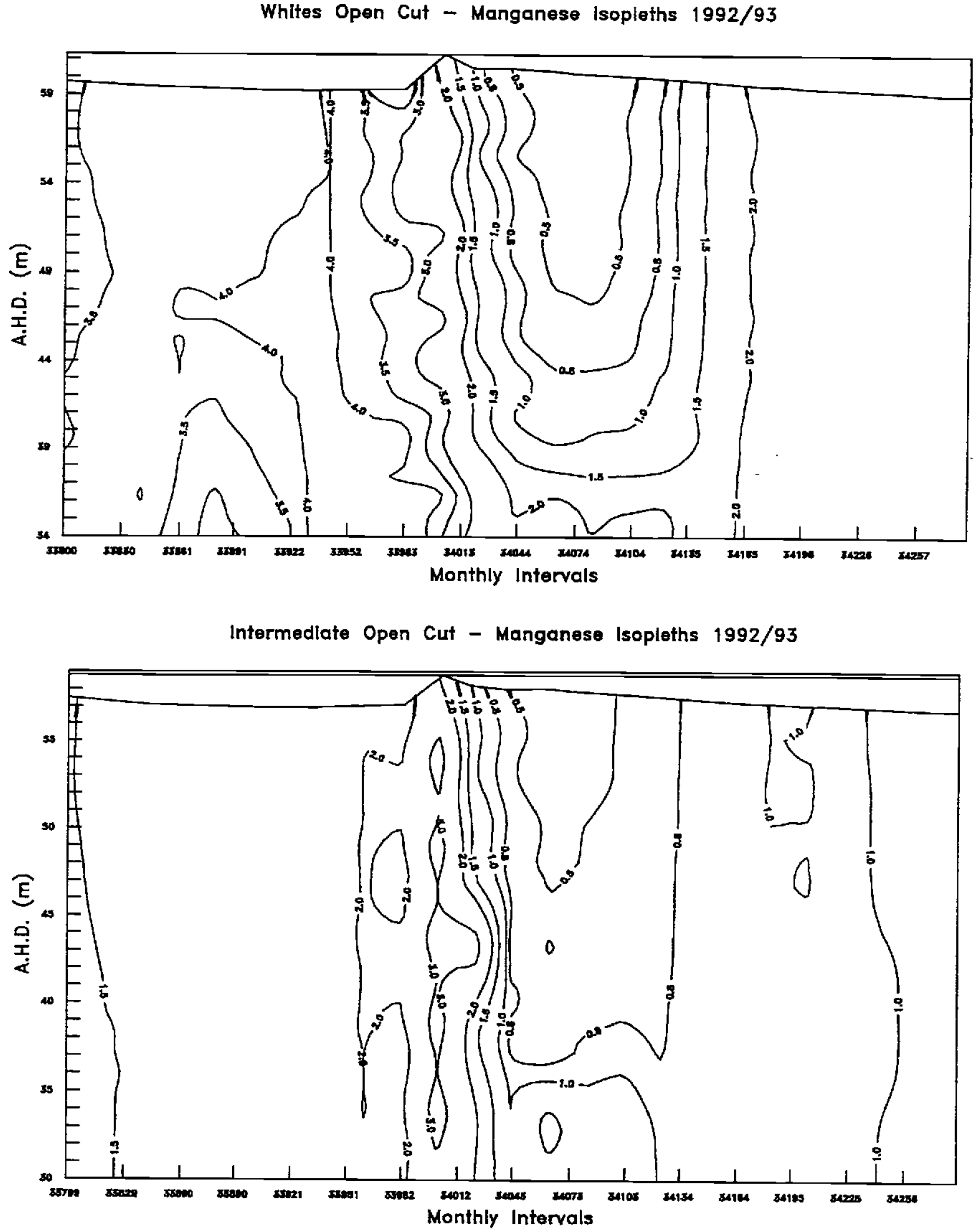


Figure 5.6 Manganese (mg/L) isopleths in Whites (to 34 m AHD) and Intermediate (to 25 m AHD) over wet season 1992/93 (note: monthly ticks at *Lotus 123* day intervals of 30.45).

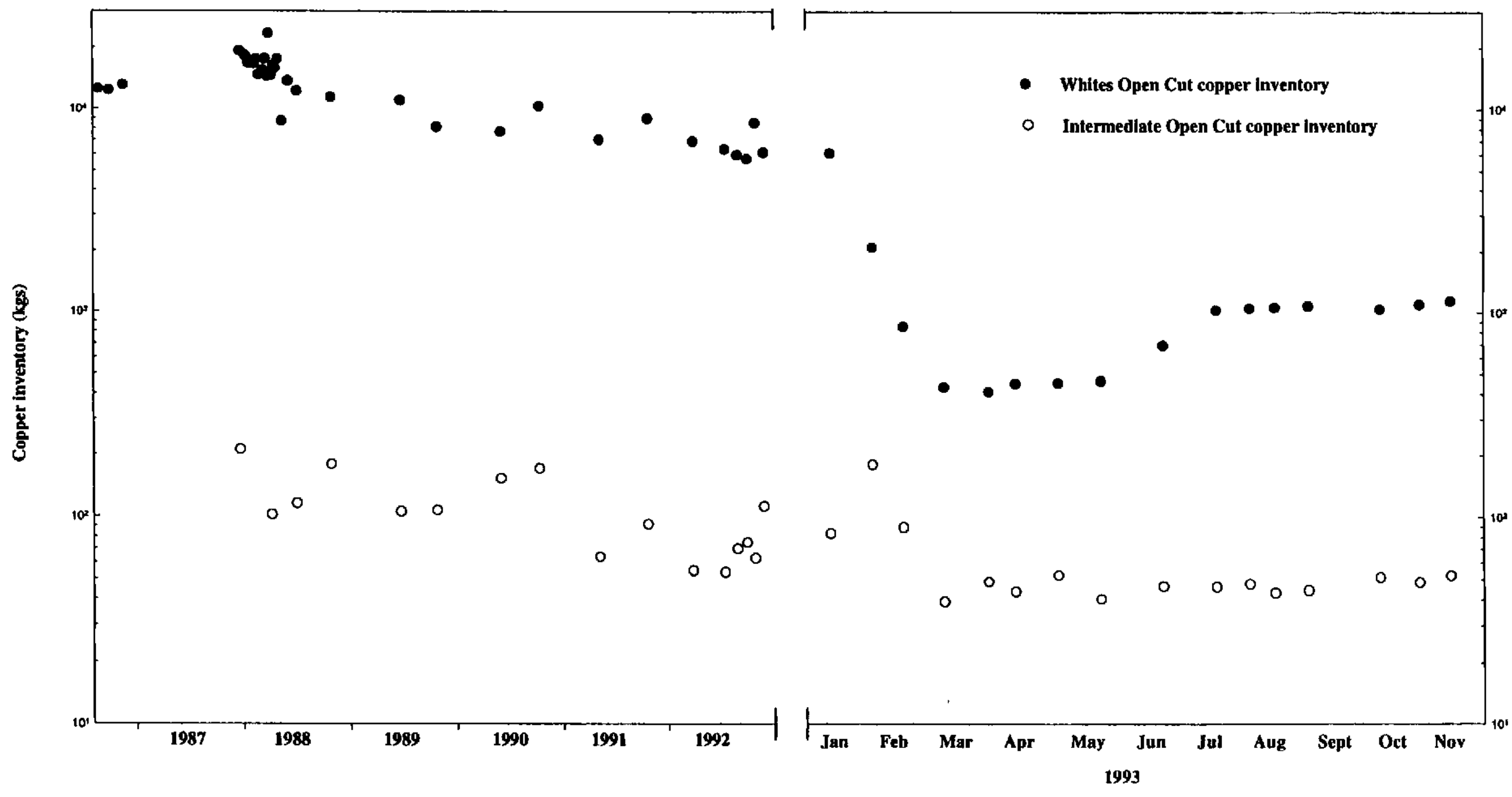


Figure 5.7 Copper inventory (kgs) in Whites Open Cut above 32m AHD from 27/8/86 to 11/11/93 and Intermediate Open Cut above 30m AHD from 9/11/87 to 11/11/93.

The cause of rapid degradation of water quality in Whites was the progressive cooling and breakdown in thermal stratification of the water body over the period from March through to July resulting in near isothermal (26^0C) conditions in July (Figure 5.2). The prevailing dry south-easterly air flow at this time of year coupled with the cooler temperatures, provide conditions conducive to mixing of the water body to a depth of at least 27 m, the depth of the pycnocline. Vertical mixing is the mechanism whereby pollutants from the dense heavily polluted waters are mobilised across the pycnocline to the upper surface mixed layer. Although near isothermal conditions (above the pycnocline) prevailed beyond July, the Cu inventory in the surface mixed layer stabilised at approximately 1100 kg. This stabilisation of pollutant levels after July is indicative of several features of the pollutant regime in Whites:

- that diffusion from the lower waters and/or pyritic oxidation by the oxygenated surface waters on the mineralised walls of the pit are relatively unimportant mechanisms for pollutant transport; and

- that the depth of vertical mixing gradually lessens (Figure 5.2), thus isolating the heavily contaminated waters from the mixing surface layer and preventing further degradation in surface water quality.

It should be noted that in each of the isopleth diagrams presented, a full depth profile is not included. The plots were generated using the software program Surfer (version 4.1.4, Golden Software Inc.). In order to produce realistic parameter contours at depths greater than 20 m, the data detailing the pycnocline and polluted lower waters in each water body were excluded.

Data was collected on a regular basis to a depth of 35 m in each water body. The pollution regime at depth over the five year period 1988/89 to 1992/93 was as follows:

- In Whites, the 'mixing zone' narrowed from six metres in late 1988 to less than two metres in June 1993 and the pycnocline was lowered from approximately 41 m AHD to approximately 32 m AHD. A typical lower profile taken on 25/6/93 when the surface level was at 59.5 m AHD is presented in Table 5.1.

- Over the same five year period the pycnocline in the Intermediate water body lowered from approximately 39 m AHD to approximately 28 m AHD. A lower profile taken in the Intermediate on the same day as above when the surface level was at 57.4 m AHD is presented in Table 5.2.

These profiles highlight some of the significant differences between the two water bodies. Whites is a reservoir of pollution from 32.5 m AHD to the bottom, with Cu concentrations of 60 mg/L in an acidic matrix. This represents approximately 33 t of Cu in solution. In Intermediate, however, there is minimal acidity throughout the profile and Cu concentrations actually decrease in the dense anoxic water below the pycnocline. Although the mixed upper layer in Intermediate has heavy metal contamination, this pollution is a function, in part at least, of the overflow water from Whites. This in turn, is dependent on the degree of flushing the water bodies receive from wet season through-flow from the upper East Finniss River.

Table 5.1 Depth profile in Whites Open Cut, 20 - 35 m (25/6/93).*

Depth (AHD)	Temp (^{0}C)	pH	D.O. (%sat)	Cond. (μS/cm)	Cu (mg/L)	Zn (mg/L)	Mn (mg/L)	Ni (mg/L)	Fe (mg/L)	SO_4 (mg/L)
39.5	26.34	4.73	89	252	0.37	0.07	1.51	0.12	0.12	106
34.5	26.34	4.72	89	252	0.38	0.07	1.53	0.12	0.13	106
33.5	26.35	4.67	88	258						
32.5	27.43	3.64	<1	7588						
31.5	27.70	3.61	<1	7998						
30.5	27.70	3.61	<1	8108						
29.5	27.64	3.62	<1	8128	60	7.45	213	14.8	253	7653
24.5	27.53	3.63	<1	8228	60	7.35	219	14.7	269	7743

**Note - physical data was collected every metre, while heavy metal and sulfate data were collected at five metre intervals only.*

Table 5.2 Depth profile in Intermediate Open Cut, 20 - 35 m (25/6/93).*

Depth (AHD)	Temp. (^{0}C)	pH	D.O. (%sat.)	Cond. (μS/cm)	Cu (mg/L)	Zn (mg/L)	Mn (mg/L)	Ni (mg/L)	Fe (mg/L)	SO_4 (mg/L)
37.4	26.76	5.89	89	244	0.28	0.10	0.89	0.12	<0.01	101
32.4	26.76	5.87	89	247	0.28	0.10	0.89	0.12	<0.01	104
31.4	26.75	5.88	89	249						
30.4	26.76	5.86	89	256						
29.4	26.76	5.84	89	259						
28.4	27.59	5.56	<1	3978						
27.4	27.56	5.63	<1	4098	0.20	0.24	4.84	0.80	9.19	3013
22.4	27.33	5.82	<1	4118	0.08	0.15	4.43	0.77	7.30	3124

**Note - physical data collected every metre, heavy metal and sulfate data collected at five metres intervals only.*

There is a minor concentration gradient below the pycnocline on each water body. For example, electrical conductivity ranges from 7588 μS/cm at 32.5 m to 8228 μS/cm at 24.5 m in Whites Open Cut (Table 5.1). This is in contrast to the major concentration change at the pycnocline where density differentials are in the order of 10 kg/m^3 over a one metre interval. Electrical conductivity varied from 258 μS/cm at 33.5 m to 7588 μS/cm at 32.5 m.

5.4 CONCLUSION

A more intensive examination of the dynamics of pollutant cycling in the open cut water bodies was implemented in 1992. The physico-chemical profiles confirm the pollution status of the two water bodies. Whites is acidic and Cu rich and Intermediate is relatively unpolluted, save for the contaminated overflow water from Whites during early wet season through-flow. The profile data collected thus far suggests that the bulk of heavy metal transported from the open cut precinct (and representing a significant proportion of the total mine site pollution load), has been sourced from the deep polluted waters of Whites. A thorough understanding of the dynamics of mixing in Whites should assist with estimates of future pollutant load transport (relative to inflow) and/or strategies for pollution transport mitigation to be formulated. To supplement this work, two additional gauging/sampling stations are to be operated from 1993/94. One will be located at the inflow to Whites and the other at the outflow of Intermediate to establish an accurate pollutant budget for this area of the mine site.

6. CHEMICAL ACTIVITY AND WATER BALANCE OF THE OVERBURDEN HEAPS

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6.1 INTRODUCTION

Following recommendations made by Bennett et al. (1989) in a report describing monitoring at Rum Jungle from 1986 to 1988, further monitoring was carried out over the five year period 1988-1993 to determine the effectiveness of the rehabilitation works on Whites and Intermediate Overburden Heaps in the longer term. The results of measurements of water balance, temperature profiles and pore gas oxygen concentration profiles in the heaps are described in this chapter. The particular aim of the water balance measurements was to monitor the continued compliance of the cover systems on the heaps with respect to the design specifications. Temperature profiles were measured to demonstrate the cooling of the heaps since rehabilitation and oxygen profiles were measured to monitor the integrity of the cover system in its capacity to reduce the ingress of oxygen.

The 1989 report outlined the rehabilitation works that had been carried out on Whites and Intermediate Heaps. It also described the operation of the lysimeters used to measure water infiltration through the covers, and how temperature profiles and pore gas oxygen concentration profiles were measured in the installed probe holes.

6.2 WATER BALANCE

The infiltration of water through the cover layers was monitored using lysimeters which had been installed in the reshaped Whites and Intermediate Heaps before emplacement of the clay layer, as described by Bennett et al. (1989). Ten lysimeters were installed in Whites Heap and eight in Intermediate, two at each of the locations shown in Figure 6.1.

The lysimeters collected water and were pumped at least once per year. The measured volumes, corrected for estimated losses due to wicking, were expressed as a percentage of incident rainfall over the period. The data for each of the heaps was averaged to provide a value for the water infiltration through the two covers. The annual results since rehabilitation are displayed in Table 6.1.

It can be clearly seen that infiltration through the cover on Whites Heap remained fairly steady since rehabilitation in 1984, the average water infiltration over the period 1988-1993 having been 2.2% of incident rainfall, compared with 2.1% from 1984 to 1988. These figures indicate that the cover is operating well within the design specification that infiltration be limited to less than

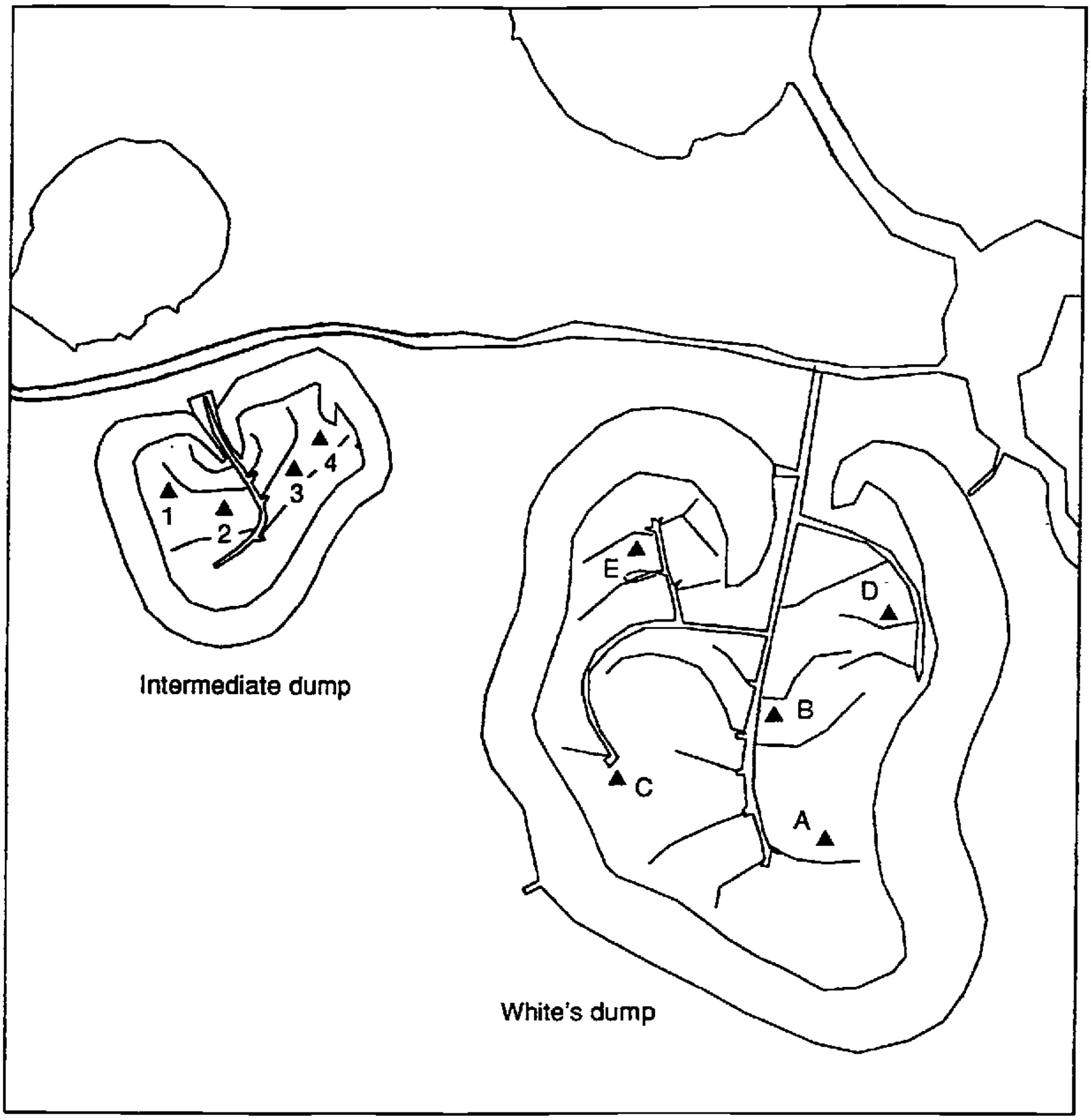

Figure 6.1 Lysimeter positions on Whites and Intermediate Overburden Heaps. Two lysimeters are located at each position marked by a triangle.

5% of incident rainfall.

The number of individual lysimeters contributing to each average value in the current five year monitoring period are also shown in Table 6.1. The lysimeters on Whites Heap have continued to operate well, with only one becoming unusable due to blockages in the pumping pipes. The physical condition of the lysimeters installed in Intermediate, however, deteriorated over the years, with pipes becoming blocked, severely restricted or developing leaks. By the end of 1989 the number of individual lysimeters which produced reliable data had fallen from eight to four, being pairs at only two locations on the heap. In the second half of 1991 this number fell to just two, at one location, at which time it was judged that there was an insufficient spread of data over the surface of the heap to be able to comment meaningfully on infiltration through the cover.

Table 6.1 Annual rainfall infiltration percentages through Whites and Intermediate Overburden Heaps.

Heap	Period	Rainfall (mm)	Number of Lysimeters	Infiltration (% of Rainfall)
Whites	Nov 84 - May 85	1 072	10	2.5
	May 85 - May 86	1 087	10	2.0
	May 86 - Jun 87	1 289	10	2.3
	Jun 87 - Jun 88	1 057	10	1.4
	Jun 88 - Aug 89	1 625	10	2.8
	Aug 89 - Oct 90	1 008	10	1.4
	Oct 90 - May 91	1 587	10	3.5
	May 91 - May 92	1 008	9	1.9
	May 92 - Jun 93	1 421	9	2.0
Intermediate	Dec 85 - May 86	935	8	3.5
	May 86 - Jun 87	1 399	8	4.8
	Jun 87 - Jun 88	1 057	8	3.6
	Jun 88 - Aug 89	1 625	8	5.9
	Aug 89 - Oct 90	1 008	4	8.0
	Oct 90 - May 91	1 587	4	10.1

The data in the table could be interpreted to indicate that water infiltration through the cover on Intermediate was significantly above the design figure of 5% in the rainfall year 1989/90 and that the trend was towards increasing infiltration with time. A more reasonable explanation is that the data is skewed due to the loss of particular lysimeters, leaving only those in locations which routinely collected above-average volumes of water. Given that the cover design was the same as that used on Whites, it is most likely that the cover on Intermediate continued to perform to specification but there is insufficient lysimeter data to demonstrate it.

It is recommended that the lysimeters on Whites Heap continue to be used to quantify water infiltration through the cover. Water infiltration data are needed to relate pollution generation rates to pollution loads leaving the base of a heap, and play an important role in describing the timescales involved in pollutant transport in the system. However, due to the cost of repair works and the possible disruption of the integrity of the cover, it is recommended that the lysimeters on Intermediate be abandoned.

In discussing the performance of the covers in terms of water balance, it is important to recognise that in waste rock heaps such as the ones at Rum Jungle, it is the oxygen supply rate to the reacting material which controls the pyritic oxidation rate and hence the pollution generation rate. The effectiveness of a cover in controlling acid mine drainage therefore is governed by its ability to limit the oxygen flux into the heap. The characteristic of the cover material which determines this is the oxygen diffusion coefficient, which in turn is strongly dependent on the moisture content. An ideal cover is one which maintains a water-saturated layer throughout the year. It is recommended that measurements be made which allow the gas-transport properties of the covers to be quantified.

6.3 TEMPERATURE PROFILES

The oxidation of pyrite is exothermic, producing 1440 kJ/mol of pyrite consumed, and so analysis of measured temperature profiles can provide information about the location and magnitude of oxidation in pyritic waste rock heaps.

Temperature profiles have continued to be measured at the locations indicated in Figure 6.2 at regular intervals over the five year period 1988-93 in both Intermediate and Whites Heaps. The series of contour diagrams shown in Figure 6.3 was produced using data from probe holes in a line on Intermediate from hole 2 to 19. A similar series, shown in Figure 6.4, was produced using the data from holes 15 to 10 in Whites Heap.

The figures show that both heaps have continued to cool with time. This is seen most clearly by the change in the contours in the lower half of each heap, away from the surface region which is most affected by insolation. In the warmer months (shown in the three contour diagrams to the left of both figures) the 30°C contour is closer to the surface. In the cooler months (to the right) the same contour is deeper, indicating a cooler surface. In the five years to 1993 the maximum temperature at the base of each heap had fallen by about 4°C, the fastest decrease being early in the period.

Temperature data from depth intervals of two metres in probe hole A in Whites Heap is presented in Figure 6.5. Before rehabilitation, temperatures in a section of hole A exceeded 50°C but were decreasing. After rehabilitation and the emplacement of the cover in late 1983, there was a more rapid decrease in temperatures at all depths. Recently, the rate of decrease has slowed as the temperatures approach lower values. It is recommended that temperature profiles continue to be measured in both dumps until a state of equilibrium is reached.

An analysis of Whites temperature data by Harries and Ritchie (1987) indicated that oxidation had been greatly reduced by the rehabilitation works. The decrease in temperatures which have been observed should therefore be due largely to natural cooling. It is recommended that the temperature data collected since rehabilitation should be analysed quantitatively on this premise to extract information about the thermal properties of the heap, (thermal conductivity for instance), which can then be compared with measurements which have been made using other techniques. It is further recommended that the temperature data be used to estimate pre-rehabilitation oxidation rates.

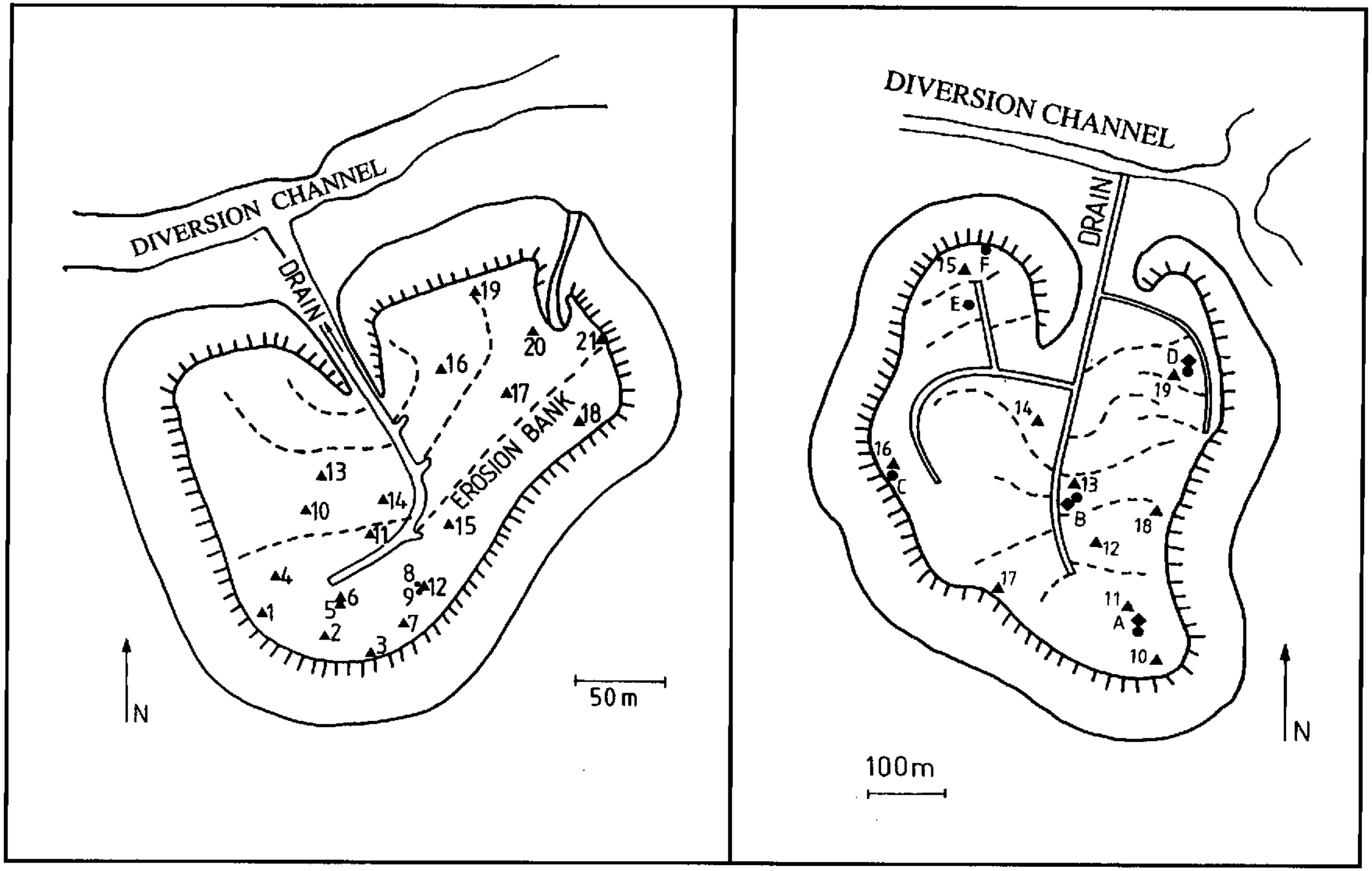

Figure 6.2 **Location of probe holes used to monitor temperature and pore gas oxygen concentration profiles in Intermediate (left) and Whites (right) Overburden Heaps. Note the difference in scale.**

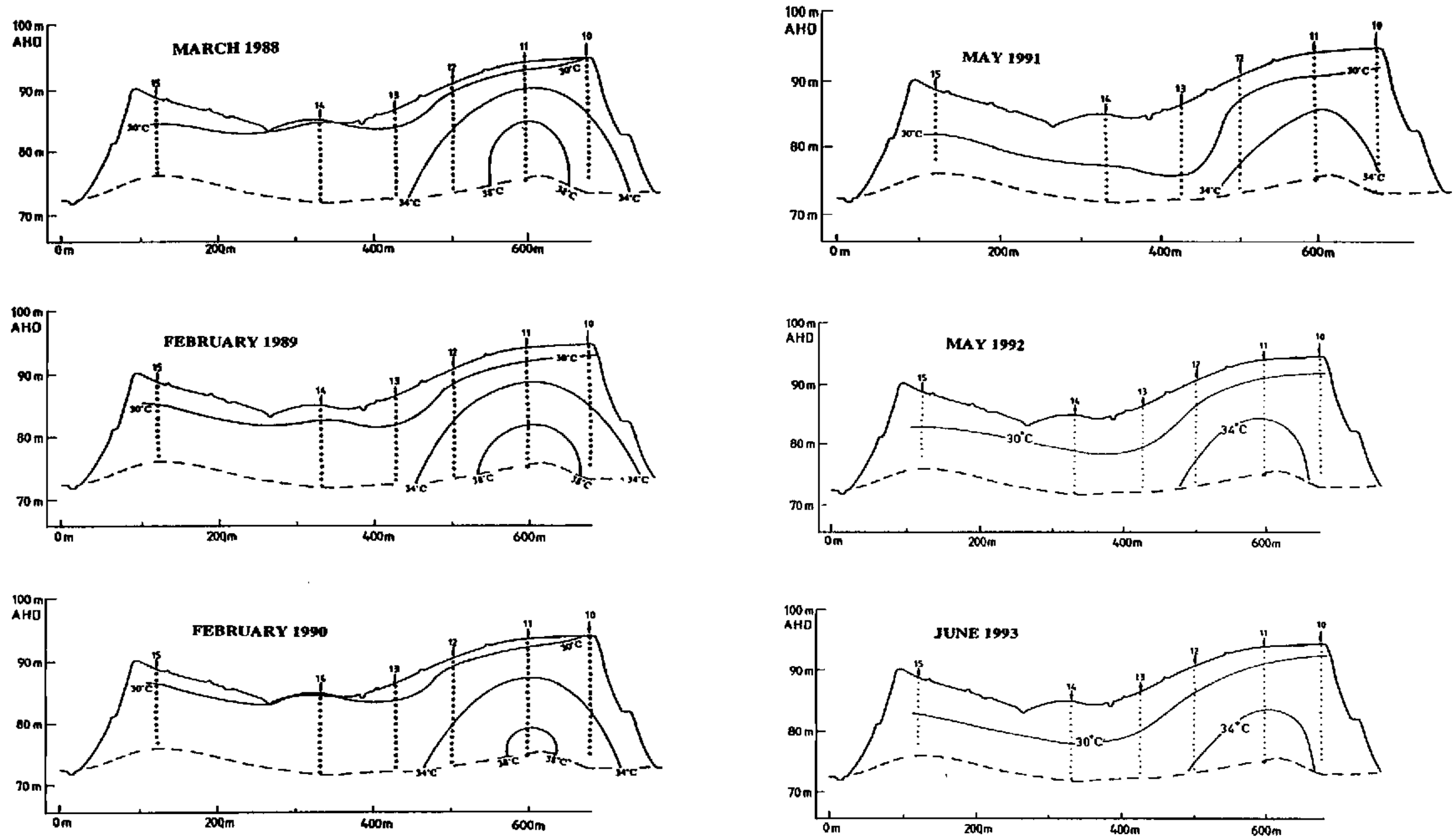

Figure 6.3 Temperature profiles measured in Whites Heap, showing cooling.

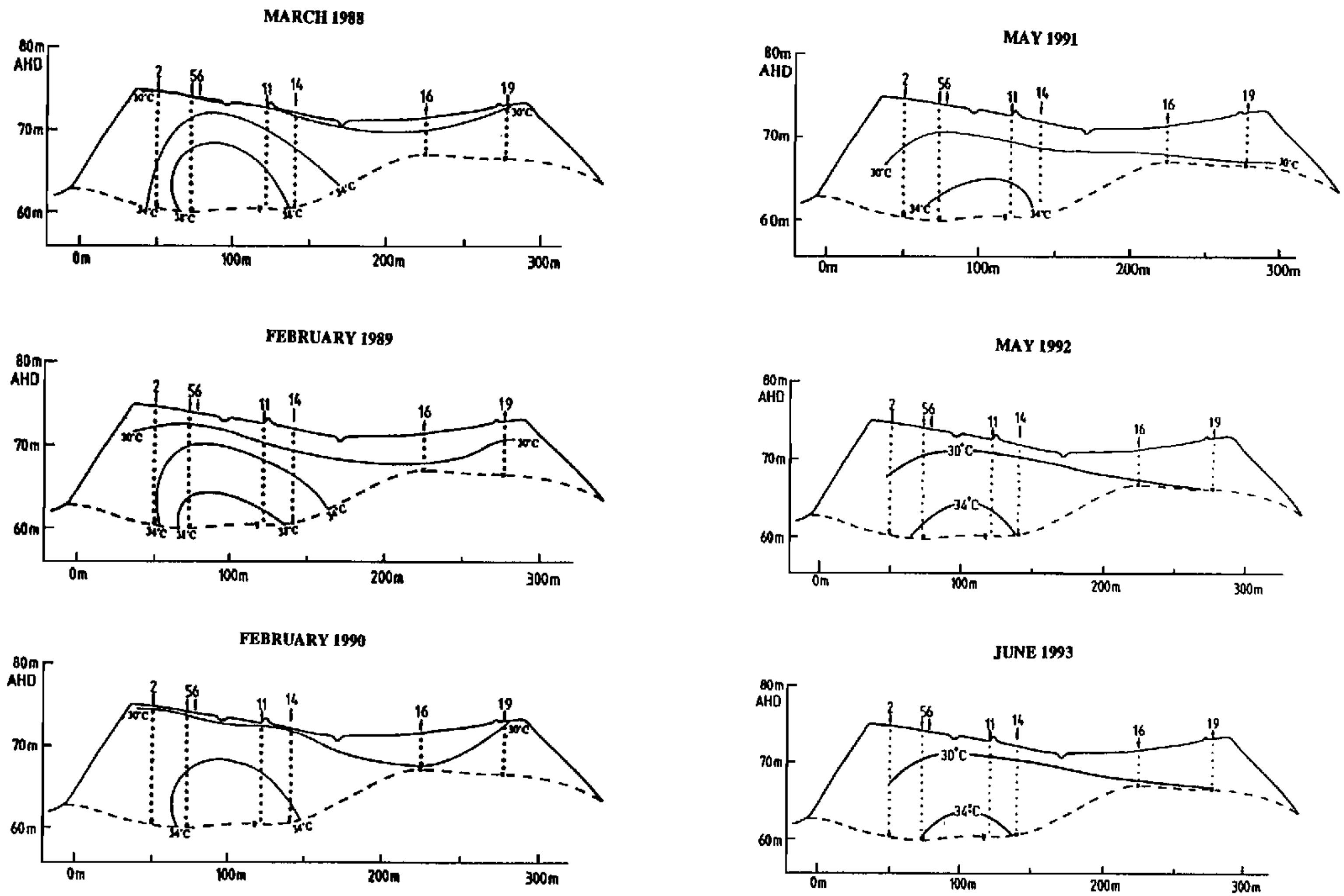

Figure 6.4 Temperature profiles measured in Intermediate Heap, showing cooling.

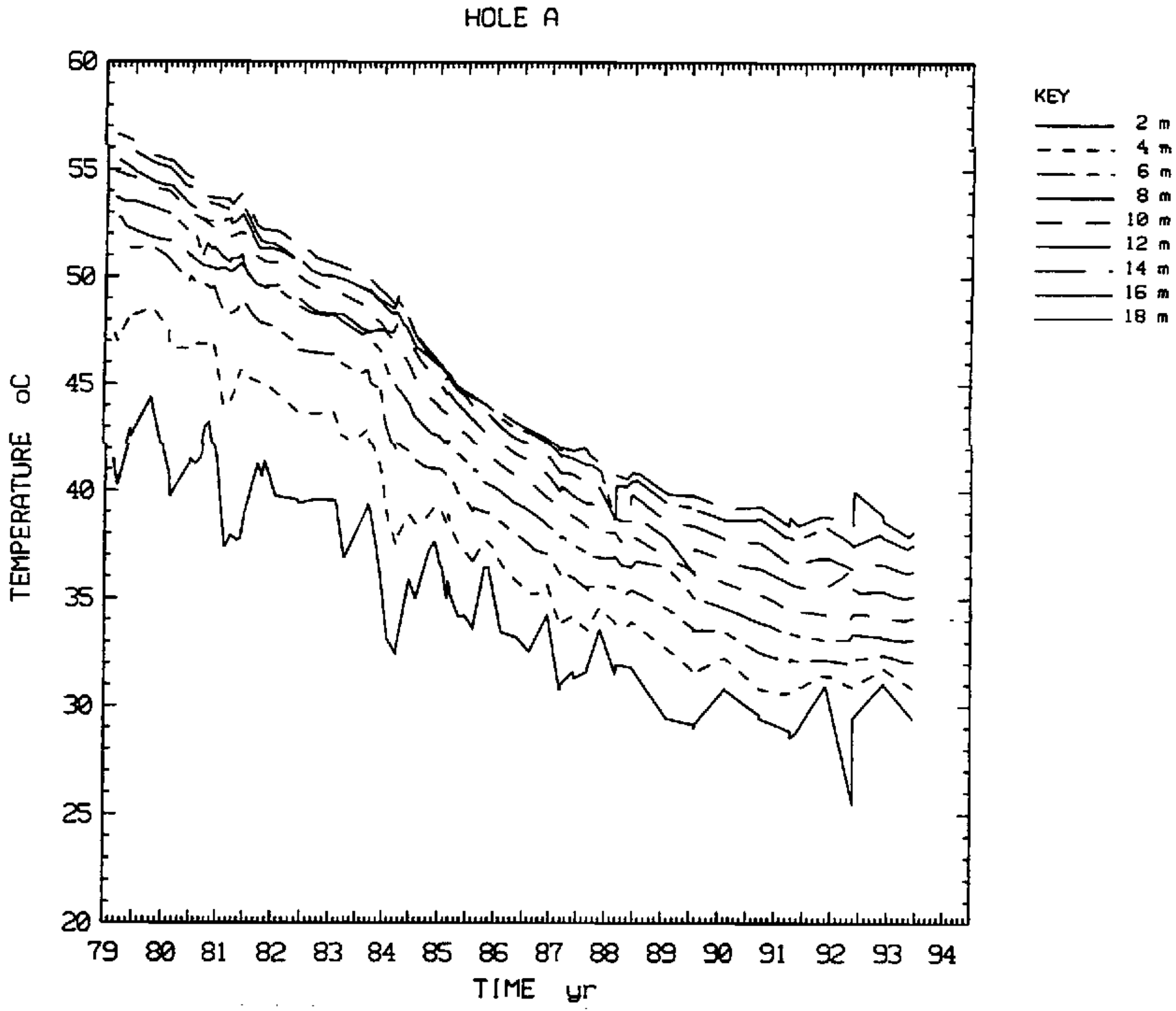

Figure 6.5 Temperatures at different depths in hole A in Whites Heap, indicating rate of cooling.

6.4 PORE GAS OXYGEN CONCENTRATION PROFILES

Pore gas oxygen concentrations continued to be measured at the locations indicated in Figure 6.2 at regular intervals in both Intermediate and Whites Heaps.

Seasonal variations

Figures 6.6 and 6.7 display pore gas oxygen concentration contours along a transect in Intermediate Heap during the five year period and Figures 6.8 and 6.9 show them for Whites.

The oxygen concentration contours in Intermediate do not show much variation with time of day or season. Over most of the dump the 0.2% contour occurs within three metres of the surface, except near the ends where it dips another metre or so, presumably due to edge effects. This indicates that diffusion through the cover is the sole oxygen supply mechanism in this heap.

In Whites Heap, however, the oxygen contours are more dynamic. Data collected from 1988 to 1990 (Figure 6.8) suggested that there was greater penetration of oxygen through the cover into the heap in the dry season months (June to November) compared with the wet season (December to May). It seems likely that the effect is related to moisture content changes in the compacted clay layer, such that as the clay dries after the end of the wet season the gas-filled porosity increases, leading to higher gas diffusion coefficients and a consequent increase in oxygen flux through the cover. This would explain the apparent increase in oxygen penetration with time from the beginning of the dry season seen in Figure 6.8, (being greater in September than in June), and the return to the wet season profiles of February and March when the clay absorbed moisture from the rain.

To gain further evidence, oxygen profiles were measured in Whites Heap in April, May and June of consecutive years 1991 to 1993, with intervening measurements being made in December. The results presented in Figure 6.9 broadly fit the picture described above, with oxygen penetration generally increasing into the dry season. The greatest penetration can be seen in the two December contour diagrams, indicating that there had been insufficient rainfall by that time to increase the moisture content of the clay cover.

Because the contour diagrams presented in Figures 6.8 and 6.9 were measured in years having differing rainfall patterns, it is not possible to draw conclusions about the detailed mechanism producing the observed changes in oxygen penetration. To provide better data, is recommended that pore gas oxygen concentration measurements be made at monthly intervals in Whites Heap over at least one year.

The oxygen profiles in Intermediate (Figures 6.6 and 6.7) do not vary much between measurements and seem to be independent of the time of year. This is different from Whites and could indicate that the cover on Intermediate is a more effective barrier to the transport of oxygen, due possibly to the maintenance of higher moisture content throughout the year. An alternative explanation is that the oxidation rate of the waste rock is high enough that oxygen is consumed near the surface of the heap, irrespective of the supply rate. As a first step in understanding the oxygen transport properties of the cover on Intermediate, it is recommended that monthly measurements be made of pore gas oxygen concentrations over the course of at least a year to detect any small seasonal variations.

It is important to recognise that the oxygen data which have been presented indicate that oxygen penetrates the covers on both Intermediate and Whites Heaps, meaning that oxidation and hence pollution generation is occurring in both. This was to be expected, given that the aim of any remediation technique dealing with the production of acid rock drainage is to reduce oxidation rates and pollution loads to environmentally acceptable levels. Stopping oxidation entirely is neither technically feasible nor desirable. It is recommended that a program be undertaken to quantify current oxidation rates in the waste rock heaps. This can be achieved by either making direct measurements of oxygen fluxes through the covers or by inferring the rates from measured oxygen profiles. If the latter option is taken then it will be necessary to know oxygen diffusion coefficients of the covers as a function of time.

It is further recommended that the effectiveness of the rehabilitation works on the heaps be quantified in terms of oxidation rates before and after emplacement of the covers. A large data base of oxygen profiles over a sufficient time-span already exists. It is therefore recommended that oxygen diffusion coefficients be measured in the bulk material of Whites and Intermediate Heaps so that the profiles can be analysed to provide the required oxidation rates.

