Technical Report Number 51

RUM JUNGLE REHABILITATION PROJECT

MONITORING REPORT

1986-88

Edited by M. Kraatz and R.J. Applegate

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THE RUM JUNGLE REHABILITATION PROJECT MONITORING REPORT (1986-88)

Edited by M. Kraatz and R.J. Applegate

Land Conservation Unit
Conservation Commission of the
Northern Territory

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Cover Photograph: Looking south-southwest from the old treatment plant area towards White's North and White's Overburden Heaps.

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CONTENTS

PAGE NO.

4. SURFACE WATER HYDROLOGY

East Finniss River and Finniss River Pollution Study 1986 - 87 (C.H.R.F. Henkel and J.F. Alcock)
East Finniss River and Finniss River Pollution Study 1987 - 88 (C.H.R.F. Henkel)

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- The staff of the East Point Laboratory and the Surface Water Monitoring Section of the Water Resources Division of the Power and Water Authority who gathered the results presented in Chapters 4 and 6.
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- Belinda Golding for typing and editing sections of the manuscript with great patience and perseverance.

ABSTRACT

In the late 1960's and 1970's it was recognised that pollutants emanating from the abandoned Rum Jungle uranium mine in the Northern Territory of Australia were responsible for severe environmental degradation of the Finniss River system. Products of Acid Mine Drainage and low level radioactive material released from the Tailings Dam resulted in the virtual absence of flora and fauna species for ten kilometres downstream of the mine.

In 1982 a joint Federal and Northern Territory government project was established to rehabilitate the abandoned Rum Jungle site. This project successfully achieved a major reduction in surface water pollution, public health hazard, (including radiation levels), pollution levels in the Open Cut water bodies and aesthetic improvement, including revegetation.

Monitoring of the site is continuing up to the present date to determine the ongoing success of the project. This includes evaluation of the surface water quality, chemical activity and water balance within the overburden heaps, groundwater hydrology and an assessment of revegetation success, erosion control structures and cover stability.

This document presents the results of monitoring activities conducted between 1986 and 1988 and outlines management and maintenance programs during that time.

LIST OF FIGURES

LIST OF PLATES

LIST OF TABLES

APPENDIX A
(Surface Water Hydrology - Figures)

APPENDIX B
(Surface Water Hydrology - Tables)

APPENDIX C
(Water Quality of the Open Cuts - Figures)

APPENDIX D
(Water Quality of the Open Cuts - Tables)

1. SUMMARY

1.1 INTRODUCTION

Rum Jungle is an abandoned uranium-copper opencut mine located about 85km south of Darwin in the Northern Territory of Australia. Mining was carried out between 1954 and 1964 and operations ceased in 1971. During the period 1954-1971 the mine produced approximately 3 500 tonnes of uranium and 20 000 tonnes of copper.

The major features at the site when it was abandoned were:

- three waste rock dumps containing a total of 10 million tonnes of material and covering a total area of 51 ha;
- three water filled opencuts covering a total area of 22 ha;
- a tailings disposal area containing about 0.6 million tonnes of tails and covering 31 ha; and
- a copper heap leach pile containing about 0.3 million tonnes of low grade copper ore and covering an area of about 2 ha.

It was apparent towards the end of the mine life that effluent from the treatment plant and leachate from mine wastes had a severe impact on the flora at the mine site and more particularly on the aquatic fauna of the East Branch of the Finniss River which flows through the site. The major pollutants in the river were copper, manganese, zinc and sulphate, copper being the most significant of these. In the early 1970's the East Branch was biologically dead from the mine site to its confluence with the main branch of the Finniss River 8.5km downstream of the mine site. There was reduced biodiversity in the aquatic life of the Finniss River for at least 15km downstream of its junction with the East Branch.

The waste rock dumps and the heap leach pile were the major sources of pollution. These contributed about 85% of the copper load in the East Branch and a similarly high fraction of other major pollutants. The next major sources were the opencuts which contributed about 10% with the tailings dam contributing about 5% of the copper load. The impact of uranium and its daughter radionuclides was of minor concern compared to the impact of heavy metals. The pollution generation mechanisms are the same in all the heaps, namely the bacterially catalysed oxidation of sulphidic material and the consequent production of sulphuric acid and soluble metal sulphates. This is a common pollution generation mechanism at mine sites throughout the world and usually is described as acid mine drainage (AMD).

In 1983, a collaborative agreement was signed between the Australian and Northern Territory (NT) 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).

This document reports on the monitoring activities which have been conducted between 1986 - 88 by the Power and Water Authority (PAWA) and the Conservation Commission of the Northern Territory (CCNT) of the NT government, and the Australian Nuclear Science and Technology Organisation (Ansto). These activities have been designed to assess the success of the rehabilitation project in reducing the quantity of pollutants being generated on site.

Results of monitoring activities conducted since 1988 have been documented in separate reports which are available from the CCNT.

1.2 SUMMARY OF MONITORING ACTIVITIES

The following section summarises the findings of the various monitoring programs outlined in detail in following chapters.

1.2.1 SURFACE WATER HYDROLOGY (CHAPTER 4)

The primary objectives of the surface water quality monitoring program on the East Finniss and Finniss Rivers were the measurement of annual flow volume and dissolved copper, manganese, zinc and sulphate loads at GS8150097.

Recorded total flow in the East Finniss River at GS8150097 in the two years following completion of the rehabilitation program was low. Flow recorded in 87/88 was the lowest seasonal flow volume recorded since the commencement of monitoring.

The original agreement between the Commonwealth and the Territory governments set a target for total dissolved pollutant load reduction in the East Finniss River. Figures for 1987/88 show that these targets for copper, manganese, zinc and sulphate have been met.

In 1987/88 radium-226 concentrations at no time exceeded the maximum recommended limit for drinking water of 0.4Bq/l. The maximum recorded concentration was 0.2Bq/l as compared to 0.61Bq/l in 86/87.

High concentrations of copper and radium were recorded in seepage from Dyson's Open Cut in 1986/87, but annual loads were low. In the following year, copper concentrations were reduced while similar radium concentrations were encountered.

Five out of seven of the subsoil drains on White's Overburden Heap discharged polluted water between 1986 and 1988. These flows were characterised by high pollutant concentrations and low flows. Water quality was similar to that recorded during the previous three seasons. This pollution is attributed to either shallow groundwater flow entering from the south or minor infiltration of rainwater through the covers.

Contributions to the total dissolved load at GS8150097 from these drains is minor and a reduction in these levels was recorded from 1986-1988. The reduction could be attributed to both the success of the rehabilitation works and the difference in seasonal rainfall.

In 1987, the sampling programme was expanded in order to pinpoint the sources of pollution entering the East Finniss River as recorded at GS8150097 and to allocate percentages of pollutant loads from each source to the total pollutant load. This program verified qualitative assessments that the open cuts were major contributors.

While targets for the reduction in pollutant loads in the East Finniss River have been met, it is concluded that the integrity of the rehabilitated structures needs to be tested by above average flows.

1.2.2 GROUNDWATER HYDROLOGY (CHAPTER 5)

The height and quality of the groundwater beneath the Rum Jungle site have been monitored since the rehabilitation of the site was started in 1983. These measurements have been studied with the aim of establishing the pathways of pollution transport and the time scale for improvement in water quality.

The average contamination concentration has not changed significantly over the five year period 1983-1988, with high concentrations being localised around former sources of contamination, such as the overburden heaps. Cyclic seasonal variation in concentration is observable in some boreholes, from which it can be implied that mixing between infiltrating rainwater and the reservoir of polluted groundwater is limited.

Mathematical modelling has been used to gain understanding of the system. The model shows that there is a large store of pollutants held in the porewater within the overburden heaps. Calculations of the movement of water through the heaps indicate that it will take from 10 to 20 years before there is noticeable drop in contaminant concentration from this source.

The groundwater measurements show that the concentration of pollutants in the water adjacent to the heaps has not been changed significantly by the rehabilitation. Nevertheless, a tenfold reduction in output must result from the reduction in infiltration through the heaps. This is consistent with the measured improvement in surface water quality.

Monitoring of groundwater should continue for at least 10 more years, given that calculations of water movements through the overburden heaps indicates that it will take from 10 to 20 years before there is a noticeable drop in contaminant concentration from this source.

1.2.3 WATER QUALITY OF THE OPEN CUTS (CHAPTER 6)

Water sampling in 1986/87 suggested that, post-rehabilitation, White's and Intermediate Open Cuts were a greater source of pollutants to the East Finniss River than previously thought. Monitoring activities in 1987/88 were increased in order to clarify a number of questions which arose from the results of the 1986-87 program.

These results indicated that the pollutant contributions from Intermediate Open Cut were not as great as originally thought. It was also determined that the higher concentrations of heavy metals in the open cut may be due to:

(i) The rise of contaminated groundwater from the Copper Heap Leach area and the transport of pollutants via the adjacent waterway;
(ii) The input of groundwater; and
(iii) The transport of pollutants from White's Open Cut.

Heavy metal concentrations at depth are low but are gradually increasing.

The relatively unpolluted top layer in White's Open Cut deepened by two metres to 44 metres AHD and the mixing zone deepened by three metres to 34 metres AHD. Increases in heavy metal pollutant concentrations in the upper White's Open Cut were attributed to mixing with the deeper, polluted waters, evaporation and input of contaminated groundwater.

The zinc contribution from both open cuts was minimal when compared to the total load measured at GS8150097, which is the sampling point on the East Finniss River for the measurement of contaminants for the rehabilitated site.

1.2.4 CHEMICAL ACTIVITY AND WATER BALANCE OF THE OVERBURDEN HEAPS (CHAPTER 7)

White's and Intermediate Overburden Heaps at Rum Jungle have been monitored to determine the effectiveness of rehabilitation. Lysimeters installed in the heaps before the emplacement of the compacted clay layer were used to measure the infiltration of rain. The results showed that less than five percent of the incident rainfall infiltrated through the cover layers.

Temperature profiles have been regularly measured using thermistor probes in both heaps. Before rehabilitation the oxidation of pyrite in the dumps led to elevated temperatures. Heat production distributions derived from the measured temperatures showed that heat production occurring before rehabilitation was effectively stopped by rehabilitation.

The supply of oxygen was the main process limiting the rate of oxidation of pyrite in the dumps before rehabilitation. Pore gas samples collected from the gas ports attached to the probe holes have shown that rehabilitation greatly reduced oxygen concentrations at depth within the dumps and effectively stopped the supply of oxygen by thermal convection.

Monitoring of the heaps has shown that rehabilitation by reshaping and covering with compacted clay was effective in reducing the ingress of water, the rate of oxidation of pyrite and the transport of oxygen.

This monitoring should be continued on the current twice-yearly schedule. This is to enable the collection of data in both the wet and dry seasons, since conditions in the overburden heaps have been found to display marked seasonal variations, with potentially important ramifications with regard to pollution generations rates.

1.2.5 REVEGETATION, EROSION CONTROL AND COVER STABILITY (CHAPTER 8)

Inspections were carried out in August 1987 and May 1988 on all rehabilitated surfaces at Rum Jungle to assess the integrity of drainage works stability, pasture status, slope stability, tree growth, and maintenance works.

Remedial works were required on sections of the main drain on White's Heap to repair damaged rip rap, lower two gabion weirs and extend mattressed outfalls. Commonly occurring weeds such as *Hyptis* and *Sida* are present to varying degrees on all rehabilitated surfaces but competition from pasture grasses has been strong to date, limiting the extent of weed growth. Removal of isolated plants of *Mimosa Pigra* has been required, however.

Assessment of the success of revegetation and surface stabilisation by ongoing monitoring should be continued at an appropriate and economically practical level. It is recommended that the current levels of maintenance should be decreased and that a review be conducted in 12 months.

Annual inspections should be continued to assess the stability of surface drainage structures, pasture status, weeds, rock mulch stability, and soil fauna. More frequent inspections are recommended, however, to control outbreaks of *Mimosa pigra.*

Tree eradication programmes are currently not considered necessary, however, a review of this situation within the next twelve months is recommended.

Primary production such as hay cutting and grazing without a guaranteed commitment to fertilisation and activities supervision is not recommended.

Unrestricted vehicular use of the site should not be allowed. The level of visitation should be controlled and a small information pamphlet be produced to complement site visits.

1.2.6 SITE MANAGEMENT (CHAPTER 11)

The original agreement between the Federal and Northern Territory (NT) Governments catered for the rehabilitation of the Rum Jungle mine site between 1982-86 and a monitoring program between 1986-88.

In order to ensure the on-going integrity of the rehabilitated structures beyond this date, continuing monitoring and maintenance is required. A Site Management Plan was drafted, describing the extent and nature of such a program.

While recognising that the future use of the Rum Jungle site is subject to determination of the Finniss River Land Claim, the Plan recommended that in order to maintain the integrity of the site, it should be declared a Restricted Use Area under Section 20B of the Soil Conservation and Land Utilization Act (1980). As the statutory body administering this Act, responsibility for site management after 1988 should be passed to the Conservation Commission of the Northern Territory.

A preventative maintenance program should be carried out by the CCNT based on annual assessments and monitoring by PAWA, Ansto and CCNT should also be continued. Both these programs should be reviewed annually with a view to gradual reductions and possible phasing out of monitoring by 1993.

2. INTRODUCTION

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The Rum Jungle mine operated between 1950 and 1971, producing uranium, copper, nickel and lead. In the late 1960's it was recognised that pollutants emanating from the abandoned mine were responsible for severe environmental degradation of the Finniss River system. In 1982, a joint rehabilitation program was conducted by the Federal and Northern Territory governments. This project achieved a major reduction in surface water pollution, public health hazard, pollution levels in the open cut water bodies and aesthetic improvement, including revegetation.

The project is perhaps the most fully documented of its kind in the world, encompassing a variety of environmental problems dealing with waste rock dumps, open cuts, tailings dams and associated with radiological pollution and Acid Mine Drainage (AMD). Dissemination of results of this project and collaboration with various international organisations such as the Canadian MEND program will contribute to a greater worldwide understanding of the mechanisms of pollutant production and transport and to the development of appropriate preventative or rehabilitative strategies.

2.1 LOCATION AND CLIMATE

The Rum Jungle rehabilitation site is located 85 kilometres south of Darwin, the capital of the Northern Territory of Australia. The site is located on the East Branch of the Finniss River in close proximity to the small township of Batchelor (See Figure 2.1). Rainfall is strongly seasonal and highly variable. Mean annual falls are around 1600mm and 90% of this is received from November to March during periods of intense rainfall.

2.2 HISTORY OF THE SITE

The existence of uranium ore in the Batchelor district was first reported as early as 1869 but at that time interest in the ore was minimal. By 1948, however, the Federal Government was offering rewards for the discovery of uranium ore. In 1949, a gold prospector reported what was to become Australia's first uranium field at Rum Jungle.

Mining of uranium, copper, nickel and lead from White's deposit was originally conducted by underground methods, however, open cut operations were later considered feasible. Uranium was also extracted from Dyson's Opencut and copper from Intermediate Opencut until 1965 when mining operations ceased (Figure 2.2). Ore treated at Rum Jungle was also extracted from Rum Jungle Creek South and Mount Burton which were within a few kilometres of the site.

A total of 3,500 tonnes of uranium oxide (U_3O_8) and 20,000 tonnes of copper concentrate were processed on site at Rum Jungle.

The major features at the site when it was abandoned were:

. three waste rock dumps containing a total of ten million tonnes of material and covering an area of 51 ha;

. three water filled opencuts covering an area of 22 ha;

. a tailings disposal area containing about 0.6 million tonnes of tails and covering 31 ha; and

. a copper heap leach pile containing about 0.3 million tonnes of low grade copper ore and covering an area of about 2 ha.

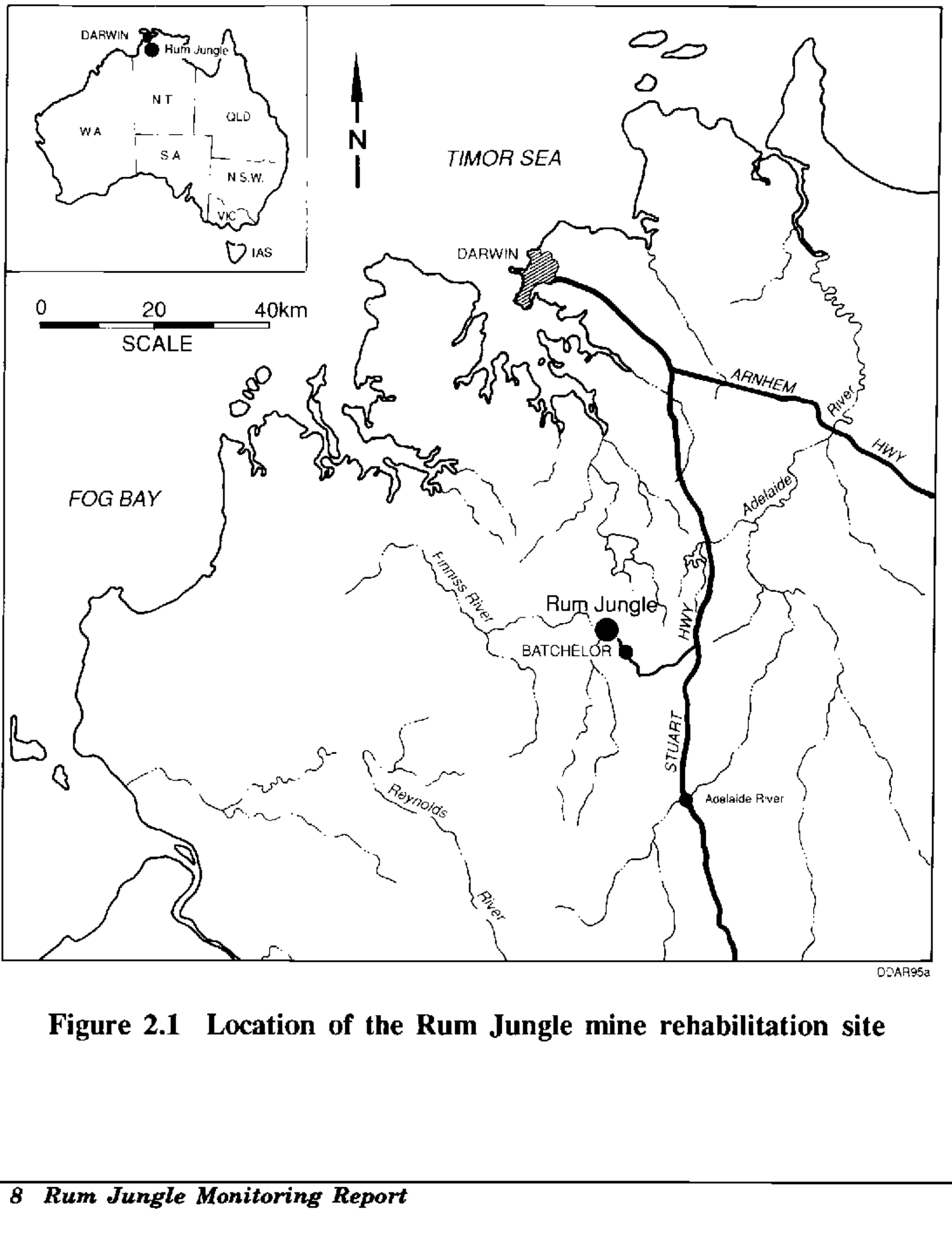

Figure 2.1 Location of the Rum Jungle mine rehabilitation site

2.3 THE LEGACY

The generation of sulphuric acid and heavy metals from the waste rock dumps and the release of large quantities of radio-nuclides from the tailings dam at Rum Jungle were responsible for severe environmental degradation of the Finniss River, the East Branch of which flows through the site, and its surrounds.

Investigations in 1973-74 showed that the waste rock dumps and heap leach pile were the major sources of pollution. These contributed about 85% of the copper load in the East Branch and a similarly high fraction of other major pollutants. The next major sources were the opencuts which contributed about 10% with the tailings dam contributing about 5 % of the copper load. The impact of uranium and its daughter radionuclides was of minor concern compared to the impact of heavy metals, particularly copper, manganese, zinc and sulphate.

The pollution generation mechanisms are the same in all dumps, namely the bacterially catalysed oxidation of sulphidic material and the consequent production of sulphuric acid and soluble metal sulphates. This is a common pollution generation mechanism at mine sites throughout the world and usually is described as Acid Mine Drainage (AMD).

Between 1954 and 1961 unneutralised tailings were released into the tailings dam where it was partially contained by a series of small impoundments (Allen & Verhoeven 1986). Supernatant liquor containing entrained tailings were released over the dam wall into Tailings Creek which fed into the Finniss River. These tailings were acidic and consisted of low levels of radio-nuclides and high levels of heavy metals. Consequently, the tailings dam area and the length of Tailings Creek were totally devoid of vegetation. On several occasions , the dam wall breached and significant quantities of tailings material entered the Finniss River system. After 1961, tailings were redirected into Dyson's Open Cut. The abandoned tailings dam wall again breached and tailings continued to be eroded and deposited into the river system for some time. It was estimated that a total of 150,000 tonnes of acidic waste were transported from the tailings dam into the river.

High concentrations of heavy metals combined with a low pH in the East Finniss River resulted in the virtual absence of flora and fauna species for 8.5 kilometres downstream of the mine to the confluence with the Finniss River. The number of species was drastically reduced due to both direct contamination from pollutants and a loss of habitat due to vegetation death along the river banks (Davy 1975). This reduced biodiversity in aquatic life in the Finniss River was evident for at least 15 kilometres downstream of the junction with the East Branch. This also contributed to increased rates of erosion.

One hundred square kilometres of the Finniss River floodplain was also affected by contaminants and levels of copper and manganese in forage grasses appeared to be on the borderline of stock injury although that had not been observed. Following closure of the mine in 1971, it became apparent that if uncontrolled, acid and heavy metal pollution generation would continue in the Rum Jungle waste rock dumps at a very slowly decreasing level for a period of some hundreds of years (Department of the Northern Territory 1978).