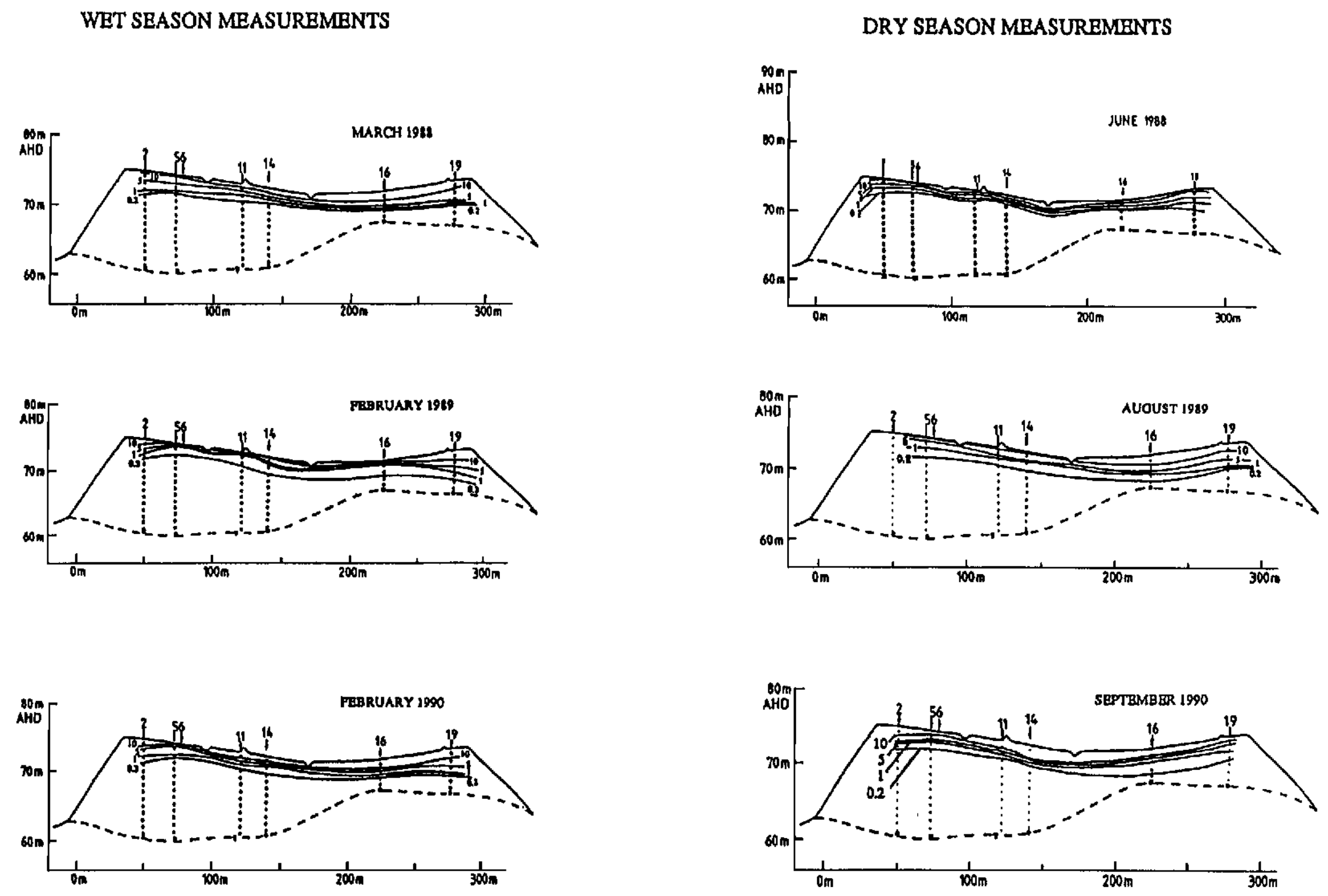

Figure 6.6 Oxygen profiles in Intermediate Heap, 1988 to 1990. The contours indicate pore gas oxygen concentration (vol. %).

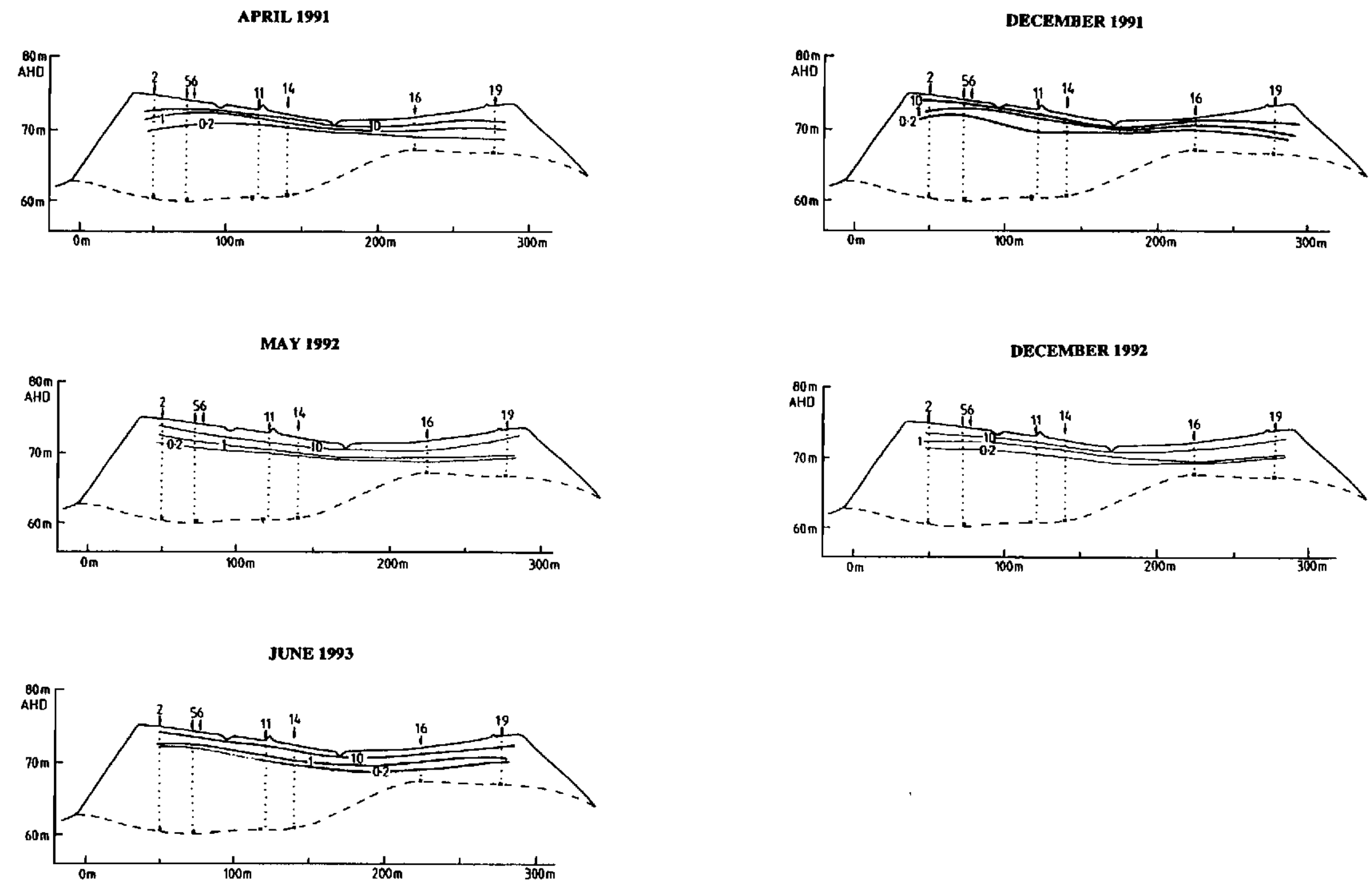

Figure 6.7 Oxygen profiles in Intermediate Heap, 1991 to 1993.

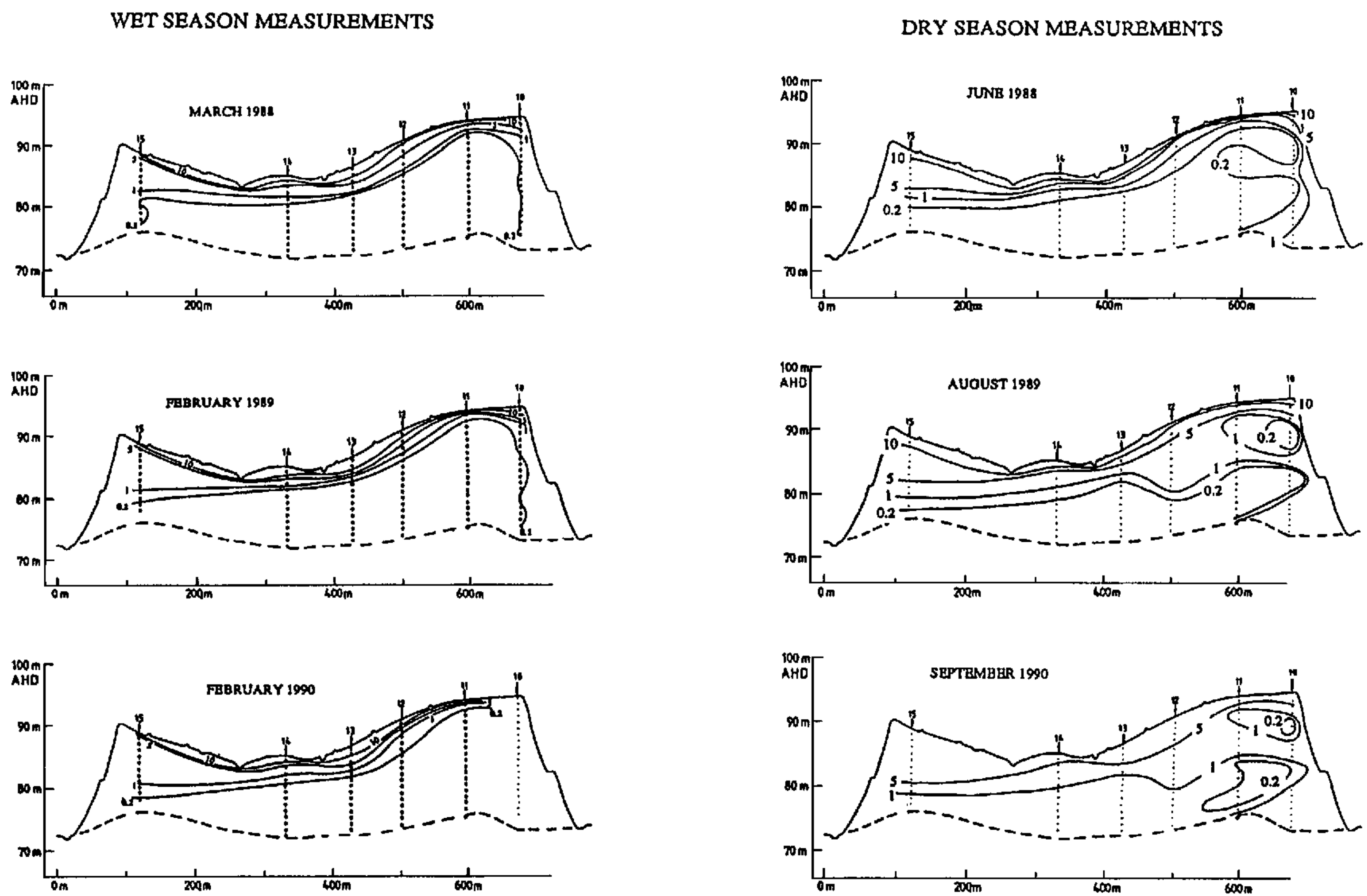

Figure 6.8 **Oxygen profiles in Whites Heap, 1988 to 1990, showing differences between measurements made in the wet season (left) and the dry season (right).**

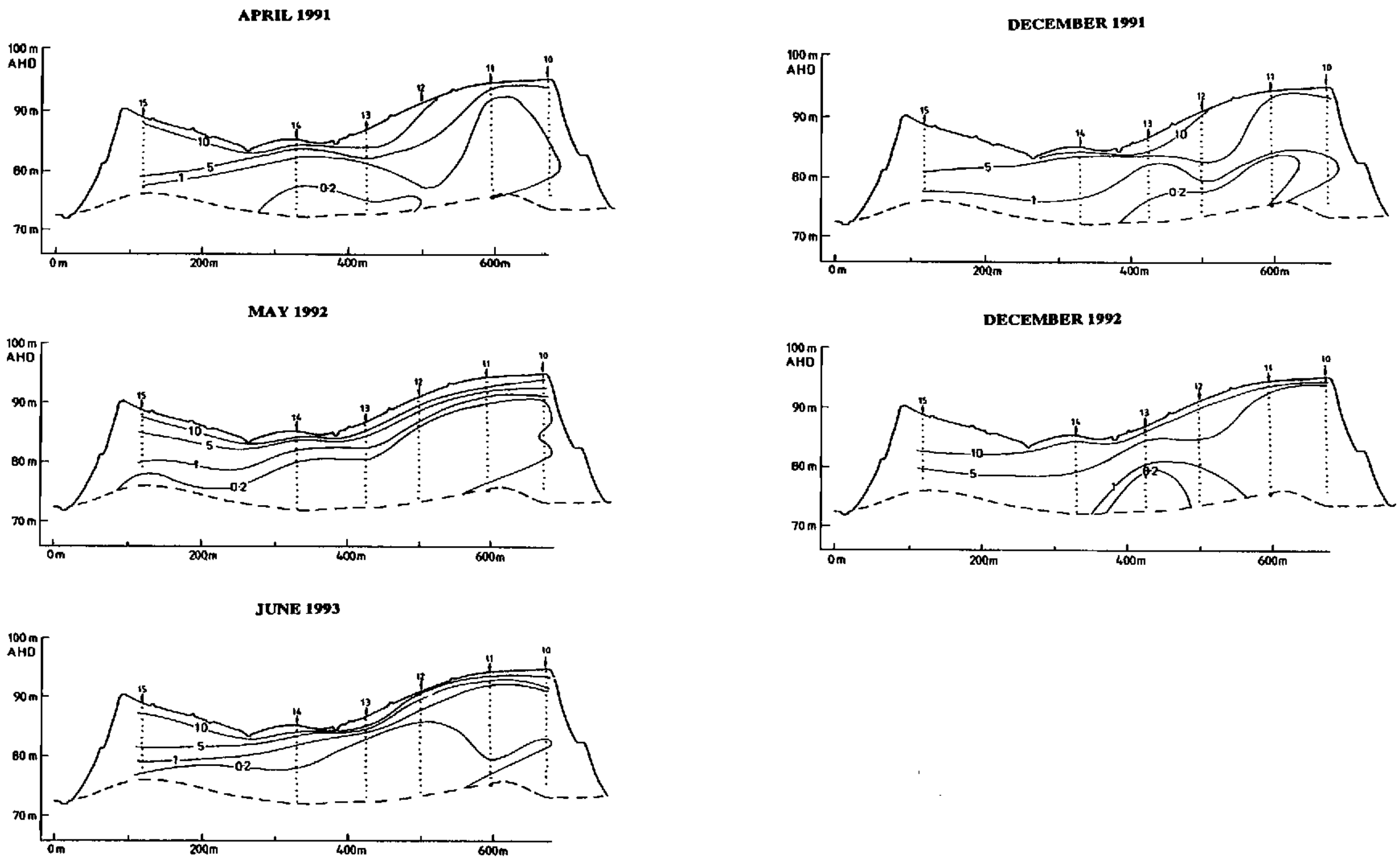

Figure 6.9 Oxygen profiles in Whites Heap, 1991 to 1993.

Diurnal variations

Most pore gas oxygen concentration profiles referred to in the preceding section were measured twice on the one day, in the morning to correspond with the diurnal air pressure peak, and in the afternoon during the pressure trough. At Rum Jungle this diurnal 'tide' typically produces a change of 4 mb (or 0.5%) between morning and afternoon air pressures. (There is a corresponding peak and trough during the night.) At some locations and at some times of year, temporal variations in oxygen concentration profiles were found to be directly correlated with changes in air pressure.

Figure 6.10 shows oxygen concentration contours produced from data measured in Whites Heap in the morning and afternoon of the same day in April 1991. There is clearly a large difference in the contours in the heap around probe holes 12 and 13. At hole number 13, the 5% oxygen contour passed 12 m below the surface in the morning, but in the afternoon only reached about four metres down. Measurements made in Whites dump in September 1990 and May 1991 did not show such large diurnal variations.

A number of possible mechanisms have been suggested to explain the phenomenon, involving preferential flow of air into the heap along the probe holes, driven by air pressure changes. It is recommended that an experimental program be undertaken at the site to provide data to allow the various hypotheses to be tested. This is likely to include measurement of oxygen profiles at frequent intervals over at least a 24 hour period, in conjunction with simultaneous air pressure measurements.

Once the mechanisms of both the seasonal and diurnal variations in oxygen ingress through the cover have been established, it is further recommended that their effect on oxidation rates and hence pollution generation rates be quantified.

6.5 CONCLUSION

Lysimeter measurements have demonstrated that the cover system on Whites Overburden Heap continues to meet the design specification that water infiltration be less than 5% of incident rainfall. Data showed that the cover on Intermediate Heap met the specification until 1988. After that time the number of operational lysimeters fell and the data became skewed, apparently indicating a rising trend in infiltration. It is likely however that the cover, having been made to the same design as the one on Whites, actually continued to meet the specification throughout the period.

Temperatures in both Whites and Intermediate Heaps have continued to decrease in the long term, at a rate which seems to be consistent with there having been a large reduction in heat generation (and therefore pollution generation) within the heaps.

Pore gas oxygen concentration measurements in Whites Heap have indicated a number of time-dependent features which suggest that the cover system may not be as effective in limiting the ingress of oxygen as it could have been. This warrants further investigation to assess the impact on oxidation rates.

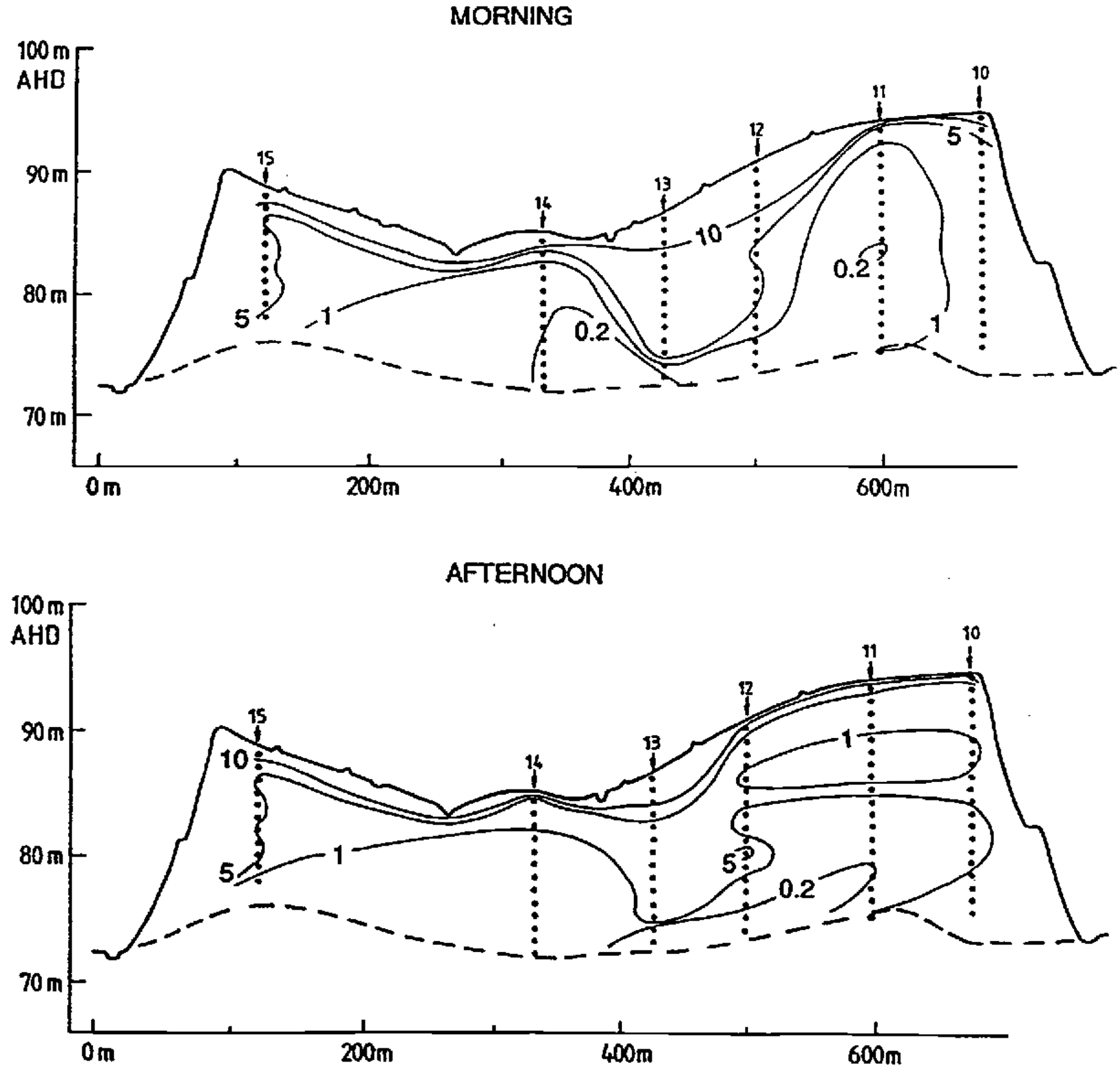

Figure 6.10 Oxygen profiles in Whites Heap showing the differences between measurements made in the morning (high air pressure) and the afternoon (low air pressure).

The oxygen concentration profiles in Intermediate Heap remain relatively constant and may be due to a somewhat better cover performance than the one on Whites, or may be due to different oxidation properties of the underlying waste rock.

6.6 RECOMMENDATIONS

The three overburden heaps on the Rum Jungle site, Whites, Intermediate and Dysons were identified in an environmental survey carried out in 1973/74 (Davy 1975) as being major sources of pollution at that time. The decision was made in the 1970's to monitor Whites and Intermediate, and this monitoring was continued after rehabilitation. The rehabilitation of Dysons was different from the other two heaps. The slope angle of the batters was not altered and the cover was only placed on the top surface, not on the batters. The effectiveness of this cheaper scheme may be of potential interest to the mining industry. It is recommended, therefore, that an estimate be made of the current pollution load coming from Dysons Overburden Heap. If it is found to be a significant pollution source, it is further recommended that measurements be made to quantify oxidation rates and pollution generation rates in Dysons and relate these to measurements of groundwater pollution loads from that heap.

The following list is a summary of recommendations. The principal aim of the suggested work is to quantify pyritic oxidation rates in the overburden heaps, to enable the effectiveness of rehabilitation to be quantified and to enable pollution generation rates to be related to measured pollution loads in groundwater.

- Lysimeters on Whites Heap should continue to be used to quantify water infiltration through the cover system.
- Lysimeters on Intermediate Heap should be abandoned.
- Temperature profiles should continue to be measured in Whites and Intermediate Heaps.
- Temperature data should be analysed to provide values for the thermal conductivity of the heaps and to quantify oxidation rates.
- Pore gas oxygen concentration profiles should be measured at monthly intervals in Whites and Intermediate Heaps over a period of at least one year.
- A program of work to understand the physical mechanisms of oxygen transport in the heaps and their affect on oxidation rates should be undertaken.
- A program to quantify oxidation rates in the overburden heaps should be undertaken.
- A quantitative assessment of the effectiveness of the rehabilitation works should be made.
- An estimate should be made of the current pollution load coming from Dysons Overburden Heap. If it is found to be a significant pollution source, measurements should be made to quantify oxidation rates and pollution generation rates in Dysons and relate these to groundwater pollution loads.

7. OBSERVATIONS OF FISH DIVERSITY AND ABUNDANCE IN THE FINNISS RIVER

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7.1 INTRODUCTION

During 1973/74, field investigations were undertaken to assess the effects of acidic and metallic pollutants derived from the abandoned Rum Jungle mine site, on the fauna of the Finniss River System (Figure 7.1) (Jeffree and Williams 1975; 1980).

Davy and Jones (1975) had estimated that the yearly pollution load delivered from Rum Jungle via the East Branch to the Finniss River was 50 t of Cu, 50 t of Mn and 20 t of Zn, during years of average rainfall. During the dry season and the beginning of the 1974 wet season the maximum 0.45 μm filtered water concentrations of metals measured in the Finniss River downstream of its junction with the East Branch were: Cu, 1 mg/L; Zn, 0.8 mg/L; and Mn, 0.9 mg/L (Jeffree and Williams 1980). These concentrations are factors of 200 to 500 for Cu, and 16 to 160 for Zn, higher than the levels recommended in the guidelines for protection of Australian freshwater ecosystems (ANZECC 1992).

The biological investigations undertaken at that time to assess the ecological impact of the pollution load showed the following general effects:

- Very few fish and macro-invertebrates survived in the East Branch of the Finniss River where concentrations as high as 55 mg/L for Cu and 44 mg/L for Zn were recorded (Jeffree and Williams 1980).

- Fish kills occurred in the Finniss River downstream of its confluence with the East Branch, for at least 15 km, when moderate inflow from the East Branch coincided with a low flow rate in the Finniss River.

- Fish were reduced in numbers of species and individuals downstream of the confluence of the East Branch and the Finniss River. Thirty kilometres downstream of the confluence, however, no effect was observed. Moreover, this pattern of faunal reduction in the Finniss River persisted throughout the dry season of 1974 during three sampling periods between May and November.

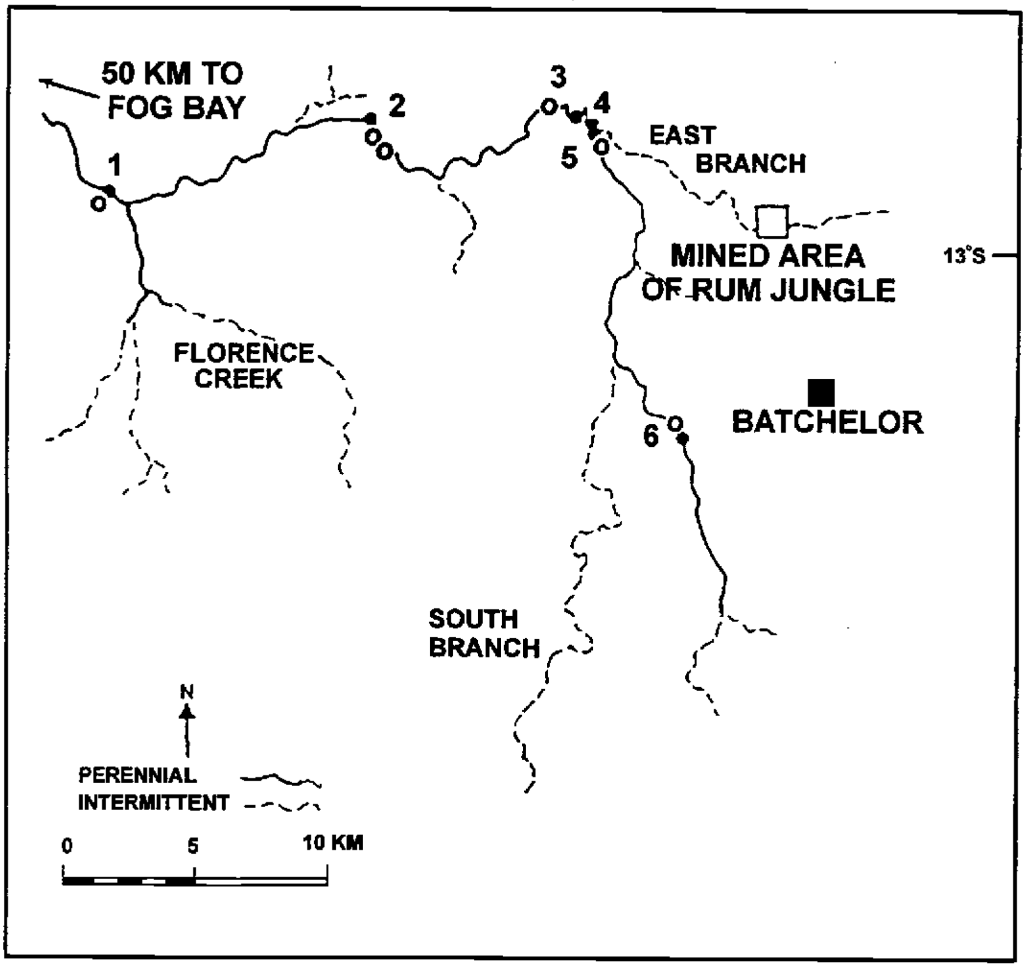

Figure 7.1 **The Finniss River in the vicinity of the mined area of Rum Jungle and the location of sites sampled in 1974 ("•" as numbered) and 1992 ("○" proceeding in the upstream sequence 1, 2a, 2b, 3a, 5 and 6).**

Following remediation during 1982/86, there has been a measured reduction in total loads of metals to the river (Kraatz and Applegate 1992). In the 1991/92 wet season, preceding our investigations in July/ August 1992, 3.7 t of Cu, 9.1 t of Mn and 2.6 t of Zn were delivered to the Finniss River.

In this investigation the distribution and abundance of fish in the region of the Finniss River that was examined prior to rehabilitation has been studied. The results allow an initial evaluation of the degree of ecological improvement in the impacted region of the Finniss River, following the reduction in the load of acid mine drainage (AMD) pollution that it continues to receive.

7.2 MATERIALS AND METHODS

Site selection

Figure 7.1 shows the sites at which fish were sampled, in both the recent study and the 1973/74 investigations. Sites 1, 2 and 5 were consistent between the two periods of sampling. However, for the other general locations, new sites were chosen in 1992 due to low water levels and altered sediment distributions. The final sites selected included three in each of the previously impacted (2a, 2b and 3a) and un-impacted (1, 5 and 6) zones of the river. The general characteristics of these water bodies have been described previously (Jeffree and Williams 1980).

Fish sampling

The earlier study had shown that three catch methods (poisoning, spotlighting and enmeshing) were similarly efficient for the measurement of the impact of pollution load on fish fauna (Jeffree and Williams 1975). For this study a single method, the setting of enmeshing nets, was used to sample fish. A standard series of 10 nets, varying from 12 to 75 mm mesh size, were set at dusk at each site and the catch to midnight determined. Individual fish were allocated to nominal species that were later confirmed by the staff of the Australian Museum. Individual weights were taken for all samples except for the abundant species, Bony bream *(Nematalosa erebi)*. From these, a subset of 20 individuals per site was randomly selected and individually weighed to calculate total mass for each sample.

Physical and chemical sampling

Prior to net-setting or other disturbances at each of the six sampling sites, triplicate depth profiles of temperature, dissolved oxygen (DO), pH, turbidity and conductivity were made to investigate any differences that could explain potential anomalies in the diversity and abundance of fish species.

Duplicate sub-surface water samples were taken at the upstream and downstream end of each site in acid-washed and river-rinsed 250 mL polyethylene bottles. The water samples were acidified with two millilitres of concentrated hydrochloric acid and were then sealed and frozen. They were then returned to ANSTO for analysis of total Ca, Mg, Cu, Zn and Mn by Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES) and total Co and Ni by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) as recommended in ANZECC (1992). The metal concentrations determined were at least one to two orders of magnitude greater than the instrumental detection limits (IDL's) as determined by ten integrated blank analyses. The IDL for ICP-MS were generally less than 0.2 μg/L and frequently less than 0.1 μg/L.

7.3 RESULTS AND DISCUSSION

In general, the water level in the river was low relative to the dry season of 1974. There was no obvious surface flow at Site 2 or upstream, nor was there any flow in the East Branch. There was flow at Site 1 due to the confluence of Florence Creek, a perennially spring-fed stream.

Water quality

There was only moderate stratification of the water column at each site, thus profile-averaged water quality measurements are shown in Figure 7.2.

The sites were generally shallow, with maximum depths of approximately two to four metres. The temperatures varied within the overall range 22 to 27°C. Site to site variation probably depended on depth, flow and the amount of shade provided by the surrounding vegetation. Dissolved oxygen varied from 70% to 100% of saturation near the water surface to a minimum of around 10% to 30% in the near bottom samples. Site 5 was characterised by relatively low oxygen throughout the water column (30% to 8% of saturation) despite having the lowest temperature. This may have been due to a high oxygen demand associated with a mat of decaying leaves which covered the bottom of the billabong.

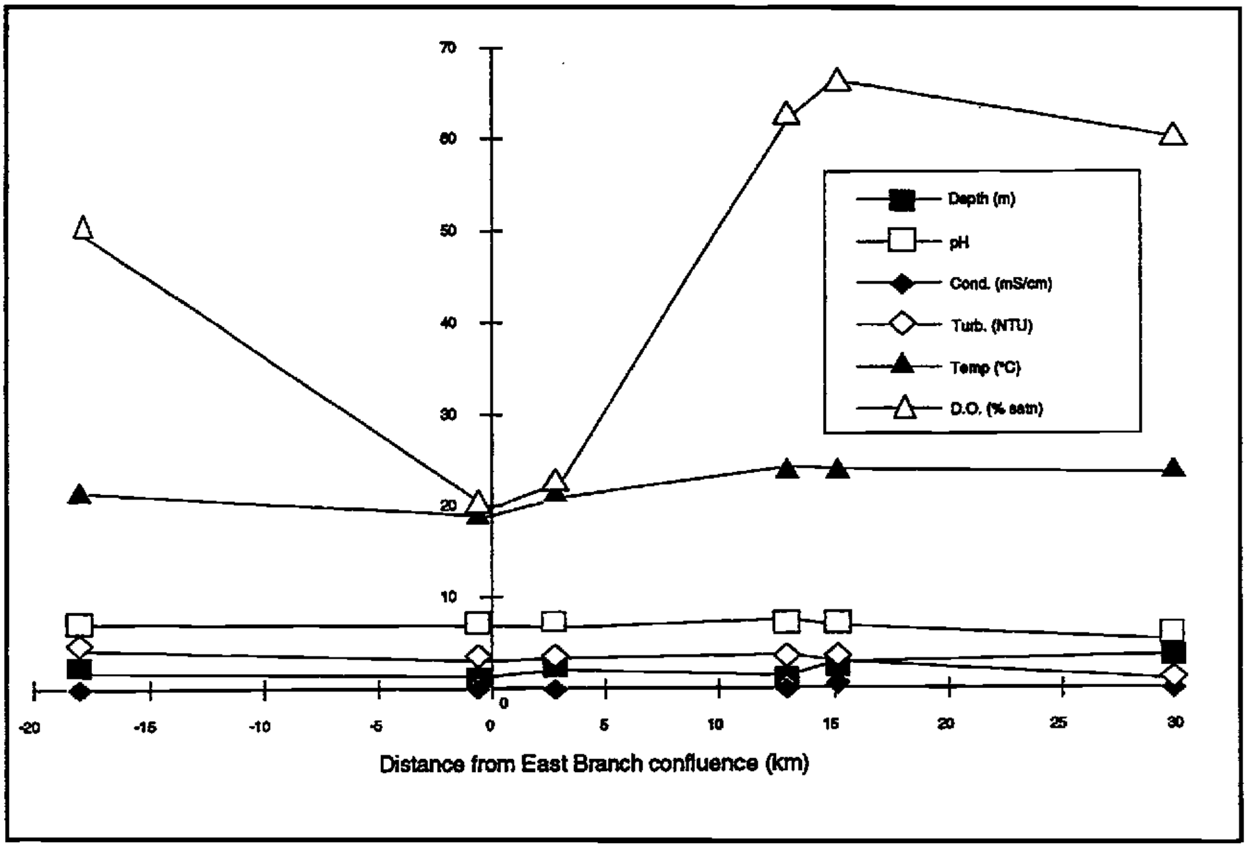

Figure 7.2 **Average values of depth, temperature, dissolved oxygen (DO), pH, turbidity and conductivity at each site. Negative distances indicate sites above the East Branch confluence.**

The pH was generally in the range from six to eight, except at Site 1, furthest downstream from the Rum Jungle mine site, where the surface pH was around six declining to around 4.5 below four metres. Turbidity was usually low, in the range less than 1 to 7 NTU, the higher values attributable to sediment disturbance by the probe. Conductivity ranged from 0.009 to 0.155 mS/cm, with sites affected by drainage from Rum Jungle being consistently higher relative to upstream sites and Site 1.

Table 7.1 shows a summary of the results of the chemical analyses performed on the replicated water samples taken at sampling sites within the impacted and un-impacted zones of the river. For the macro-nutrients Ca and Mg, the water concentrations were relatively constant at sites both upstream and downstream of the junction with the East Branch. This was with the exception of Site 1, however, where concentrations of both elements were reduced by more than an order of magnitude. Given that there was no flow observed at the other five sampling sites within the Finniss River, it follows that the water sampled at Site 1 was predominantly composed of water from the perennial tributary Florence Creek.

Table 7.1 Total metal concentrations (mean ± sd) in each zone of the river during the 1992 sampling program.

Zone	Ca (mg/L)	Mg (mg/L)	Mn (μg/L)	Cu (μg/L)	Zn (μg/L)	Co (μg/L)	Ni (μg/L)
Un-impacted	4.9±3.6	7.0±5.0	42.1±17.8	4.5±1.4	5.7±2.9	1.4±1.0	8.0±3.9
Impacted	8.0±0.6	15.2±1.0	112 ±30.2	18.9±6.6	11.2±2.1	4.2±1.4	10.4±0.8

The levels of Cu, Mn, Co and Zn were elevated at the sites within the impacted zone compared to Sites 6 and 5 upstream and also Site 1. For each of these trace metals, measured concentrations were always highest at the site closest to the East Branch confluence (3a). Here the increase in mean water concentration, compared to the means for three sites in the unaffected region of the river, ranged between a factor of six for Cu down to about two for Zn. These elevated levels may have resulted, at least in part, from the presence of tailings material that was observed on the banks of the billabongs sampled within the impacted zone. The significance of these water concentrations can be assessed in the context of the Australian Water Quality Guidelines (ANZECC 1992) shown in Table 7.2.

With respect to raw water for drinking supply, levels of Cu, Ni and Zn were considerably below the maximum acceptable concentrations while they were comparable for Mn. For freshwater ecosystems the maximum Cu concentrations measures were above the guideline range, but Zn and Ni values were within the below range, respectively.

Table 7.2 Comparison of measured values with the Australian Water Quality Guidelines (ANZECC 1992).

Metal	Max. water conc. measured in 1992 (μg/L)	Max. acceptable conc. for drinking (μg/L)	Guidelines for fresh-water ecosystems (μg/L)
Cu	28.3	1 000	2-5
Mn	159.0	100	
Zn	12.5	5 000	5-50
Ni	6.1	100	15-150

Fish diversity and abundance

Appendix E gives the total number of each species caught, normalised for catch effort, as well as the total number of species and the normalised total mass of all individuals from each site.

Figure 7.3 shows the total number of species and individuals caught in each of the sites at similar times of the year during the 1974 and 1992 surveys, normalised for effort.

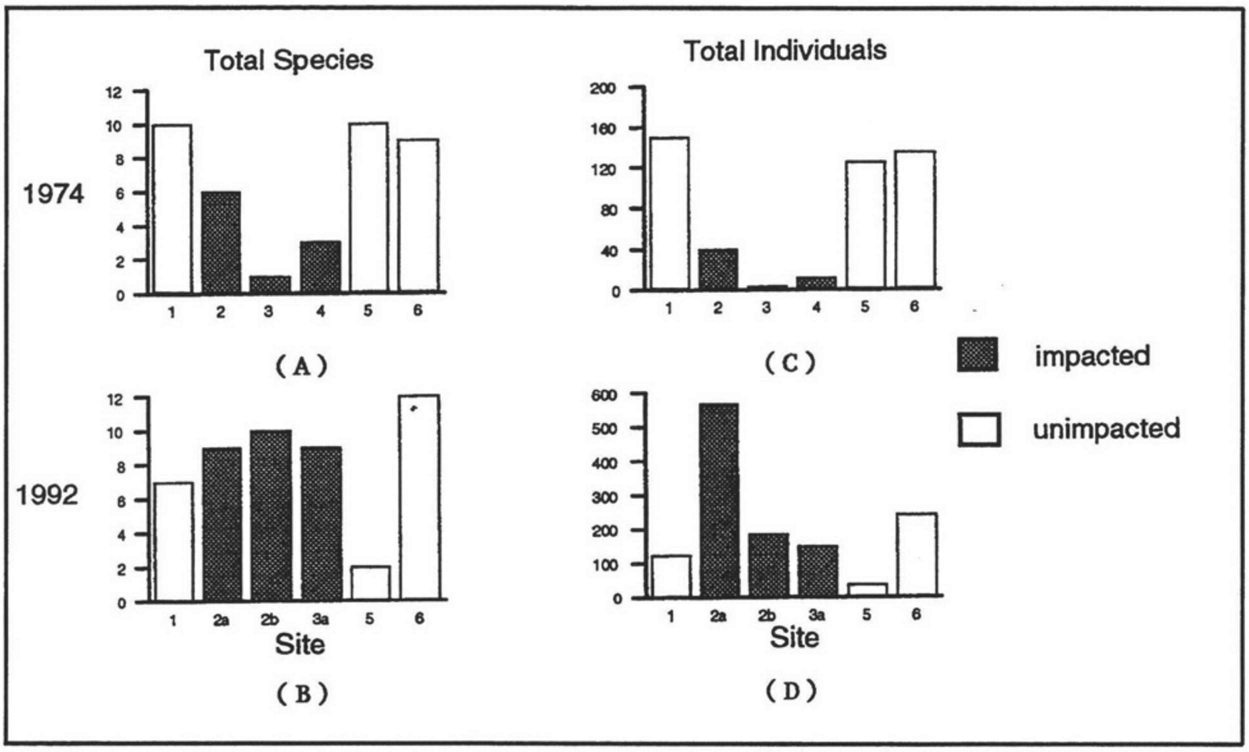

Figure 7.3 Species diversity and abundance in a typical 1974 effort compared with the catch from 1992.

The following observations are consistent with there being a recovery of the fish fauna in the impacted zone of the Finniss River that has followed the reduction in annual loads of Cu, Zn and Mn reaching the Finniss River.

- ***A similar number of species of fish taken during 1992 from sites within both zones of the river.***

  During the three sampling periods of 1974 the numbers of fish species taken by enmeshing nets within the impacted zone of the Finniss River were consistently low. For example, the values from a single sampling period (May/June) ranged from one to six, with an average of about three (Figure 7.3(A)). In contrast, the number of species taken from sites within the un-impacted zone was as high as ten.

  During the current study (Figure 7.3(B)), an average of seven species were taken from the un-impacted zone compared to nine to ten species collected at sites in the impacted zone. The numbers from impacted sites in the 1992 study were also equal to, or comparable with, those taken from any un-impacted site in 1974 (Figure 7.3(A)).

- ***Comparable total number of fish taken during 1992 from sites within both zones of the river.***

  Whereas previous investigations had shown a marked reduction in the total numbers of fish of all species in the impacted zone (Figure 7.3(C)), our recent study has shown that the numbers in the previously impacted zone were similar to or greater than those in the un-impacted zone of the river (Figure 7.3(D)).

- ***The presence of indicator species in the impacted zone.***

  The previous investigations (Appendix E), where fishing effort greatly exceeded that of the present survey, showed that three species of fish were extremely low in abundance within the impacted zone, even though they were caught at each of the sites upstream and downstream of this region of the river. These species, which can accordingly be regarded as good indicators of the severity of biological impact from Acid Mine Drainage, were Eel-tailed catfish (*Neosilurus ater*), Archer fish (*Toxotes chatareus*) and the Banded grunter (*Amniataba percoides*). Each of these species was captured at one or more sites within the impacted zone during our recent investigations. Similarly, previous investigations demonstrated that the following species were present but reduced in abundance in the impacted zone during the dry season: Ox-eye herring (*Megalops cyprinoides*); Bony bream (*Nematalosa erebi*); Black bream (*Hepaestus fuliginosus, Syncomistes butleri* and *Syncomistes(?) nov. sp.*); and Longtom (*Strongylura kreffti*). Among these species, Ox-eye herring and Bony bream were found to be comparably high in abundance in both zones of the river during the latest survey.