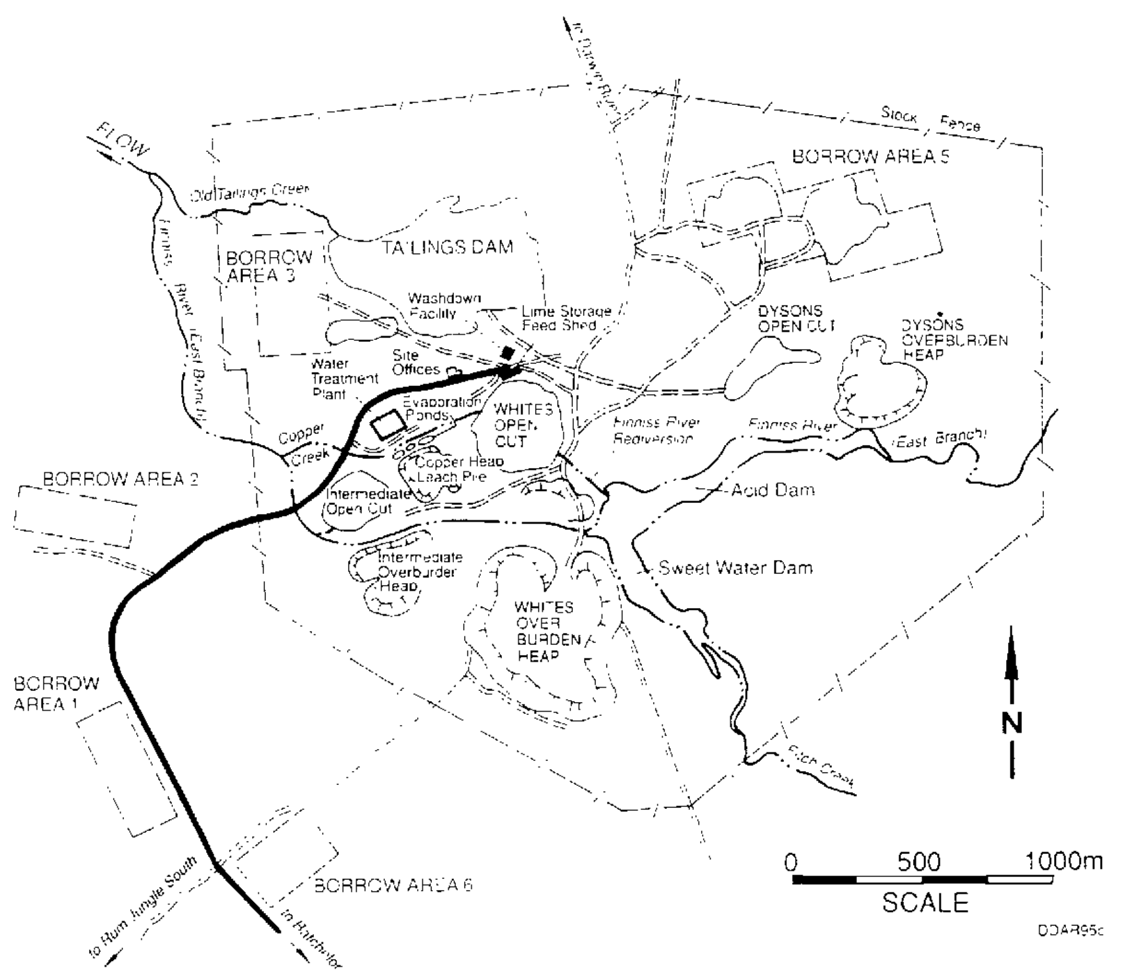

Figure 2.2 Rum Jungle Site Plan

2.4 THE REHABILITATION PROJECT

The Australian Nuclear Science and Technology Organisation (Ansto, formerly the Australian Atomic Energy Commission, AAEC) conducted a series of studies aimed at identifying the extent and major sources of pollution at Rum Jungle. Following the release of these studies and mounting public concern regarding the ongoing pollution of the Finniss River system, the Australian Government announced in 1977 that it was considering the rehabilitation of the Rum Jungle site. It stated that the Rum Jungle operation was carried out with inadequate concern for the environment and would not be permitted by today's standards. (Department of the Northern Territory 1978).

An initial clean up was conducted in late 1977. However, the measures taken were largely aesthetic and were not aimed at reducing the generation of pollutants on site.

A number of strategies had been proposed world-wide to counter the problem of Acid Mine Drainage, but none of these had been tested. A working group was established to develop a series of strategies for the rehabilitation of the Rum Jungle site and in 1982 an agreement was signed between the Federal and Northern Territory Governments which established the Rum Jungle Rehabilitation Project. The agreement established a project which was clearly beyond the scope of a single company or mine and which was not hindered by ongoing mining operations. Rehabilitation was completed in 1986 on time and within budget at a total cost of about M$18 (in 1986 terms).

The objectives of the rehabilitation project were:

(i) to achieve a major reduction in surface water pollution, aimed at reducing the average annual quantities of copper, zinc and manganese by 70%, 70% and 56% respectively as measured at the confluence of the East Finniss River and the Finniss River;

(ii) to reduce public health hazards, including radiation levels;

(iii) to reduce pollution levels in the waters of White's and Intermediate Open Cuts; and

(iv) to implement aesthetic improvements including revegetation.

Each of these objectives is dealt with in detail in the Final Project Report (Allen & Verhoeven 1986).

The following works were completed under the project, which was carried out over a four year period commencing in 1982.

(i) The rehabilitation of White's, White's North, Intermediate and Dyson's Overburden Heaps.

(ii) The treatment of water contained in White's and Intermediate Open Cut pits.

(iii) The removal of the tailings contained in the Old Tailings Dam to Dyson's Open Cut and the rehabilitation of the area previously occupied by the tailings.

(iv) The removal of the low grade copper ore from the Copper Heap Leach Pile to Dyson's Open Cut, and the rehabilitation of the Copper Heap Leach Pile area.

(v) The rehabilitation of the Treatment Plant and stockpile areas.

(vi) The partial rediversion of the East branch of the Finniss River and the removal of the Acid and Sweetwater Dams.

Monitoring was established as a crucial part of the project to determine the success of the project as outlined in the original agreement. This document reports on the monitoring activities which have been conducted between 1986 - 88 by the Power and Water Authority (PAWA) and the Conservation Commission of the Northern Territory (CCNT) of the NT government, and the Australian Nuclear Science and Technology Organisation (Ansto). Results collected and analysed prior to and including 1986 were reported in detail in the Final Project Report (Allen & Verhoeven 1986). Results of monitoring activities conducted since 1988 have been documented in separate reports which are available from the CCNT.

3. MONITORING - GENERAL

From Chapter 12 Allen & Verhoeven (1986)

3.1 INTRODUCTION

The Agreement between the Commonwealth and Northern Territory governments which established the Rum Jungle Rehabilitation Project defined monitoring as "...that part of the rehabilitation programme that calls for investigatory work to be carried out to determine the effect of the rehabilitation work on the site and the river and maintenance measures as necessary to preserve the integrity of the rehabilitation work".

The monitoring period was defined as 1st July, 1982 to 1st July, 1988. It was recognised, however, that monitoring would probably extend beyond that date to 1992, (a total period of ten years), in order to determine the long term success of the project (Mining and Process Engineering Services, 1982).

3.2 MONITORING PROGRAMME

3.2.1 THE COPPER HEAP LEACH PILE

(i) Monitor revegetation of the area.
Visual inspection of the revegetation of the area by the Conservation Commission of the Northern Territory (CCNT).

(ii) Monitor erosion of the area.
Visual inspection by the CCNT.

3.2.2 THE OLD TAILINGS DAM

(i) Monitor the migration of radium in the subsoil. A study by the Australian Nuclear Science and Technology Organisation (Ansto, formerly the Australian Atomic Energy Commission, AAEC) to determine the extent of migration of radium in the subsoil below the tailings in the Old Tailings Dam, if any.

(ii) Monitor revegetation of the area.
Visual inspection of the revegetation of the area by the CCNT.

(iii) Monitor erosion of the area.
Visual inspection by the CCNT.

3.2.3 DYSON'S OPEN CUT

(i) Monitor local groundwater regime.
A number of observation bores have been established on the down slope side of Dyson's Open Cut (Figure 3.1) monitoring the groundwater around the opencut to confirm the containment of the tailings material. Monitoring by Water Resources Division of the Power and Water Authority (PAWA)(formerly the Water Resources Division of the Department of Mines and Energy).

(ii) Monitor erosion of covers and drains.
Visual inspection of the covers and drains by the CCNT.

(iii) Monitor vegetation condition.
Visual inspection of the condition of the vegetation on the fill in the open cut by the CCNT.

(iv) Monitor settlement of fill.
Periodic survey of the established grid system on the open cut to determine the extent of, and any changes to, the settlement of the fill material in the open cut. The survey is conducted on request by the Northern Territory Department of Lands.

3.2.4 WHITES'S OPEN CUT

(i) Monitor water quality and temperature profiles.
Regular assessment of the quality and temperature of the vertical profiles of the open cut by Water Resources Division of PAWA.

(ii) Monitor revegetation of embankments.
A visual programme conducted by the CCNT.

3.2.5 INTERMEDIATE OPEN CUT

(i) Monitor water quality and temperature profiles.
Regular assessment of the quality and temperature of the vertical profiles of the open cut by Water Resources Division of the PAWA.

(ii) Monitor revegetation of embankments.
A visual programme conducted by the CCNT.

3.2.6 DYSON'S OVERBURDEN HEAP

(i) Monitor erosion of covers and drains.
A visual programme of inspection by the CCNT.

(ii) Monitor condition of vegetation.
A visual programme by the CCNT.

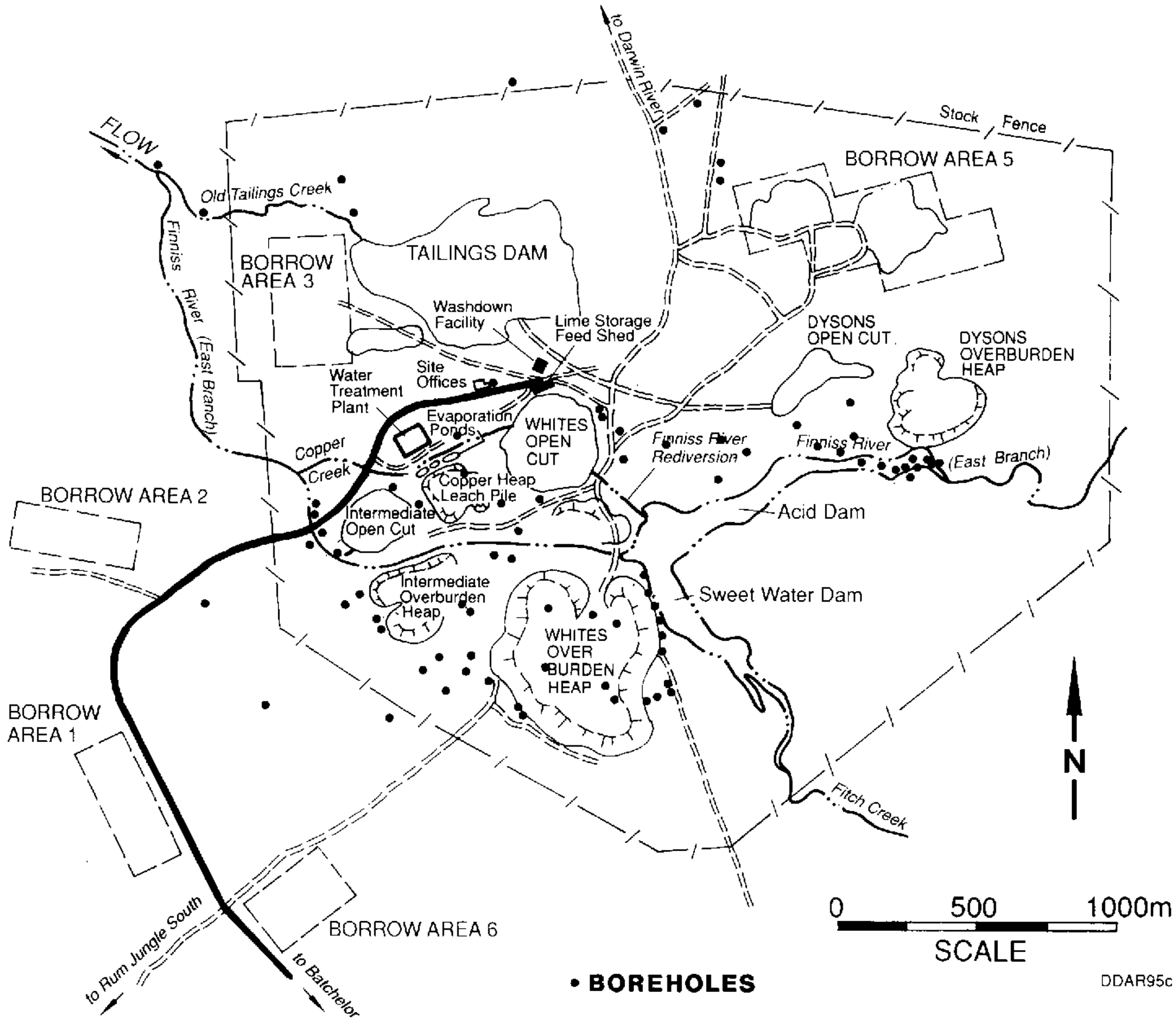

Figure 3.1 Borehole Locations

3.2.7 WHITE'S OVERBURDEN HEAP

(i) Monitor the water balance of the heap.
Programme of measurement of infiltration through the cover system (by Ansto) and run off from the heap (by the Water Resources Division of PAWA).