Our previous investigations had clearly demonstrated that metal concentrations at low pH in the East Branch killed fish that entered from the side-streams. The influx of this water from the East Branch into the Finniss River also resulted in fish kills in the Finniss River. These fish kills extended for a distance of 15 km downstream of the junction with the East Branch (Jeffree and Williams 1975). There has been a marked reduction in the total annual loads of Cu, Mn and Zn delivered to the Finniss via the East Branch since the initial biological investigations were conducted in 1973/74. A comparison of the total loads of Cu, Mn and Zn in the 1973/74 wet season with those loads during the wet season preceding our recent study, has shown an order of magnitude reduction of Cu and Zn loads, with Mn reduced by about a factor of five. It would follow that the recovery in the abundance and diversity of fish species in the impacted zone of the Finniss River is generally due to this reduction in metal loads.

The following factors may have also attributed to the observed recovery of the fish fauna in the impacted zone:

- The liming of water in the open cuts at the Rum Jungle mine site, to increase pH (Kraatz and Applegate 1992) may have also led to an increase in the Ca water concentration of effluent from this site which reduces the toxicity of metals like Cu and Zn. It is therefore feasible that this effect may have ameliorated the toxicity of the East Branch effluent and may continue to do so until it is washed out of the open cuts. The possible increase in pH of the effluent from the East Branch due to this procedure could also be expected to ameliorate its toxicity, particularly with respect to Cu.

- Our previous investigations had shown that within the impacted zone of the river, the site that was least affected was Site 2, the one furthest downstream of the junction with the East Branch. In our present investigation, two billabongs in the vicinity of the original Site 2 were sampled due to the absence of a suitable site immediately downstream of the junction with the East Branch. This change in the geographical distribution of sampling sites within the impacted zone may have contributed to the observed degree of improvement in the fish fauna, compared to the pattern established in the original study.

- This study was carried out at a time of particularly low river-water levels. It may be that the relatively high population densities observed may partly have been due to habitat restriction as a consequence of this condition. Despite this, the number of species observed within the polluted zone still implies improvement in the biological diversity.

The results of our physico-chemical measurements indicated that each of the billabongs sampled had similar water qualities except for Site 5, where oxygen levels approached anoxia during the evening sampling. The number of species and individuals taken at Site 5 during the recent survey were also very reduced relative to those taken at other sites within both zones of the river (Figures 7.3 (C) and (D). Our explanation for the absence of other species of fish at this site is that it was due to the low oxygen tension of the water in this billabong. The rationale for this conclusion is expanded upon below.

The measured oxygen levels in this billabong could be expected to decline further during the night as a result of the large amount of organic matter present, reflected in the high densities of decaying leaves in the water. Subsequent measurement during the period of the field trip showed that early morning levels of dissolved oxygen approximated zero (Boland and Lawton, pers. comm.).

This explanation is also consistent with the physiological attributes of the species that were present in this billabong. Ox-eye herring, the most abundant species present, is known to survive very low oxygen water concentrations (Townsend et al. 1992). Moreover, Eel-tailed catfish were observed to survive for eight hours after removal from the river during the 1992 survey. In general, catfish are tolerant of low oxygen tensions due to a variety of traits. These include: morphological adaptations for an improved air-sac; skin and gill oxygen diffusion; the ability to air-breathe (eg. Hughes et al. 1992); other behavioural adaptations to crowding, desiccation and anoxia (such as hyperventilation); and physiological adaptations enabling the animals to undertake some anaerobic metabolism (eg. Burggren and Cameron 1980).

An alternative explanation for the reduction in fishes at Site 5 is that the entry of contaminated effluent into this billabong by backflow from the East Branch may have taken place during the previous wet season, as observed during 1973/74 (Jeffree and Williams 1975). However, the results of conductivity measurements and metal analyses from this billabong showed that, apart from Ni, the levels were comparable to those measured from Site 6. At both Sites 5 and 6 the values for these measurements were not as high as those from sites within the impacted zone of the Finniss River, where much higher catches of a greater variety of fish species were made compared to Site 5.

Additionally, previous investigations had indicated that Eel-tailed catfish were very sensitive indicators of AMD pollution, being greatly reduced in the impacted zone but abundant in the un-impacted zone (Jeffree and Williams 1975). The high Ni values recorded were much lower than the upper limits set out in the guidelines for ecosystem water quality (ANZECC 1992). In summary, these results are not consistent with the reduction of fish species at Site 5 being due to metal pollution from Rum Jungle, but rather the reduction may be explained by low oxygen concentrations.

7.4 CONCLUSION

The overall pattern of fish distribution and abundance, observed during the 1992 survey, agrees with there being a recovery in the fish fauna within the previously impacted section of the river, given the conditions prevailing at the time of sampling. The improvement is most likely due to a reduction in Acid Mine Drainage from the East Branch of the Finniss River following remediation of the Rum Jungle mine site.

8. MACRO-INVERTEBRATE ECOLOGY of the FINNISS RIVER EAST BRANCH at the BEGINNING of the 1993 DRY SEASON

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8.1 INTRODUCTION

Acid mine drainage (AMD) from the Rum Jungle mine site, affects the ecosystem of the Finniss River by decreasing pH and increasing the concentration of heavy metals, particularly Cu, in the water flowing down the East Branch of the river and into the Finniss River proper. The populations of fish and macro-invertebrates on which they feed were investigated during the 1973/74 survey to assess the effects of acidic and metallic pollutants on the fauna of the Finniss River system.

These early biological investigations showed the severe impact of heavy metal pollution prior to any remedial treatment of the mine site. The general findings were that:

- very few fish and macro-invertebrates survived in the East Branch of the Finniss River downstream of the mined area;

- fish kills occurred over at least 15 km of the Finniss River, downstream of its confluence with the East Branch, when moderate inflow from the East Branch combined with a low flow rate in the Finniss River to give relatively high pollutant concentrations; and

- the populations of fish and their macro-invertebrate prey were apparently unaffected at a site 30 km downstream of the point where the East Branch joins the Finniss River.

Following rehabilitation of the Rum Jungle mine site, the annual loads of dissolved metals being carried via the East Branch to the Finniss River have fallen markedly. In May 1993, a survey of macro-invertebrates in the East Branch repeated and extended the earlier work with the aim of assessing the degree of improvement in this part of the broader Finniss River ecosystem. The following reports on the results of this investigation.

8.2 METHODS

Physical and chemical sampling

Water quality measurements and water chemistry analyses were conducted to support the interpretation of the biological data for each sampling site (Figure 8.1). Field measurements were made of temperature, conductivity, dissolved oxygen, pH and turbidity using a Horiba U-10 water quality meter. Duplicate, sub-surface, 0.45 μm filtered water samples were collected for analysis of metals, specifically Cu, Mn, Zn, Co and Ni using Inductively Coupled Plasma - Atomic Emission or Mass Spectrometry (ICP - AES or MS). The essential elements, Ca, Mg and Na were also determined.

Sampling of macro-invertebrates

The macro-invertebrate populations of pools were sampled semi-quantitatively by systematically disturbing 1 m^2 of substrate for three minutes (that is, kick-sampling). A fine-meshed (1.0 mm^2), triangular dip net was used to capture dislodged animals. Up to four replicates were obtained at each sampled site, from substrates with at least 50-60% leaf litter cover. Macro-invertebrates were also obtained incidentally from the seining and poisoning used to catch fish.

All taxa were identified to family level. A variety of univariate and multivariate statistical procedures were employed to compare:

- the diversity and abundance of macro-invertebrates found at polluted sites (that is, those in the East Branch downstream of Rum Jungle mine site) versus control sites comprising sites in the East Branch above the mine site and in side streams below the mine site;
- the structure of the macro-invertebrate community found at polluted versus control sites;
- the structure of the macro-invertebrate community in relation to measured physical and chemical variables; and
- the diversity of macro-invertebrates found at polluted sites before and after rehabilitation of the mine site.

8.3 RESULTS

General water quality

No vertical stratification was observed in the profiles taken in pools along the East Branch. There was a general trend of increasing pH with increasing distance from the Rum Jungle mine site. However, the pH at Sites 4U, 4AD and 4AU (6.1, 6.2 and 6.2 respectively) were greater than at Site 4D (5.7). There was also a marked decrease in pH from Site 4AU to Site 6 (pH 3.6).

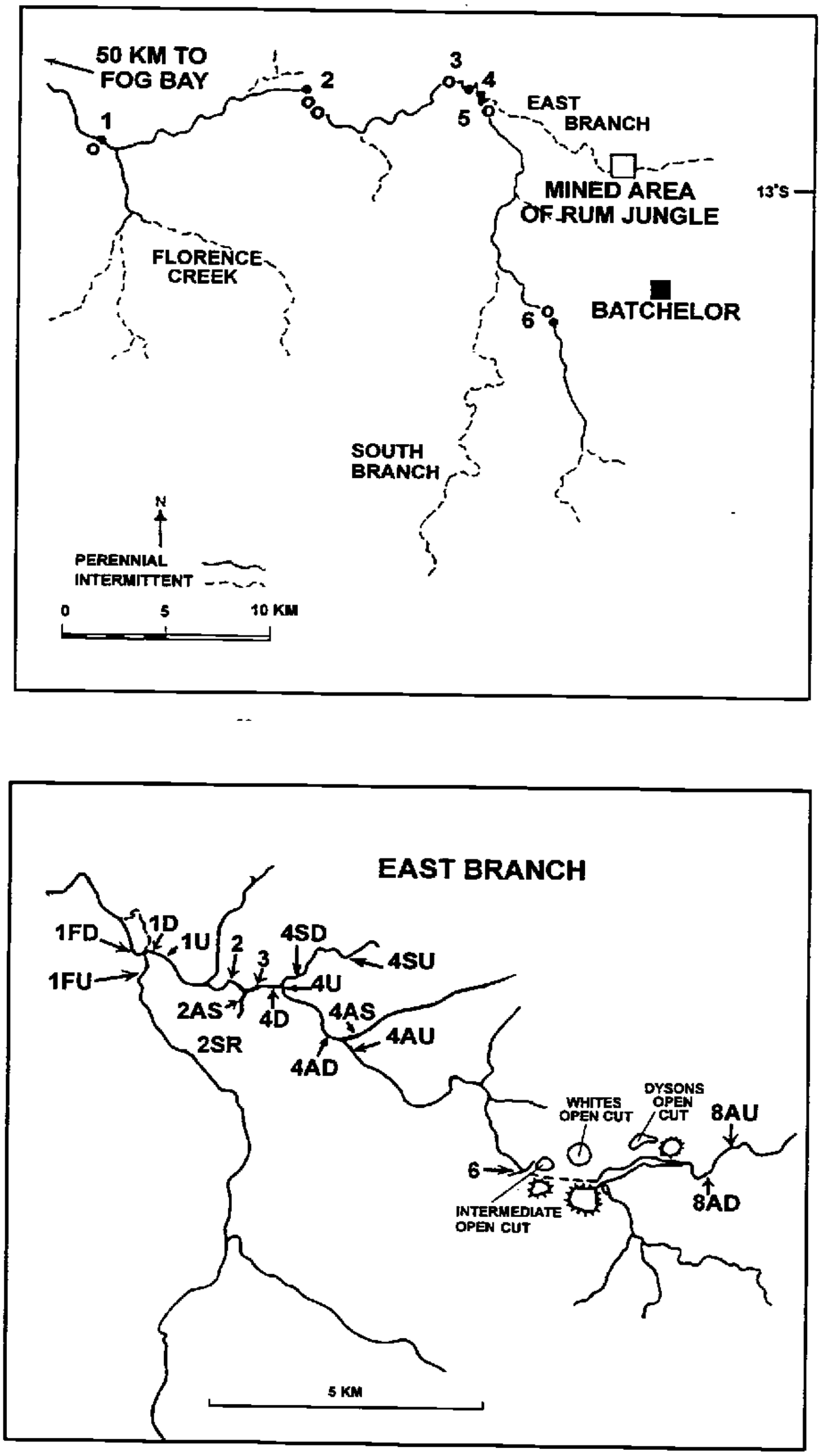

Figure 8.1 **Location of the study area and sites on the East Branch of the Finniss River and its tributaries.**

Conductivity of the sampled sites reached a maximum of 3.51 mS/cm at Site 6 and decreased with increasing distance downstream from the mine site to 0.33 mS/cm Site 1D. The control sites all had conductivities in the range from 0.04 to 0.34 mS/cm. Turbidity was generally low at all sites, with values ranging from 0 to 10 NTU. Oxygen saturation was generally higher in polluted sites, ranging from 89-127%, compared with 30-98% at control sites. Temperatures ranged between 22.0 and 29.8°C across all sample sites. Although there was no simple trend in the temperatures between sites, the polluted sites were significantly warmer on average compared with the control sites. This may result from the lower density of trees along the banks of the East Branch below the mine site.

Specific water chemistry (Ca, Mg & Na; Cu, Mn & Zn)

In the East Branch in 1993, the total and dissolved concentrations of the essential elements Ca, Mg and Na increased by one order of magnitude immediately downstream of the mine site, relative to the levels found at Site 8a above the mine site (Figure 8.2). These levels then decline towards background concentrations with distance downstream from the mine site.

The total concentrations of Cu, Mn and Zn in water samples from the sampled sites are shown in Figure 8.2. Both total and dissolved concentrations of Cu, Zn and Mn increased by two or more orders of magnitude immediately downstream of the mine site compared with upstream sites. These concentrations then declined to background levels at about 6.6 km downstream of the mine site (Site 2).

Macro-invertebrates (1973/74 & 1993)

There were clear and statistically significant ($P<0.05$), distinctions between the polluted and control sites in respect of the diversity and abundance of macro-invertebrates. Control sites had significantly ($P<0.05$) higher numbers of families of macro-invertebrates as well as significantly ($P<0.05$) more individuals (Figures 8.3 and 8.4). Chironomids (bloodworms, that is larval midges) and Dytiscids (water beetles) were almost always the numerically dominant and subdominant taxa at polluted sites. At the control sites, several other taxa shared dominance with the Chironomids, and the Dytiscids were notably less common. Polluted sites were also characterised by the absence of certain taxa. These were, for example, Ephemeropterans (mayflies), Odonatans (dragon and damsel flies), Corbiculid and Hyriid mussels, and the Planorbid and Thiarid snails.

It is possible to compare the total numbers of families found at polluted sites of the East Branch in 1993 with those found in 1973/74, by grouping some of the 1993 sites (Figure 8.5). Both the parametric (paired t-test, one-tailed) and non-parametric (Wilcoxon signed-rank) tests indicate that there is significant improvement at the 10% level of probability (Table 8.1). This supports the general impression gained from Figure 8.5, which shows increased numbers of families at Sites 3, 4 and 6 in 1993. The apparent lack of improvement at Sites 1 and 2 may show the beneficial effects of flushing and recolonisation from Hanna's Spring (Site 2AS in Figure 8.1). Water-respiring species are generally more susceptible to dissolved Cu poisoning than air-breathing species of macro-invertebrates. The observation of water-respiring decapod Crustacea and Trichopteran larvae in this polluted reach of the East Branch provides further evidence of water quality improvement.

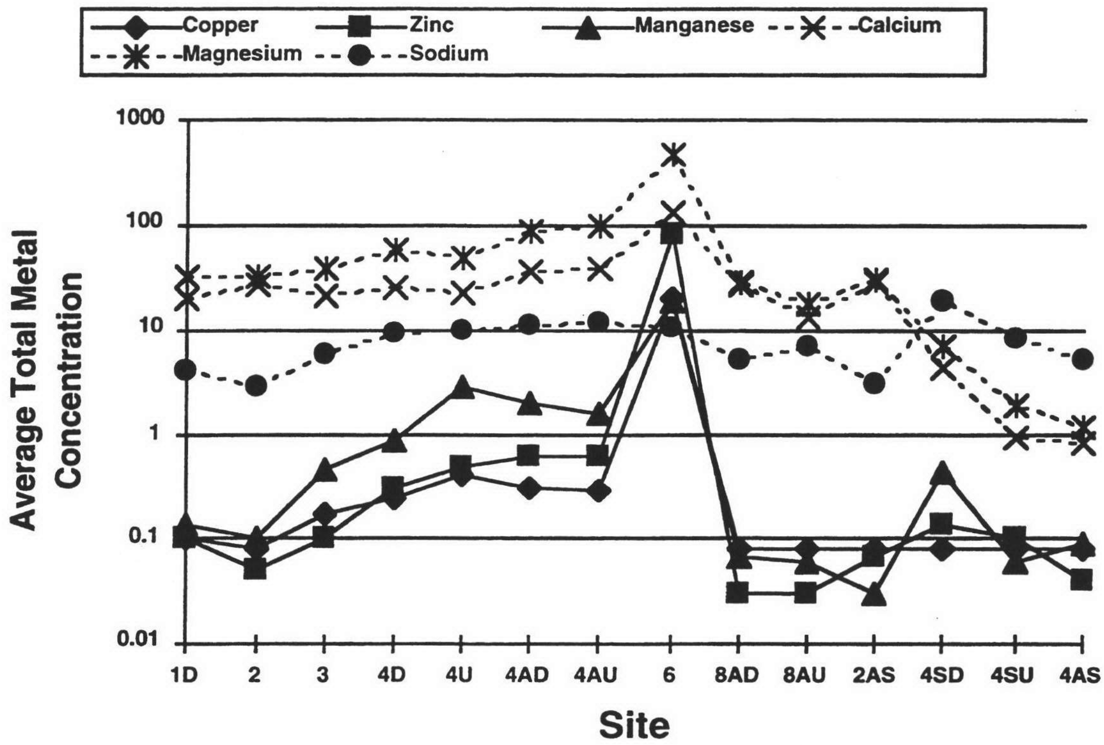

Figure 8.2 Average total concentrations of metals in the early dry season of 1993 for the East Branch of the Finniss River and its tributaries. Sites to the left of the plot (1D to 6) are polluted sites, while those on the right (8AD to 4AS) are control sites. (The lines joining sites are for ease of observation and comparison and do not indicate a succession).

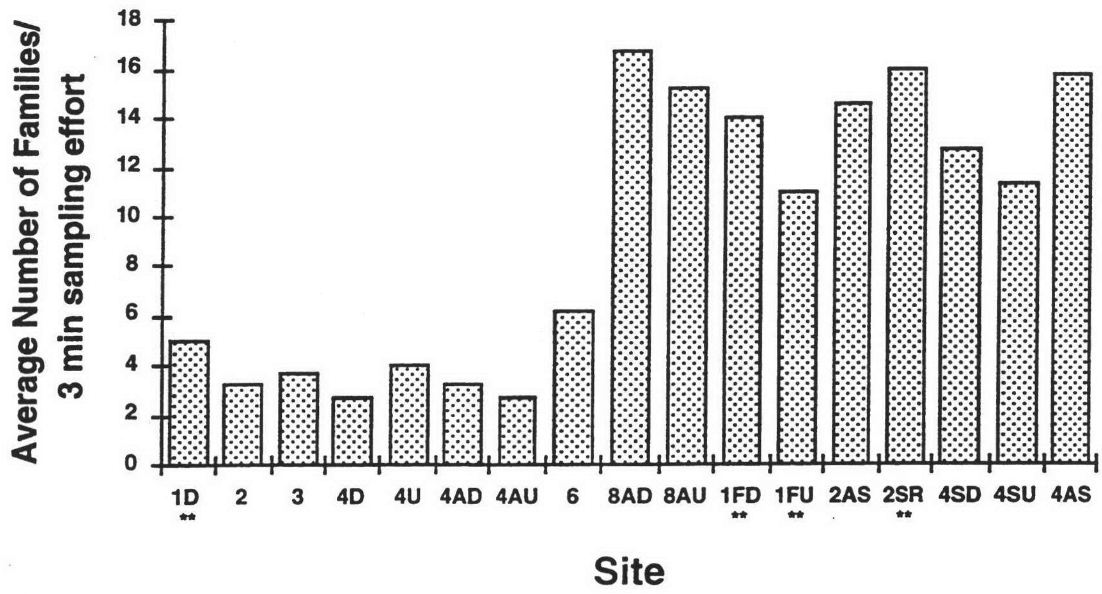

Figure 8.3 Average number of families of macro-invertebrates collected in 1993 at each site of the East Branch of the Finniss River and its tributaries. Sites to the left of the plot (1D to 6) are polluted sites, while those on the right (8AD to 4AS) are control sites. (** Indicates where only one sample was taken).

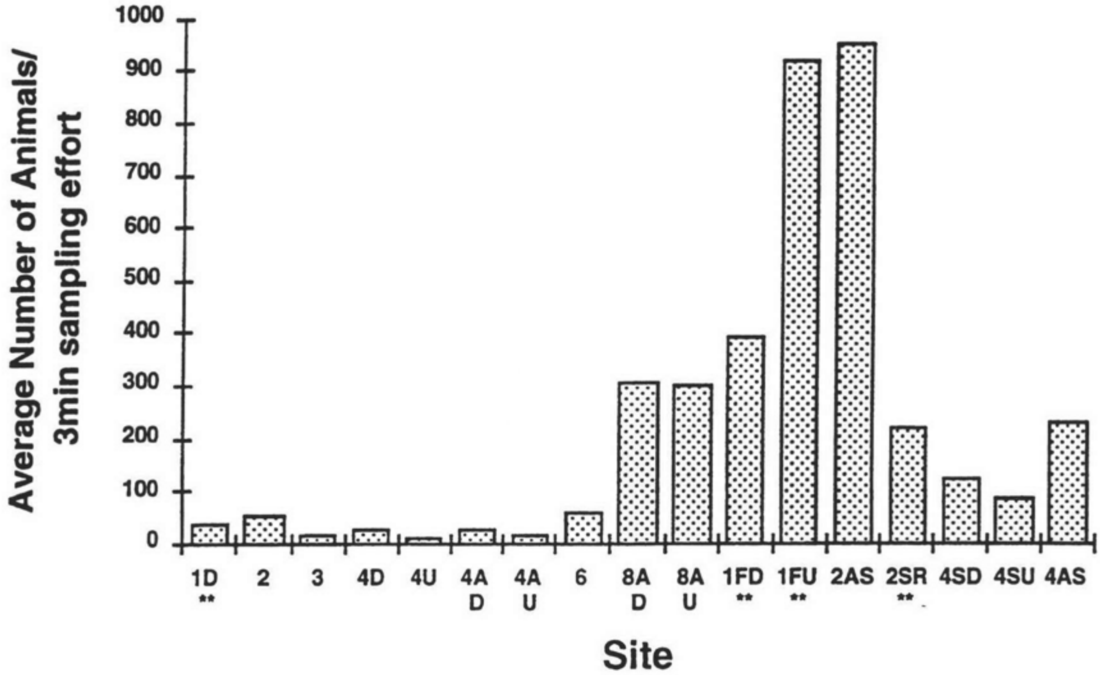

Figure 8.4 Average number of macro-invertebrates collected in 1993 at each site of the East Branch of the Finniss River and its tributaries. Sites to the left of the plot (1D to 6) are polluted sites, while those on the right (8AD to 4AS) are control sites. (** Indicates where only one sample was taken).

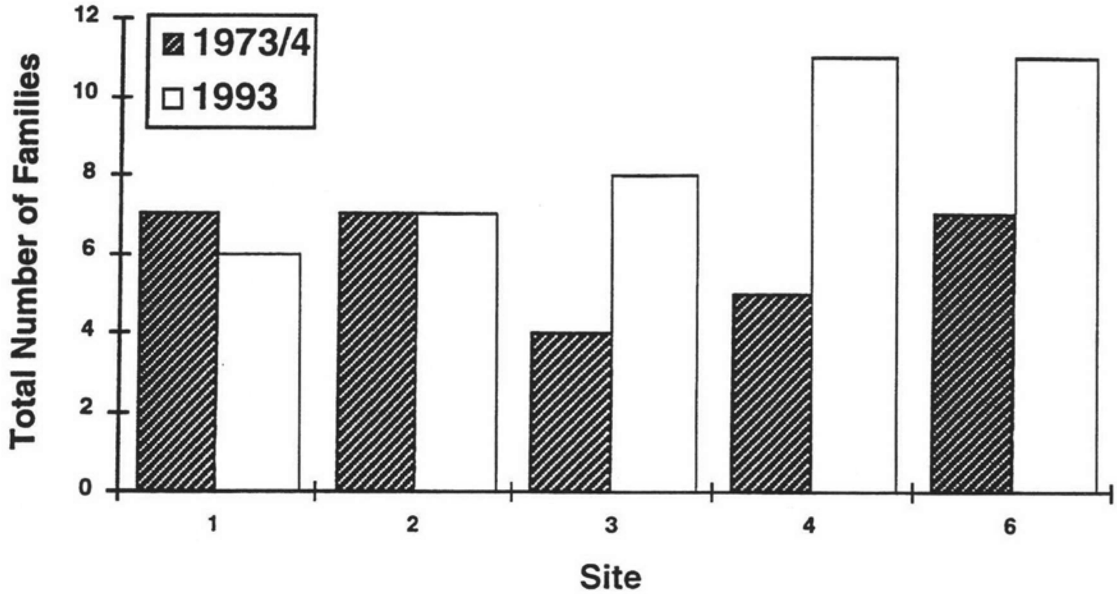

Figure 8.5 Total number of families of macro-invertebrates collected at polluted sites in the East Branch of the Finniss River before rehabilitation (1973/4) and after rehabilitation (1993). In the present survey, Site 1 includes Sites 1D and 1U, Site 2 includes Site 2 only, Site 3 includes Site 3 only, Site 4 includes Sites 4D and 4U, Site 6 includes Site 6 only.

Table 8.1 Statistical comparisons of the total number of macro-invertebrate families found at polluted sites in the East Branch in 1973/74 and 1993.

t-Test: Parametric

	Degrees of Freedom	Mean X-Y	Paired t Value	Probability (1-tailed)
	4	-2.6	-1.96	0.06 Significant at 10%

WILCOXON SIGNED-RANK TEST: Non-parametric

	Number	Σ Rank	Mean Rank	Corrected Z	Probability
-ve Ranks	3	9	3	-1.47	0.07
+ve Ranks	1	1	1	(1group tied)	Significant at 10%

8.4 CONCLUSION

The macro-invertebrate fauna remains significantly less diverse and less abundant in the lower reach of the East Branch compared with clean (control) sites. There is evidence of some recovery of the macro-invertebrate fauna in the East Branch of the Finniss River below the Rum Jungle mine site (statistically significant at a probability of 10%) compared with the severe environmental degradation evident in this stream section in 1973/74.

9. SITE INTEGRITY

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9.1 INTRODUCTION

The monitoring and maintenance of rehabilitated surfaces at the Rum Jungle site was continued in order to ensure their ongoing integrity. Major aspects of monitoring were qualitative assessments of surface stability and pasture status including weed presence. Weed and fire management subsequently formed a major component of maintenance.

Annual rainfall throughout the monitoring period varied from average to below average, with a high of 1600 mm in 1988/89 and a low of 900 mm in 1989/90. This compared with an average rainfall in the Rum Jungle area of 1500 mm as reported by Davy (1975). In general, rehabilitated structures performed well throughout the period.

9.2 SURFACE STABILITY

Quantitative assessments of surface stability were not possible given that the instrumentation to undertake such measurements was not installed on site at the completion of rehabilitation.

Surface drainage structures were annually inspected following each Wet season. Whilst instances of erosion occurred throughout the site, repair works were primarily conducted in areas where clay covers were under threat or where access across the site was compromised. Some additional work was undertaken where minimal resources were required. Specific works are described on an area by area basis below.

No gross movement or failure of the rock mulch occurred on any of the Heaps. *Colopogonium mucunoides* (Colopo) continued to colonise these areas, thereby providing additional stability.

Whites Overburden Heap

Damage to the main drain on Whites Heap as discussed by Ryan in the 1986-88 Monitoring Report (Kraatz and Applegate 1992:121) has been repaired and no further instability was experienced in this area (Plate 9.1 “A”). Scouring on a feeder drain (Plate 9.1 “B”) was identified in April 1993, however, due to excessive gradient. Minor rilling of the access road down Whites batter and on its top surface was identified in 1990 (Plate 9.1 “C”). Repairs to both of these areas was scheduled for the 1993 dry season.

Weed infestation within the western perimeter drain at the base of the heap led to heavy siltation and overflow onto the south-western access road of Rum Jungle. This led to substantial erosion throughout the 1992/93 wet season (Plate 9.1 "D"). Removal of vegetation and silt from the drain, the repair of erosion along the road was scheduled for the 1993 Dry season.

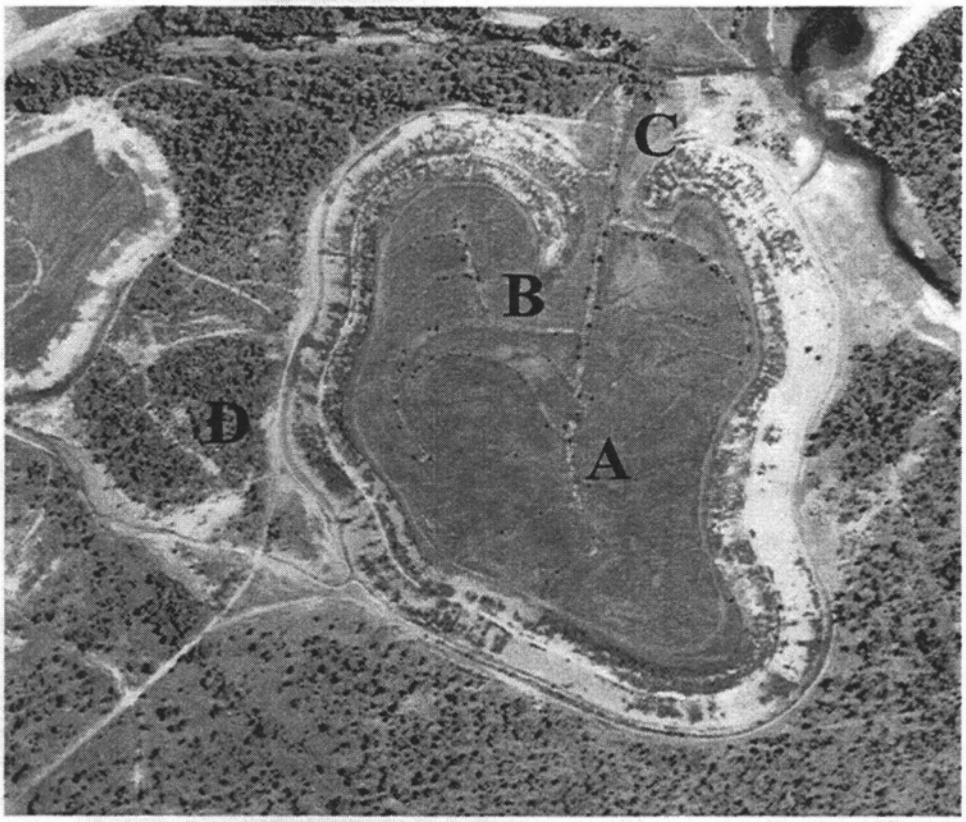

Plate 9.1 Whites Overburden Heap, indicating surface stability, pasture and weed problems as indicated in the text (taken from aerial photography flown 12/4/88 at an original scale of 1:15,000).

Dysons Open Cut landform and Overburden Heap

While not threatening the rehabilitated surface, gullying down a track to the west of Dysons Open Cut landform (Plate 9.2 "A") was identified as requiring attention in 1990. A bank was constructed near the crest of the track to divert water into the adjacent vegetated area and the gully was filled.

Scouring also developed on the main access track to Dysons (Plate 9.2 "B"). Poor location was identified as the cause with a recommendation being made in 1993 to close the existing track and reopen an older, better located track.

The main drain on the open cut continued to pond water as mentioned by Ryan (in Kraatz and Applegate 1992), however, no ill effects were observable (Plate 9.2 "C").

Work was conducted in 1990 to repair erosion at the western base drain of Dysons Overburden Heap immediately downstream of the confluence with the drain from Dysons Open Cut (Plate 9.2

"D") which had the potential to threaten the stability of the heap batter. The eastern batter of the drain was filled with rock and lined with gabions and mattressing at the base of the drain was extended further downstream.

Drains on the Overburden Heap remained stable, as does the main approach track.

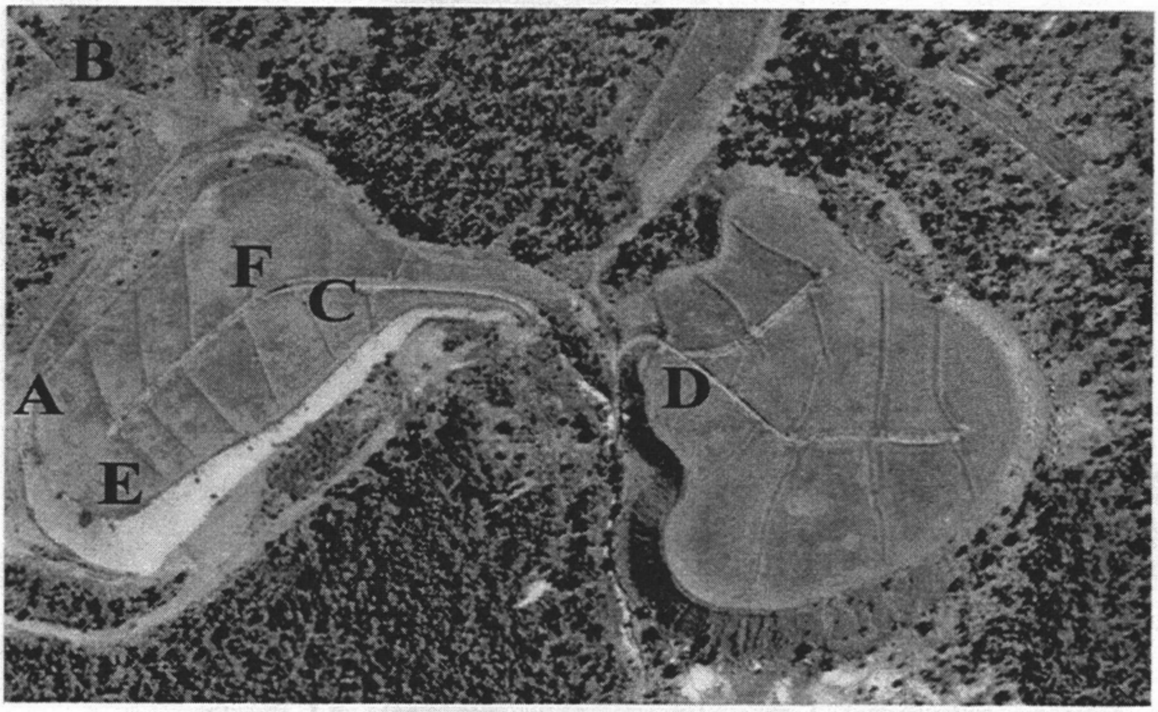

Plate 9.2 **Dysons Overburden Heap and Open Cut, indicating surface stability, pasture and weed problems as indicated in the text (taken from aerial photography flown 12/4/88 at an original scale of 1:15,000).**

Intermediate Overburden Heap

Minor sheeting previously occurring on either side of the drop structure above the outfall of the main drain is no longer a concern.

Whites North and the copper heap leach area

The contour drainage and outfall systems on Whites North and the old copper heap leach area continued to operate effectively. Sheeting on the flank of Whites North at the East Finniss Channel to Whites Open Cut remains minor.

Tailings dam, treatment plant and stockpile area

Drains and banks on the tailings dam are stable and continue to perform effectively. Minor rilling continued to the southwest of the tailings dam area (Plate 9.3 "A"). A small gully was also identified in 1990 on the western edge of the treatment plant area, however remedial works were not considered a priority and have not been undertaken (Plate 9.4 "B").

Filter cake disposal area and borrow pits

Minimal erosion occurred in these areas and no remedial works were undertaken.

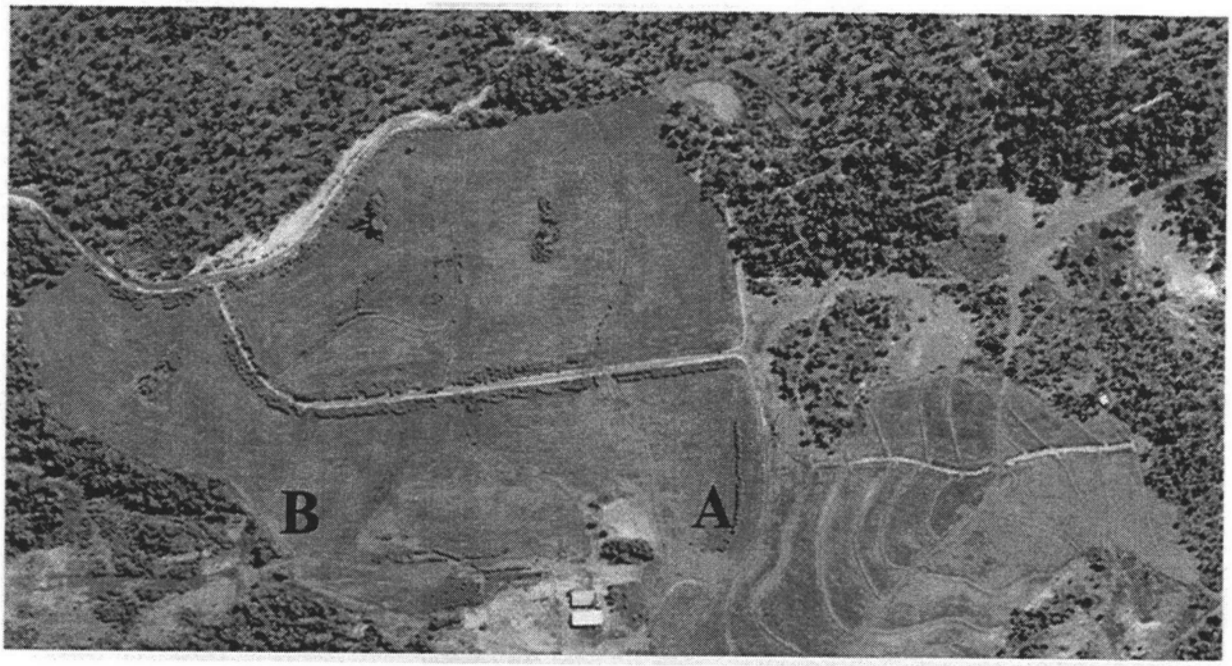

Plate 9.3 **Tailings dam, treatment plant and stockpile areas, indicating surface stability, pasture and weed problems as indicated in the text (taken from aerial photography flown 12/4/88 at an original scale of 1:15,000).**

9.3 PASTURE STATUS AND WEEDS

No formal, quantitative assessment of the diversity and abundance of pasture species was undertaken throughout the monitoring period, however, pastures generally remained healthy and vigourous, apart from minor areas of die-back described below.

Pastures on all rehabilitated surfaces were slashed and fertilised in 1989 and 1990 in order to encourage growth and development of the A horizon. This activity was subsequently ceased due to prohibitive costs and the judgement that such active encouragement of pastures was no longer required. Maintenance work therefore focussed solely on the control of major weed infestations and the upkeep of firebreaks.

Weeds presented a major problem and were considered to have been introduced through the importation of contaminated borrow material during rehabilitation, and through transport by vehicles, wind and birds. *Hyptis suaveolens* and *Sida acuta* were identified as the most commonly occurring weeds in 1986-88 with isolated outbreaks of *Mimosa pigra* (Ryan 1992). Whilst these continued to be a problem, large infestations of the noxious weed *Themeda quadrivalvis* (Grader Grass) developed and required greater attention. The NT Department of Primary Industries and Fisheries assisted with some weed control, however, the majority of weed control was conducted using 'in house' resources and Commonwealth Government funding.

Continuing weed control at the site will be essential to maintaining the value of previous efforts and to containing existing weed infestations within a manageable level. Increased efforts will be required to enable eventual eradication, if that is considered to be a necessary outcome.

The installation of graded firebreaks and the annual burning of key areas around the site boundary assisted in protecting the site from fire. A fire appeared to have been intentionally lit on Whites Overburden Heap in 1989, however, pastures appeared to regenerate satisfactorily in the following Wet season.

Fire also entered the site from the north in 1990, affecting the northern half of the tailings dam and the stockpile area. Pastures here also do not appear to have been seriously affected.

Whites Overburden Heap

A small patch of die-back was identified in 1989 on the northern end of the heap (Plate 9.1 "E") which did not regenerate or increase in size throughout the remainder of the monitoring period.

Grader grass, was repeatedly slashed and treated with herbicide. Whilst this appeared to be an appropriate control strategy, more prolonged treatment was considered necessary for eradication. *Hyptis suaveolens* within the drains were also repeatedly sprayed and further control work was recommended in April 1993. Isolated *Mimosa pigra* plants were removed from the main north/south drain.

Dysons Open Cut and Overburden Heap

Patchy growth evident on the highest, south-western end of the open cut in 1985 remained constant in area until 1988, however by 1990 it has increased in size extending down to the first contour bank (Plate 9.2 "E"). An additional area of die-back was identified in 1990 at the northern end of the open cut (Plate 9.2 "F"). Both these areas require closer investigation throughout the next monitoring period.

Small infestations of Grader grass were evident on both the heap and open cut, but were thought to be well under control, particularly on the heap, at the end of the monitoring period. Hyptis increased in abundance on the open cut but was also under control in June 1993.

Intermediate Overburden Heap

Small weed infestations were sprayed and brought under control.

Whites North and the copper heap leach area

Pastures continued to be healthy in both these areas and native shrub and tree species sown along the northern flank of the Copper Heap Leach area continued to grow well and protect Whites discharge channel.

Only minimal weed control was required in these areas.

Tailings dam, treatment plant and stockpile area

Tree belts and clumps of native trees and shrubs dominated by *Acacia holosericea* persisted on the tailings dam. Major infestations of Grader grass and Hyptis and isolated *Mimosa pigra* plants were treated, however, and it was anticipated that ongoing treatment would be required into the next monitoring period.

Spraying and slashing were undertaken to control infestations of Grader grass on the treatment plant and stockpile areas and smaller infestations of Hyptis were brought under control to the east of the track (Plate 9.3). The comparatively lighter pasture density on the these two areas reported on by Ryan (in Kraatz and Applegate 1992), no longer appeared to be evident by casual inspection.

Filter cake disposal area and borrow pits

No weed control was carried out on these areas.

9.4 OTHER

Aspects of the revegetation covered by Ryan in 1992 (Kraatz and Applegate), such as soil fauna and chemistry and tree colonisation, were not addressed in any detail throughout the 1988-93 monitoring period. Ant and termite species continued to be observed, however, and tree species (particularly *Acacia holosericea*), continued to grow barring the effects of slashing and occasional wildfires.

9.5 CONCLUSION

Rehabilitated surfaces at Rum Jungle remained stable throughout the 1988-1993 monitoring period. Some isolated repairs were undertaken, however, where the integrity of surface covers or access accross the site were currently or potentially compromised.

Active management of pastures through fertilisation and slashing was ceased due to prohibitive costs and the judgement that this was no longer required. Improved pastures at the site generally remained healthy, however, weeds and wildfire posed significant management problems.

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APPENDIX A

CHEMICAL ANALYSIS OF FLOW SAMPLES*
East Finniss River 1992/1993

Table A.1 Sample dates and flow volumes associated with ICP-MS analyses.