(ii) Monitor groundwater in and around the heap.
An observation bore has been established through White's Overburden Heap and a network of shallow and deep observation bores have been established around the heap (Figure 3.1). The water levels and quality of the aquifer system are monitored. The recording of levels, sampling and data analysis for this programme were being conducted by the Water Resources Division of the Department of Mines and Energy (now PAWA). However, after June 1986 responsibility for the assessment of the data passed to Ansto.

(iii) Monitor erosion of covers and drains.
A visual programme of inspection and assessment by the CCNT.

(iv) Monitor chemical activity.
Chemical activity within the overburden heap is monitored by the measurement of temperature and gas composition within the heap. This programme is conducted by Ansto.

(v) Monitor condition of vegetation on the heap.
A visual programme of monitoring the condition and extent of vegetation by the CCNT.

3.2.8 INTERMEDIATE OVERBURDEN HEAP

(i) Monitor infiltration into the heap.
Programme of measurement of infiltration through the cover system by Ansto.

(ii) Monitor groundwater in and around the heap.
A network of shallow and deep observation bores has been established around the heap (Figure 3.1). Water levels and quality of the aquifer system are monitored. The sampling and data assessment for this programme was being carried out by the Water Resources Division of the Department of Mines and Energy (now PAWA). However, after June 1986, responsibility for the assessment of the data passed to Ansto.

(iii) Monitor erosion of covers and drains.
A visual programme of inspection and assessment by the CCNT.

(iv) Monitor chemical activity.
Chemical activity within the overburden heap is monitored by the measurement of temperature and gas composition within the heap. This programme is carried out by Ansto.

(v) Monitor condition of vegetation on the heap.
A visual programme of monitoring condition and extent of vegetation carried out by the CCNT.

3.2.9 AREA OF FORMER WHITE'S NORTH OVERBURDEN HEAP

(i) Monitor erosion of the area.
A visual programme of inspection by the CCNT.

(ii) Monitor condition of vegetation.
A visual programme carried out by the CCNT.

3.2.10 ACID AND SWEETWATER DAMS

Monitor stream bed and embankment condition.
A visual assessment of the condition and vegetation of the stream beds and banks by the CCNT.

3.2.11 OTHER AREAS

Monitor the regeneration of vegetation around the site, in particular on the rehabilitated borrow areas. Conducted by the CCNT.

3.2.12 WATER TREATMENT PLANT

Groundwater at filter cake disposal site.
Regular sampling of groundwater observation bores around the filter cake disposal site by the Water Resources Division of PAWA.

3.2.13 REGIONAL MONITORING

(i) Regional groundwater monitoring to detect possible movement of heavy metals away from the mine site.
Regular monitoring of water levels and sampling of established observation bores in and around the mine site, and monitoring of spring flows (Figure 3.1). Conducted by the Water Resources Division of PAWA.

(ii) Water quality of the Finniss River system.
Stream flows in the Finniss River and the East Branch of the Finniss River are measured at sites shown in Figure 4.1 and 4.2. Monitoring for water quality and flow regime during each wet season is conducted by the Water Resources Division of PAWA.

(iii) Stream bed sediments of the East Branch of the Finniss River.

Random sampling and analysis of the sediment deposits in the bed of the East Branch of the Finniss River by the Water Resources Division of PAWA.

4. SURFACE WATER HYDROLOGY

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4.1 INTRODUCTION

4.1.1 BACKGROUND

The pollution regime of the East Finniss and Finniss Rivers was monitored during the Rum Jungle Rehabilitation Project from 1982-83 to 1985-86, (Alcock & Henkel 1984, 85, 86 and Henkel & Alcock 1987). One of the main objectives of these studies was the measurement of annual flow volume and copper, manganese, zinc and sulphate loads at GS8150097 on the East Finniss River. These studies showed that the project was a success and that copper and zinc loads were substantially reduced. The Commonwealth and Northern Territory Governments agreed to continue detailed monitoring, including surface water quality monitoring for the 1986-87 and 1987-88 wet seasons.

4.1.2 THE 1986-87 AND 1987-88 SURFACE WATER QUALITY PROGRAMMES

The purpose of the 1986-87 surface water monitoring programme was to measure pollution in the Finniss River system and on the mine site, and to relate these measurements to the rehabilitation programme. Specifically, the objectives of the 1986-87 monitoring were to:

- Accurately measure daily and annual copper, manganese, zinc, sulphate and radium-226 loads transported by the East Finniss River at GS8150097.
- Describe the rainfall and stream discharge and the pollutant concentrations and loads in the East Finniss River.
- Monitor water quality in the Finniss River at GS8150204 below the confluence with the East Branch.
- Collect mine site water quality data to provide information on the location of pollution sources and their contribution to stream pollution.

4.1.3 THE STUDY AREA

Figure 4.1 shows the surface water monitoring locations including gauging stations GS8150097 on the East Finniss River and GS8150204 on the Finniss River.

Figure 4.2 shows the mine site gauge stations and sampling locations in greater detail.

4.2 THE 1986-87 AND 1987-88 EAST FINNISS RIVER MONITORING PROGRAMME AT GS8150097

4.2.1 INTRODUCTION

The sampling programme, described in Section 4.1.2 , comprised the measurement of daily rainfall at pluviometer station R815202A (in 1986-87) and R815205 (in 1987-88), daily flow volumes and daily discharge weighted pH, specific conductance and copper, manganese, zinc, sulphate and radium-226 concentrations at GS8150097.

Gauging station GS8150097 is downstream of all mine site pollution input and is the site identified by the Commonwealth and Northern Territory Governments for the measurement of pollution loads.

4.2.2 SAMPLE COLLECTION AT GS8150097

The technique for sample collection was the same as that used since the inception of monitoring in 1982-83, (Alcock et al. 1984, 1985, 1986 and Henkel & Alcock 1987). This involved the collection of twelve, two hourly samples, each comprised of three samples taken at 40 minute intervals using an automatic sampler. A daily composite was prepared according to the average discharge for the twelve two hour periods. Discharge weighted samples were also collected for soluble radium-226 analysis.

4.2.3 RUM JUNGLE MINE SITE RAINFALL

The daily rainfall at mine site pluvios R815202A and R815205 is shown in Appendix A Figures 4.3 and 4.4. Annual rainfall at pluviometers R815202A and R815205 since 1982-83 are shown in Table 4.1. The pluviometer locations are shown in Figure 4.1.

Table 4.1 Annual Rainfall Rum Jungle Mine Site (mm)

WATER YEAR	R815202A	R815205
1982-83	1 121	-
1984-85	1 112	1 136
1985-86	1 207	1 185
1986-87	1 345	1 222
1987-88	1 058	1 064

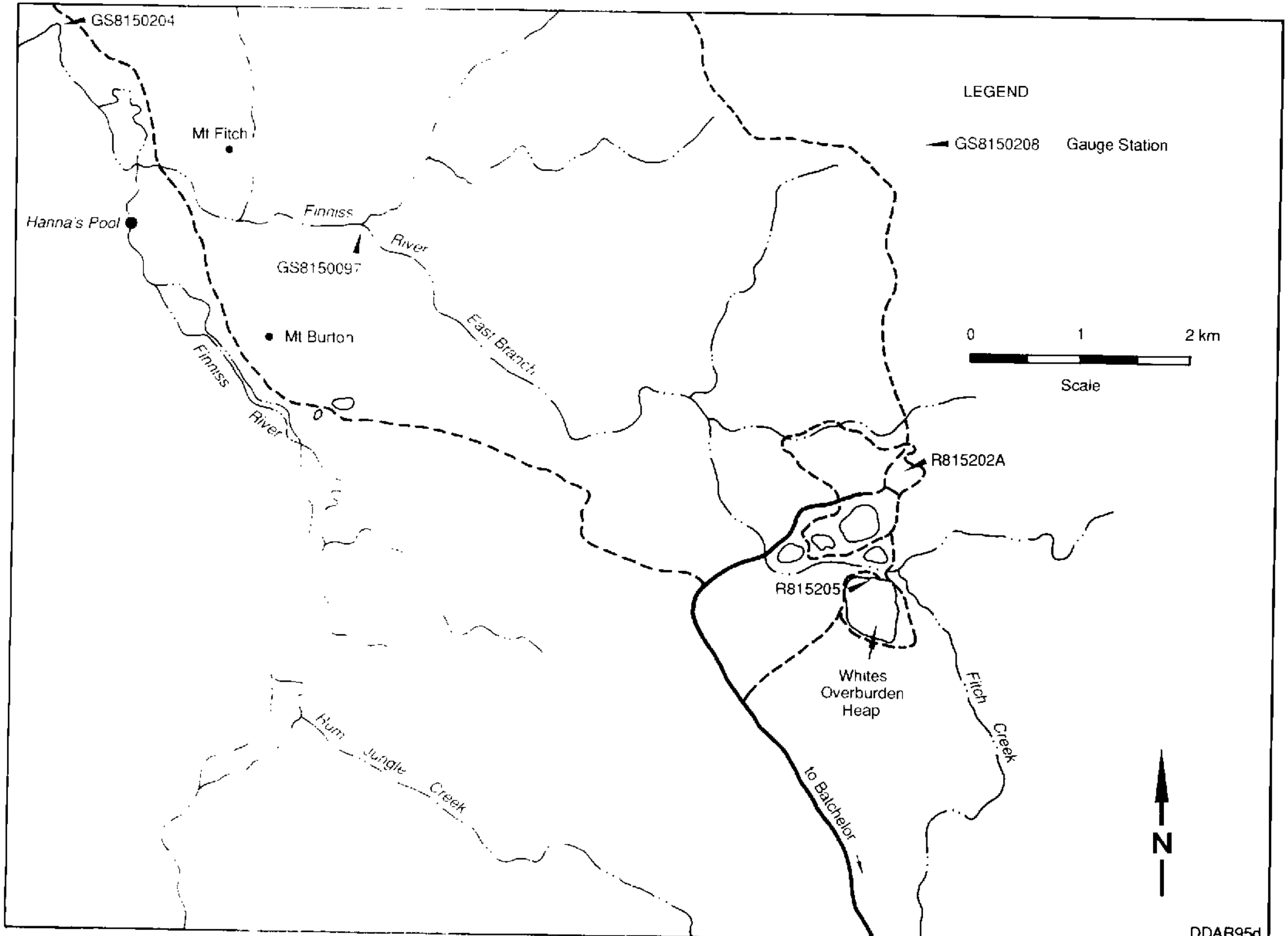

Figure 4.1 Surface water monitoring locations

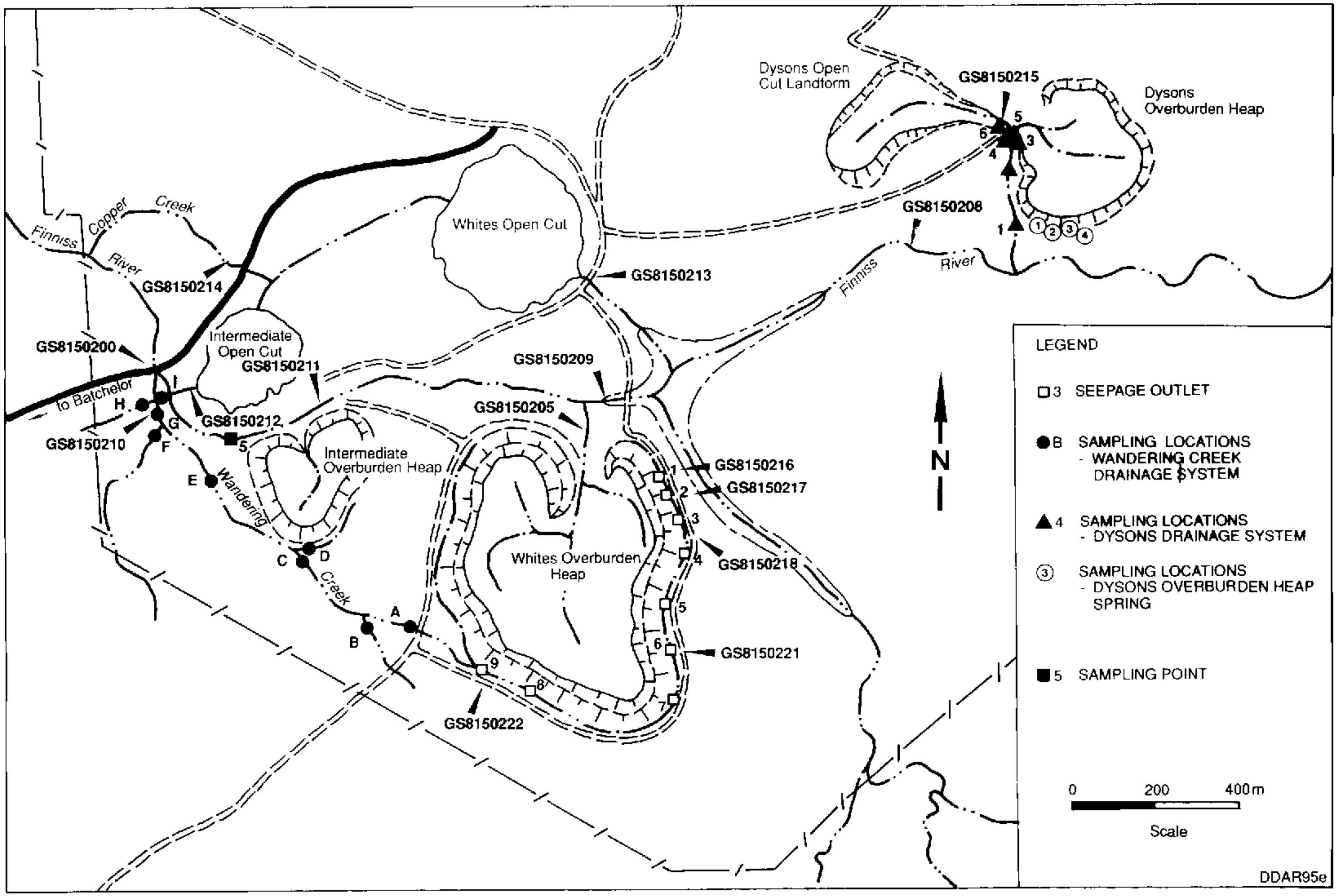

Figure 4.2 Mine site sampling locations

4.2.4 FLOW CHARACTERISTICS AT GS8150097

The 1986-87 wet season flow commenced on the 4th December 1986. Flow ceased on the 12th December 1986, recommenced on the 14th January 1987, and then continued uninterrupted until the 3rd May, 1987. The 1987-88 flow commenced on the 21st December 1987 and continued uninterrupted until the 9th May, 1988. Day to date conversions for both years are given in Appendix B Tables 4.2 and 4.3. Daily flow volumes at GS8150097 are shown in Appendix A Figures 4.5 and 4.6 and in Appendix B Tables 4.4 and 4.5. The total flow volume for 1986/87 was 13.2 x 10^6 m^3, similar to the flow volumes for 1982-83, 1984-85, and 1985-86. The total flow for 1987-88 was 6.3 x 10^6 m^3 which was the lowest flow recorded since the inception of the sampling programme. The total and monthly flow volumes for these years are shown in Table 4.6.

Table 4.6 East Finniss River total monthly and annual flow volumes (10^3 m^3) at GS8150097

YEAR	DEC	JAN	FEB	MAR	APR	MAY	TOTAL
1982-83	237	46	225	6 190	2 800	89	9 700
1984-85	0	662	1 820	4 900	3 780	34	11 700
1985-86	88	6 060	2 730	1 030	1 270	45	11 400
1986-87	43	581	8 710	3 510	386	1	13 200
1987-88	230	480	2 700	1 500	10	10	6 300

Run off characteristics and stream flow have altered because of rehabilitation. The major alteration to stream flow resulted from the partial rediversion of the East Finniss River to flow through White's and Intermediate Open Cuts. Water began to flow from White's Open Cut via Copper Creek and from the Intermediate Open Cut outflow some time between midday 17th January 1987 and midday 18th January 1987.

Overflow from White's commenced on the 16th January, 1988 (day 27) and continued until the 29th April, 1988 (day 131). The Intermediate Open Cut started to flow on day 33, the 22th January, 1988 and flowed intermittently until finally ceasing on day 110, the 8th April, 1988.

4.2.5 WATER QUALITY AT GS8150097

1986-87

The temporal variation of pollutant concentrations at GS8150097 is the result of the interaction of all of the mine site pollution sources. The mine site hydrology is complex and incompletely understood and this limits the interpretation of the pollution regime at GS8150097. The temporal contribution of the major mine site pollution sources is discussed in Section 4.5.

The 1986-87 daily discharge and discharge based daily pH, specific conductance, copper, manganese, zinc, and sulphate concentrations are shown in Appendix A Figures 4.5 and 4.7 to 4.12 respectively. The data are in Appendix B Table 4.4.

Flow commenced at GS8150097 on the 4th December 1986 which is defined as day 1. Hydrographic data from GS8150097 suggest that the first two days of flow at GS8150097 were the result of local run-off. This is supported by the fact that pollutant concentrations were very low. The next three days' water quality data were lost due to equipment malfunction.

The water quality for days six to ten showed low pH, increased specific conductance and increased concentrations of copper, manganese, zinc and sulphate. Low flows through the mine site are designed to flow in the Diversion Channel. Contamination of water flowing in the Diversion Channel occurred through: the dissolution of salts in the stream bed and on the banks, by polluted groundwater and by seepage from the Overburden Heaps.

There was no flow for the next 32 days. Flow at GS8150097 recommenced on day 42, the 4th January, 1987. As flow increased, more water was diverted to the Open Cuts which overflowed on day 45, the 17th January, 1987. Days 45 to 49 had low flow which resulted in relatively high concentrations of pollutants at GS8150097. Low flow conditions were conducive to relatively high pollutant concentration in the Diversion channel and Wandering Creek. Also, early low volume flows through the Open Cuts resulted in seasonal highs for Open Cut outflow pollutant concentrations.

Daily flow volumes increased on day 60 and by day 63 the effect of reduced pollutant concentrations in the Open Cuts outflow waters and reduced pollutant concentrations in the Diversion Channel and Wandering Creek was manifested by steadily reducing pollutant concentrations at GS8150097. Pollutant concentrations remained low until around day 120.

Following day 120, pollutant concentrations at GS8150097 increased. Low flows in the East Branch were diverted toward the Diversion Channel and water quality was markedly influenced by polluted ground water and seepage particularly from the Intermediate Overburden Heap.

The maximum average daily dissolved pollutant concentrations measured for the six years of monitoring are given in Table 4.7.

Table 4.7 Maximum concentrations of pollutants at GS8150097 (mg/l)

YEAR	COPPER	MANGANESE	ZINC	SULPHATE
1982-83	182	13	3.7	1 290
1983-84	69	6.2	3.8	1 350
1984-85	10.5	7.0	2.8	700
1985-86	5.3	3.5	2.8	1 060
1986-87	3.4	3.7	3.6	600
1987-88	4.4	4.0	6.9	950

The maximum daily metal concentrations at GS8150097 occurred during very low flow on the 13th December 1986, in waters that had flowed from the Diversion Channel and Wandering Creek.

The maximum daily concentration of copper, environmentally the most significant pollutant, continued to decrease in comparison to the maximum concentrations measured in previous years. The maximum daily concentration of zinc, which is also toxic to aquatic life, was greater than that recorded in 1985-86 and 1984-85 and similar to that of 1982-83 and 1983-84. The maximum daily concentration of manganese was near to that of 1985-86, and much less than that recorded in 1982-83. The maximum daily concentration of sulphate decreased significantly from 1060 mg/l in 1985-86 to 600 mg/l in 1986-87, (Henkel & Alcock 1987). The maximum daily concentration of sulphate was recorded on day 45, the first day that water overflowed from the open cuts.

1987-88

Due to the increased sampling frequency at the mine site sampling points, a better understanding of the pollution sources and the interpretation of the pollution regime at GS8150097 was possible during the 1987-88 sampling program.

Good agreement was obtained between measured total mine site pollution loads and pollution loads measured at GS8150097. This applies to both the calculated and synthesised loads. This is further dealt with in Section 4.4.2.

The 1987-88 daily discharge and discharge based daily pH, specific conductance, dissolved copper, manganese, zinc, and sulphate concentrations are shown in Appendix A Figures 4.6 and 4.13 to 4.18 respectively. The data are shown in Appendix B Table 4.5.

Flow commenced at GS8150097 on the 21st December 1987 which is defined as day 1, and continued to flow uninterrupted until the 9th May 1988, day 141.

As with previous initial flows at GS8150097, the pollutant concentrations were high as salts deposited at the end of the past wet season were redissolved.

The concentrations again gradually increase with diminishing flows unless high rainfalls establish a good soaking of the ground and a constant flow in the river system is established.

Copper Creek started flowing on day 27, the 16th January 1988, coinciding with a rainfall of 38mm. Notable are the high zinc concentrations found at GS8150097 until this date, pointing to the fact that most of the pollution, other than that caused by the redissolving of salts in the river and creek beds, originated from groundwater seepages from White's and Intermediate Overburden Heaps into the Diversion Channel (see section 4.4.2).

As the run off from the catchment increased, more water diverted through the open cuts. White's Open Cut started releasing water on day 27, the 16th January 1988, into Copper Creek and then into Intermediate Open Cut.

The initial release of water from the open cuts resulted in temporarily high pollutant loads at GS8150097. After a constant flow through the open cuts was established, however, pollutant concentrations abated.

It is worthwhile to note that pollutant concentrations remained relatively low at the end of flow for the 1987-88 season. This is particularly the case for sulphate and copper concentrations, which had less than half the concentrations at end of flow in the 1986-87 season.

The maximum daily metal concentrations at GS8150097 occurred during very low flow on day 25 to 26, the 14/15th January 1988, in waters that had flowed from the Diversion Channel and Wandering Creek only (Table 4.7).

The maximum daily concentration of all measured pollutants were greater in 1987-88 than in 1986-87. This does not mean that pollution in the East Finniss River is worsening, as these concentrations were measured on days of low flow, hence only a small amount of pollution load was carried.