DATE	SAMPLE NUMBER	FLOW VOLUME (gL)
28/1/93	1M	1.24
29/1/93	2M	1.09
1/2/93	3M	5.25
2/2/93	4M	2.43
3/2/93	5M	2.69
5/2/93	6M	2.02
8/2/93	7M	1.38
12/2/93	8M	2.78
16/2/93	9M	1.42
22/2/93	10M	1.05
1/3/93	11M	2.27
9/3/93	12M	3.12
25/3/93	13M	2.16
8/4/93	14M	0.74
29/4/93	15M	0.26
10/5/93	16M	0.00026

**State Chemistry Laboratory ICP-MS analyses November 1993.*

Table A.2 ICP-MS Semi Quantitative Analyses East Finniss River (GS8150097) (1M-9M) (SCL Reference: 45808, Date: 1/11/93).

Elements		1M μg/L	2M μg/L	3M μg/L	4M μg/L	5M μg/L	6M μg/L	7M μg/L	8M μg/L	9M μg/L
Lithium	*	30	10	9	3	5	5	6	5	4
Beryllium	*	3	1	1	0.3	0.5	0.6	0.7	0.6	0.6
Boron		Loss	Loss	Loss	Loss	Loss	Loss	Loss	Loss	Loss
Sodium	*	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a
Magnesium	*	18000	13000	9500	5900	14000	14000	19000	13000	15000
Aluminium		>>9000	>>9000	8300	3100	2500	3600	3200	4300	2300
Silicon		n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Phosphorus		n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Calcium	*	7300	7100	5500	4200	9200	9000	10000	6700	7300
Scandium		9	3	3	0.3	<0.2	0.8	0.5	0.7	<0.2
Titanium		400	130	120	35	25	37	30	40	14
Vanadium	*	53	15	15	4	2	3	1	3	0.8
Chromium	*	33	10	11	3	2	3	1	2	3
Manganese	*	560	610	740	490	1200	1200	1500	900	870
Iron		14000	3800	3500	770	490	740	430	690	300
Cobalt	*	140	110	93	53	130	130	170	120	140
Nickel	*	170	120	100	53	130	130	160	120	140
Copper	*	1100	560	540	180	480	500	630	460	480
Zinc	*	250	150	92	49	130	110	170	110	130
Gallium		15	5	4	1	0.8	0.9	0.6	1	0.3
Germanium		<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Arsenic	*	41	8	6	0.9	1	1	1	2	0.6
Selenium	*	<5	<5	<5	<5	<5	12	<5	<5	5
Bromine		Loss	Loss	Loss	Loss	Loss	Loss	Loss	Loss	Loss
Rubidium	*	58	24	20	9	8	9	7	9	6
Strontium	*	13	9	8	6	9	9	10	8	9
Yttrium		18	8	8	3	5	6	7	6	5
Zirconium		14	6	5	1	0.7	1	1	1	0.4
Niobum		0.4	0.2	0.1	<0.05	<0.05	0.09	<0.05	<0.05	<0.05
Molybdenum	*	3	0.6	0.8	0.2	<0.2	0.2	<0.2	0.2	0.3
Ruthenium		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Rhodium		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Palladium		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Silver	*	0.5	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Cadmium	*	0.8	0.5	0.4	<0.2	1	<0.2	0.6	0.3	<0.2
Indium		Int.Std.	Int.Std.	Int.Std.	Int.Std.	Int.Std.	Int.Std.	Int.Std.	Int.Std.	Int.Std.
Tin		<0.1	<0.1	85	<0.1	<0.1	<0.1	110	<0.1	<0.1
Antimony		<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Iodine		Loss	Loss	Loss	Loss	Loss	Loss	Loss	Loss	Loss
Tellurium	*	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Caesium		3	1	2	0.5	0.2	0.2	0.2	0.2	<0.05
Barium	*	120	58	55	26	25	27	24	24	21
Lanthanum		58	21	24	7	6	9	7	7	5
Cerium		120	43	40	11	14	21	19	17	14
Praseodymium		11	4	4	1	1	2	2	2	1
Neodymium		37	13	13	4	5	8	7	6	4

Elements		1M	2M	3M	4M	5M	6M	7M	8M	9M
Samarium		6	2	2	0.9	1	1	2	2	1
Europium		1	0.5	0.4	0.2	0.3	0.4	0.4	0.4	0.2
Gadolinium		7	3	3	1	1	2	2	2	1
Terbium		0.8	0.3	0.3	0.1	0.2	0.2	0.3	0.2	0.2
Dysprosium		4	2	1	0.6	1	1	2	1	0.9
Holmium		0.7	0.3	0.3	0.1	0.2	0.2	0.3	0.2	0.2
Erbium		2	0.8	0.7	0.2	0.5	0.5	0.9	0.5	0.4
Thulium		0.2	0.09	0.1	<0.04	<0.04	0.05	0.07	0.08	0.05
Ytterbium		2	0.6	0.7	0.2	0.3	0.4	0.6	0.4	0.3
Lutetium		0.2	0.1	0.1	<0.04	0.05	0.06	0.09	0.08	0.04
Hafnium		0.5	0.2	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Tantalum		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Tungsten		0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Rhenium		0.1	<0.1	<0.1	<0.1	0.1	<0.1	0.1	<0.1	0.1
Osmium		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Iridium		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Platinum		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Gold		<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Mercury		<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4
Thallium	*	0.4	0.1	0.1	<0.04	0.06	<0.04	<0.04	<0.04	<0.04
Lead	*	880	130	77	16	14	17	11	17	5
Bismuth	*	2	3	3	0.7	0.4	0.6	0.3	0.4	0.1
Thorium		26	8	7	2	1	2	1	2	0.5
Uranium		63	33	41	18	39	47	56	46	35

Notes: 1. *All concentrations are reported in μg/L. The samples were digested with nitric acid spiked with Indium and analysed by Inductively Coupled Plasma Mass Spectrometry (ICPMS).*

2. *The elements marked "*" are corrected against Reference Water (NBS 1643c) thus producing an accuracy of +/- 20%. All other elements are accurate to within a factor of two. The precision between samples for all elements is +/- 20%.*

3. *Abbreviations are as follows:*

n.a. :*Not Analysed*
Int. Std. :*Internal Standard*
Loss :*Element lost during digestion process*
\>\> :*Concentration is much greater than value indicated due to ICPMS being unable to analyse the sample at this high concentration.*
< :*Less than, which is equivalent to the detection limit of the method.*
/> :*Not greater than the value specified, this being due to an interference in the particular element.*

Table A.3 ICP-MS Semi Quantitive Analyses East Finniss River (GS8150097) (10M-16M) (SCL Reference: 45808, Date: 1/11/93).

Elements		10M µg/L	11M µg/L	12M µg/L	13M µg/L	14M µg/L	15M µg/L	16M µg/L
Lithium	*	4	4	3	3	4	7	6
Beryllium	*	0.8	0.6	0.6	0.5	<0.1	0.2	0.3
Boron		Loss	Loss	Loss	Loss	Loss	Loss	Loss
Sodium	*	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Magnesium	*	17000	15000	13000	20000	30000	53000	59000
Aluminium		3700	2700	3000	1900	320	340	210
Silicon		n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Phosphorus		n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Calcium	*	7600	6200	6100	8100	12000	23000	29000
Scandium		0.3	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Titanium		26	15	26	14	13	28	21
Vanadium	*	1	1	2	0.9	<0.5	<0.5	<0.5
Chromium	*	2	2	4	1	0.7	1	0.8
Manganese	*	610	530	460	430	560	1100	2000
Iron		650	540	690	470	100	170	96
Cobalt	*	150	120	120	170	230	460	480
Nickel	*	140	120	120	160	210	430	400
Copper	*	540	430	470	370	200	340	480
Zinc	*	170	120	120	200	280	670	600
Gallium		0.6	0.5	0.9	0.5	<0.2	<0.2	<0.2
Germanium		<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Arsenic	*	0.7	<0.5	0.8	0.6	<0.5	<0.5	<0.5
Selenium	*	<5	<5	<5	<5	<5	<5	<5
Bromine		Loss	Loss	Loss	Loss	Loss	Loss	Loss
Rubidium	*	6	6	7	6	5	6	9
Strontium	*	8	8	8	9	12	17	24
Yttrium		6	5	5	4	1	2	3
Zirconium		0.9	1	0.9	0.6	<0.1	0.6	0.2
Niobum		0.1	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Molybdenum	*	0.2	0.3	0.4	<0.2	<0.2	<0.2	0.2
Ruthenium		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Rhodium		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Palladium		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Silver	*	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	<0.1
Cadmium	*	0.6	<0.2	0.4	0.9	1	3	2
Indium		Int. Std.	Int. Std.	Int. Std.	Int. Std.	Int. Std.	Int. Std.	Int. Std.
Tin		<0.1	240	<0.1	<0.1	<0.1	<0.1	<0.1
Antimony		0.08	<0.05	<0.05	<0.05	<0.05	<0.05	2
Iodine		Loss	Loss	Loss	Loss	Loss	Loss	Loss
Tellurium	*	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Caesium		0.1	0.2	0.3	0.09	0.09	0.09	<0.05
Barium	*	22	21	23	24	25	32	67
Lanthanum		7	6	7	5	3	7	11
Cerium		20	16	20	13	5	10	18
Praseodymium		2	1	2	1	0.4	0.7	1
Neodymium		7	5	7	4	1	2	4

Elements		10M	11M	12M	13M	14M	15M	16M
Samarium		2	1	1	0.8	0.3	0.3	0.4
Europium		0.5	0.2	0.3	0.1	0.06	0.05	0.1
Gadolinium		2	1	2	0.8	0.3	0.4	0.5
Terbium		0.2	0.2	0.2	0.1	0.04	0.04	0.05
Dysprosium		2	0.9	1	0.6	0.2	0.2	0.2
Holmium		0.2	0.2	0.2	0.08	<0.04	<0.04	<0.04
Erbium		0.7	0.5	0.4	0.3	0.07	0.1	0.1
Thulium		0.09	0.06	0.07	<0.04	<0.04	<0.04	<0.04
Ytterbium		0.7	0.3	0.4	0.2	0.05	0.08	<0.04
Lutetium		0.1	0.04	0.06	<0.04	<0.04	<0.04	<0.04
Hafnium		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Tantalum		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Tungsten		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Rhenium		0.1	<0.1	0.1	0.1	0.2	0.4	0.4
Osmium		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Iridium		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Platinum		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Gold		<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Mercury		<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4
Thallium	*	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Lead	*	12	10	9	6	2	2	2
Bismuth	*	0.2	0.3	0.2	0.1	0.02	0.03	<0.02
Thorium		1	0.8	1	0.7	0.07	0.08	0.02
Uranium		52	31	28	19	8	7	6

Notes: 1. *All concentrations are reported in µg/L. The samples were digested with nitric acid spiked with Indium and analysed by Inductively Coupled Plasma Mass Spectrometry (ICPMS).*

2. *The elements marked "*" are corrected against Reference Water (NBS 1643c) thus producing an accuracy of +/- 20%. All other elements are accurate to within a factor of two. The precision between samples for all elements is +/- 20%.*

3. *Abbreviations are as follows:*

n.a. :*Not Analysed*
Int. Std. :*Internal Standard*
Loss :*Element lost during digestion process*
>> :*Concentration is much greater than value indicated due to ICPMS being unable to analyse the sample at this high concentration.*
< :*Less than, which is equivalent to the detection limit of the method.*
/> :*Not greater than the value specified, this being due to an interference in the particular element.*

APPENDIX B

ANALYSES OF SEDIMENT AND ALGAE SAMPLES*
East Finniss River

SAMPLES

Twenty-seven sediment and seventeen algae samples were received from the Power and Water Authority on April 29, 1993. Sediments were labelled S1-S27 and algae S11-S27. Samples were analysed on an "as received" basis.

SAMPLE PREPARATION

Representative portions of sediment and algae samples were dried in a vacuum oven at 50°C for 48 hours. Sediment samples were then sieved to less than two millimetre grainsize and were digested in Nitric Acid at 130°C for eight hours. All samples were filtered before analysis.

ANALYTICAL METHOD

Acid digests were analysed by Inductively Coupled Plasma - Atomic Emission Spectrometry (ICP - AES) for Zn, Ni, Fe, Mn and Cu.

RESULTS

Metal concentrations are given mg/kg (ppm) on a dry weight basis and are shown in Tables B.1 and B.2.

**Analysis performed by the Northern Territory University.*

Table B.1 ICP-AES analysis of sediments in the East Finniss River 29/4/93.

	Zn	Ni	Fe	Mn	Cu
S1	49	33	16 500	171	370
S2	14.5	25	23 500	96	168
S3	68	63	21 100	72	400
S4	60	64	16 200	95	560
S5	75	45	14 500	197	450
S6	56	78	16 800	151	570
S7	117	230	11 500	67	1 380
S8	85	59	12 700	105	460
S9	108	130	21 900	54	1 450
S10	37	46	39 900	900	360
S11	65	56	43 900	133	389
S12	61	45	21 700	390	560
S13	161	84	11 500	101	1 350
S14	95	85	30 500	151	630
S15	171	116	17 000	320	990
S16	47	41	39 100	230	350
S17	67	60	18 000	142	500
S18	64	110	37 100	97	510
S19	164	106	24 500	106	1 460
S20	51	78	46 000	260	320
S21	193	103	38 800	270	1 020
S22	174	135	33 800	104	1 480
S23	137	91	40 700	170	710
S24	101	80	83 800	680	480
S25	103	106	65 900	520	390
S26	70	67	72 400	820	340
S27	174	84	20 600	92	1 060

Table B.2 ICP-AES analysis of algae in the East Finniss River 29/4/93.

	Zn	Ni	Fe	Mn	Cu
S11	1 130	450	72 100	2 400	14 500
S12	350	93	31 000	121	4 900
S13 *	650	450	23 000	507	5 200
S14	1 270	460	60 800	1 200	9 300
S15	1 010	490	71 800	230	13 800
S16 *	1 350	840	46 600	670	10 600
S17 *	1 200	810	47 000	470	10 800
S18 *	700	240	98 000	97	9 700
S19 *	960	370	131 000	120	11 900
S20 *	810	390	61 000	125	7 000
S21 *	1 640	1 680	156 000	1 190	13 000
S22 *	830	380	80 200	186	8 500
S23 *	530	310	66 800	230	4 200
S24	880	410	68 100	350	8 500
S25	750	280	98 200	300	7 100
S26	910	500	141 000	830	2 500
S27	1 150	600	99 300	950	1 650

* *Sample contains significant amount of fine grained sediment which could not be separated.*

QUALITY CONTROL

Reference materials were analysed in conjunction with sediment and algal samples and the results are shown in Table B.3.

Table B.3 ICP-AES analysis of reference material.

NIST 2704 Buffalo River Sediment (mg/kg)

	Zn	Ni	Fe	Mn	Cu
Result	430	41	33 200	510	92
Certified Value	438	44	41 100	555	98.6

NBS 1572 Citrus Leaves (mg/kg)

	Zn	Ni	Fe	Mn	Cu
Result	27	<2.8	76	20	16.0
Certified Value	29	0.6	90	23	16.5

APPENDIX C

MINESITE WATER QUALITY MONITORING 1989/90 & 1990/91

Extracts from: Henkel (1991a) and Henkel (1991b)

C.1 MINE SITE MONITORING 1989/90

Introduction

During the 1989-90 wet season, samples from various mine site locations were collected on eight occasions. The samples collected were analysed in the same manner as those for GS8150097.

Insufficient data prevented any estimation of loads originating from the various mine site locations. The sampling locations are shown in Figure C.1.

Diversion channel (GS8150209 and GS8150211)

The results obtained confirmed that seepage from the overburden heaps still contributes freely to the contamination of water in the Diversion Channel of the East Finniss River.

An indication of the magnitude of contamination due to seepage can be gleaned by comparing results obtained for gauging stations GS8150209 and GS8150211. These results are shown in tables C.1 and C.2.

Water passing GS8150209, which is the gauging point at the beginning of the Diversion Channel, originates from the relatively undisturbed upper reaches of Fitch Creek.

Gauging station GS8150211 is located approximately 700 m downstream from GS8150209, opposite Intermediate Overburden Heap.

Since the establishment of vegetation, which followed covering of the overburden heaps during the rehabilitation programme, samples taken in previous wet seasons show that the run off water during periods of heavy rainfall is practically unpolluted.

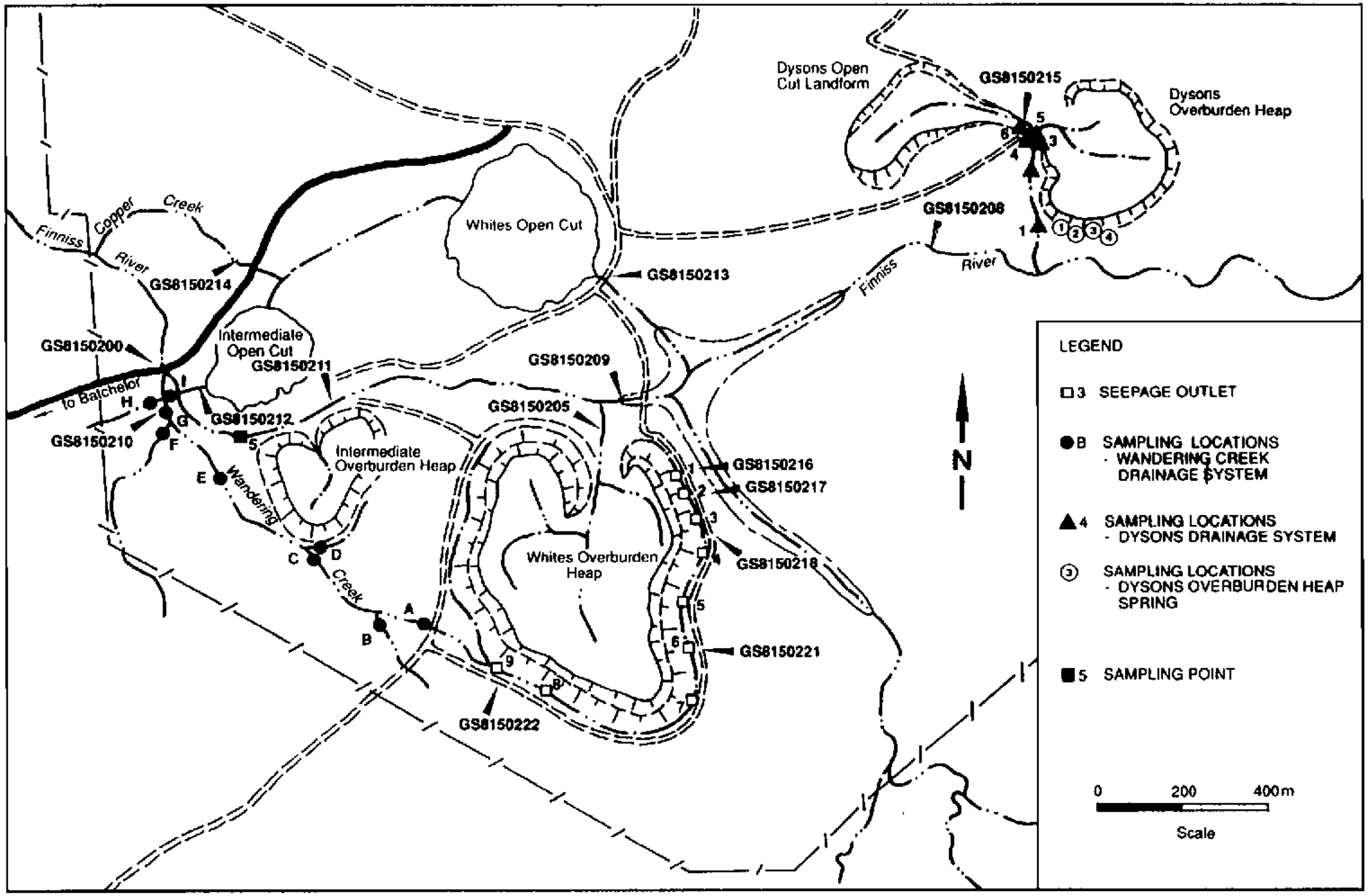

Figure C.1 Rum Jungle mine site sampling locations.

Table C.1 Water quality at East Branch Diversion Channel (GS8150209).

DATE	FLOW (L/s)	pH	SC (μS/cm)	Cu (mg/L)	Mn (mg/L)	Zn (mg/L)	SO_4 (mg/L)
21-01-90	59	5.8	510	0.72	0.72	0.43	240
09-02-90	22	6.9	420	0.06	0.06	0.24	180
02-03-90	5	3.7	2100	3.0	3.0	2.2	1300
23-03-90	113	6.9	190	0.07	0.12	0.10	67
20-04-90	140	6.8	320	0.01	0.20	0.18	130
04-05-90	14	7.0	390	0.06	0.21	0.20	170
18-05-90	81	7.1	190	0.08	0.10	0.08	65
30-05-90	65	6.9	200	0.05	0.12	0.09	70

Table C.2 Water quality at East Branch Diversion Channel (GS8150211).

DATE	FLOW (L/s)	pH	SC (μS/cm)	Cu (mg/L)	Mn (mg/L)	Zn (mg/L)	SO_4 (mg/L)
24-01-90	57	4.5	880	0.64	0.64	0.67	460
09-02-90	28	4.0	1000	1.0	1.8	2.5	530
02-03-90	5	3.4	2400	25	25	24	1500
26-03-90	103	5.9	430	0.06	0.37	0.79	200
20-04-90	88	6.1	520	0.31	0.45	0.96	250
04-05-90	12	3.8	1370	2.0	2.9	4.6	790
18-05-90	92	6.6	380	0.20	0.33	0.79	170
30-05-90	65	6.2	470	0.09	0.50	1.10	220

Wandering Creek (GS8150210)

Contaminants carried by Wandering Creek are measured at GS8150210. The water quality in Wandering Creek is affected by the springs occurring at the toe of Whites Overburden Heap which traditionally discharged highly contaminated water.

Considering the low flow conditions during the 1989-90 wet season, the water quality as sampled at GS8150210 was greatly improved when compared with previous wet seasons. This could mean that the covering of Whites Overburden Heap is working effectively at reducing acid drainage.

Water quality data for Wandering Creek for the 1989-90 wet season are shown in Table C.3.

Table C.3 Water quality at Wandering Creek (GS8150210).

DATE	FLOW (L/s)	pH	SC (μS/cm)	Cu (mg/L)	Mn (mg/L)	Zn (mg/L)	SO_4 (mg/L)
24-01-90	26	4.4	1 630	4.4	2.0	2.0	1 000
09-02-90	4	4.5	1 400	3.2	1.7	1.6	840
02-03-90			NO	FLOW			
23-03-90	10	4.5	1 400	3.6	1.8	1.5	830
20-04-90	19	4.5	990	2.1	0.96	0.90	540
04-05-90	2	5.0	850	0.98	0.52	0.56	450
18-05-90	10	5.4	490	0.45	0.21	0.33	230
30-5-90	4	6.7	85	0.01	0.01	0.01	28

Intermediate Open Cut outflow (GS8150212)

On the eight sampling trips on the Rum Jungle mine site during the 1989-90 wet season, Intermediate Open Cut was found to have discharged to the river twice only.

The water quality on both occasions was in line with the water quality expected to exist in the Intermediate Open Cut at the time of sampling. This is essentially equivalent to the quality of water discharged from Whites Open Cut, plus some increase of heavy metals which were picked up from seepages from the banks of the water course connecting the open cuts (Table C.4). This water course is the old bed of the East Finniss River and also drains the rehabilitated Copper Leach Heap area.

Whites Open Cut inflow (GS8150213)

Water quality at GS8150213 was good and of similar quality to that of the previous two wet seasons. The data are shown in Table C.5.

Considering the much reduced flow and consequent reduced capacity to dilute contaminants, the indication is that the integrity of the rehabilitated Dysons Open Cut area has been maintained.

Table C.4 Water quality at Intermediate Open Cut outflow (GS8150212).

DATE	FLOW (L/s)	pH	SC (μS/cm)	Cu (mg/L)	Mn (mg/L)	Zn (mg/L)	SO_4 (mg/L)
24-1-90			NO	FLOW			
9-2-90			NO	FLOW			
2-3-90			NO	FLOW			
23-3-90	79	5.3	500	0.77	1.3	0.16	230
20-4-90	1	5.3	520	0.89	1.3	0.17	230
4-5-90			NO	FLOW			
18-5-90			NO	FLOW			
30-5-90			NO	FLOW			

Table C.5 Water quality at Whites Open Cut inflow (GS8150213).

DATE	FLOW (L/s)	pH	SC (μS/cm)	Cu (mg/L)	Mn (mg/L)	Zn (mg/L)	SO_4 (mg/L)
24-1-90	2	4.0	650	0.97	1.4	0.45	310
9-2-90			NO	FLOW			
2-3-90			NO	FLOW			
23-3-90	416	6.7	160	0.01	0.06	0.01	53
20-4-90	85	6.6	230	0.01	0.16	0.06	86
4-5-90			NO	FLOW			
18-5-90	90	6.8	150	0.01	0.01	0.01	47
30-5-90	16	6.4	330	0.01	0.19	0.13	140

Copper Creek (GS8150214)

Part of the outflow from Whites Open Cut is directed through Copper Creek to the East Finniss River downstream of GS8150200. The water quality measured at GS8150214 is similar to that of the outflow of the open cut, but some heavy metals were picked up in the water course between the Whites Open Cut outflow culvert and GS8150214. The data are presented in Table C.6.

Table C.6 Water quality at Copper Creek (GS8150214).

DATE	FLOW (L/s)	pH	SC (μS/cm)	Cu (mg/L)	Mn (mg/L)	Zn (mg/L)	SO_4 (mg/L)
24-1-90			NO	FLOW			
9-2-90			NO	FLOW			
2-3-90			NO	FLOW			
23-3-90	348	6.3	330	0.15	0.95	0.09	140
20-4-90	139	6.1	390	0.37	1.2	0.13	170
4-5-90			NO	FLOW			
18-5-90	110	6.2	410	0.32	1.3	0.12	180
30-5-90	12	5.6	480	0.7	1.9	0.17	220

East Finniss River (GS8150200)

GS8151200 is the sampling point on the East Finniss River where most of the immediate mine site contamination is measured. Only some of the contaminants originating from Whites Open Cut reach the East Finniss River through Copper Creek which has its confluence with the East Finniss River downstream from GS8150200.

The results obtained at GS8150200 are notable in that the heavy metal concentrations are significantly higher than would be expected from results obtained at GS8150097.

This phenomenon has been noticed since rehabilitation was completed in 1986 when pH values of run-off water from the mine site were raised. Thus, seepages with low pH values carrying high contaminant concentrations, are not only diluted, but the pH values have increased sufficiently to permit precipitation of metals. These precipitated metals are carried as a light floc and, subject to the velocity of flow, can settle as far away as the flood plains of the Finniss River.

Precipitates that settled in the bed of the East Finniss River and remained as solids during the dry season, would be redissolved during the first flush of following wet season, when the initial flow of normally low pH water, is transported in the East Finniss River system. Table C.7 lists results obtained at GS8150200 for the 1989-90 wet season.

Tables C.8 to C.15 list the mine site sampling data and data collected at GS8150097 for the days samples were taken at the mine site.

Table C.7 Water quality at East Finniss River (GS8150200).

DATE	FLOW (L/s)	pH	SC (μS/cm)	Cu (mg/L)	Mn (mg/L)	Zn (mg/L)	SO_4 (mg/L)
24-01-90	74	4.4	1120	2.3	1.8	1.7	640
09-02-90	26	4.1	1060	1.7	1.9	2.4	590
02-03-90	5	3.5	2260	3.8	5.5	6.8	1430
23-03-90	178	5.4	520	0.39	0.78	0.62	260
20-04-90	116	5	620	0.87	0.86	1	320
04-05-90	11	3.7	1290	2	2.9	3.8	740
18-05-90	92	6.3	400	0.12	0.43	0.74	180
30-05-90	69	6.2	430	0.24	0.52	0.98	200

Table C.8 Mine site water quality (*Sampling date: 24/01/90*).

GS8150	FLOW (L/s)	pH	SC (μS/cm)	Cu (mg/L)	Mn (mg/L)	Zn (mg/L)	SO_4 (mg/L)
097	85	6.2	530	0.78	0.67	0.94	340
200	74	4.4	1 120	2.3	1.8	1.7	641
209	59	5.8	510	0.72	0.83	0.43	240
210	26	4.4	1 630	4.4	2.0	2.0	1 000
211	57	4.5	880	0.64	0.64	0.67	460
212			NO	FLOW			
213	2	4.0	650	0.97	1.4	0.45	310
214			NO	FLOW			

Table C.9 **Mine site water quality** ***(Sampling date: 09/02/90).***

GS8150	FLOW (L/s)	pH	SC (μS/cm)	Cu (mg/L)	Mn (mg/L)	Zn (mg/L)	SO_4 (mg/L)
097	24	4.8	830	1.5	1.5	1.5	430
200	26	4.1	1 060	1.7	1.9	2.4	590
209	22	6.9	420	0.06	0.25	0.24	180
210	4	4.5	1 400	3.2	1.7	1.6	840
211	28	4.0	1 000	1.0	1.8	1.6	530
212			NO	FLOW			
213			NO	FLOW			
214			NO	FLOW			

Table C.10 **Mine site water quality** ***(Sampling date: 02/03/90).***

GS8150	FLOW (L/s)	pH	SC (μS/cm)	Cu (mg/L)	Mn (mg/L)	Zn (mg/L)	SO_4 (mg/L)
097	3	5.8	510	0.15	1.2	0.45	230
200	5	3.5	2260	3.8	5.5	6.8	1430
209	5	3.7	2100	3.0	3.0	2.2	1300
210			NO	FLOW			
211	5	3.4	2400	25.0	25	24	1500
212			NO	FLOW			
213			NO	FLOW			
214			NO	FLOW			

Table C.11 Mine site water quality (*Sampling date: 23/03/90*).

GS8150	FLOW (L/s)	pH	SC (μS/cm)	Cu (mg/L)	Mn (mg/L)	Zn (mg/L)	SO_4 (mg/L)
097	545	5.5	420	0.16	1.1	0.22	190
200	178	5.4	520	0.39	0.78	0.62	260
209	113	6.9	190	0.07	0.12	0.10	67
210	10	4.5	1 400	3.6	1.8	1.5	830
211	103	5.9	430	0.06	0.37	0.79	200
212	79	5.3	500	0.77	1.3	0.16	230
213	416	6.7	160	0.01	0.06	0.01	53
214	348	6.3	330	0.15	0.95	0.09	140

Table C.12 Mine site water quality (*Sampling date: 20/04/90*).

GS8150	FLOW (L/s)	pH	SC (μS/cm)	Cu (mg/L)	Mn (mg/L)	Zn (mg/L)	SO_4 (mg/L)
097	285	6.1	520	0.42	1.4	0.55	240
200	116	5.0	620	0.87	0.86	1.0	320
209	140	6.8	320	0.01	0.20	0.18	130
210	19	4.5	990	2.1	0.96	0.90	540
211	88	6.1	520	0.31	0.45	0.96	250
212	1	5.3	520	0.89	1.3	0.17	230
213	85	6.6	230	0.01	0.16	0.06	86
214	139	6.1	390	0.37	1.2	0.13	170

Table C.13 Mine site water quality (*Sampling date: 04/05/90*).

GS8150	FLOW (L/s)	pH	SC (μS/cm)	Cu (mg/L)	Mn (mg/L)	Zn (mg/L)	SO_4 (mg/L)
097	11	6.1	780	0.44	1.1	1.1	410
200	11	3.7	1 290	2.0	2.9	3.8	740
209	14	7.0	390	0.06	0.21	0.20	170
210	2	5.0	850	0.98	0.52	0.56	450
211	12	3.8	1 370	2.0	2.9	4.6	790
212			NO	FLOW			
213			NO	FLOW			
214			NO	FLOW			

Table C.14 Mine site water quality (*Sampling date: 18/05/90*).

GS8150	FLOW (L/s)	pH	SC (μS/cm)	Cu (mg/L)	Mn (mg/L)	Zn (mg/L)	SO_4 (mg/L)
097	189	6.6	470	0.09	1.1	0.32	220
200	92	6.3	400	0.12	0.43	0.74	180
209	81	7.1	190	0.08	0.10	0.08	65
210	10	5.4	490	0.45	0.21	0.33	230
211	92	6.6	380	0.20	0.33	0.79	170
212			NO	FLOW			
213	90	6.8	150	0.01	0.01	0.01	47
214	110	6.2	410	0.32	1.3	0.12	180

Table C.15 Mine site water quality (*Sampling date: 30/05/90*).

GS8150	FLOW (L/s)	pH	SC (μS/cm)	Cu (mg/L)	Mn (mg/L)	Zn (mg/L)	SO_4 (mg/L)
097	57	6.6	550	0.02	0.81	0.42	250
200	69	6.2	430	0.24	0.52	0.98	200
209	65	6.9	200	0.05	0.12	0.09	70
210	4	6.7	85	0.01	0.01	0.01	28
211	65	6.2	470	0.09	0.50	1.1	220
212			NO	FLOW			
213	16	6.4	330	0.01	0.19	0.13	140
214	12	5.6	480	0.70	1.9	0.17	220

C.2 MINE SITE MONITORING 1990/91

Mine Site Water Quality

Sampling of seven mine site gauging stations was carried out at approximately three week intervals during the 1990/91 wet season. Data collected from these sampling points were useful to verify the data obtained at GS8150097.

The information obtained showed that a major source of mine site Zn, SO_4 and Cu contamination appears to be seepages from Whites and Intermediate Overburden Heaps. The magnitude of contaminant input over such a relatively short distance can be demonstrated by calculating the difference of contaminant concentrations between GS8150209 and GS8150211. Tables C.16 through to C.23 present the 1990-91 mine site sampling data. Figure C.1 shows the mine site sampling locations for this period.

There are also significant amounts of contaminated seepage from the north eastern side of Whites Overburden Heap entering Fitch Creek above GS8150209.

Some of the mine site Mn and SO_4 contaminant loads originated from the contaminated bed of the East Finniss River adjacent to the Dysons Open Cut regeneration area. There is no evidence, however, of significant amounts of Cu or Zn coming from this area.

The rehabilitated Copper Leach Heap area is also a major contributor to Cu contamination, with an estimated 2.6-3.0 tonnes of Cu having entered the re-diversion channel, which follows the original bed of the East Finniss River connecting Whites and Intermediate Open Cuts.

Table C.16 Mine site water quality (*Sampling date: 14/12/90*).

GS8150	FLOW (L/s)	pH	COND (μS/cm)	Cu DISS (mg/L)	Mn DISS (mg/L)	Zn DISS (mg/L)	SO_4 (mg/L)	Cu TOT (mg/L)	Mn TOT (mg/L)	Zn TOT (mg/L)
097	510	5.0	700	0.95	2.5	0.6	370	1.00	2.7	0.76
200	153	5.1	700	0.79	0.90	0.65	330	1.21	1.14	0.69
209	95	7.3	198	0.13	0.13	0.11	66	0.23	0.16	0.19
210	26	4.4	1 472	3.10	1.60	1.64	883	3.65	1.62	1.70
211	97	6.8	382	0.11	0.31	0.27	163	0.58	0.58	0.48
212	42	4.6	844	1.04	2.53	0.34	427	1.30	2.37	0.39
213	283	6.9	167	0.09	0.21	0.07	61	0.18	0.25	0.10
214	293	4.7	577	0.77	3.51	0.28	265	0.99	3.5	0.24

Table C.17 Mine site water quality (*Sampling date: 04/01/91*).

GS8150	FLOW (L/s)	pH	COND (μS/cm)	Cu DISS (mg/L)	Mn DISS (mg/L)	Zn DISS (mg/L)	SO_4 (mg/L)	Cu TOT (mg/L)	Mn TOT (mg/L)	Zn TOT (mg/L)
097	371	5.1	310	0.10	0.34	0.10	130	0.09	0.61	0.23
200	131	5.9	430	0.18	0.44	0.59	185	0.56	0.73	0.64
209	88	6.8	255	0.02	0.13	0.17	101	0.27	0.23	0.22
210	24	5.4	422	0.45	0.24	0.29	196	0.74	0.39	0.37
211	95	5.9	409	0.20	0.37	0.74	187	0.52	0.65	0.72
212	6	5.8	436	0.56	1.86	0.24	202	0.94	1.98	0.23
213	221	6.8	197	0.04	0.20	0.06	76	0.11	0.21	0.14
214	237	6.7	210	0.11	0.79	0.08	83	0.29	0.81	0.12

Table C.18 **Mine site water quality (*Sampling date: 15/01/91*).**

GS8150	FLOW (L/s)	pH	COND (μS/cm)	Cu DISS (mg/L)	Mn DISS (mg/L)	Zn DISS (mg/L)	SO_4 (mg/L)	Cu TOT (mg/L)	Mn TOT (mg/L)	Zn TOT (mg/L)
097	3 570	5.7	300	0.20	1.51	0.19	130	0.31	1.56	0.18
200	1 856	5.0	322	0.48	1.56	0.25	130	0.56	1.64	0.17
209	135	6.1	337	0.10	0.19	0.34	151	0.39	0.33	0.30
210	222	6.4	270	0.18	0.13	0.15	112	0.42	0.23	0.30
211	141	5.5	550	0.49	0.54	0.85	277	0.74	0.88	0.85
212	1 685	4.9	295	0.58	1.91	0.18	124	0.62	1.95	0.20
213	2 052	6.5	128	0.01	0.19	0.05	48	0.14	0.20	0.10
214	678	5.0	234	0.40	1.62	0.13	97	0.48	1.58	0.13

Table C.19 **Mine site water quality (*Sampling date: 05/02/91*).**

GS8150	FLOW (L/s)	pH	COND (μS/cm)	Cu DISS (mg/L)	Mn DISS (mg/L)	Zn DISS (mg/L)	SO_4 (mg/L)	Cu TOT (mg/L)	Mn TOT (mg/L)	Zn TOT (mg/L)
097	4 040	6.5	251	0.06	0.65	0.14	115	0.59	0.84	0.20
200	2 084	5.4	254	0.32	0.87	0.22	98	0.44	0.99	0.21
209	341	6.0	358	0.26	0.19	0.34	163	0.61	0.35	0.33
210	257	6.7	255	0.20	0.14	0.15	105	0.40	0.23	0.26
211	374	5.7	453	0.57	0.40	0.66	224	0.74	0.65	0.65
212	1 658	5.0	198	0.39	1.16	0.07	81	0.52	1.18	0.12
213	2 027	6.6	119	0.03	0.18	0.04	46	0.10	0.18	0.07
214	674	5.1	179	0.41	1.05	0.08	74	0.44	1.01	0.11

Table C.20 Mine site water quality (*Sampling date: 27/02/91*).

GS8150	FLOW (L/s)	pH	COND (μS/cm)	Cu DISS (mg/L)	Mn DISS (mg/L)	Zn DISS (mg/L)	SO_4 (mg/L)	Cu TOT (mg/L)	Mn TOT (mg/L)	Zn TOT (mg/L)
097	3 600	6.3	288	0.15	0.74	0.18	120	0.74	0.92	0.28
200	2 569	5.1	278	0.52	0.82	0.26	113	0.60	0.90	0.30
209	432	5.8	329	0.21	0.15	0.35	149	0.39	0.29	0.38
210	227	6.2	293	0.28	0.19	0.19	122	0.58	0.29	0.30
211	530	4.8	511	0.96	0.67	1.02	257	0.9	0.78	0.96
212	1 769	5.2	188	0.39	1.02	0.10	76	0.54	1.01	0.09
213	1 887	6.3	118	0.02	0.17	0.01	44	0.16	0.18	0.07
214	618	5.2	186	0.47	1.04	0.08	76	0.51	1.01	0.06

Table C.21 Mine site water quality (*Sampling date: 19/03/91*).

GS1850	FLOW (L/s)	pH	COND (μS/cm)	Cu DISS (mg/L)	Mn DISS (mg/L)	Zn DISS (mg/L)	SO_4 (mg/L)	Cu TOT (mg/)	Mn TOT (mg/L)	Zn TOT (mg/L)
097	989	6.8	361	0.06	0.49	0.17	155	0.11	0.53	0.25
200	471	6.0	398	0.37	0.71	0.67	191	0.63	0.75	0.69
209	312	6.8	324	0.08	0.33	0.29	159	0.37	0.25	0.36
210	47	5.7	358	0.60	0.40	0.35	164	0.75	0.42	0.35
211	282	5.8	477	0.38	0.74	0.84	213	0.59	0.76	0.87
212	66	6.4	167	0.36	0.66	0.09	65	0.42	0.67	0.09
213	566	6.9	182	0.07	0.33	0.11	68	0.12	0.33	0.12
214	415	6.6	188	0.20	0.57	0.10	73	0.33	0.58	0.09

Table C.22 **Mine site water quality** ***(Sampling date: 09/04/91).***

GS8150	FLOW (L/s)	pH	COND (μS/cm)	Cu DISS (mg/L)	Mn DISS (mg/L)	Zn DISS (mg/L)	SO_4 (mg/L)	Cu TOT (mg/L)	Mn TOT (mg/L)	Zn TOT (mg/L)
097	1 910	6.6	271	0.05	0.61	0.11	109	0.15	0.69	0.19
200	1 057	6.3	304	0.37	0.73	0.39	142	0.67	0.76	0.38
209	280	6.8	300	0.12	0.30	0.25	138	0.33	0.32	0.30
210	88	5.0	467	1.04	0.55	0.44	234	1.12	0.55	0.46
211	362	6.2	385	0.25	0.66	0.68	184	0.48	0.69	0.67
212	506	6.5	165	0.25	0.74	0.08	71	0.37	0.77	0.09
213	1 617	6.9	143	0.08	0.34	0.07	52	0.16	0.34	0.09
214	627	6.5	172	0.23	0.78	0.07	68	0.38	0.75	0.09

Table C.23 **Mine site water quality** (***Sampling date: 30/04/91).***

GS8150	FLOW (L/s)	pH	COND (μS/cm)	Cu DISS (mg/L)	Mn DISS (mg/L)	Zn DISS (mg/L)	SO_4 (mg/L)	Cu TOT (mg/L)	Mn TOT (mg/L)	Zn TOT (mg/L)
097	386	6.9	420	0.02	0.74	0.18	190	0.05	0.74	0.20
200	129	6.0	538	0.51	1.02	1.14	268	1.27	1.21	1.18
209	112	7.0	353	0.08	0.40	0.26	267	0.27	0.43	0.30
210	19	6.5	339	0.19	0.30	0.27	150	0.48	0.32	0.28
211	98	6.3	563	0.22	1.07	1.29	288	0.50	11.13	1.35
212	<1	6.5	177	0.39	0.83	0.09	67	0.43	0.82	0.09
213	160	6.9	131	0.04	0.30	0.04	46	0.08	0.29	0.04
214	144	6.7	184	0.22	0.75	0.07	71	0.34	0.72	0.09

It is estimated that during the 1990-91 wet season 80% of mine site wet season flow went through GS8150213 into the open cuts, with the remaining 20% of mine site flow through GS8150209 (at the start of the Diversion Channel) and GS8150210 (Wandering Creek).

Comparison of percentage contributions by selected mine site locations to the loads measured at GS8150097 are shown in Table C.24. These contaminant loads are based on total contaminant concentration measured at the various mine site sampling points and GS8150097.

Table C.24 Mine site contaminant loads.

SOURCE	Cu (t)	Cu (%)	Mn (t)	Mn (%)	Zn (t)	Zn (%)	SO_4 (t)	SO_4 (%)
East Finniss River and Fitch Creek upstream from GS8150209 and GS8150213	4.3	29	7.1	23	2.1	28	1500	37
Whites and Intermediate Overburden Heaps down stream of GS8150209	4.4	29	4.2	14	4.6	62	1400	35
Open cuts (estimated using mine site data)	6.3*	42	19	63	0.7	9	1100	28
Open cuts (estimated from gaugings in May 1991 and October 1990 to 35m AHD)	3.8	25	20	65	0.8	11	1100	28
GS8150097 (188 days of gauging and analytical data)	15		31		7.4		4000	

* *Includes an estimated 2.6 to 3.0 t of Cu contributed by the rehabilitated Copper Leach Heap area.*

Data obtained from mine site sampling also showed that dissolved Cu concentrations are greatly affected by the rise of pH and the distance travelled away from the contamination source.

It is interesting to note that Cu appears to fall out of solution freely at pH values as low as 5.2. The effect of pH in the range found in the East Finniss River, however, has less pronounced effect on total and dissolved Zn and Mn concentrations.

It is thought that aeration caused by rapids and eddies is sufficient to increase the pH enough to cause the precipitation of metal contaminants. Table C.25 shows the ratios of the mean dissolved and total metal contaminants at the various gauging stations.

Table C.25 Comparison of dissolved and total contaminant concentrations.

	GS	8150097	8150200	8150209	8150210	8150211	8150212	8150213	8150214
	MEAN pH	6.2	5.4	6.4	6.2	5.6	5.2	6.5	5.6
Cu	DISSOLVED (mg/L)	0.08	0.43	0.15	0.41	0.52	0.44	0.04	0.37
	TOTAL (mg/L)	0.37	0.58	0.39	0.64	0.68	0.55	0.14	0.47
	RATIO DISS/TOTAL	1:4.9	1:1.3	1:2.6	1:1.6	1:1.3	1:1.3	1:3.7	1:1.3
Mn	DISSOLVED (mg/L)	0.6	0.97	0.23	0.25	0.61	1.3	0.22	1.2
	TOTAL (mg/L)	0.75	1.1	0.31	0.33	0.74	1.3	0.23	1.2
	RATIO DISS/TOTAL	1:1.3	1:1.1	1:1.4	1:1.3	1:1.2	1:1.0	1:1.0	1:1.0
Zn	DISSOLVED (mg/L)	0.15	0.3	0.29	0.25	0.82	0.11	0.05	0.1
	TOTAL (mg/L)	0.18	0.3	0.33	0.35	0.82	0.13	0.09	0.11
	RATIO DISS/TOTAL	1:1.2	1:1.0	1:1.1	1:1.4	1:1.0	1:1.2	1:1.8	1:1.1

APPENDIX D

SURFACE WATER QUALITY AND HYDROLOGY EAST FINNISS RIVER 1988/89 TO 1992/93

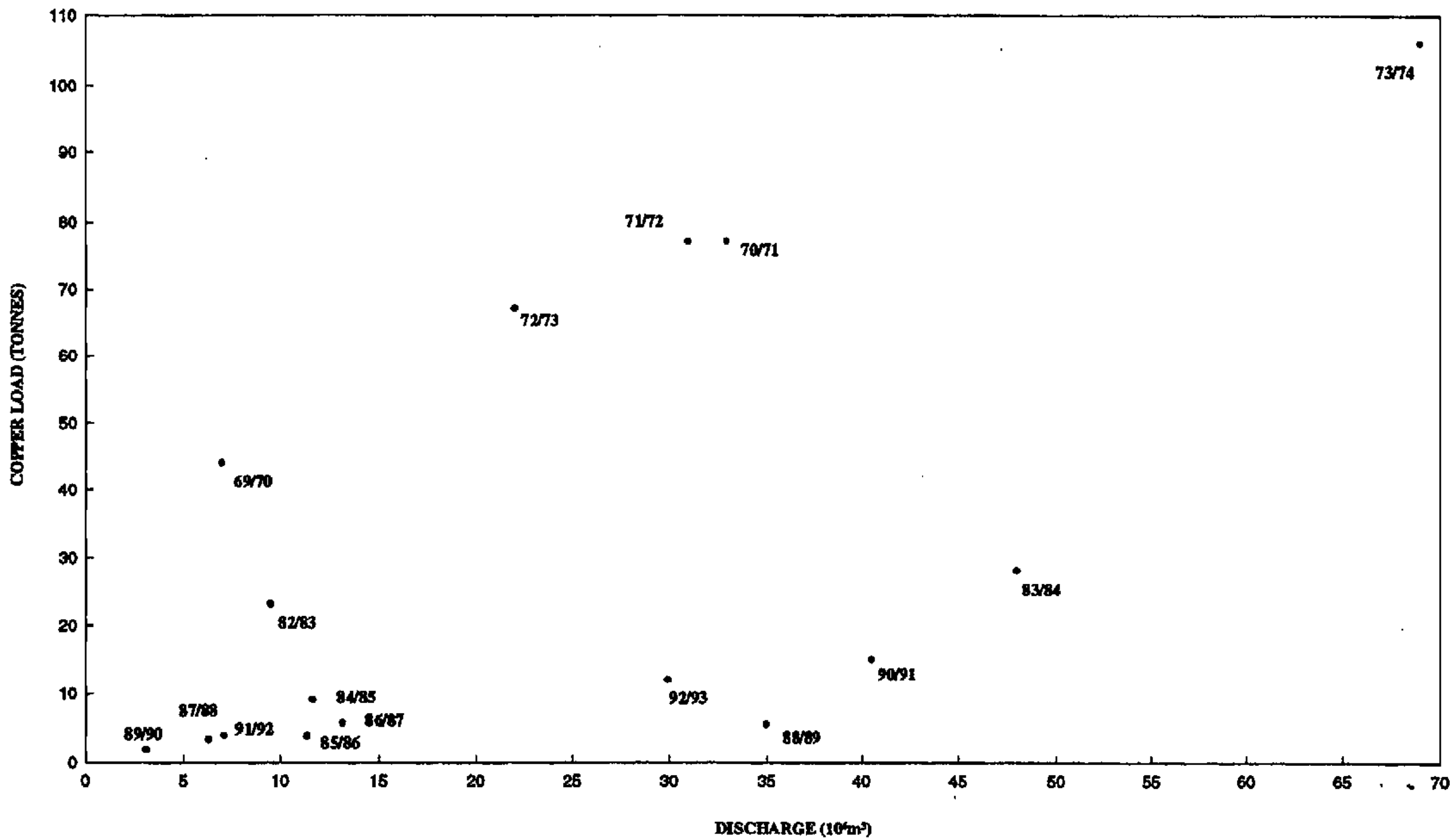

Figure D.1 Annual Cu loads as measured at GS8150097 East Finniss River.

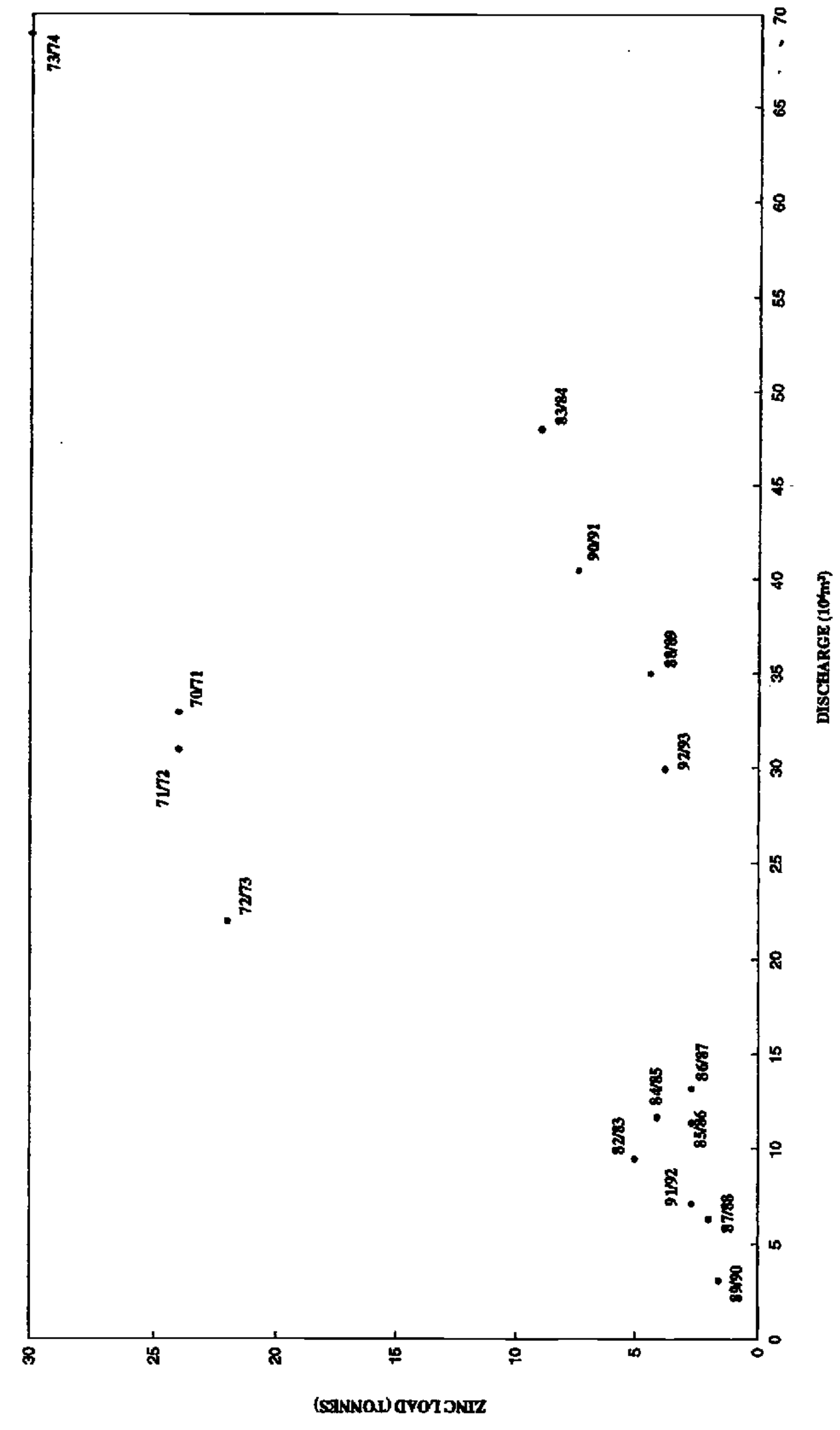

Figure D.2 Annual Zn loads as measured at GS8150097 East Finniss River.

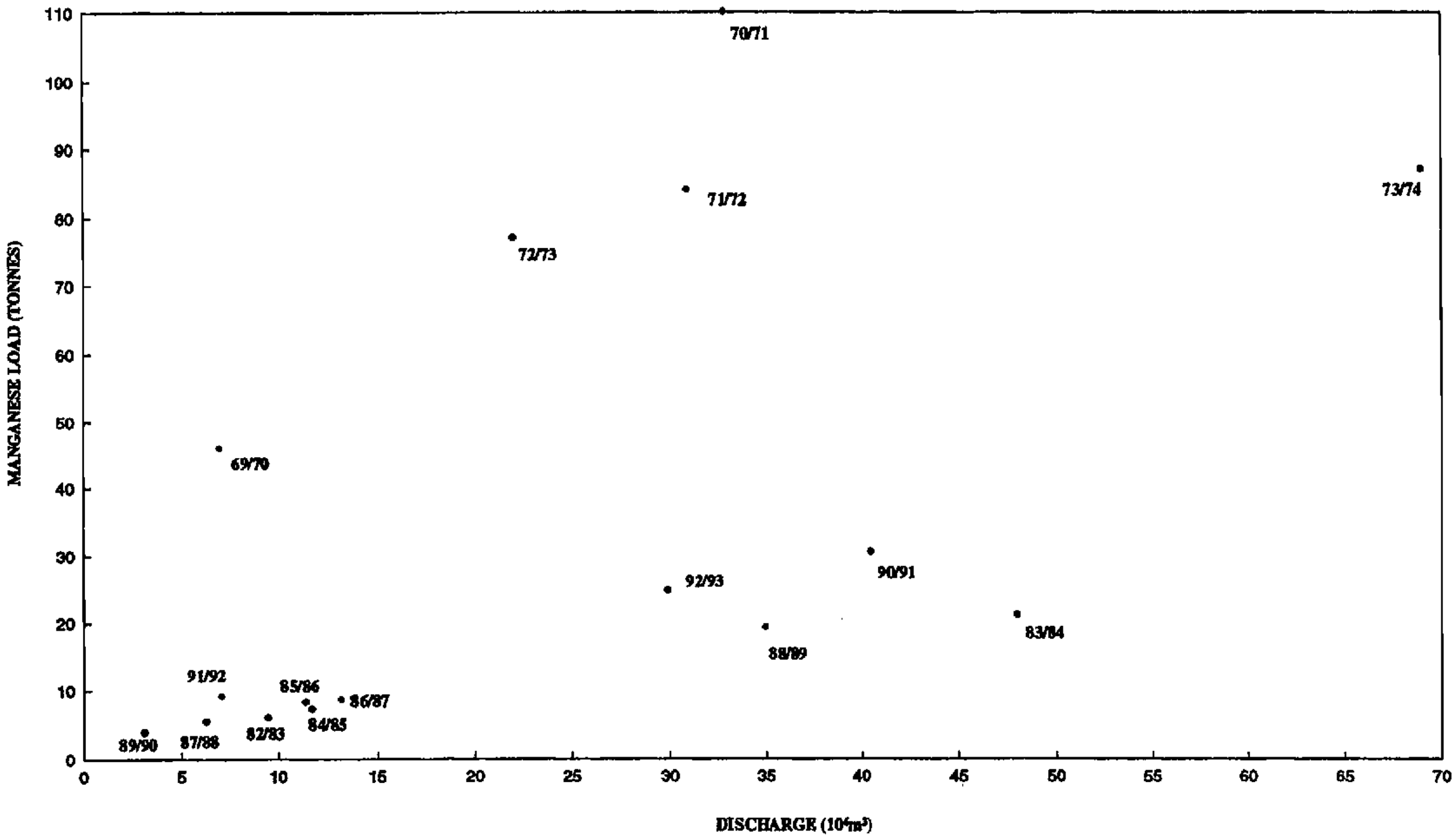

Figure D.3 Annual Mn loads as measured at GS8150097 East Finniss River.

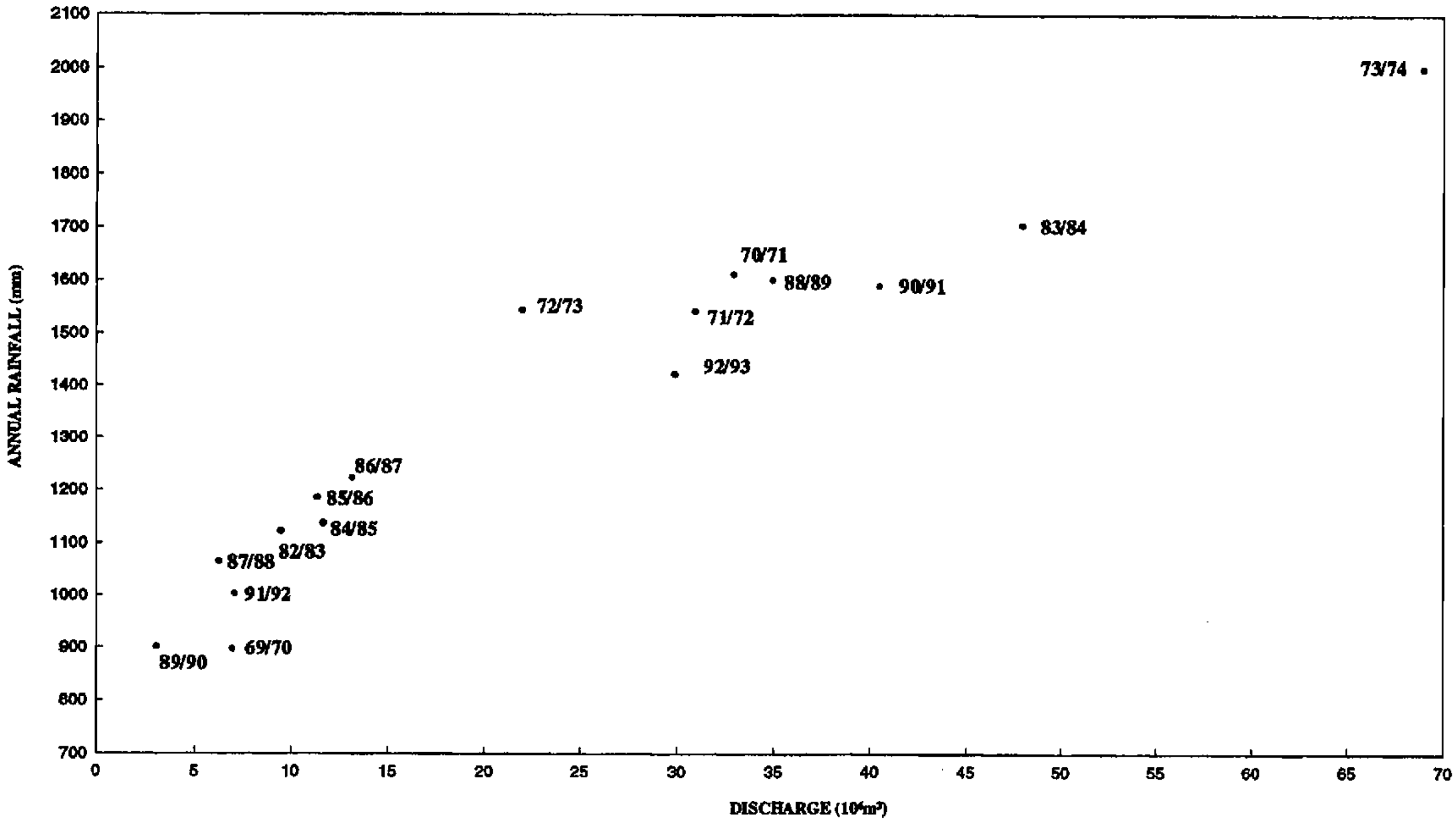

Figure D.4 Annual rainfall, as measured at pluviometer R8150205, versus annual total discharge at GS8150097.

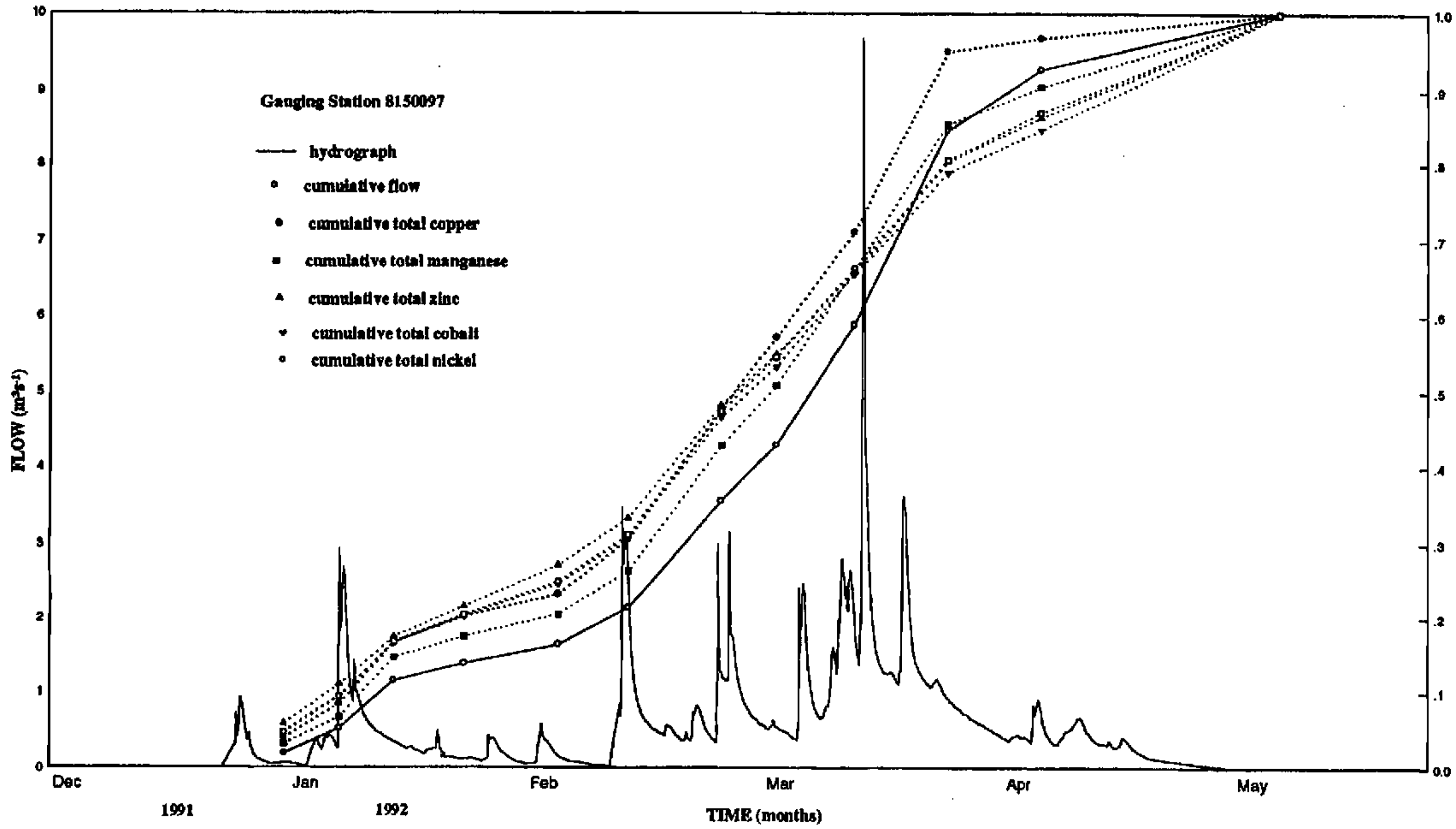

Figure D.5 East Finniss River Gauging Station 8150097 - plot of cumulative total Cu, Mn, Zn, Co and Ni loads with cumulative flow and hydrograph from 24/12/91 to 15/05/92.

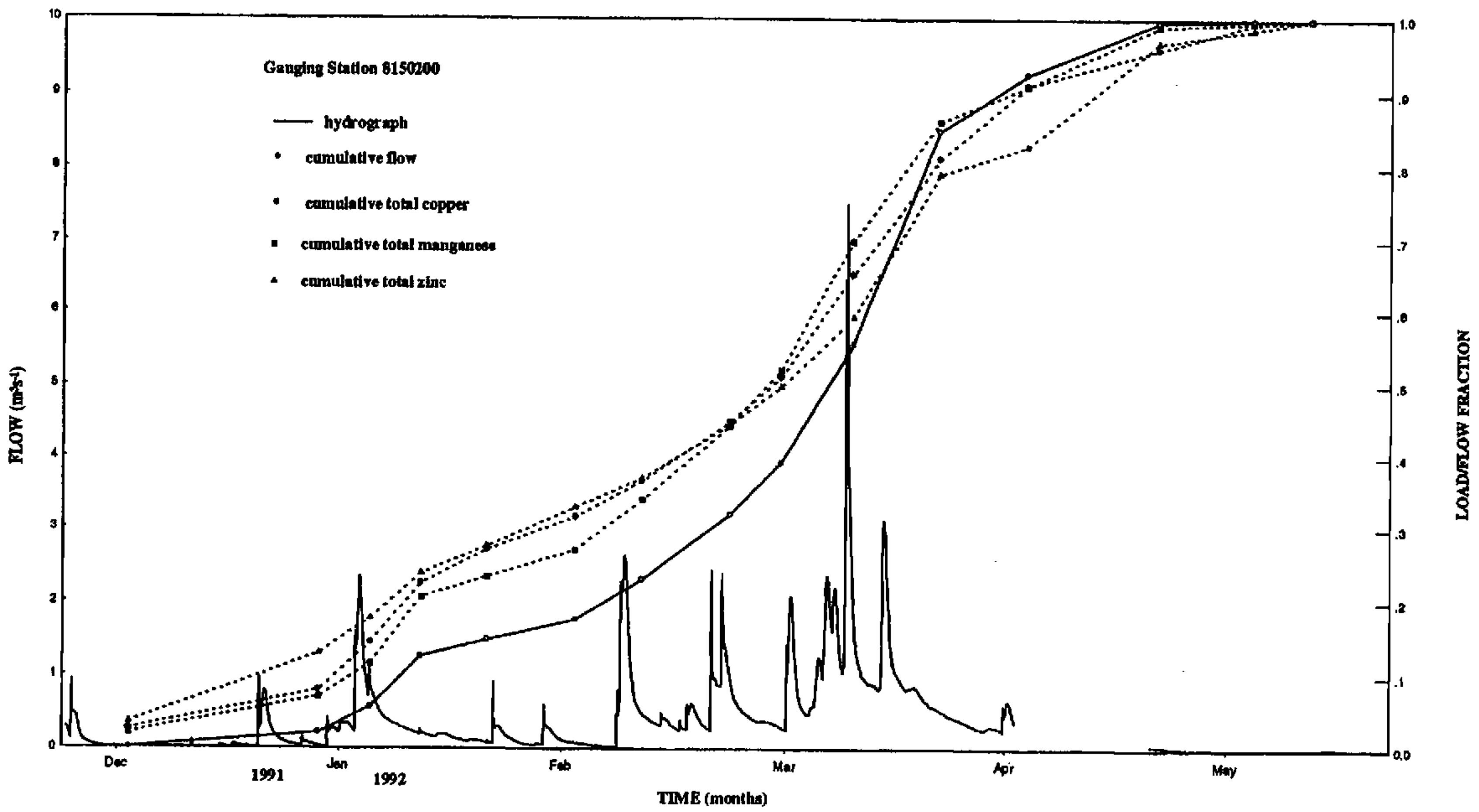

Figure D.6 East Finniss River at Gauging Station 8150200 - plot of cumulative total Cu, Mn and Zn loads with cumulative flow and hydrograph from 05/12/91 to 15/05/92.

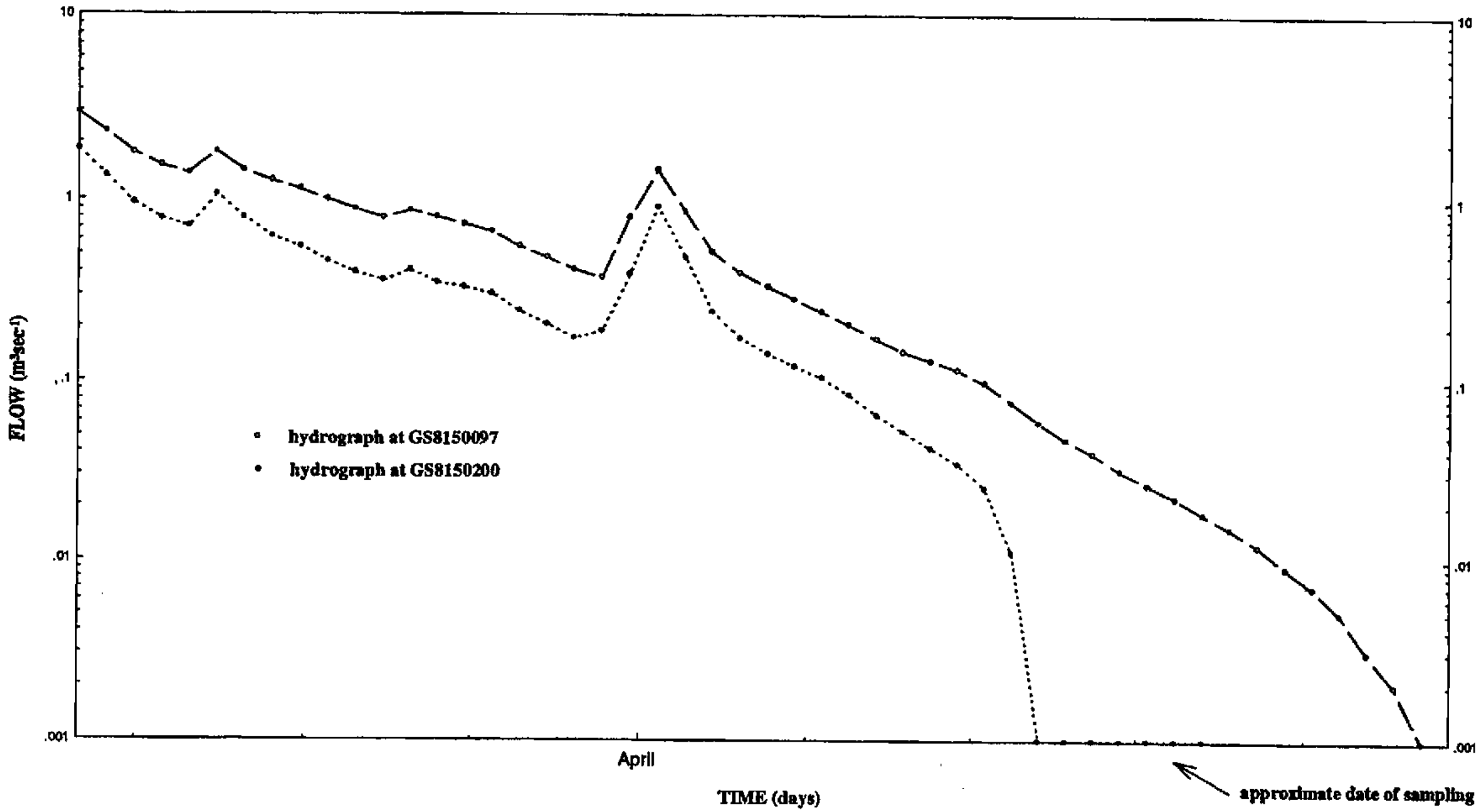

Figure D.7 Discharge (in cumecs) at GS8150200 and GS8150097 from 12/03/93 to 30/04/93.

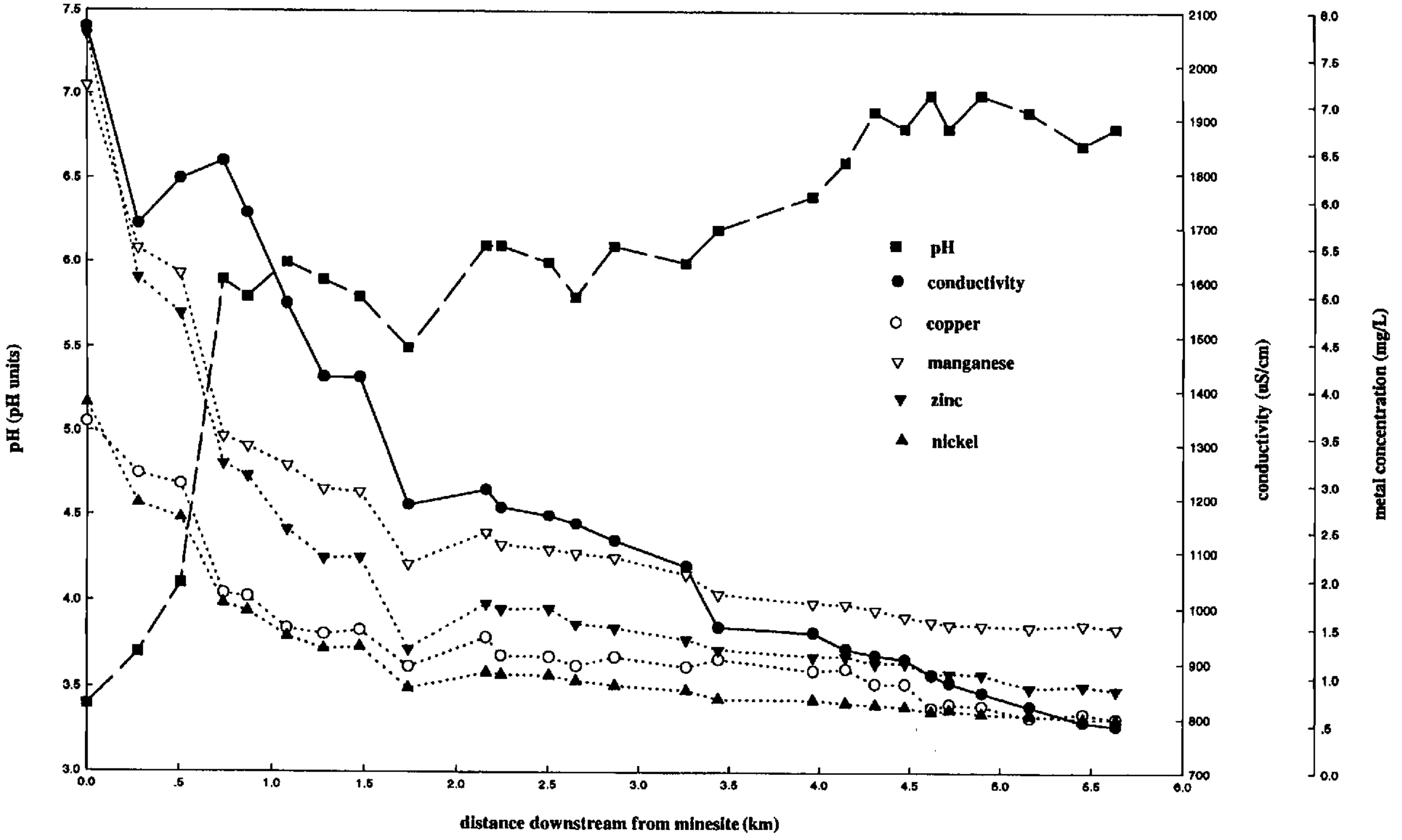

Figure D.8 Plots of pH, conductivity, Cu, Mn, Zn and Ni in water samples collected at sites along the East Finniss on 22/04/93.

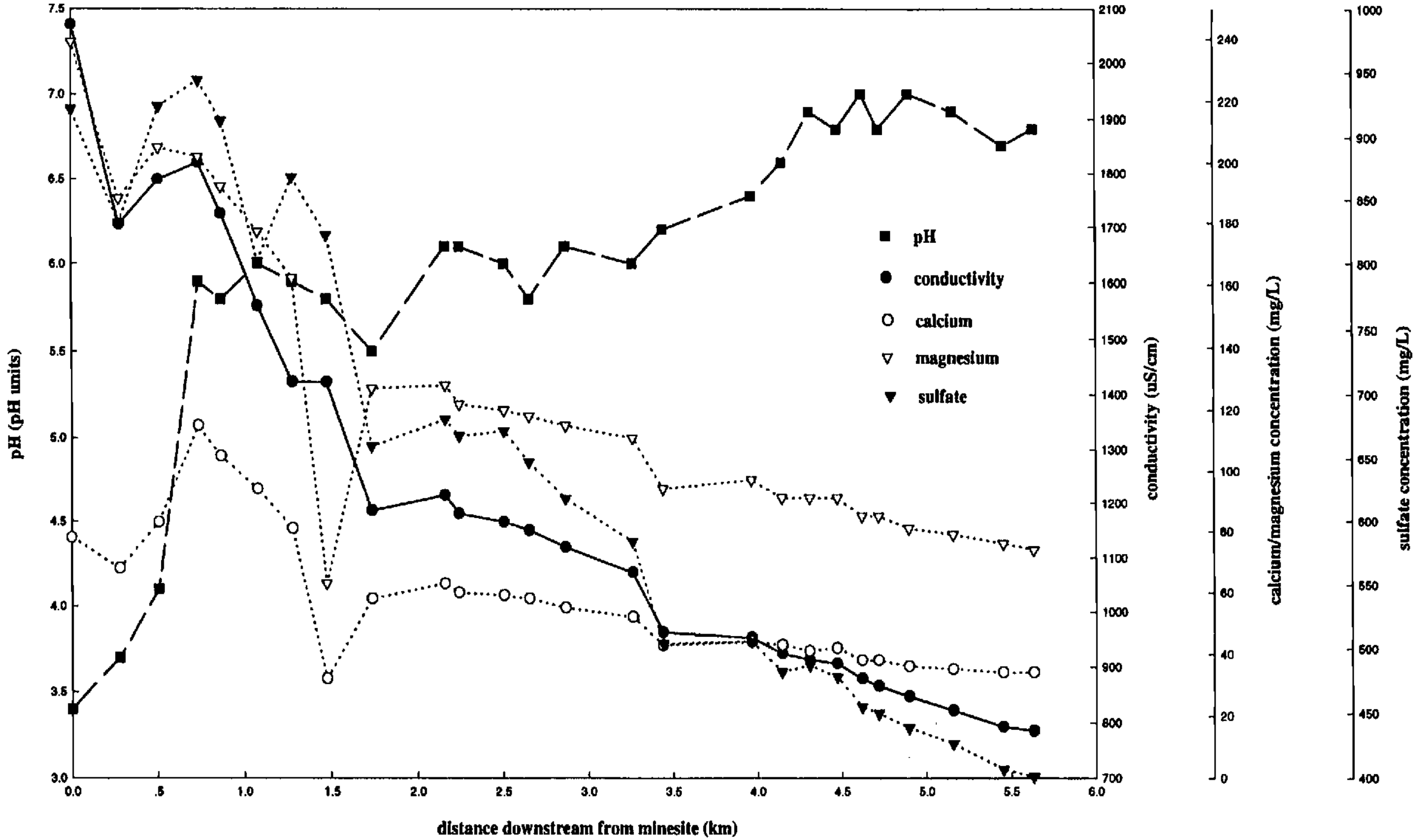

Figure D.9 Plots of pH, conductivity, Ca, Mg, SO_4 in water samples collected at sites along the East Finniss on 22/04/93.

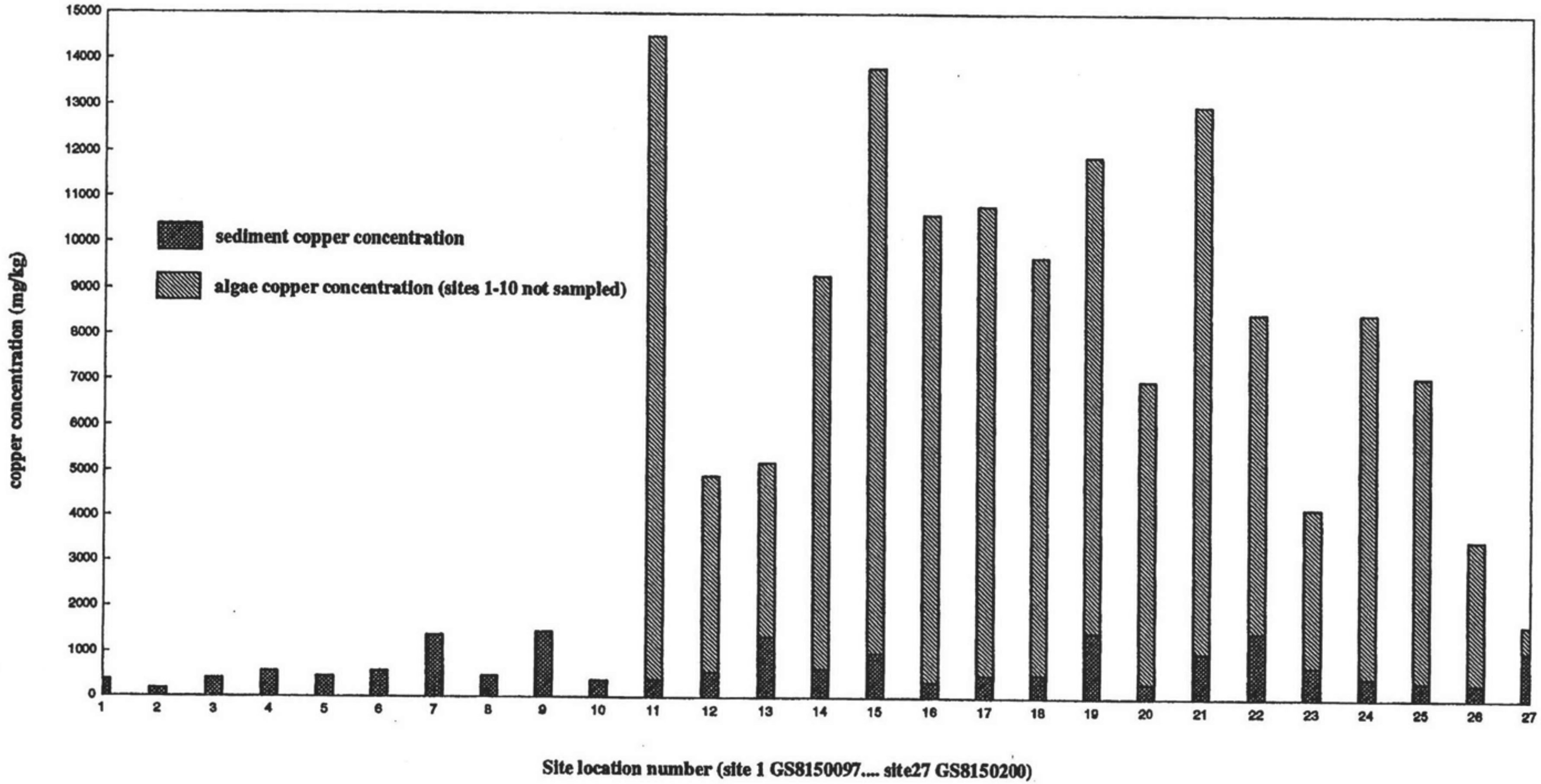

Figure D.10 **Copper concentrations in benthic algae and sediment at numbered sites on 22/04/93.**

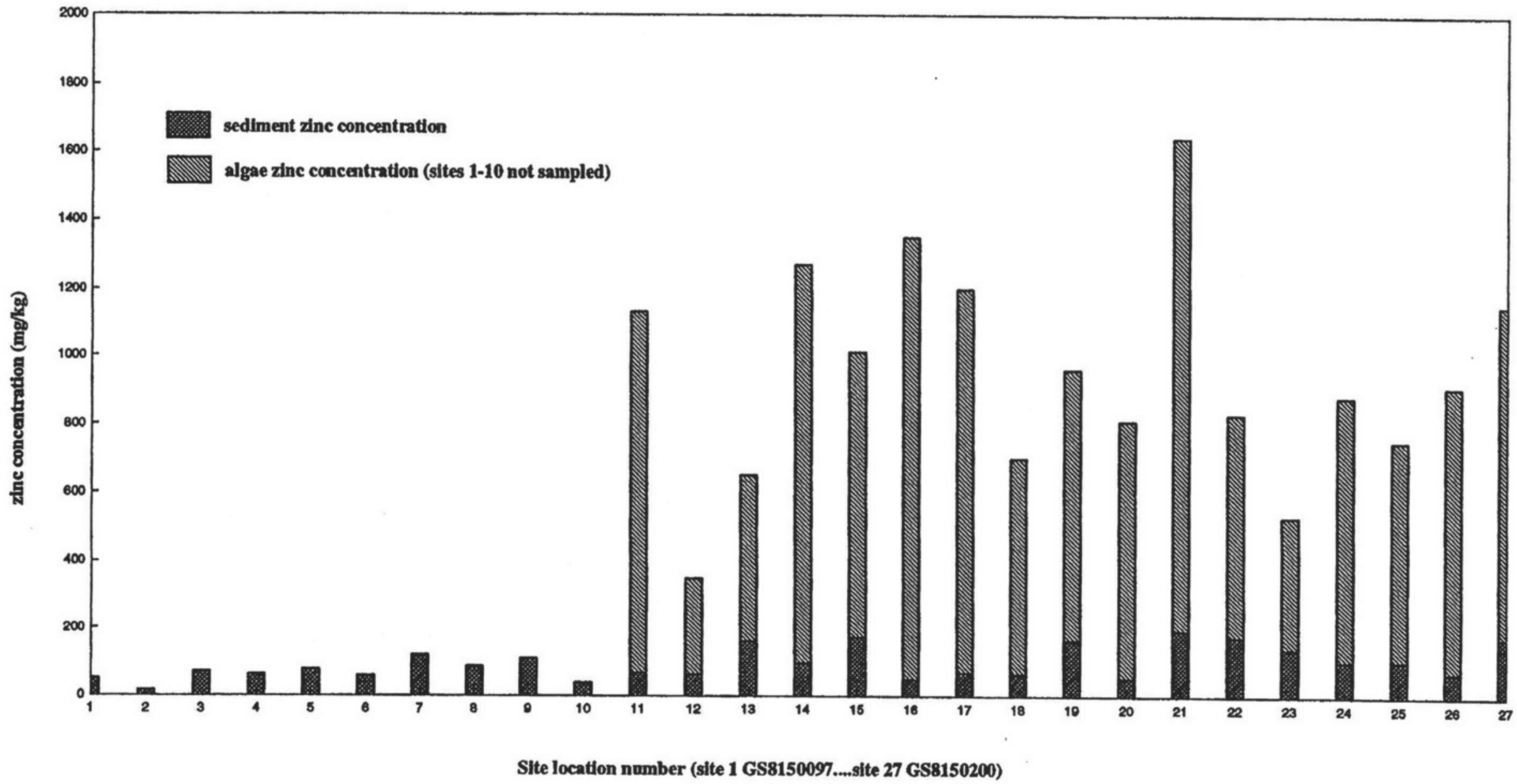

Figure D.11 Zinc concentrations in benthic algae and sediment at numbered sites on 22/04/93.