The mean concentrations from 1986-87 to 1987-88 increased for copper manganese and zinc by 16, 28 and 48 percent respectively. Sulphate and radium-226 mean daily concentrations reduced by seven percent. The increases in concentrations for the heavy metals should be seen in the light of the reduced flow for the season. The decrease for sulphate shows a non-flow related trend, and could indicate, that a general cleansing of the mine site is taking place. Table 4.8 gives the comparison of mean daily concentrations at GS8150097 between 1987-88 and 1986-87,

Table 4.8 Mean daily dissolved pollutant concentrations at GS8150097

		1986-87	1987-88
Copper	mg/l	.44	.51
Manganese	"	.67	.85
Zinc	"	.21	.31
Sulphate	"	213	199
Radium	Bq/l	.059	.055

4.2.6 POLLUTANT LOADS AT GS8150097

The 1986-87 wet season total flow volume of 13.2 x 10^6 m^3 resulted in the transport of 5.6 tonnes of copper, 8.6 tonnes of manganese, 2.7 tonnes of zinc and 2 870 tonnes of sulphate.

In 1987-88, 3.2 tonnes of copper, 5.4 tonnes of manganese, 2.0 tonnes of zinc and 1230 tonnes of sulphate were carried by a total flow volume of 6.3 x 10^6 m^3.

The daily loads for copper, manganese, zinc and sulphate at GS8150097 for 1986-87 are shown in Appendix A Figures 4.19 to 4.22 respectively, and in Appendix B Table 4.9. Loads for 1987-88 are shown in Appendix A Figures 4.23 to 4.26 and Appendix B Table 4.10. The pollutant loads for the past five years are given in Table 4.11.

Table 4.11 East Finniss River annual pollutant loads at GS8150097

	TOTAL FLOW VOL ($m^3 \times 10^6$)	LOAD (tonnes) COPPER	MANGANESE	ZINC	SULPHATE
1982-83	9.7	22.7	6.1	5.2	1 520
1984-85	11.7	9.1	7.2	4.1	1 600
1985-86	11.4	3.7	8.2	2.7	4 400
1986-87	13.2	5.6	8.6	2.7	2 870
1987-88	6.3	3.2	5.4	2.0	1 230

In order to compare pollutant loads for 1986-87 with the pre-rehabilitation loads of 1982-83 it was originally considered necessary to make an adjustment for the difference in total flow volumes for the two years. For the purpose of comparison, the 1982-83 load data were adjusted by a factor of 1.3, which is the ratio of the total flow volume in 1986-87 to the total flow volume in 1982-83. It was then decided, however, that total load carried did not increase proportionally to increased flow and figures for 1987-88 were not adjusted. The percentage improvement in 1986-87 and 1987-88 loads in comparison to 1982-83 pre-rehabilitation loads is given in Table 4.12. Table 4.12 also shows the percentage improvement in the 1986-87 copper, manganese and zinc loads in comparison to the loads anticipated on the basis of the 1971-72 to 1973-74 "possible pre-rehabilitation relationship" between annual discharge and annual load described in the "Final Project Report" (Allen & Verhoeven 1986).

The agreement between the Northern Territory and Commonwealth Governments refers to target load improvements of 70% for copper, 56% for manganese and 70% for zinc in comparison to the loads anticipated on the basis of the 1969-74 monitoring data. Table 4.12 shows that the targets have been achieved.

Table 4.12 Percentage reduction in pollutant loads at GS8150097

	1986-87 (adjusted)		1987-88 (non-adjusted)	
POLLUTANT	1982-83 to 1986-87	1971-74 to 1986-87	1982-83 to 1987-88	1971-74 to 1987-88
Copper	80	85	85	95
Manganese	Nil	85	10	90
Zinc	60	80	60	90
Sulphate	-40	-	20	85

Comparison of the 1982-83, 1986-87 and 1987-88 load data shows that rehabilitation has successfully reduced the copper and zinc loads in the East Finniss River, particularly copper.

No improvement was shown in manganese loads from 1982-83 to 1986-87, however, a slight improvement was shown in 1987-88. Comparison of the 1982-83 pollutant loads with those measured in 1969-74 showed that the pollution momentum had decreased. This decrease was very marked for manganese, as was discussed in Alcock & Johnston (1984). Currently there is still insufficient understanding of the pollution process to warrant speculation as to the future trend for manganese loads.

The increase in sulphate load in 1986-87 was the result of the partial rediversion of the East Branch to flow through the open cuts. The treated water in the open cuts contained high concentrations of sulphate which are being progressively flushed into the East Finniss River. Sulphate loads, however, decreased in 1987-88 to bring about a 20% improvement since 1982-83. It is not possible to further discuss the significance of the 1986-87 or 1987-88 loads or to make predictions without a more detailed understanding of the pollution regime.

4.2.7 RADIUM-226 DAILY CONCENTRATION AND LOADS AT GS8150097

Discharge based daily composite samples were collected during the 1986-87 and 1987-88 wet seasons, and the filtrate analysed for radium-226.

Prior to the burial of the tailings material and sub-soil in Dyson's Open Cut during the 1984 dry season, radium-226 concentrations exceeded the drinking water criterion on about one day in three, (Alcock & Johnston 1984, 85). The highest concentrations in both years were measured early in the wet season. After 1984, radium concentrations in the East Branch decreased. The drinking water criterion of 0.4 Bq/l was exceeded once in 1984-85 and not at all in 1985-86.

In 1986-87, five of the daily discharge based samples had soluble radium-226 concentrations above the drinking water criterion. Two of these were only slightly in excess of the drinking water criterion. In common with previous years, these occurred with the low flows early in the wet season. Radium concentrations decreased with increased flow and increased modestly during the flow recession. No 1987-88 samples showed concentrations higher that the drinking water criterion. Daily discharge based radium-226 concentrations at GS8150097 are shown in Appendix A Figures 4.27 and 4.28.

The 1986-87 and 1987-88 radium-226 loads at GS8150097 were 800 and 350 megaBecquerels respectively. The daily loads are shown in Appendix A Figures 4.29 and 4.30.

A comparison of the previous two seasons and 1987-88 radium-226 pollution data are given in Table 4.13.

Table 4.13 East Finniss River GS8150097 radium-226 pollution

	1985-86	1986-87	1987-88
No. Samples analysed	97	114	141
No. days exceeding drinking water criterion	Nil	5	Nil
Maximum daily Ra-226 concentrations	0.37	0.61	0.29
Mean daily Ra-226 concentrations	0.090	0.095	0.05
Maximum daily Ra-226 load	95	90	26
Mean daily Ra-226 load	8	10	2.5
Total Ra-226 load	800	800	350

Units: Concentration Bq/l
Load MBq

A "one-off" sampling programme was carried out on the 16th January 1987 to provide an indication as to the source of radium contamination. The results of the sampling are shown in Table 4.14.

Table 4.14 Radium-226 concentration in the vicinity of tailings creek (16th January 1987)

LOCATION	Ra-226 CONCENTRATION
East Finniss River upstream of Tailings Creek	0.042
East Finniss River downstream of Tailings Creek	0.14
Tailings Creek - 50 metres downstream of the end of the lined channel	0.016

The radium-226 concentrations listed in Table 4.14 imply that Tailings Creek provided the bulk of the radium-226 pollution and that the pollution input to Tailings Creek is more than 50 metres downstream of the lined creek channel. Aerial photographs show that prior to rehabilitation tailings material was widely distributed by erosion in the area downstream of Tailings Creek. Confirmation would require further measurements.

Another potential source of radium-226 is Dyson's Open Cut, in which the tailings material was buried in 1984. Cracks and slumping occurred in the cover during 1986-87. These were expected and the integrity of the cover was not breached (Verhoeven 1988). The seepage from Dyson's Open Cut was analysed for radium-226 on three occasions.

The results are shown in Table 4.15.

Table 4.15 Radium-226 in Dyson's Open Cut seepage

DATE	FLOW (l/s)	RADIUM-226 (Bq/l)
12/2/87	2.0	0.64
3/3/87	0.5	0.59
10/3/87	0.4	0.74

The low flows carried sufficiently high concentrations of radium-226 to justify regular analysis of the seepage from Dyson's Open Cut during the 1987-88 season, (Section 4.5.2).

4.3 FINNISS RIVER WATER QUALITY

Minor to moderate fish kills were observed and recorded in the Finniss River following mining at Rum Jungle (Davy 1975, Chaloupka 1984). Fish kills occurred when the early wet season flows of polluted water from the East Branch entered the Finniss River. The initial wet season flows in the East Branch have the highest concentrations of metal pollutants.

Early in the wet season, stream flows are generally low and variable, and the potential exists for low dilution of the polluted East Branch water by the water of the Finniss River. The pollutants of main concern are copper and zinc, particularly copper.

The previous four studies of the Finniss River involved the collection of twice weekly samples from GS8150204. Samples were also collected from the upstream reference water quality location GS8150205. The sample locations are shown in Figure 4.1.

It was concluded in the (1985-86) report that sufficient data had been collected from the reference sample location GS8150205, and that future sampling programmes should concentrate at GS8150204, and include an emphasis on water quality early in the wet season.

4.3.1 1986-87

Spot samples were collected on 18 days between the 17th January 1987 and the 10th February 1987, and a further 18 samples during the remainder of the season. The samples were analysed for general parameters and copper, manganese and zinc in solution and sediment. The data are recorded in Appendix B Tables 4.16 and 4.17.

The highest concentration of sulphate, and soluble and total copper, manganese and zinc were recorded on the first day of sampling, the 17th January 1987. This was coincident with the start of outflow from the open cuts and was the second day of flow for the wet season at GS8150204. The maximum pollutant concentrations measured at GS8150204 from 1982-83 to 1987-88 are given in Table 4.18.

Table 4.18 Maximum concentrations of pollutants at GS8150204 (µg/l)

	COPPER		MANGANESE		ZINC		SULPHATE
YEAR	FILTRATE	TOTAL	FILTRATE	TOTAL	FILTRATE	TOTAL	(mg/l)
1982-83	21 000	21 020	4 000	4 030	1 000	-	370
1983-84	9 500	9 530	2 500	2 500	1 750	-	390
1984-85	1 360	2 380	1 630	1 645	40	-	190
1985-86	83	123	95	115	60	-	270
1986-87	850	950	800	920	500	530	150
1987-88	220	1 100	530	640	310	900	140

4.3.2 1987-88

During 1987-88 the Finniss River at GS8150204 was sampled on 68 occasions. Good agreement exists for the calculated loads of soluble copper, zinc and sulphate when compared to the loads carried at GS8150097 at the East Finniss River. No reasonable relationship could be established for the manganese load.

The behaviour of manganese in most environmental studies has been hard to predict and no explanation is offered for the discrepancy for the dissolved manganese loads between these two gauging stations other than the likelihood of precipitation or the absorption on particulate matter of both organic and inorganic origin.

The Finniss River upstream of the East Finniss River confluence is generally unaffected by Rum Jungle mine site pollutants. All heavy metals and most of the sulphate found at GS8150204, which is below the confluence with the East Finniss River, originate from the various Rum Jungle mine site pollution sources. It has been estimated that the background concentration of sulphate in the Finniss River above its confluence with the East Finniss River is approximately 12 mg/l.

Table 4.19 shows the loads calculated for GS8150204 and compares them with the loads found at GS8150097. The sulphate concentration of 12mg/l estimated to be the background concentration in the Finniss river above its confluence with the East Branch is included in the calculations. Data collected at GS8150204 are shown in Appendix B Tables 4.20, 4.21 and 4.22.

Table 4.19 Comparison of Dissolved Pollutant Load carried at GS8150097 and GS8150204

	FLOW ($m^3 \times 10^6$)	Cu	Mn	Zn (tonnes)	SO_4
GS8150097	6.3	3.2	5.4	2.0	1 260
GS8150204	55.0	3.2	1.5	2.0	1 300

The release of water from the open cuts was marked by a significant increase in sulphate concentration and load at GS8150204. High sulphate concentrations persisted until the open cuts were flushed and relatively unpolluted water flowed from the open cuts. This occurred between day 58 and 61, the 16th and 19th February, 1988.

Maximum soluble heavy metal concentrations in 1987-88 were lower than those for the 1986-87 season. When considering the poor wet season of 1987-88, it is an indication, that pollution from the mine site is lessening, providing the generally accepted statement that low flows are conducive to high concentrations, is valid.

The decrease in concentrations between 1982-83 and 1987-88 shows that a significant improvement in water quality has resulted from the rehabilitation of the mine site.

4.4 MINE SITE POLLUTION SOURCES

4.4.1 1986-87

The second part of the surface water study involved measurements of discharge and water quality at selected mine site locations. The information gathered from the analysis of this data is intended for:

- assessing the contribution of individual sources to the pollution of the East Finniss River in the 1986-87 wet season;
- providing information to aid other agencies in their studies; and
- evaluating the success of the rehabilitation programme.

The studies described in this Section are:

- the Dyson's Open Cut and Overburden Heap drainage system;
- the Wandering Creek drainage system;
- the White's Overburden Heap subsoil drainage outflow; and
- a qualitative description of the seasonal load contributions from the Diversion Channel, Wandering Creek and the Open Cuts.

Mine site sample locations are shown in Figure 4.2.

DYSON'S DRAINAGE SYSTEM

The copper leach heap material and tailings material were buried in Dyson's Open Cut. Water seeps from Dyson's Open Cut to a drain which also receives seepage from Dyson's Overburden Heap before flowing into the East Finniss River. Some cracks appeared in the top of Dyson's Open Cut in 1986 and there was some slumping of material towards the centre. Some subsidence was expected and the cover did not appear to fail (Verhoeven 1988). The small volume of outflow was probably due to minor inflow through the cover and water squeezed from the tailings material.

The 1986-87 monitoring consisted of collecting water quality data and measuring flows in the drain that carries the seepage from Dyson's Open Cut and Overburden Heap to the East Branch. Sampling was carried out on ten occasions, at six locations, from the 17th of February 1987 to the 21st of April 1987.

The following conclusions were made:

- Water seeping from Dyson's Open Cut was acidic, (pH from about 3.2 to 4.0), and contained high concentrations of copper, manganese and radium-226 at small flow volume. The maximum, minimum and flow weighted mean concentrations for the spot samples are in Table 4.23.

- The pH of the water seeping from the Overburden Heap (sites 3 and 4) ranged between 2.4 and 3.6 and the copper, manganese and zinc concentrations were much lower than in the seepage from the Open Cut. Maximum, minimum and discharge weighted mean concentrations for copper, manganese, zinc and sulphate are in Table 4.24.

Table 4.23 Water quality from Dyson's Open Cut Seepage Site 6

	MAX. CONC.	FLOW	DATE	MIN. CONC.	FLOW	DATE	MEAN CONC.
Copper	784	0.50	3/3/87	110	2.0	17/2/87	290
Manganese	457	0.05	21/4/87	51	1.0	24/2/87	110
Zinc	36	0.05	21/4/87	2.5	1.0	24/2/87	5.7
Sulphate	12 570	0.05	21/4/87	2 840	1.0	24/2/87	4 620
Ra-226*	0.74	0.40	10/3/87	0.54	2.0	3/3/87	0.62

* Only three samples were analysed for radium-226.

Number of samples: 0
Samples collected: 17/2/87 to 21/4/87
Units: Concentration mg/l
Flow l/s
Radium-226 Bq/l

Table 4.24 Water quality from Dyson's Overburden Heap Seepage Site 3

	MAX. CONC.	FLOW	DATE	MIN. CONC.	FLOW	DATE	MEAN CONC.
Copper	1.5	0.300	17/2/87	0.73	0.01	21/4/87	1.2
Manganese	6.3	0.001	24/3/87	2.60	0.01	21/4/87	3.4
Zinc	1.5	0.050	3/3/87	0.58	0.02	17/3/87	0.8
Sulphate	9 480	0.050	3/3/87	3 090	0.01	21/4/87	7 920

Number of samples: 10
Samples collected: 17/2/87 to 21/4/87
Units: Concentration mg/l
Flow l/s

Pollution also enters the East Finniss River from a series of springs and seepage at the south side of the base of Dyson's Overburden Heap. The four sampling locations are shown in Figure 4.2.

The seepages were acidic (pH <3.0) and characterised by high manganese concentrations. Maximum, minimum and discharge weighted mean concentrations for copper, manganese, zinc, and sulphate for the four springs are in Tables 4.25.

Table 4.25 Water quality from Dyson's Springs

Dyson's Spring 1

	MAX. CONC.	FLOW	DATE	MIN CONC.	FLOW	DATE	MEAN CONC
Copper	3.0	1.0	14/2/87	1.30	0.05	22/4/87	2.2
Manganese	43.0	0.1	17/3/87	20.00	2.00	24/2/87	27.0
Zinc	1.8	2.0	3/3/87	0.94	0.13	24/3/87	1.4
Sulphate	20 800	2.0	24/2/87	9 760	0.05	22/4/87	17 250

Number of samples: 11
Samples collected: 15/2/87 to 22/4/87
Units: Concentration mg/l
Flow l/s

Table 4.25 Cont'd

Dyson's Spring 2

	MAX. CONC.	FLOW	DATE	MIN. CONC.	FLOW	DATE	MEAN CONC.
Copper	1.3	0.10	17/2/87	0.57	0.01	17/3/87	1.00
Manganese	40.0	0.01	17/3/87	16.00	0.10	17/2/87	24.00
Zinc	0.6	1.00	24/2/87	0.38	0.47	10/3/87	0.52
Sulphate	11 700	1.00	24/2/87	6 200	0.07	17/3/87	8 950

Number of samples: 5
Samples collected: 14/2/87 to 17/3/87
Units: as above

Dyson's Spring 3

	MAX. CONC.	FLOW	DATE	MIN. CONC.	FLOW	DATE	MEAN CONC.
Copper	0.95	3.00	14/2/87	0.48	0.17	17/3/87	0.80
Manganese	35.00	0.15	31/3/87	14.00	0.41	17/2/87	19.00
Zinc	0.84	0.02	22/4/87	0.28	1.50	24/2/87	0.33
Sulphate	6 340	0.01	7/4/87	4 490	0.26	10/3/87	4 990

Number of samples: 10
Samples Collected: 14/2/87 to 22/4/87
Units: as above

Table 4.25 Cont'd

Dyson's Spring 4

	MAX. CONC.	FLOW	DATE	MIN. CONC.	FLOW	DATE	MEAN CONC.
Copper	0.95	0.10	14/2/87	0.50	0.05	10/3/87	0.78
Manganese	31.00	0.10	14/2/87	17.00	0.07	17/2/87	23.00
Zinc	0.92	0.01	14/4/87	0.34	0.05	10/3/87	0.46
Sulphate	6 690	0.10	14/2/87	4 650	0.05	10/3/87	6 000

Number of samples: 10
Samples Collected: 14/2/87 to 22/4/87
Units: as above

These sources and contaminated groundwater contribute to the water quality of the downstream sampling site GS8150208, which is summarised in Table 4.26.

Table 4.26 Water quality at GS8150208

	MAX. CONC.	DISCHARGE	DATE	MIN. CONC.	DISCHARGE	DATE
Copper	1.00	64.0	15/1/87	0.01	73	13/4/87
Manganese	11.50	8.0	23/4/87	0.01	NM	12/3/87
Zinc	0.53	64.0	15/1/87	0.01	-	24 occasions
Sulphate	750	2.0	27/4/87	23.00	200	30/3/87

Number of samples: 50
Samples collected: 14/1/87 to 27/4/87
Units: Concentration mg/l
Flow l/s
NM: not measured

The mean concentrations were not calculated because flow data could not be derived for periods of high flow.

WANDERING CREEK

Wandering Creek flows from near the south west corner of White's Overburden Heap to its junction with the East Branch of the Finniss River. The junction is upstream of the road bridge and almost directly opposite the outflow from Intermediate Open Cut (Figure 4.1).

The 1985-86 study found that early in the wet season Wandering Creek carried high concentrations of pollutants, but near the end of the wet season it was essentially unpolluted (Henkel & Alcock 1987).

Polluted water flows into Wandering Creek from two sources, White's and Intermediate Overburden Heaps. The creek is fed by three separate streamlets entering from a southerly direction. Stream flow and analytical data were collected from nine sites commencing on the 25th February 1987. The following conclusions were made:

- White's Overburden Heap was the major contributor to the pollution of Wandering Creek. The flow volumes and concentrations of pollutants from this heap were considerably greater than the pollutant concentrations and flow volumes from Intermediate Overburden Heap. Water quality data from the output of White's and the Intermediate Overburden Heaps (sample sites A and D) are given in Tables 4.27 and 4.28 respectively.

- The major source of pollutants from White's Overburden Heap is drain 9, (refer later section). The water quality from Drain 9 was similar to that at Point A. On four occasions both sites were sampled on the same day. The analyses are shown in Table 4.29.

- Discharge from Wandering Creek can be a significant contributor to high early wet season pollutant concentrations in the East Branch. The water quality data for sample location GS8150210 are shown in Table 4.30.

- Three streamlets feed Wandering Creek from a southerly direction. The first of these is represented by sample Site B. The other two streamlets are unpolluted. The second of these, represented by sample location F, provides the greatest flow of water in Wandering Creek.

- During flow recession, flow from White's Overburden Heap either ceases or infiltrates the soil and does not reach Wandering Creek. Flow is maintained in Wandering Creek mainly by the streamlet represented by sample site F. Pollutant concentrations were low.

- Pollutant loads transported in Wandering Creek were low. The calculated pollutant loads from Drain No. 9 are discussed in the next section.

It is recommended that the 1987-88 investigation be restricted to GS8150210 and White's Overburden Heap Drain 9.

Table 4.27 **Water quality at Wandering Creek Site A**

	CONCENTRATION (mg/l) Maximum	Minimum
Copper	47	24
Manganese	61	18
Zinc	45	23
Sulphate	12 600	6 290

Number of samples: 5

Table 4.28 Water quality at Wandering Creek Drainage system Site D

	CONCENTRATION (mg/l) Maximum	Minimum
Copper	6.4	0.7
Manganese	4.8	0.5
Zinc	4.5	0.3
Sulphate	1 250	525

Number of samples: 4

Table 4.29 Water quality at White's Overburden Heap Drain 9 and Wandering Creek Site A

	DRAIN NO. 9 (mg/l)				SITE A (mg/l)			
DATE	Cu	Mn	Zn	SO_4	Cu	Mn	Zn	SO_4
25/2/87	28	26	32	8 250	24	18	30	6 290
04/3/87	33	28	21	9 650	35	30	45	9 390
11/3/87	35	32	23	10 630	34	34	24	9 080
24/3/87	36	20	24	11 000	38	35	23	10 400

Table 4.30 Water quality at Wandering Creek GS8150210

	CONCENTRATION (mg/l)		
	MAXIMUM	MINIMUM	DISCHARGE WEIGHTED MEAN
Copper	8.5	0.01	11.16
Manganese	2.6	0.01	0.48
Zinc	3.3	0.01	0.61
Sulphate	1 360	6.00	250

Number of samples: 44

WHITE'S OVERBURDEN HEAP SUBSOIL DRAINS

Prior to the rehabilitation of White's Overburden Heap, highly polluted water flowed from springs at its northeast and southwest base.