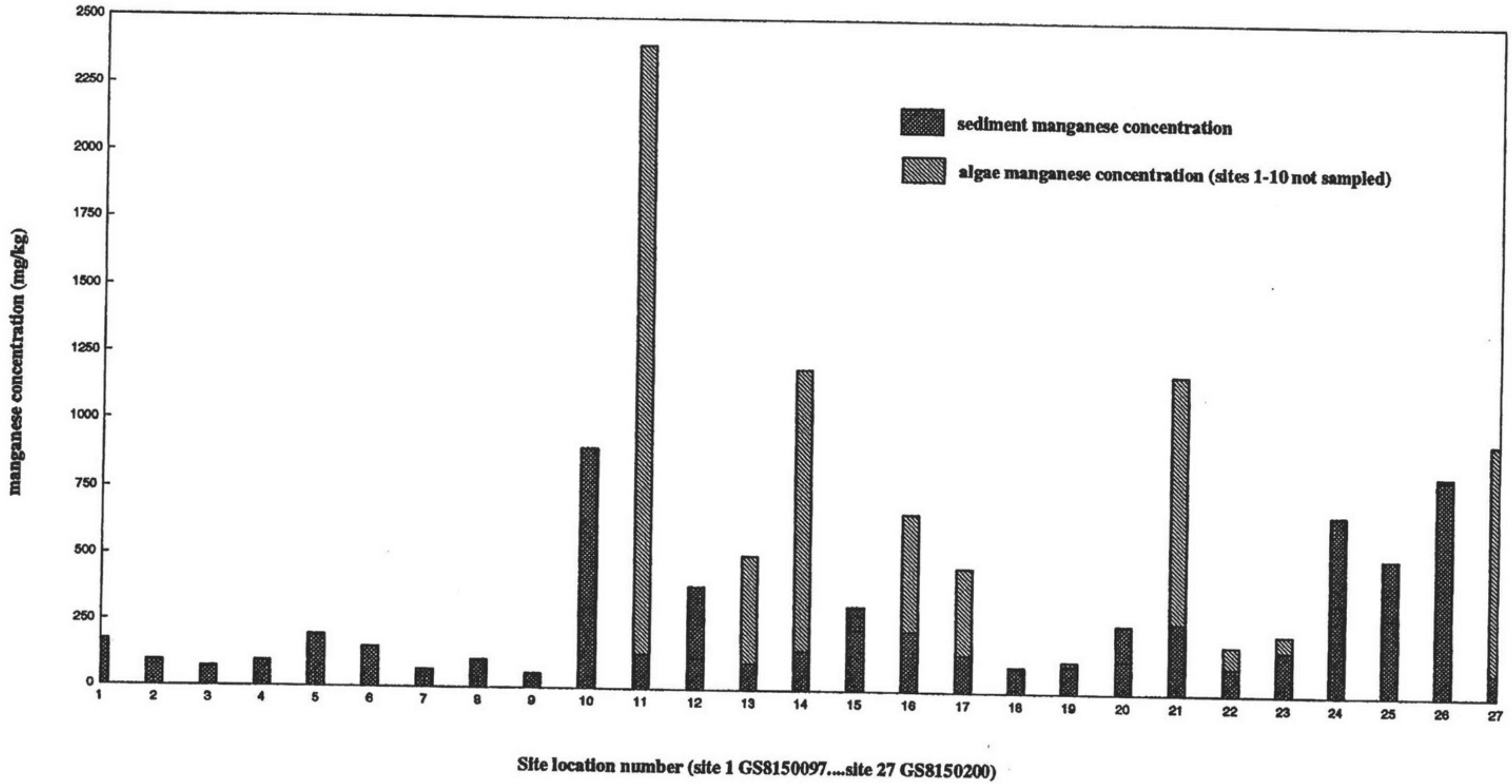

Figure D.12 Manganese concentrations in benthic algae and sediment at numbered sites on 22/04/93.

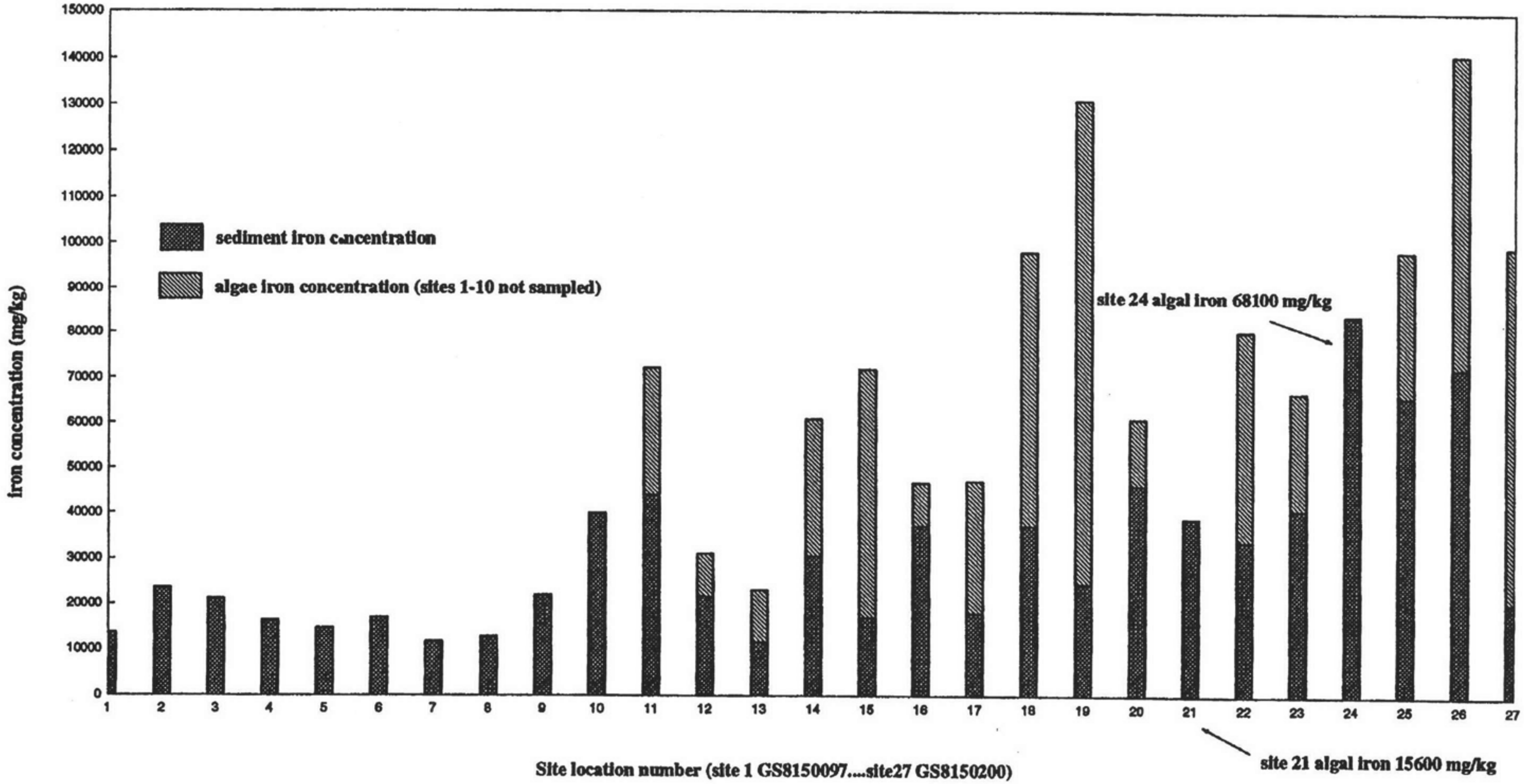

Figure D.13 Iron concentrations in benthic algae and sediment at numbered sites on 22/04/93.

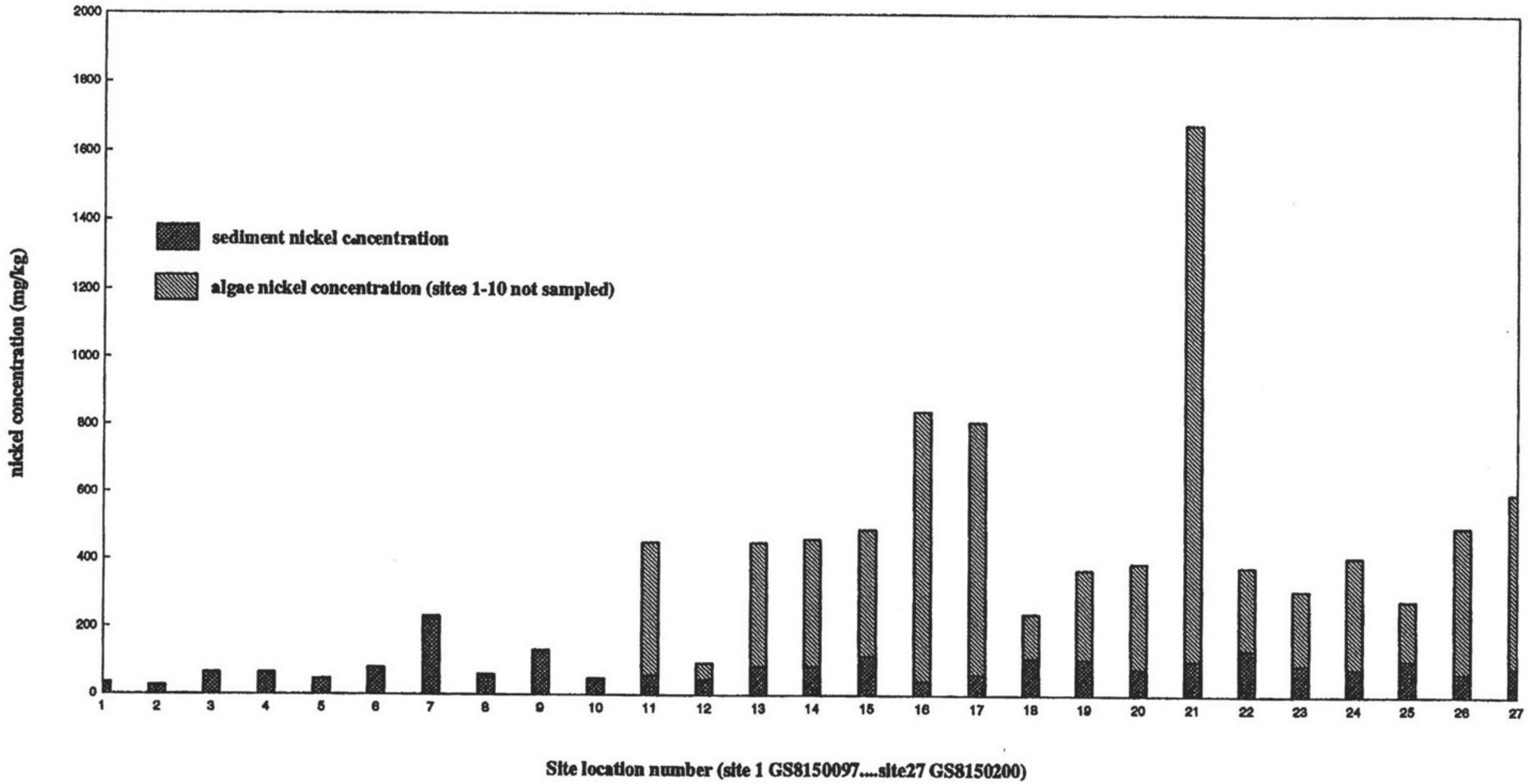

Figure D.14 Nickel concentrations in benthic algae and sediment at numbered sites on 22/04/93.

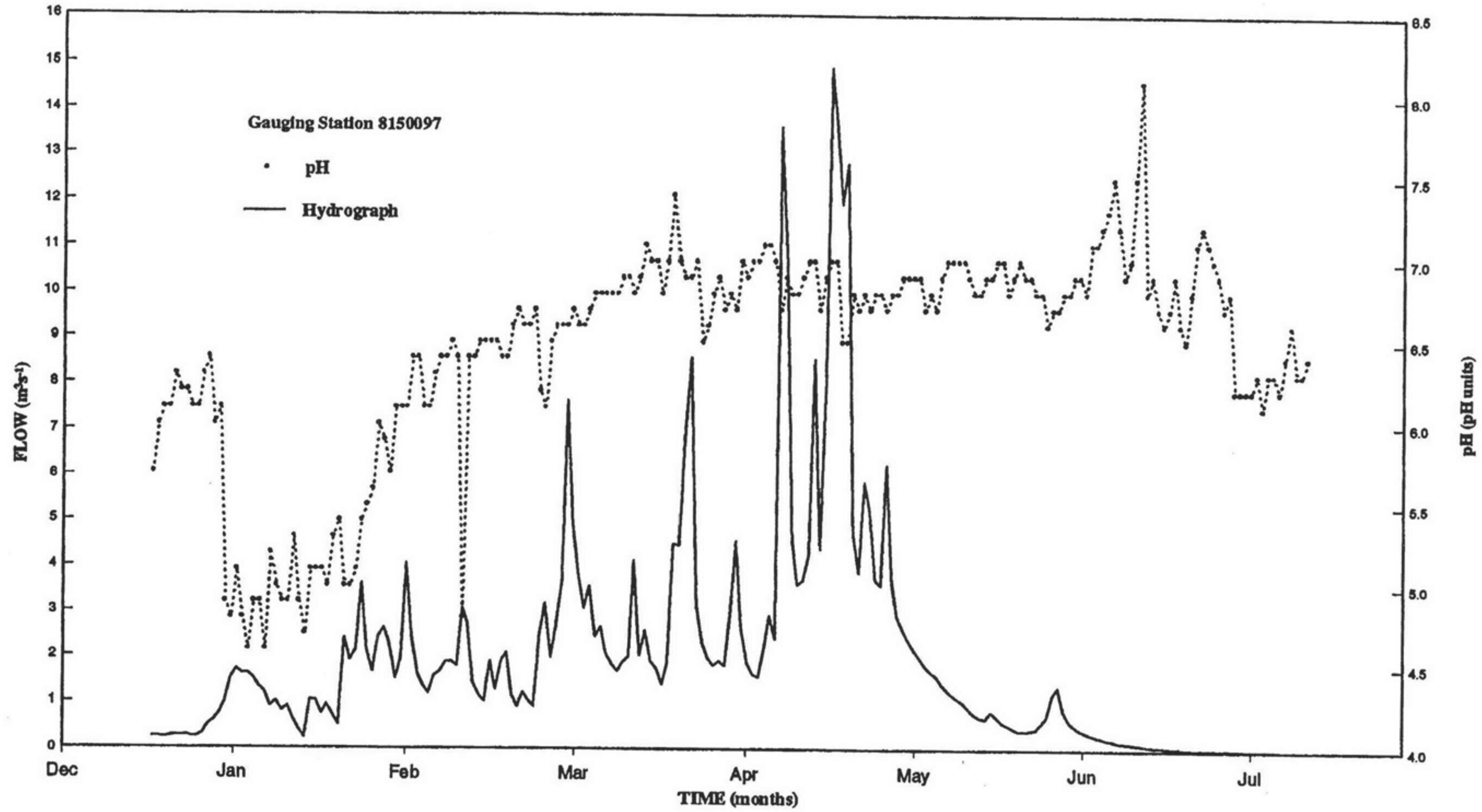

Figure D.15 East Finniss River at Gauging Station 8150097 - variation in pH with hydrograph from 1988 to 1989.

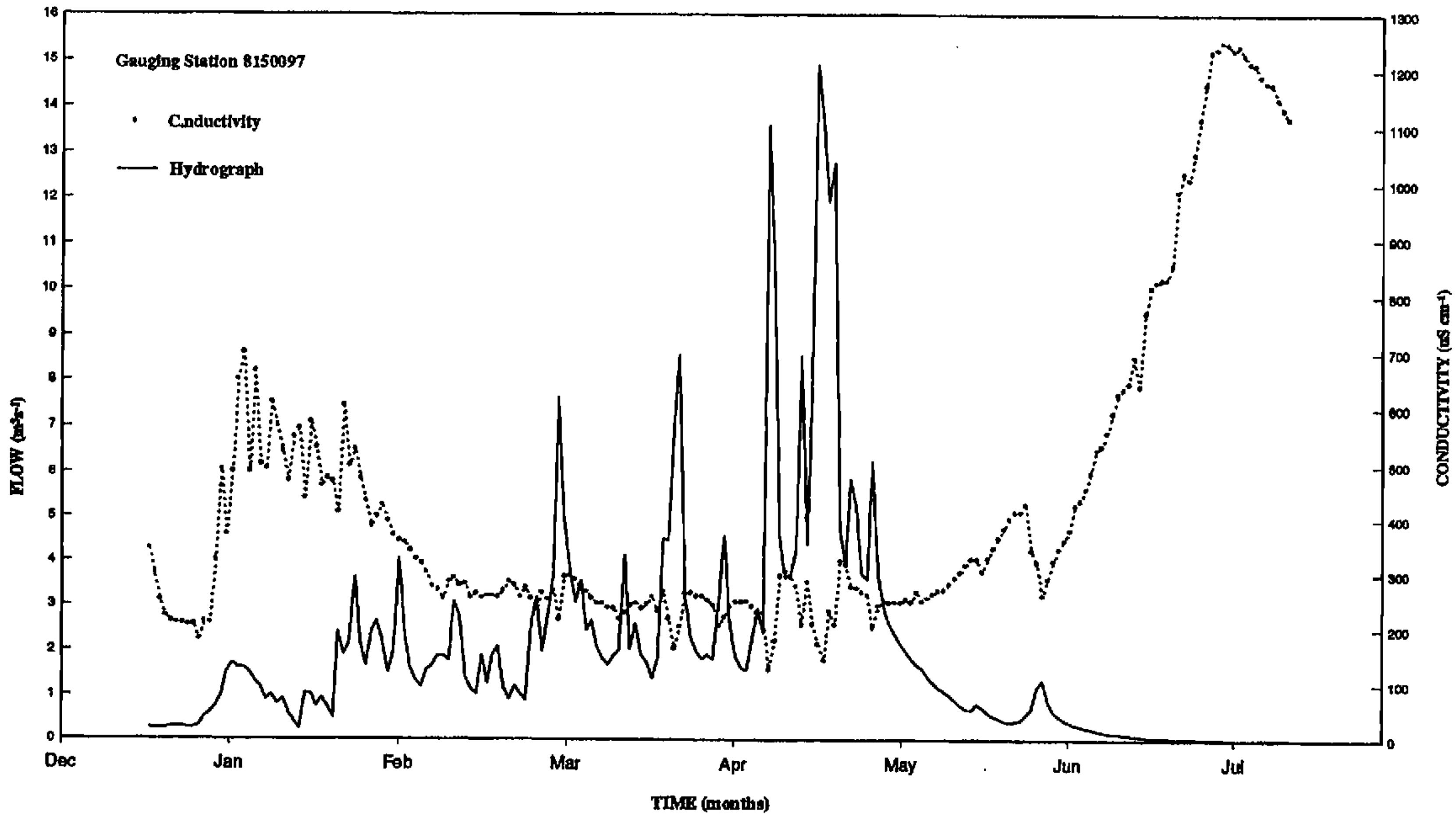

Figure D.16 **East Finniss River at Gauging Station 8150097 - variation in conductivity with hydrograph from 1988 to 1989.**

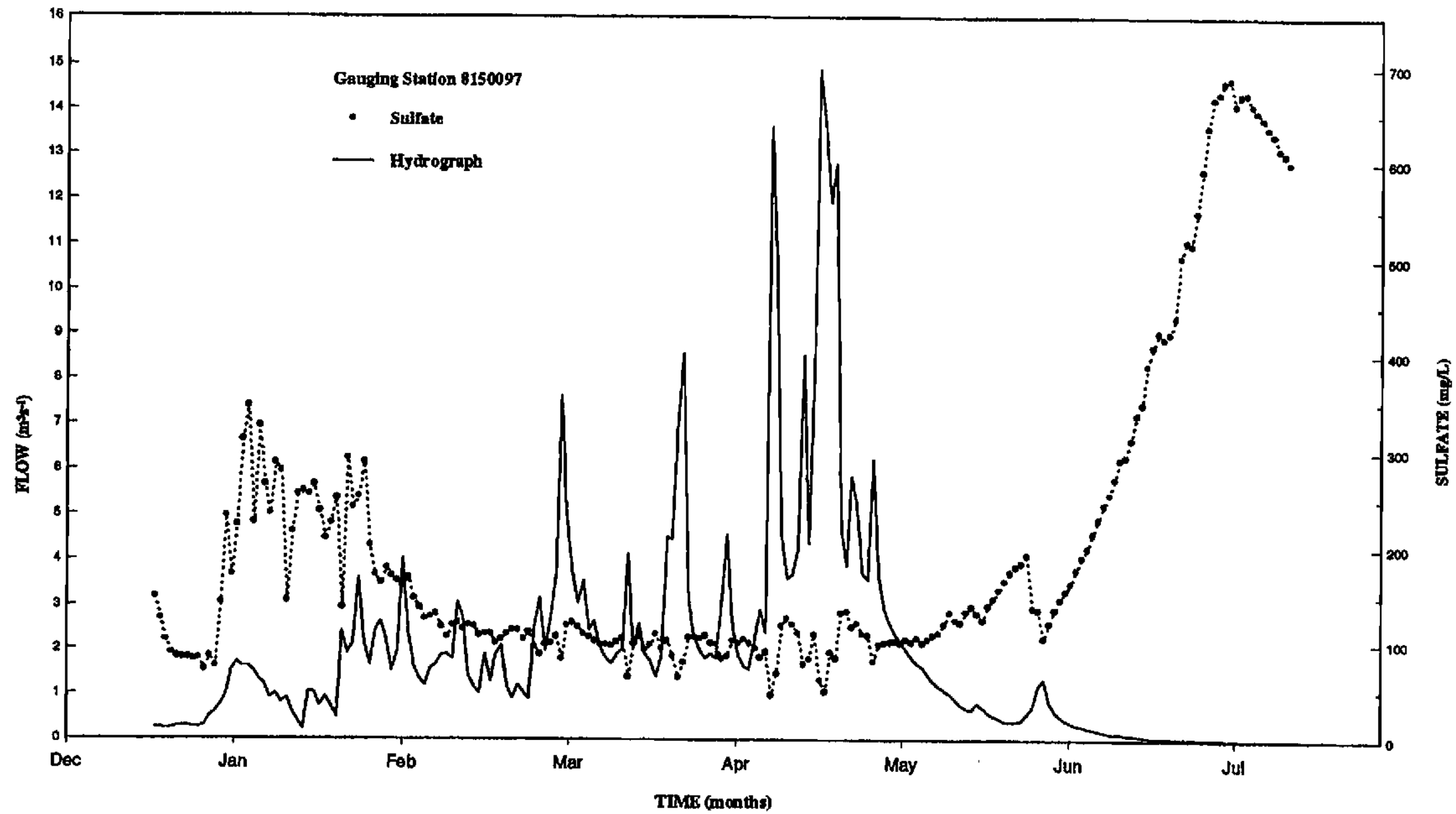

Figure D.17 **East Finniss River at Gauging Station 8150097 - variations in SO_4 concentration with hydrograph from 1988 to 1989.**

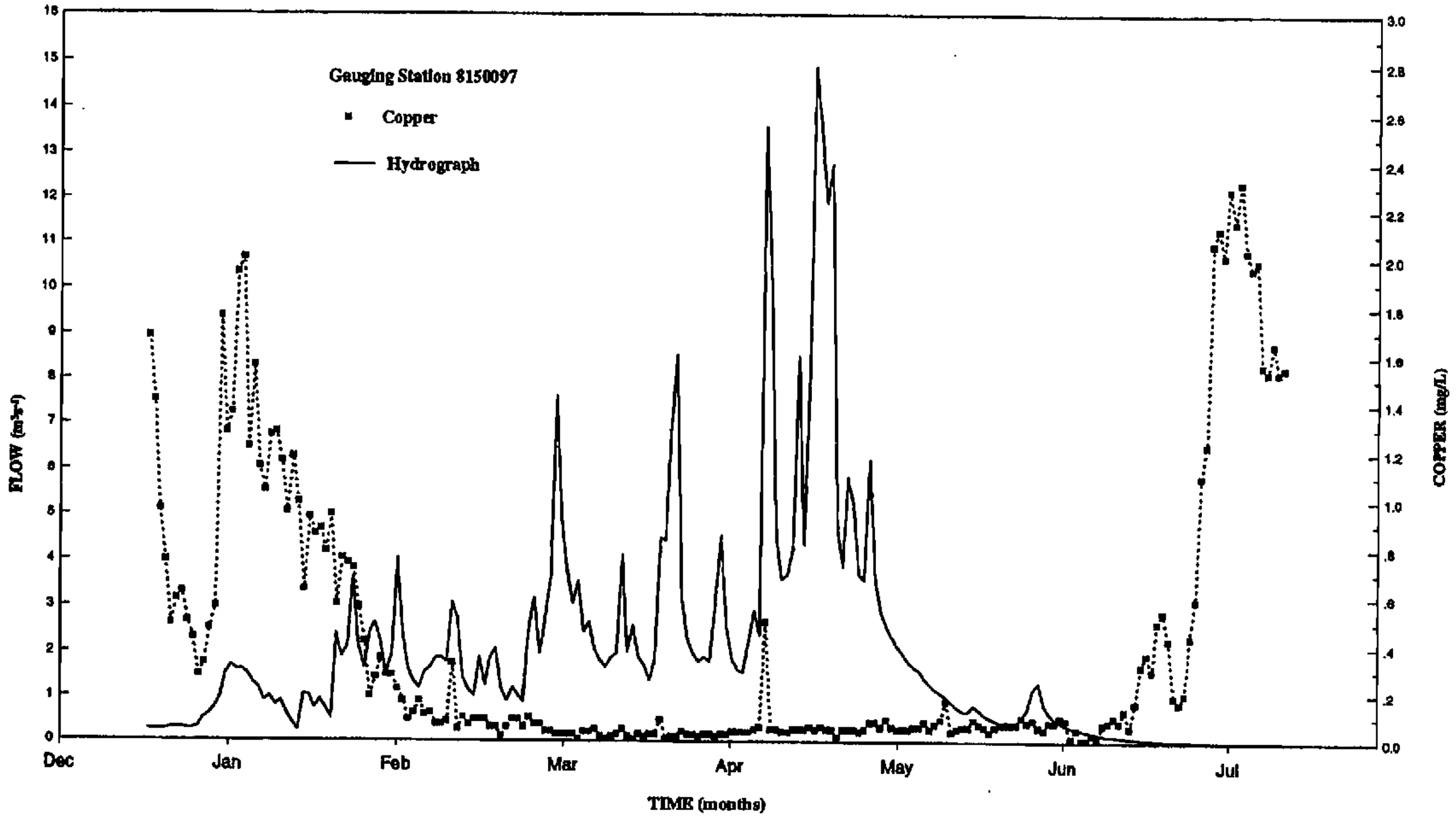

Figure D.18 **East Finniss River at Gauging Station 8150087 - variation in Cu concentration with hydrograph from 1988 to 1989.**

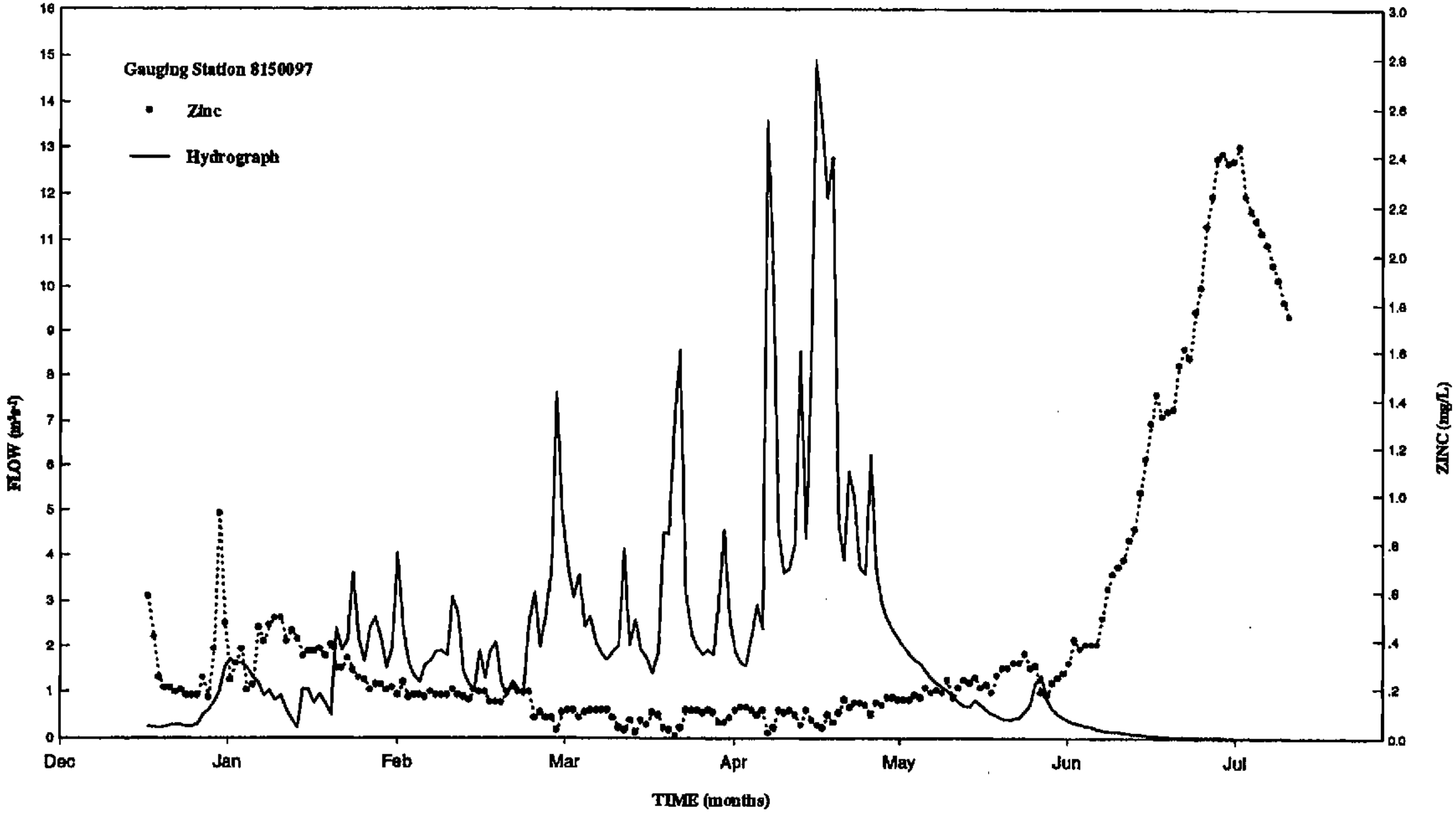

Figure D.19 East Finniss River at Gauging Station 8150097 - variation in Zn concentration with hydrograph from 1988 to 1989.

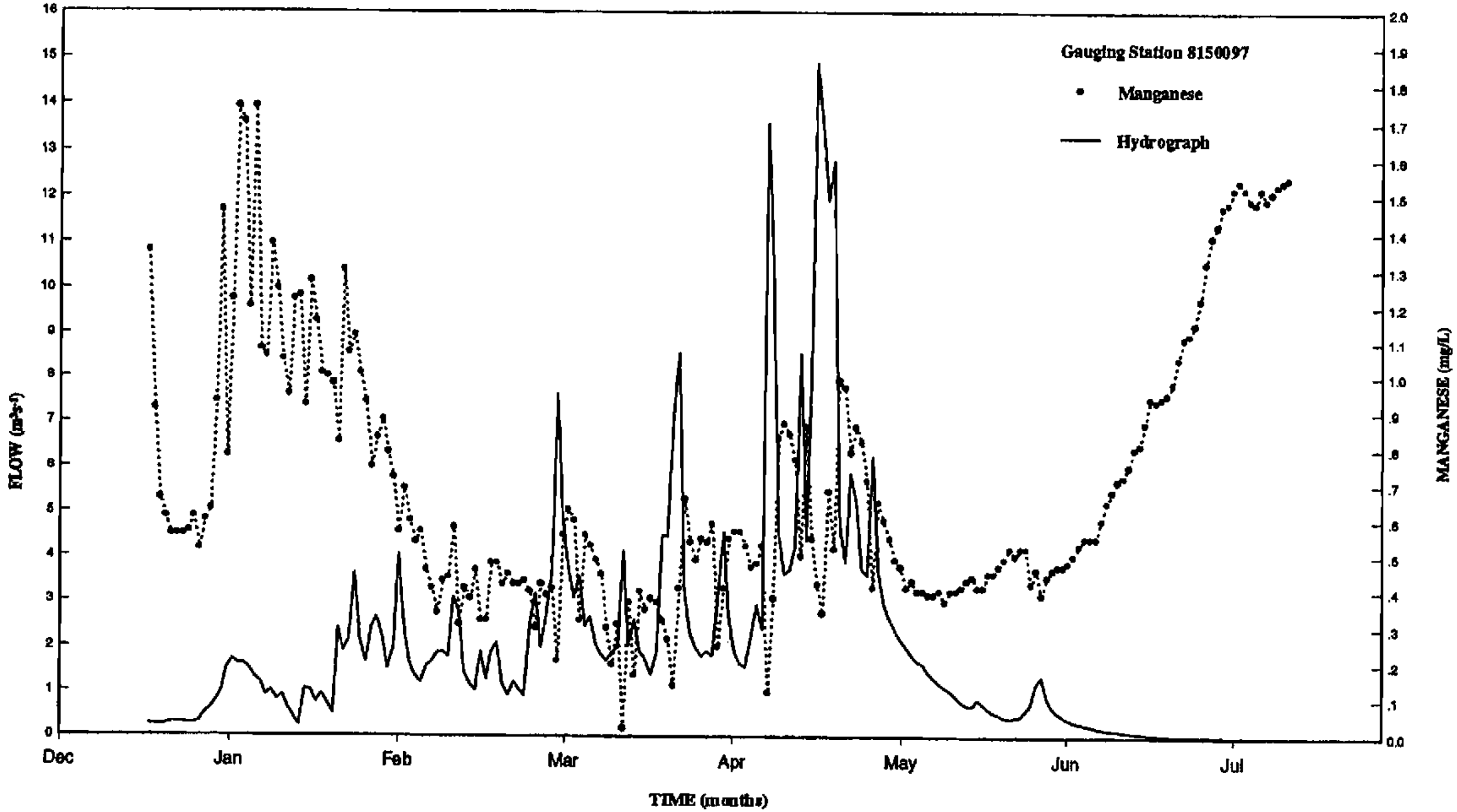

Figure D.20 East Finniss River Gauging Station 8150097 - variation in Mn concentration with hydrograph from 1988 to 1989.

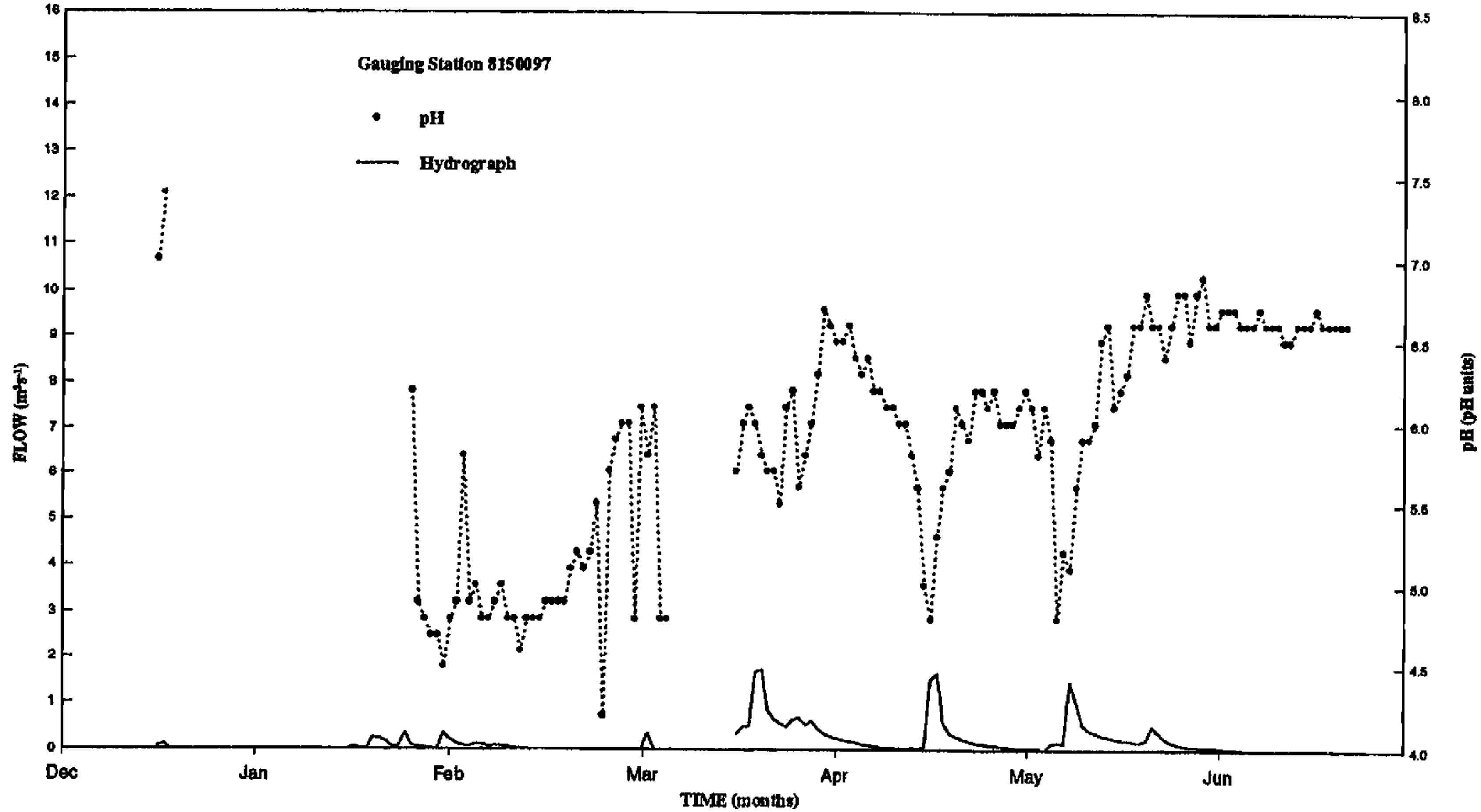

Figure D.21 East Finniss River at Gauging Station 8150097 - variation in pH with hydrograph from 1989 to 1990.

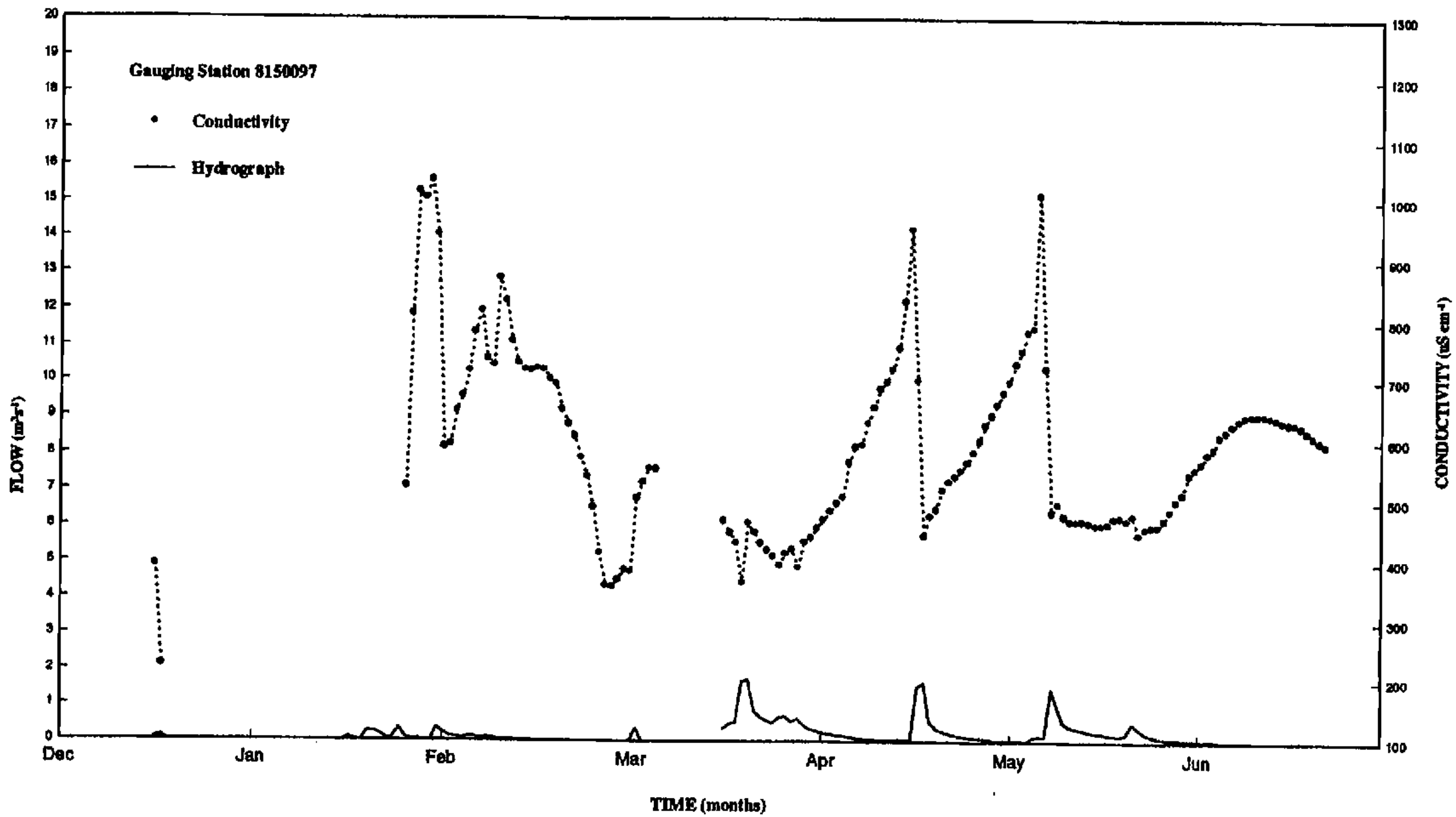

Figure D.22 East Finniss River at Gauging Station 8150097 - variation in conductivity with hydrograph from 1989 to 1990.

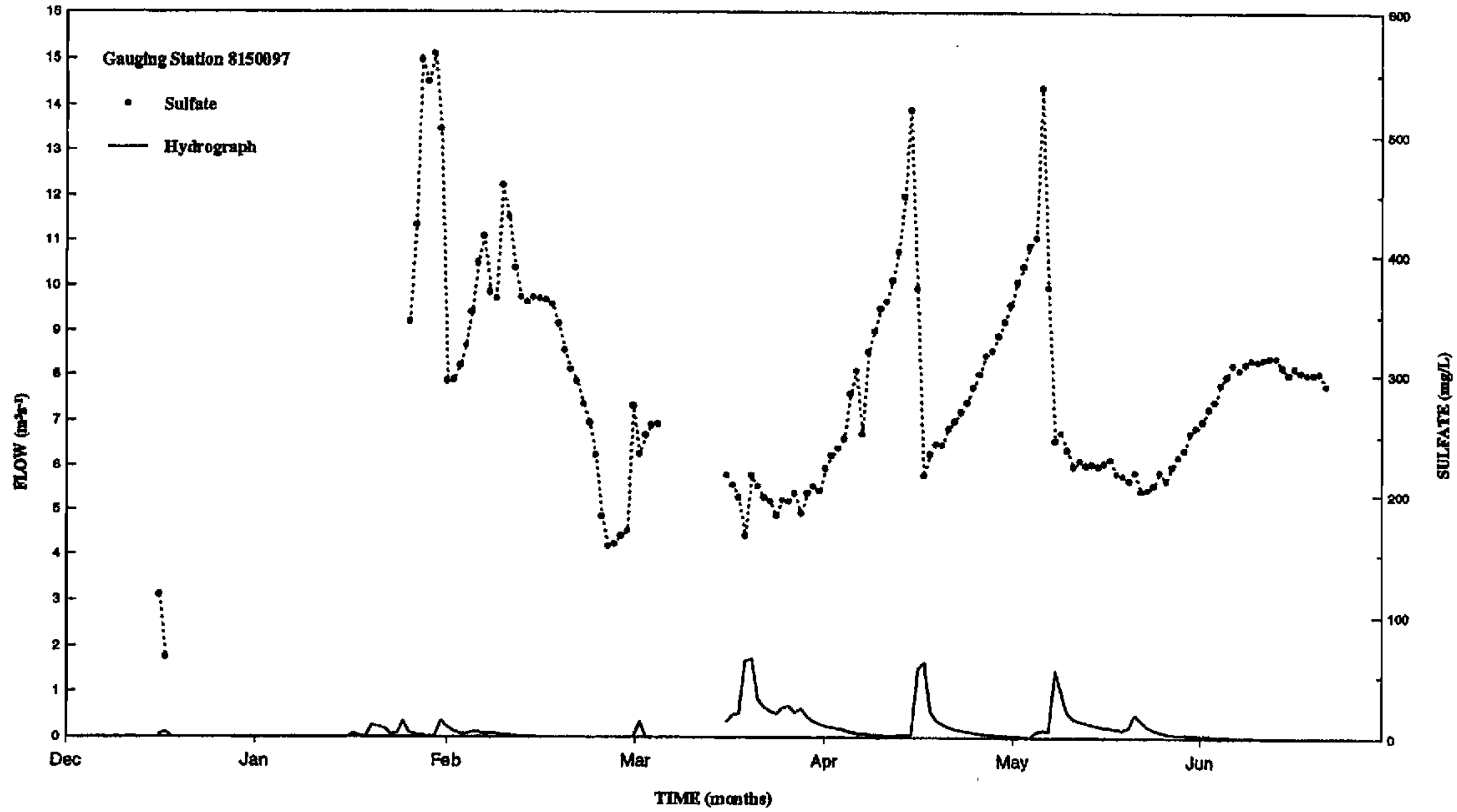

Figure D.23 East Finniss River at Gauging Station 8150097 - variation in SO concentration with hydrograph from 1989 to 1990.

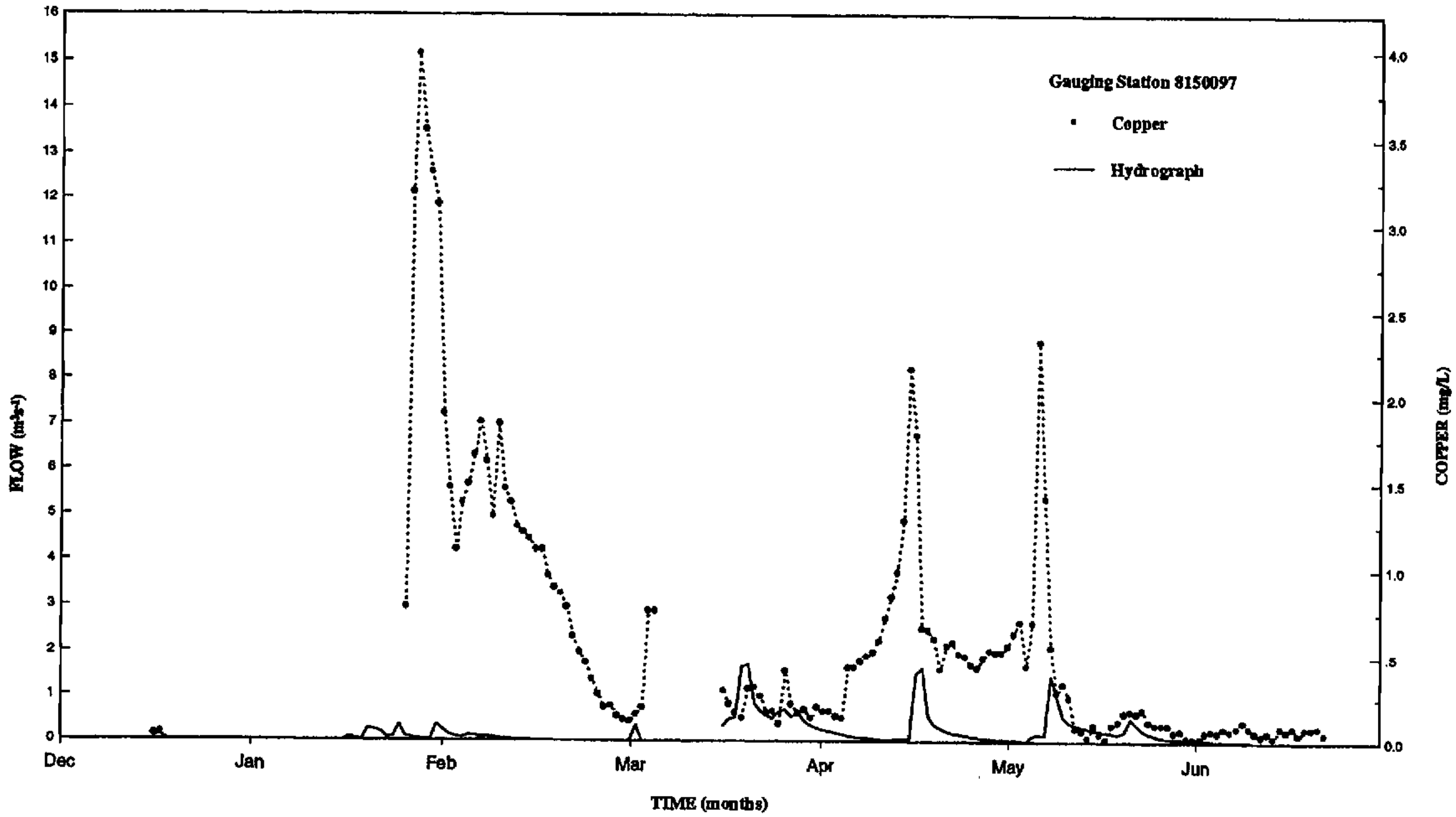

Figure D.24 East Finniss River at Gauging Station 8150097 - variation in Cu concentration from 1989 to 1990.

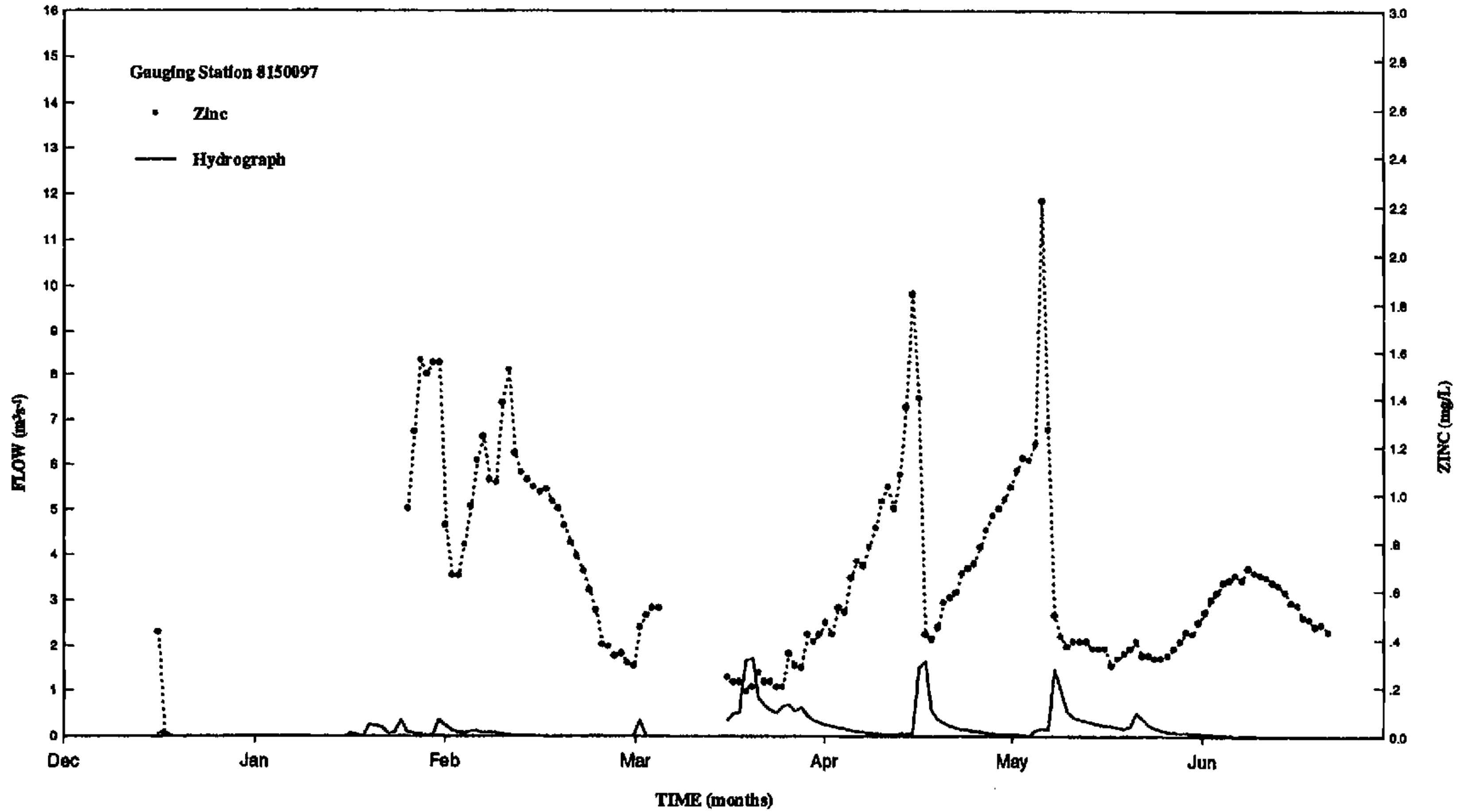

Figure D.25 East Finniss River at Gauging Station 8150097 - variation in Zn concentration with hydrograph from 1989 to 1990.

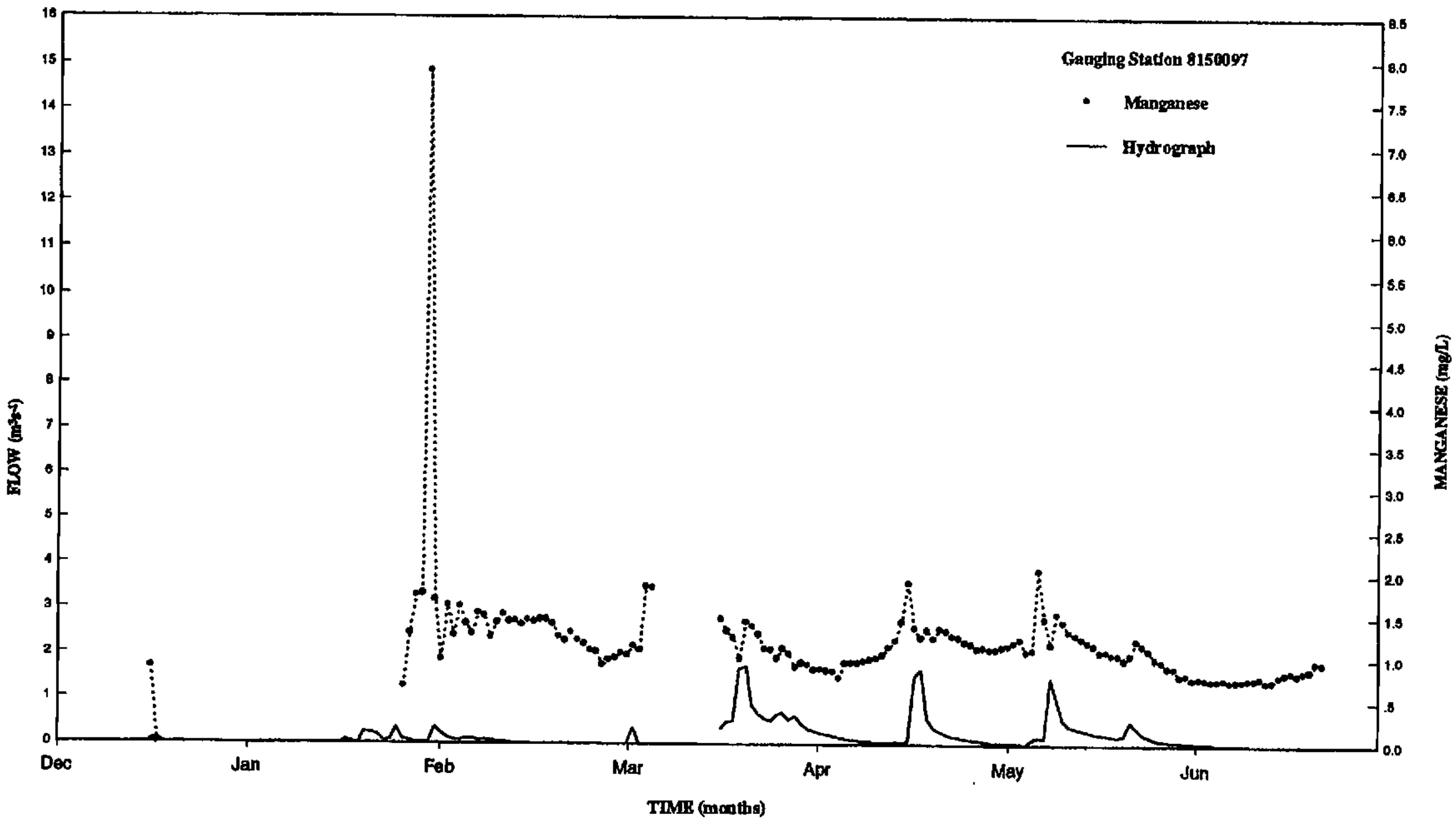

Figure D.26 East Finniss River at Gauging Station 8150097 - variation in Mn concentration with hydrograph from 1990 to 1991.

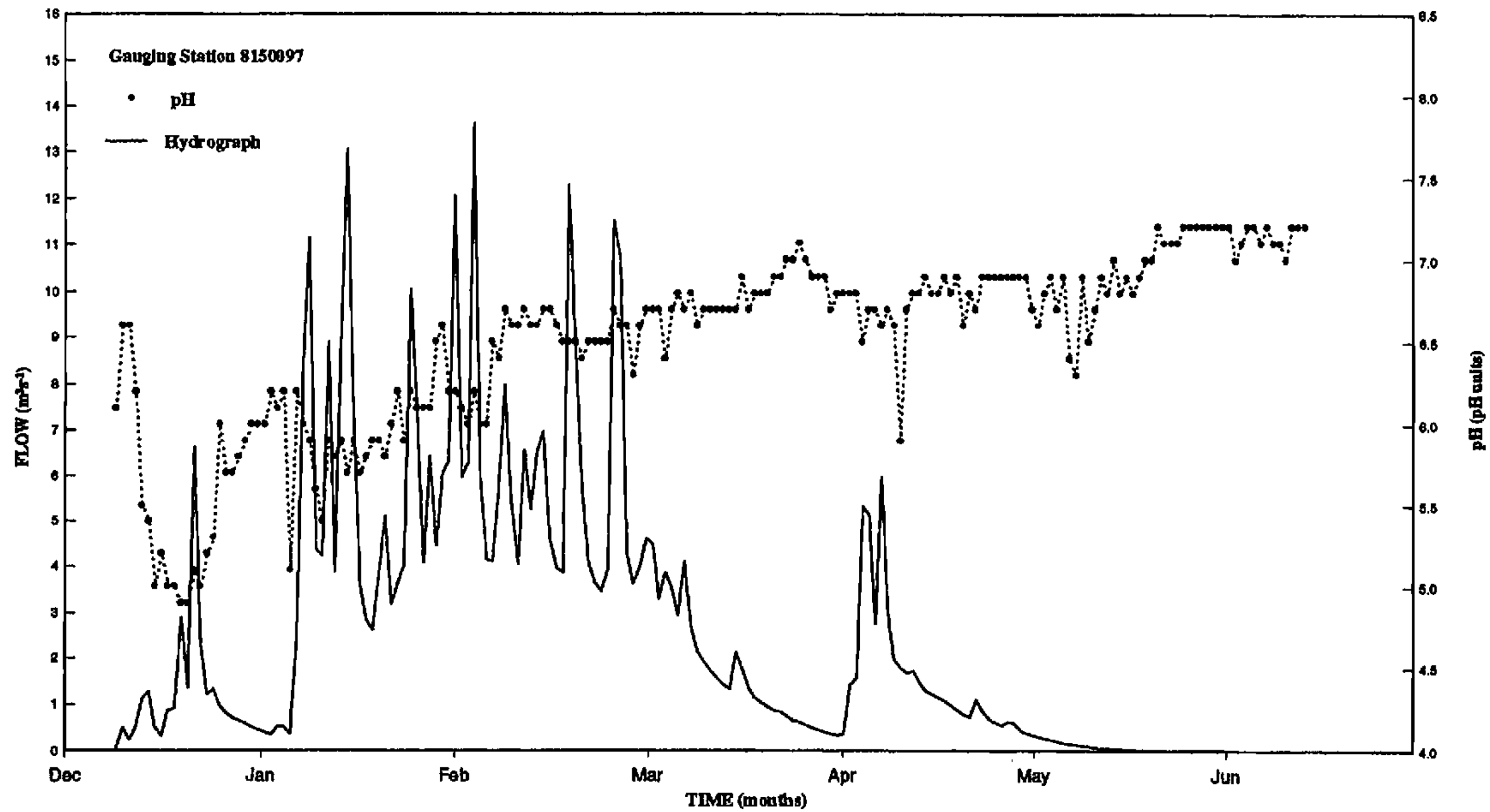

Figure D.27 East Finniss River at Gauging Station 8150097 - variation in pH with hydrograph from 1990 to 1991.

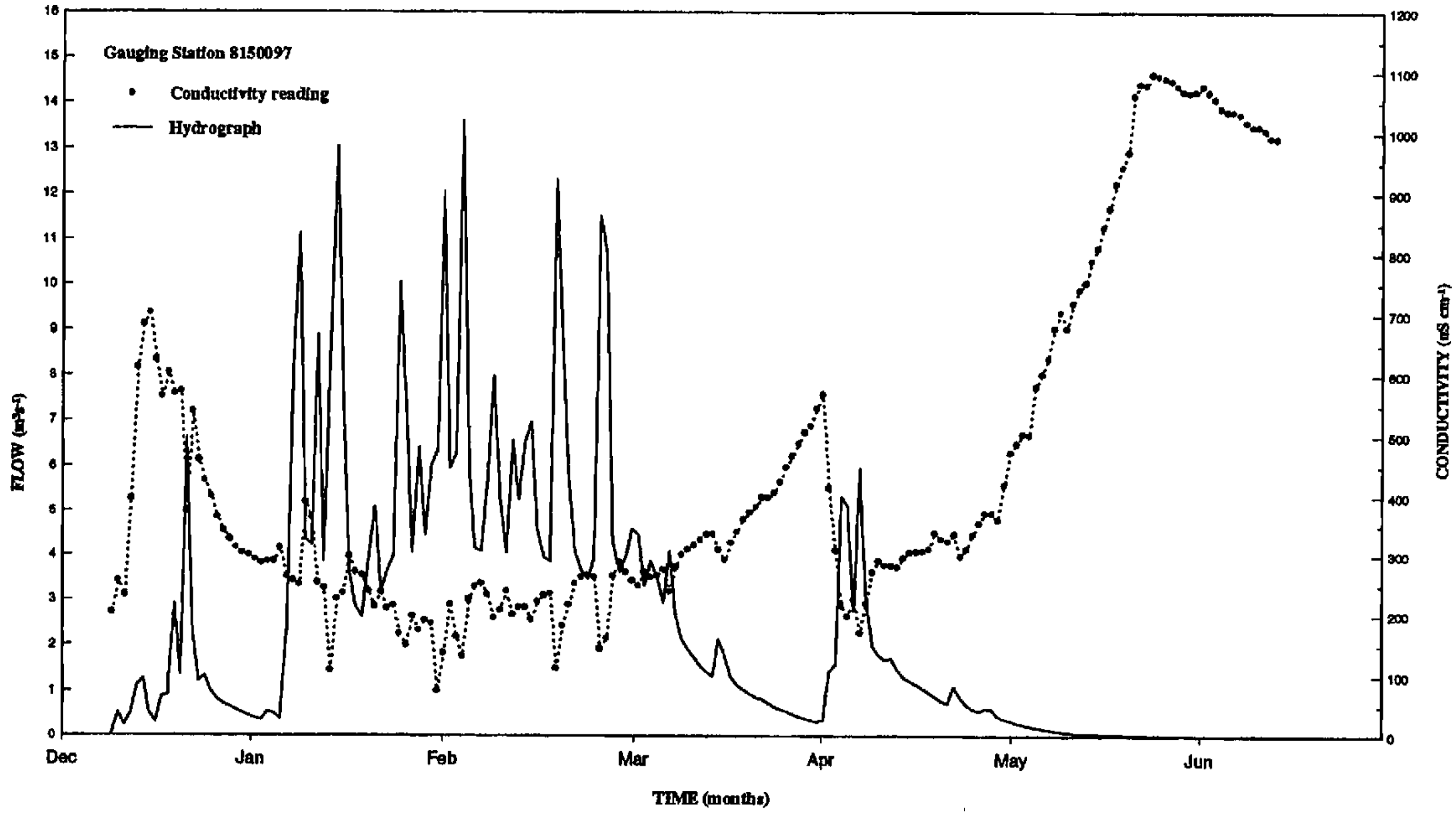

Figure D.28 East Finniss River at Gauging Station 8150097 - variation in conductivity with hydrograph from 1990 to 1991.

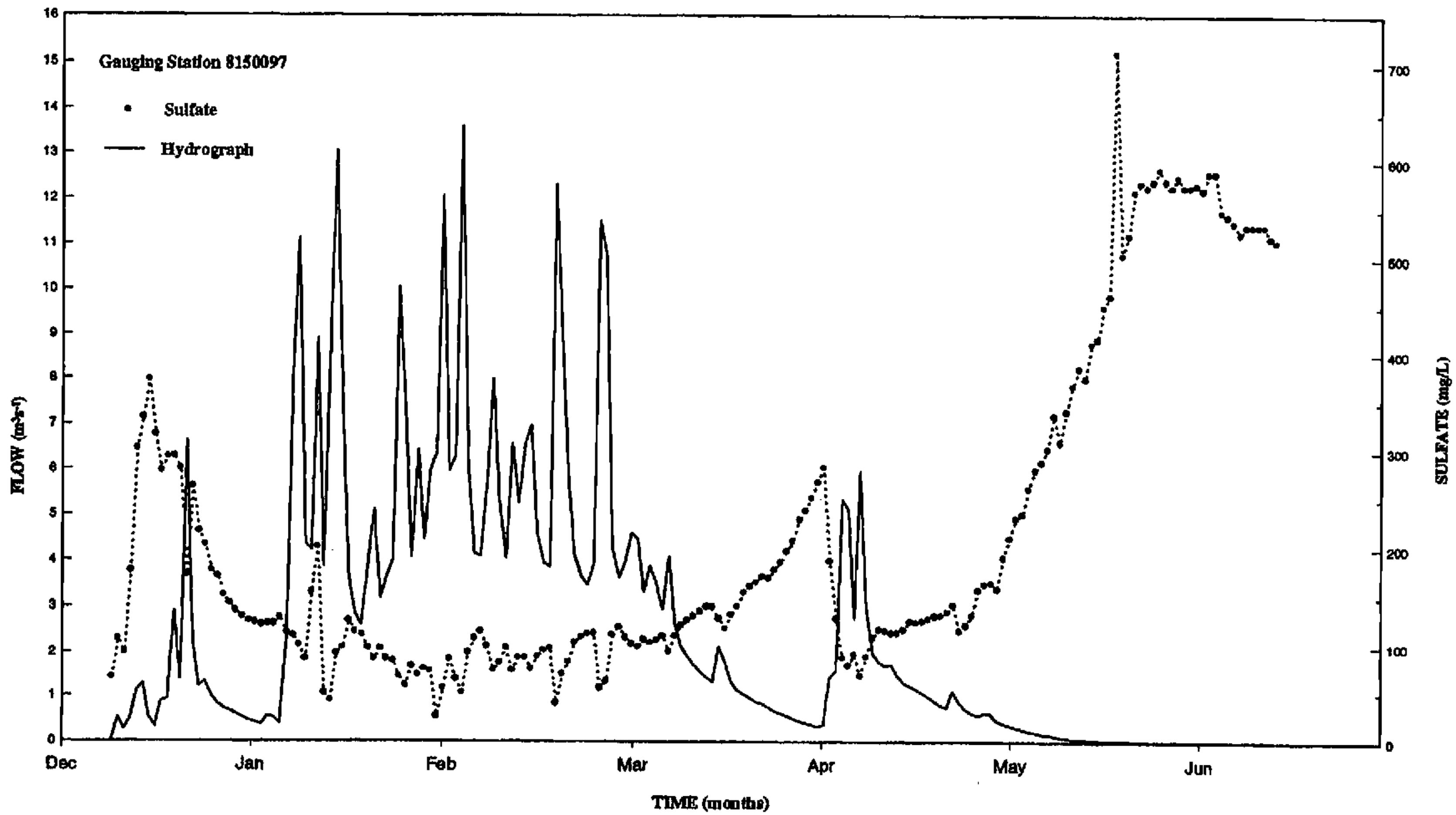

Figure D.29 East Finniss River at Gauging Station 8150097 - variation in SO concentration with hydrograph from 1990 to 1991.

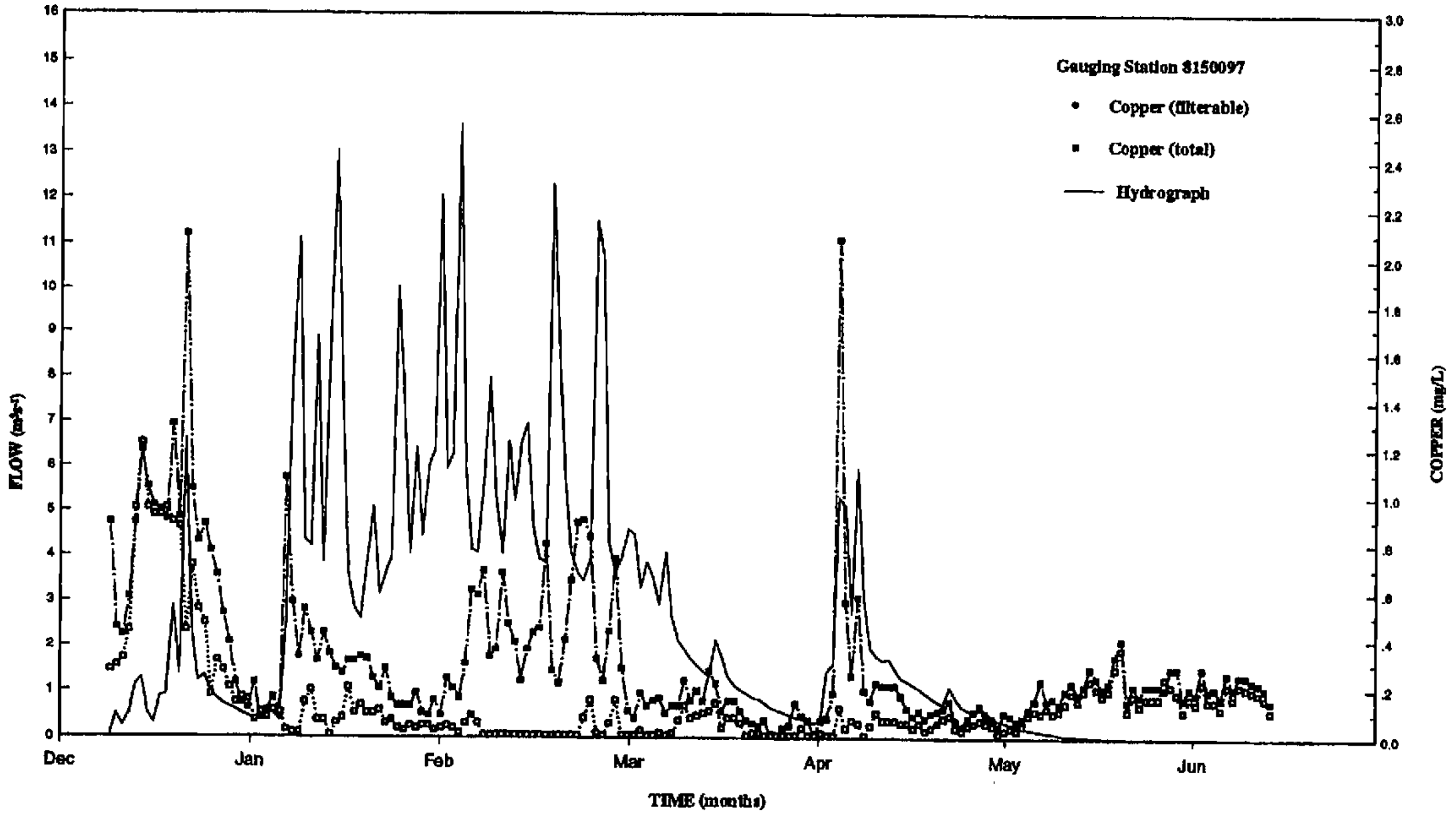

Figure D.30 East Finniss River at Gauging Station 8150097 - variation in Cu concentration with hydrograph from 1990 to 1991.

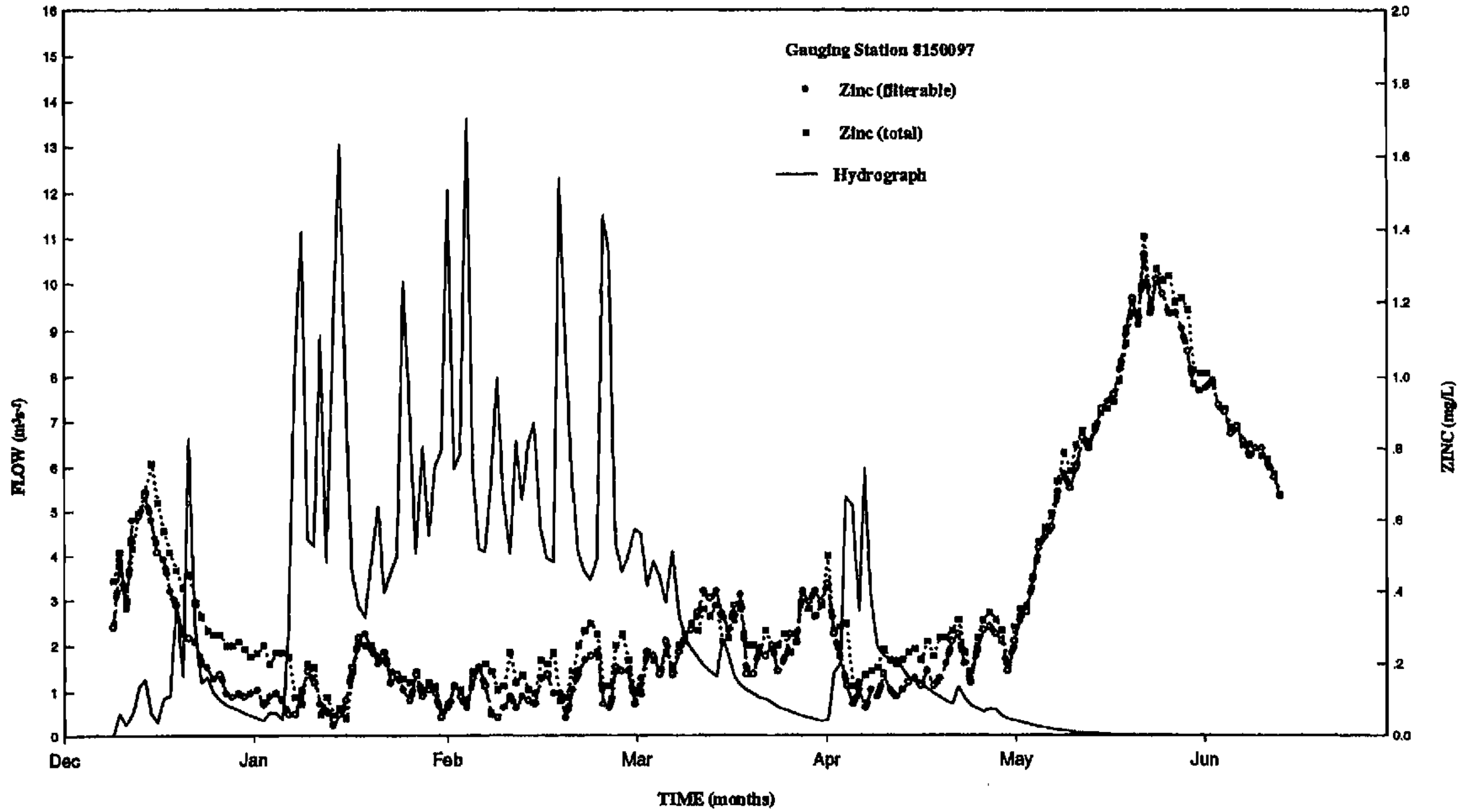

Figure D.31 **East Finniss River at Gauging Station 8150097 - variation in Zn concentration with hydrograph from 1990 to 1991.**

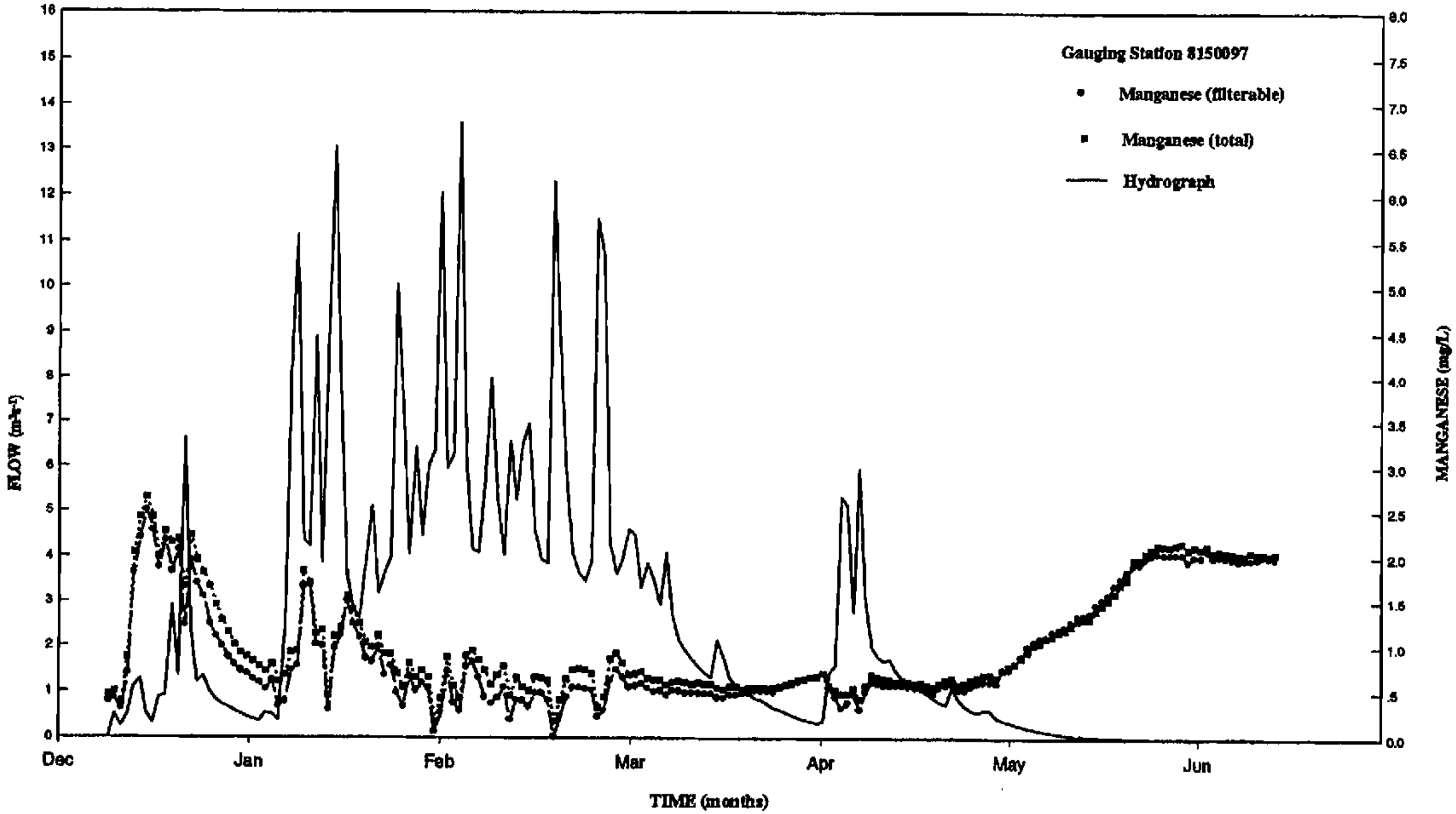

Figure D.32 **East Finniss River at Gauging Station 8150097 - variation in Mn concentration with hydrograph from 1990 to 1991.**

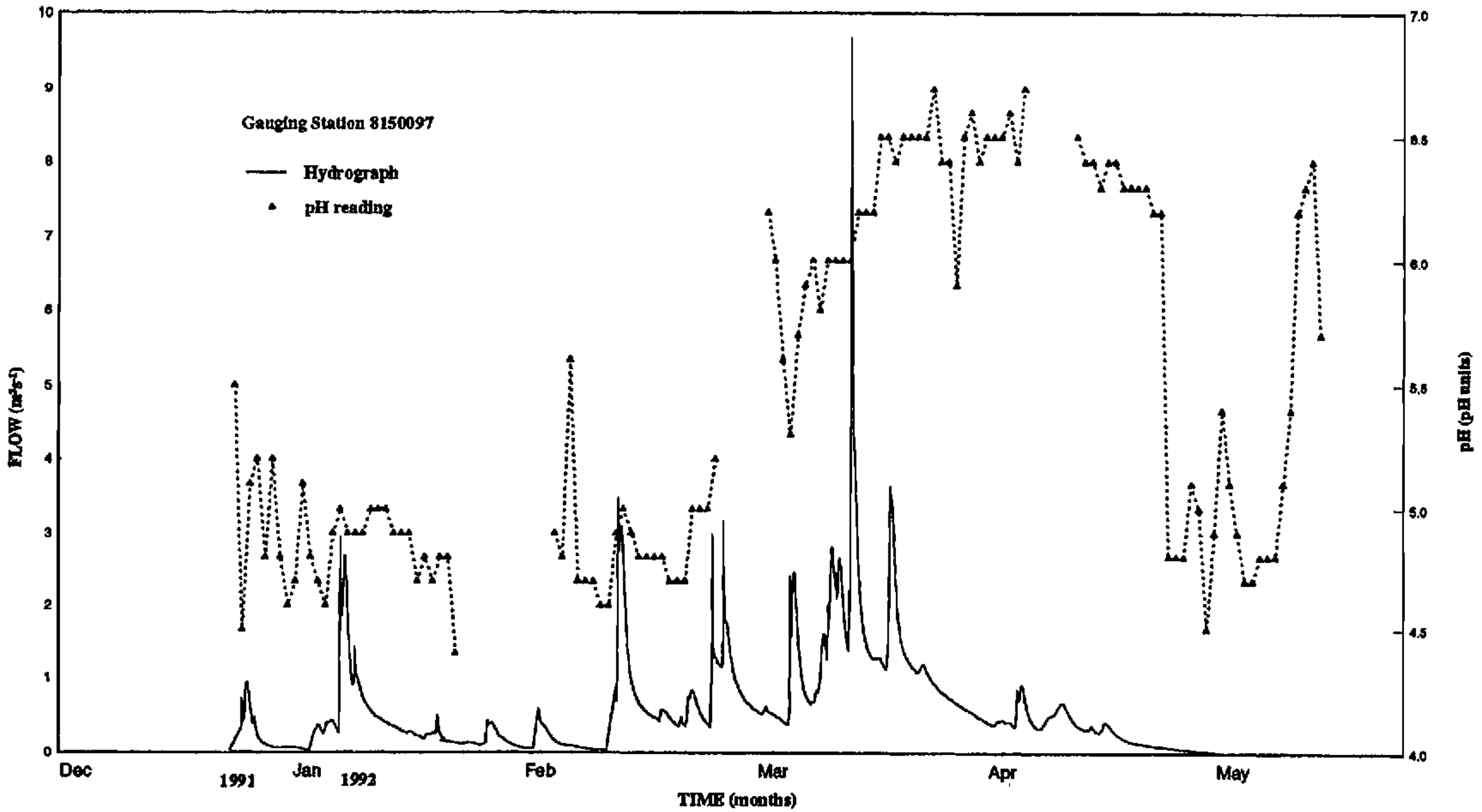

Figure D.33 East Finniss River at Gauging Station 8150097 - variation in pH with hydrograph from 24/12/91 to 15/05/92.

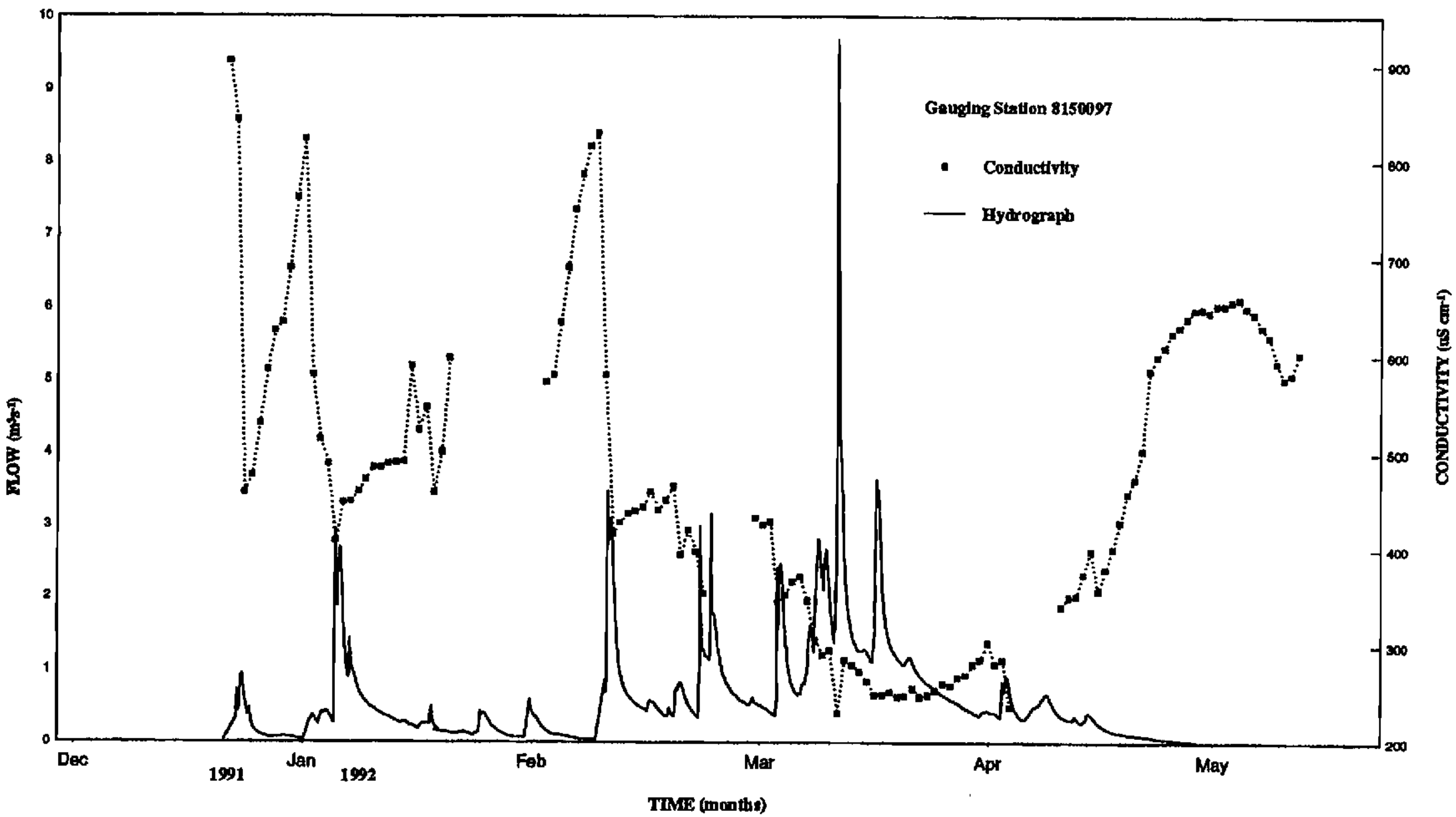

Figure D.34 East Finniss River at Gauging Station 8150097 - variation in conductivity with hydrograph from 24/12/91 to 15/05/92.

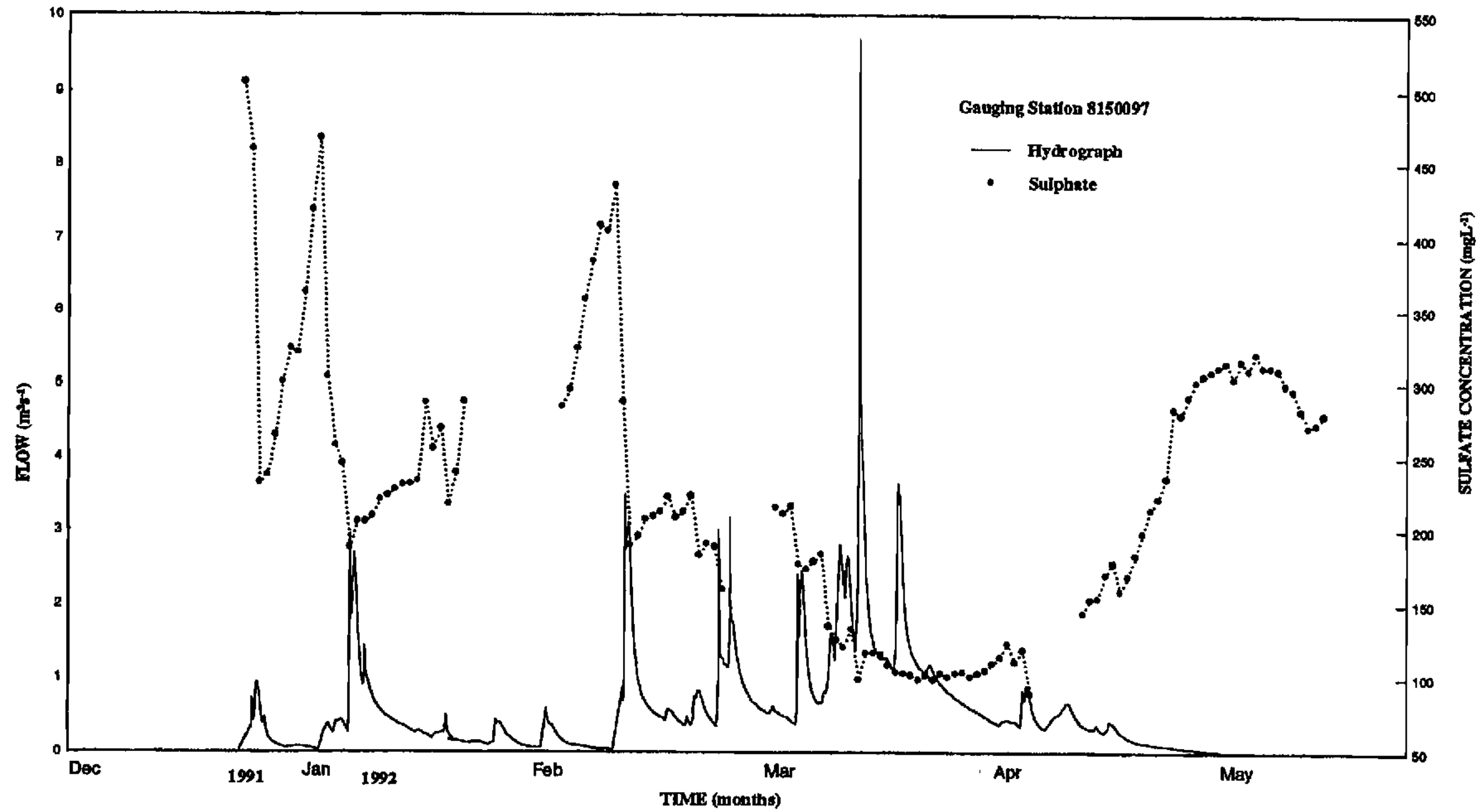

Figure D.35 **East Finniss River at Gauging Station 8150097 - variation in SO_4 concentration with hydrograph from 24/12/91 to 15/05/92.**

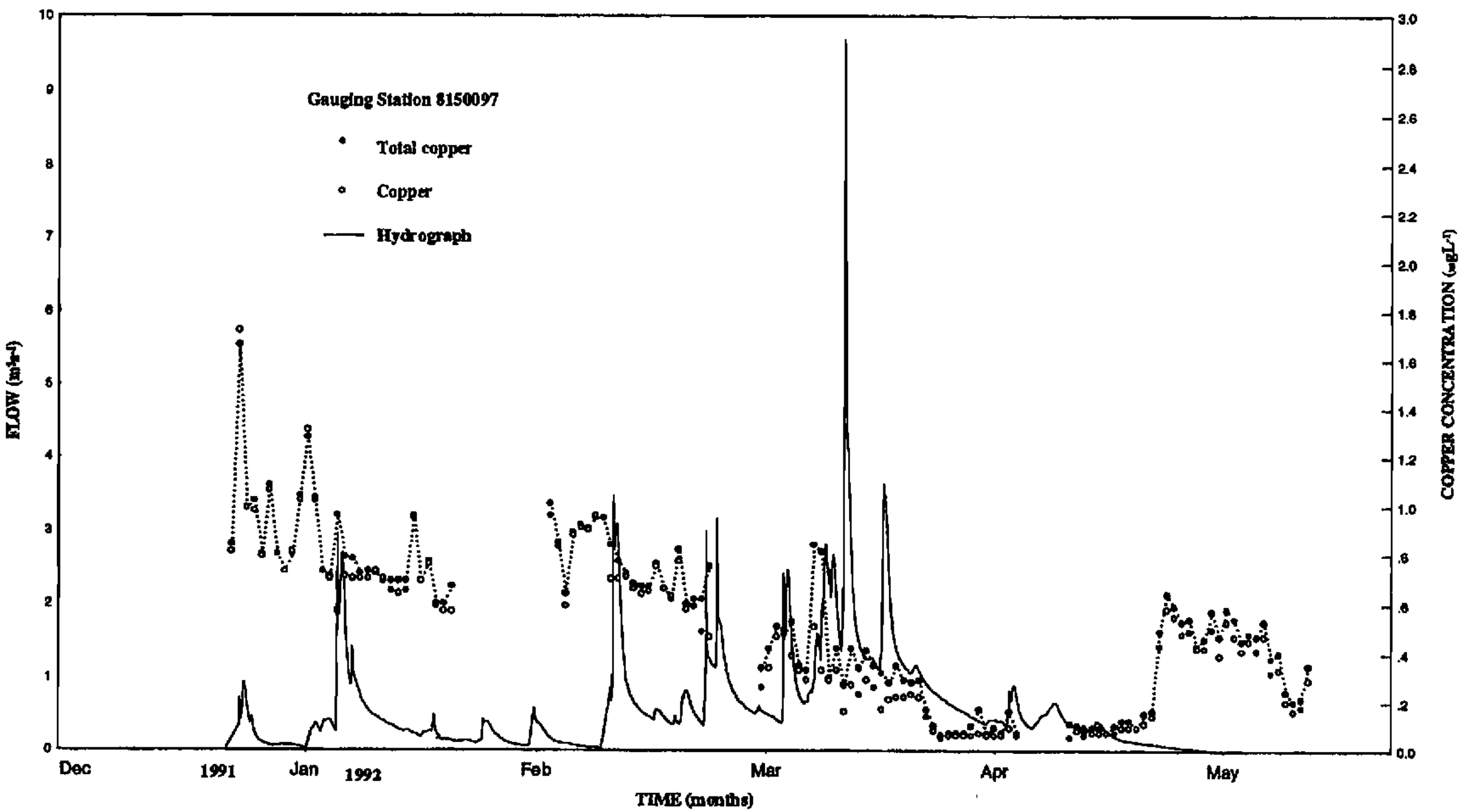

Figure D.36 East Finniss River at Gauging Station 8150097 - variation in total and dissolved Cu with hydrograph from 24/12/91 to 15/05/92.

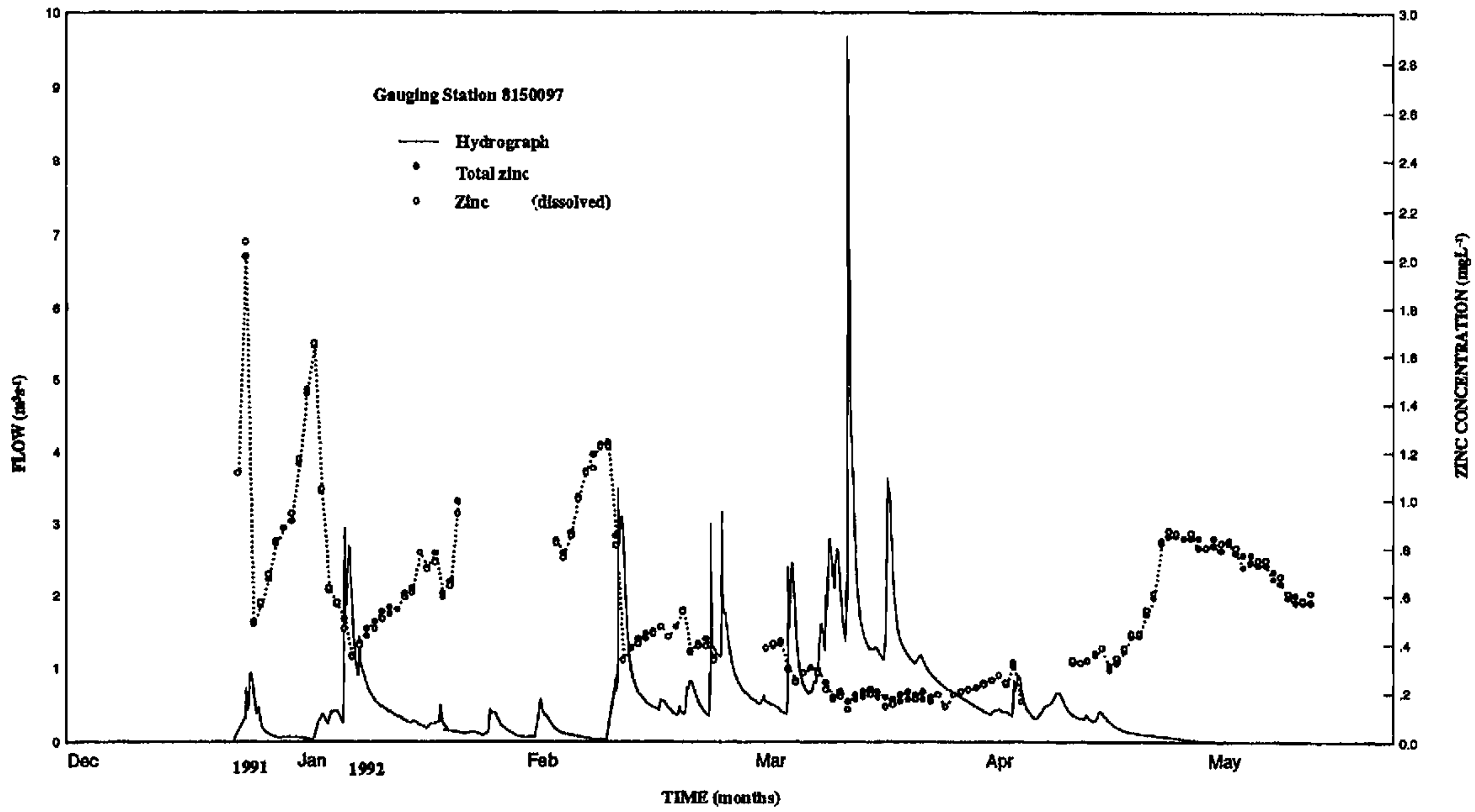

Figure D.37 **East Finniss River at Gauging Station 8150097 - variation in total and dissolved Zn with hydrograph from 24/12/91 to 15/05/92.**

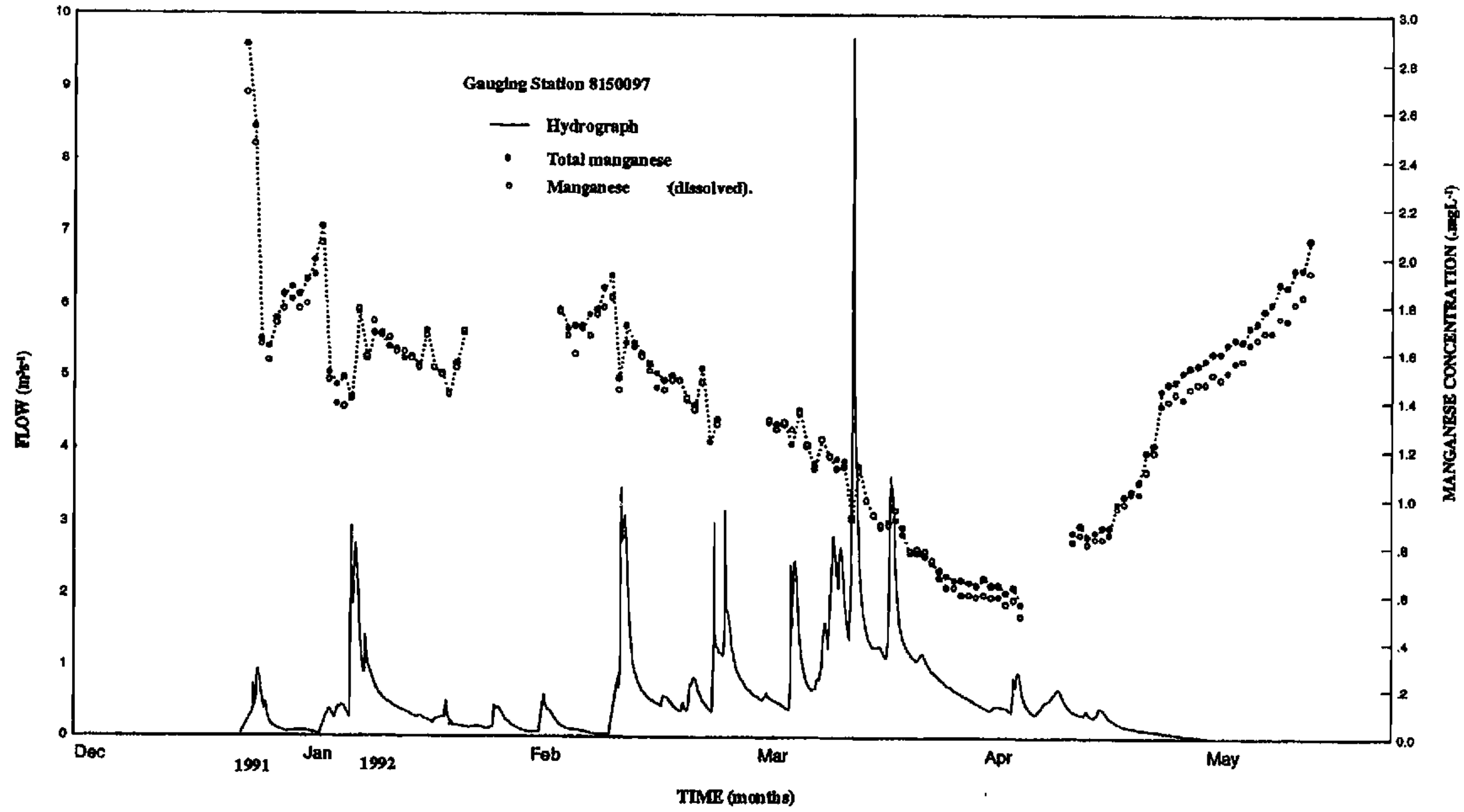

Figure D.38 **East Finniss River at Gauging Station 8150097 - variation in total and dissolved Mn with hydrograph from 24/12/91 to 15/05/92.**

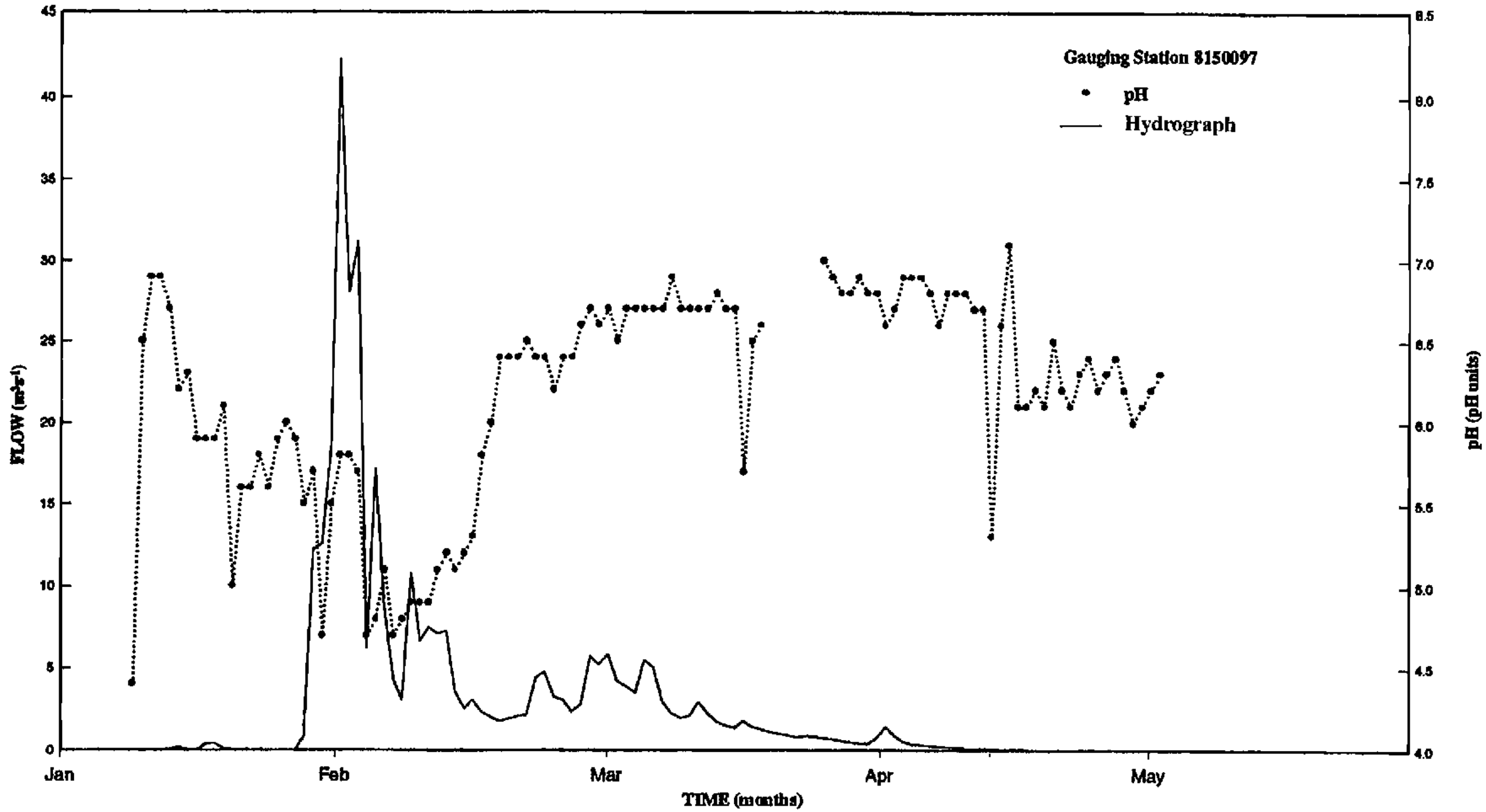

Figure D.39 East Finniss River at Gauging Station 8150097 - variation in pH with hydrograph from 1992 to 1993.

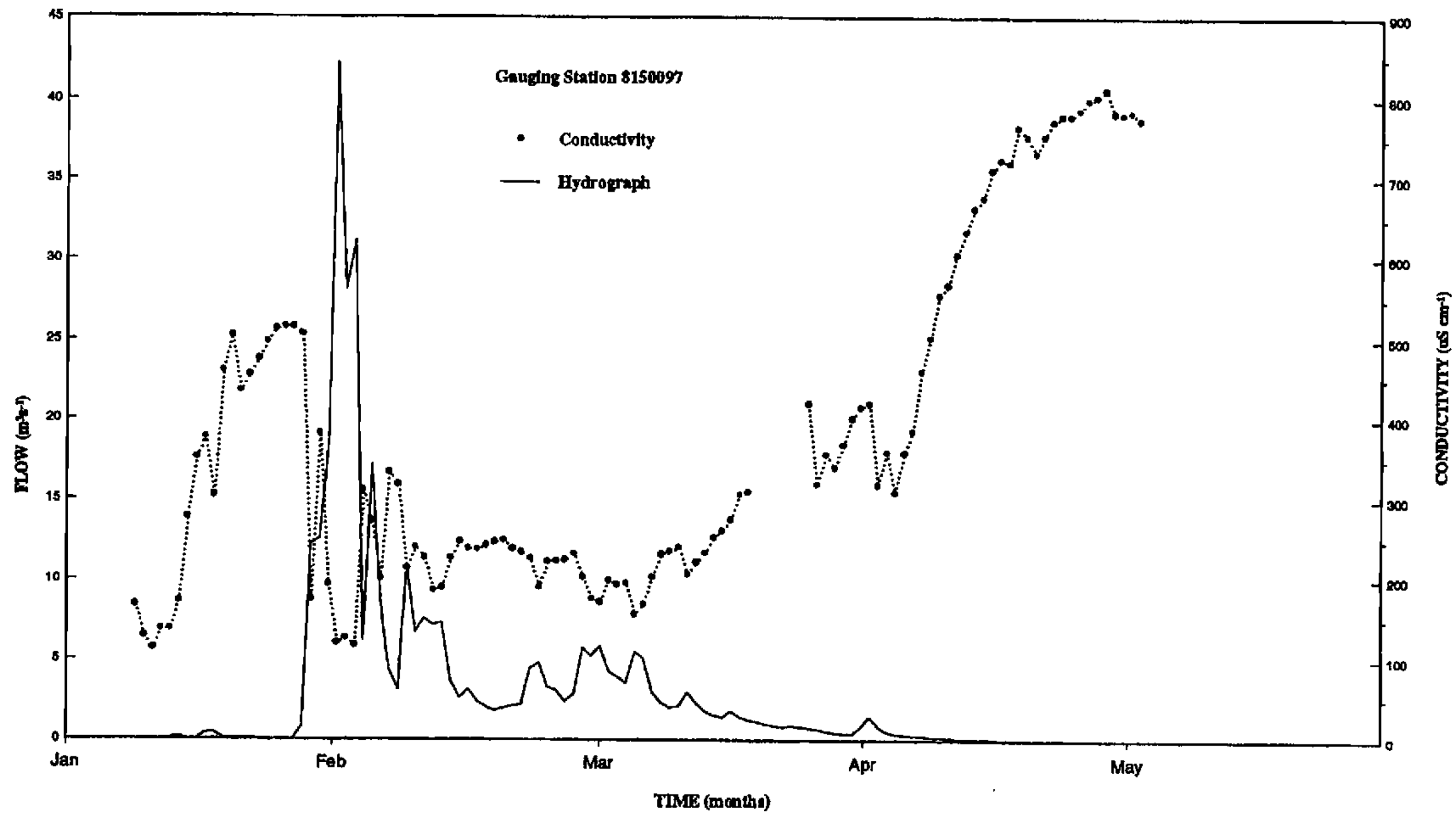

Figure D.40 East Finniss River at Gauging Station 8150097 - variation in conductivity with hydrograph from 1992 to 1993.

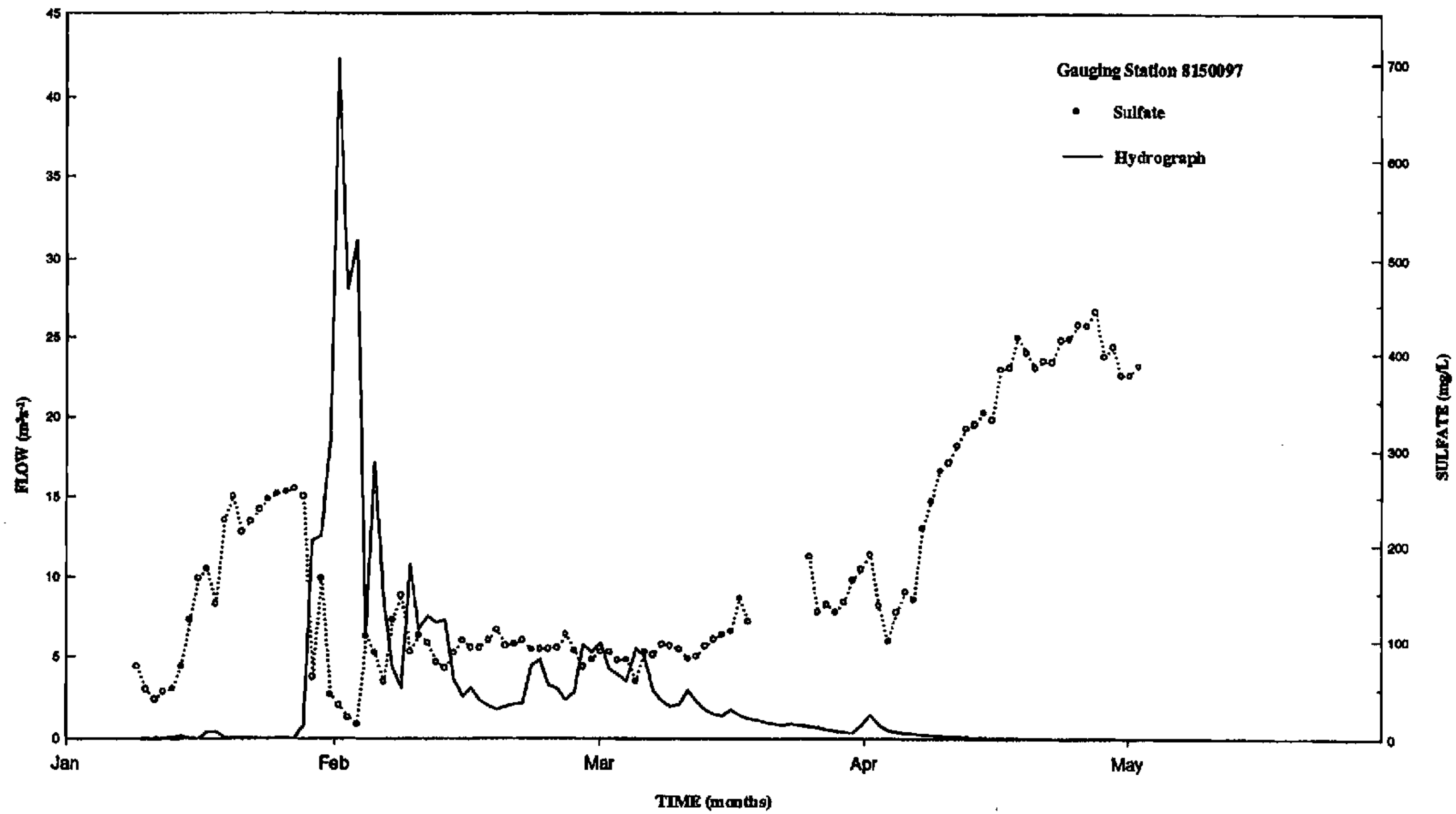

Figure D.41 East Finniss River at Gauging Station 8150097 - variation in SO_4 concentration with hydrograph from 1992 to 1993.

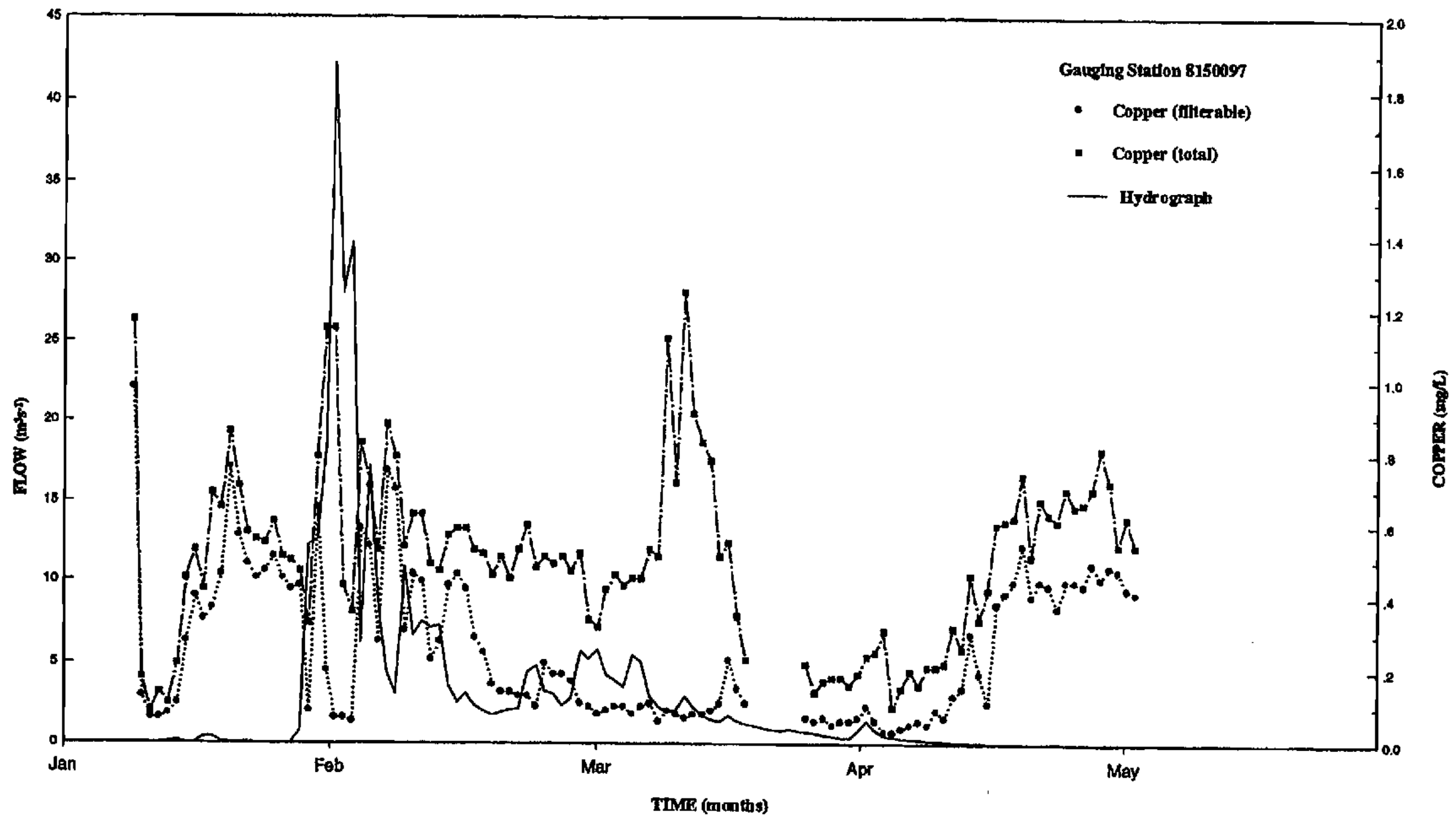

Figure D.42 **East Finniss River at Gauging Station 8150097 - variation in Cu concentration with hydrograph from 1992 to 1993.**

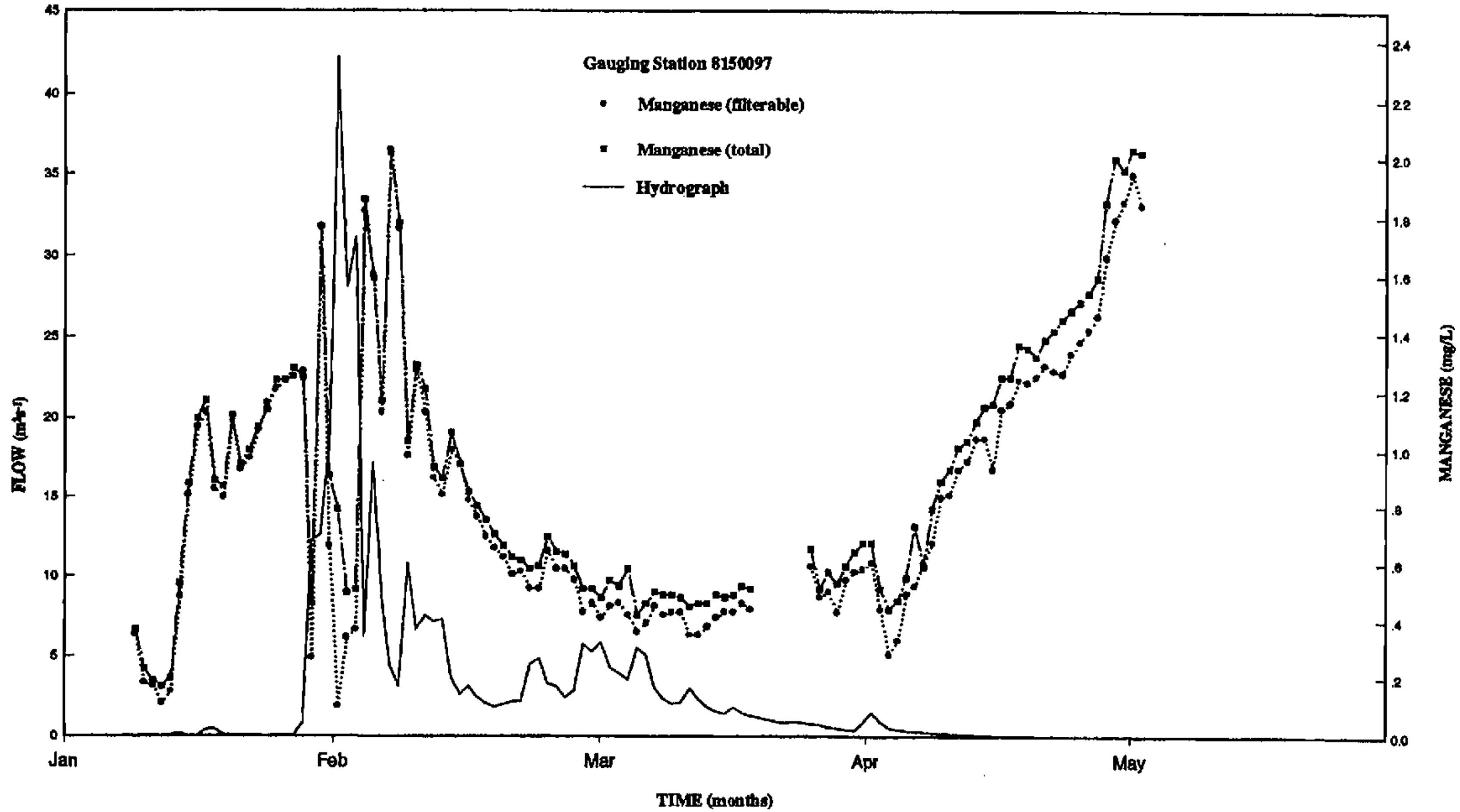

Figure D.43 East Finniss River at Gauging Station 8150097 - variation in Zn concentration with hydrograph from 1992 to 1993.

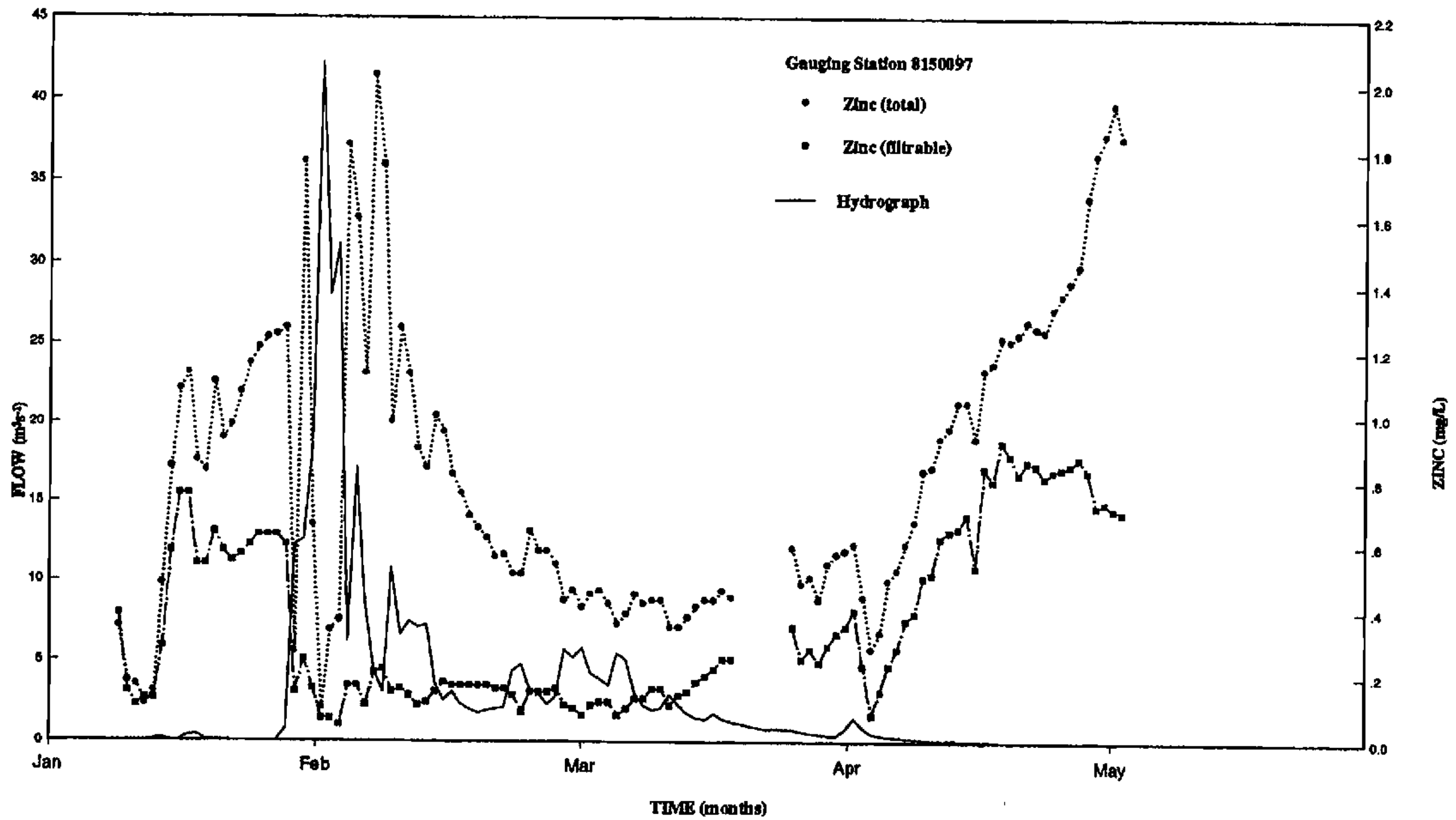

Figure D.44 East Finniss River at Gauging Station 8150097 - variation in Mn concentration with hydrograph from 1992 to 1993.

APPENDIX E

FISH SPECIES AND BIOMASS IN THE FINNISS RIVER

Table E.1 Number of fish species and biomass captured in the Finniss River.

SPECIES*	SITE													
	1		2a		2b		3a		5		6		All Sites	
	No.	grams	No.	grams	No.	grams	No.	grams	No.	grams	No.	grams	No.	grams
Bony bream *(Nematolosa erebi)*	92	18109	496	58217	131	9743	109	17256	0	0	171	20681	999	124006
Eeltail catfish *(Neosiluris ater)*	6	1488	18	1556	17	829	17	932	6	576	50	3399	114	8780
Forktail catfish *(Arius leptaspis)*	1	357	0	0	0	0	0	0	0	0	0	0	1	357
Barramundi *(Lates calcarifer)*	1	509	8	3677	5	2483	3	1635	0	0	5	2674	22	10978
Ox-eye herring *(Megalops cyprinoides)*	15	7218	31	9103	17	2114	16	4982	31	9956	9	2147	119	35520
Archer fish (*Toxotes chatareus*)	5	1017	7	724	0	0	0	0	0	0	1	173	13	1914
Mouth almighty *(Glossamia aprion)*	0	0	1	60	4	117	0	0	0	0	1	14	6	191
Rainbow fish *(Melanotaenia splendida inornata)*	4	2	6	6	7	13	1	1	0	0	1	1	19	23
Banded grunter *(Amniataba percoides)*	0	0	1	21	1	8	1	7	0	0	3	81	6	117
Perchlet *(Ambassis macleayi)*	0	0	0	0	1	6	0	0	0	0	1	10	2	16
Black bream A. (*Hephaestus fuliginosus*)	0	0	0	0	0	0	0	0	0	0	1	115	1	115
Black bream B. *(Syncomistes butleri)*	0	0	0	0	0	0	0	0	0	0	1	101	1	101
Black bream C. *(Syncomistes (?) nov. sp)*	0	0	0	0	0	0	1	39	0	0	1	27	2	66
Long tom *(Strongylura kreffti)*	0	0	1	63	1	36	0	0	0	0	0	0	2	99
Spangled grunter *(Leiopotherapon unicolor)*	0	0	0	0	0	0	1	40	0	0	0	0	1	40
Sleepy cod *(Oxyeleotris sp. A.)*	0	0	0	0	1	424	1	252	0	0	0	0	2	676
All species	124	28700	569	73427	185	15773	149	25105	37	10532	243	29207	1307	182717
Diversity Index	0.44		0.56		0.63		0.56		0.13		0.75		1	

* *Values have been normalised for catch effort but not site volume and have been rounded up to the nearest whole number.*