Part of the drainage design for the rehabilitated White's Overburden Heap included a subsoil drainage system constructed to intercept groundwater at the interface between the original ground surface and the base of the heap.

The subsoil drainage system was located in areas where springs had previously been observed. A description of the design of the drainage system is given in Allen & Verhoeven (1986).

Nine seepage pits are located around White's Overburden Heap. The locations are shown in Figure 4.2. Only seven have drainage outlets. Flows were observed in five of the outlets during the wet season. Volumetric and water quality measurements were made throughout the periods of flow. Volumetric flow measurement were made on a daily basis during the early flows and twice a week thereafter. pH, specific conductance, copper, manganese, zinc and sulphate concentrations were measured on a weekly basis. Pollutant loads were calculated using the following approach.

Recorded daily flows were plotted as a daily volume in cubic metres and a seasonal hydrograph was interpolated using the daily flow and the recorded daily rainfall at White's Overburden Heap pluviometer R815205. Daily and then weekly total flow volumes were extracted from the resulting hydrograph.

The following observations were made:

- The temperature of the water flowing from the drains was about 30° to 32° C. Early in the season the pH was about 3.5. The pH then fell to about 3.0 during mid season flows.

- Drains one, three and nine flowed for the longest period with one and nine carrying the greatest flow volumes. Response to rainfall was typically 24 to 48 hours, (Masters, pers. comm.).

- Pollutant concentrations in the water flowing from the drains were high. Generally the early wet season flows had lower pollutant concentrations. Once flow was established pollutant concentrations became fairly constant.

- Drains one and nine showed marked increases in zinc concentrations toward the end of the wet season. Maximum, minimum and mean discharge weighted pollutant concentrations for pollutants in all drains are shown in Table 4.31.

- Drains one and nine carried the largest pollutant loads (Table 4.32). Drain nine is the major source of pollutants in Wandering Creek.

- The White's Overburden Heap sub-soil drains contained high concentrations of copper, manganese, zinc and sulphate, but contributed only four, two, nine and two percent respectively of the total loads of those pollutants at GS8150097.

- High concentrations of zinc were observed in the end of season flow in the Diversion Channel and from the Drains.

Table 4.31 Water Quality in White's Overburden Heap Subsoil Drains

DRAIN 1

	MAX. CONC.	FLOW	DATE	MIN.	FLOW	DATE CONC.	MEAN CONC.
Copper 53	0.12	17/3/87	16.0	0.01	22/1/87	33	
Manganese	47	0.01	24/4/87	3.0	0.01	22/1/87	20
						23/1/87	"
Zinc	190	0.04	14/4/87	6.1	0.01	22/1/87	45
	"	0.01	22/4/87				
	"	0.01	24/4/87	2 640	0.01	22/1/87	1 140
Sulphate 18 070	0.04	14/4/87					

Number of samples: 16
Period of flow: 22/1/87 to 24/4/87.
Units: Concentration mg/l
Discharge l/s

DRAIN 2

	MAX. CONC.	FLOW	DATE	MIN. CONC.	FLOW	DATE	MEAN CONC.
Copper	31	0.04	11/3/87	27	0.50	25/2/87	28
Manganese	25	0.13	13/2/87	10	0.06	6/2/87	19
Zinc	55	0.07	21/2/87	13	0.06	6/2/87	42
Sulphate	12 600	0.04	11/3/87	5 350	0.06	6/2/87	1 050

Number of samples: 7
Period of flow: 6/2/87 to 11/3/87
Units: as above

Table 4.31 Cont'd

DRAIN 3

	MAX. CONC.	FLOW	DATE	MIN. CONC.	FLOW	DATE	MEAN CONC.
Copper	39	0.01	22/1/87	25	0.10	25/2/87	27
				"	0.08	4/3/87	
Manganese	30	0.05	1/4/87	11	0.16	11/3/87	23
	"	0.02	14/4/87	"	0.01	22/1/87	
Zinc	88	0.02	14/4/87	21	0.01	22/1/87	34
Sulphate	11 650	0.06	17/3/87	15 700	0.01	22/1/87	9 700

Number of samples: 13
Period of flow: 22/1/87 to 14/4/87
Units: as above

DRAIN 6

	MAX. CONC.	FLOW	DATE	MIN. CONC.	FLOW	DATE	MEAN CONC.
Copper	48	0.07	13/2/87	29	0.00	7/2/87	39
Manganese	27	0.07	13/2/87	11	0.08	7/2/87	21
Zinc	36	0.07	13/2/87	22	0.08	7/2/87	44
Sulphate	10 600	0.07	13/2/87	6 600	0.08	7/2/87	8 600

Number of samples: 6
Period of flow: 7/2/87 to 11/3/87
Units: as above

DRAIN 9

	MAX. CONC.	FLOW	DATE	MIN.	FLOW	DATE CONC.	MEAN CONC.
Copper	53	0.12	1/4/87	23	0.02	22/1/87	33
Manganese	54	0.02	24/4/87	18	0.02	22/1/87	28
Zinc	88	0.06	14/4/87	14	0.02	22/1/87	25
Sulphate	13 950	0.04	22/4/87	6 950	0.02	22/1/87	9 360

Number of samples: 17
Period of flow: 22/1/87 to 24/4/87
Units: as above

Table 4.32 White's Overburden Heap subsoil drains pollutant loads 1986-87

	DRAIN No.	VOLUME (m^3)	COPPER (kg)	MANGANESE (kg)	ZINC (kg)	SULPHATE (tonnes)
	1	3 150	95	65	190	36.0
	2	520	15	10	22	5.5
	3	450	12	10	16	4.4
	6	260	10	6	13	2.2
	9	2 020	67	60	50	18.9
TOTAL	6 400	200	150	240		67.0

The total volume of water that flowed from the drains was 6,400 m^3. By comparison, the rainfall incident on the top of the overburden heap was approximately 230,000 m^3, and that on the top and sides was approximately 350,000 m^3. The source of the water flowing from the drains may be groundwater or rain water that has infiltrated the cover.

Three new holes were drilled into White's Overburden Heap during the 1987 dry season. More bores were also drilled in the White's Overburden Heap surrounds. Water level studies at these bores, lysimeter data, heap moisture profiles and toe drain water volume measurements will help to clarify the hydrodynamics and pollution process within the heap. This will aid the prediction of future groundwater and mine site pollution trends.

It was recommended that the program to determine the water quality and pollutant loads in the water from White's Overburden Heap sub soil drains be continued in 1987-88, and that detailed groundwater level measurements be taken on and around the heap.

RUN-OFF FROM WHITE'S AND INTERMEDIATE OVERBURDEN HEAPS

Decreases in the early wet season pollutant concentrations and falls in seasonal pollutant loads since rehabilitation have been attributed in various degrees to the improved quality of run-off water from White's and Intermediate Overburden Heaps. (Alcock & Johnston 1985 Henkel & Alcock 1985). The heaps were previously identified as the major contributors to pollution of the East Branch through polluted run-off, seepage and pollution of groundwater.

The run-off from White's Overburden Heap at GS8150205 was analysed on three occasions in January of 1987. The average water quality is shown in Table 4.33. The run-off was unpolluted.

Table 4.33 Average water quality at GS8150205

pH	SPECIFIC CONDUCTANCE (μS/cm)	POLLUTANT CONCENTRATIONS (mg/l) Cu	Mn	Zn	SO_4
5.4	62	0.04	0.04	0.04	20

Run-off from Intermediate Overburden Heap was analysed on two occasions in January of 1987. The average water quality is shown in Table 4.34. The water was of good quality.

Table 4.34 Average water quality of run-off from the Intermediate Overburden Heap

pH	SPECIFIC CONDUCTANCE (μS/cm)	POLLUTANT CONCENTRATIONS (mg/l) Cu	Mn	Zn	SO_4
5.2	52	0.08	0.10	0.04	19

THE OPEN CUTS, THE DIVERSION CHANNEL AND WANDERING CREEK

INTRODUCTION

Low flows in the East Branch of the Finniss River bypass the open cuts and flow through the Diversion Channel. Higher flows are divided between the Diversion Channel and White's Open Cut. Low outflow from White's Open Cut follows Copper Creek to the East Branch of the Finniss River. Greater flows are divided between Copper Creek and the Intermediate Open Cut inflow. The Intermediate Open Cut outflows to the East branch of the Finniss River directly opposite another source of pollution, Wandering Creek (Figure 4.2). Water quality in the open cuts is discussed in Chapter Six. The Wandering Creek drainage system was discussed previously.

During the wet season, 33 grab samples and stream gaugings were taken at:

- GS8150209 at the top of the Diversion Channel;
- GS8150210 (Wandering Creek);
- Point 5 in the Diversion Channel above the junction with the Intermediate Open Cut outflow and Wandering Creek; and
- GS8150200 at the East Finniss River below the junction with Wandering Creek and the Intermediate Open Cut outflow.

In some instances, samples and gaugings were made at the inflow to the Open Cuts, the Intermediate Open Cut outflow and Copper Creek (the outflow from White's Open Cut).

The samples were taken consecutively to minimise the effects of changing flow conditions in an endeavour to provide an instant view of the mine site pollution regime. There is not necessarily any relationship between spot measurements of pollutant concentrations and discharge at these locations with daily flow volumes and discharge based daily concentrations and loads at GS8150097. The measurements give a qualitative picture of the seasonal variation of flow, pollutant concentrations and loads from pollution sources on the mine site.

FLOW

The wet season flow data for locations GS8150209, GS8150210, Point 5 and GS8150200 are shown in Appendix A, Figure 4.31. The following observations are made:

- A comparison of Figures 4.7 and 4.31 indicates that the wet season flow pattern at GS8150200 was similar to that at GS8150097; and

- Most of the water flowing by GS8150200 came from the Intermediate Open Cut outflow. Stream gaugings at the inflow to White's Open Cut and at the top of the Diversion Channel at GS8150209 indicated that for 1986-87, approximately 90% of the annual flow was diverted through the Open Cuts. The open cut outflows were minor contributors to flow during low flow periods in the early part of the wet season and during the flow recession.

POLLUTANT CONCENTRATIONS

The wet season pollutant concentration data for copper, manganese, zinc and sulphate are in Appendix A Figures 4.32 to 4.35. Sampling at point 5 did not commence until day 62. Only four samples were taken from the Intermediate Open Cut outflow and White's outflow, and these were taken after the major flushing of the open cuts had occurred. The following observations are made:

- Wandering Creek carried high concentrations of pollutants during the early part of the wet season. The principal source of pollution was White's Drain 9. Concentrations decreased as the wet season progressed;

- Pollutant concentrations at GS8150209 were high at the early low flows. This was presumably due to dissolved salts from the creek bed and banks and the influence of polluted groundwater. Pollutant concentrations decreased rapidly as flow increased and increased again during flow recession due to the contribution of polluted groundwater;

- Pollutant concentration at Point 5 were much higher than those at GS8150209. The Diversion Channel is polluted through dissolution of salts, groundwater and seepage from the overburden heaps. Seepage from Intermediate Overburden Heap was readily observed, and demonstrated by specific conductance surveys from GS8150200 to GS8150209.

- During flow recession, the pollutant concentrations at GS8150200 were similar in magnitude to those at Point 5; and

- Zinc concentrations increased significantly in the Diversion Channel as the river neared cease to flow. This was consistent with the trend shown in the White's Overburden Heap drains.

POLLUTANT LOADS

The copper, manganese, zinc and sulphate loads measured at GS8150209, GS8150210, Point 5 and GS8150200 and the loads calculated for the Diversion Channel (Point 5 - GS8150209) and the Intermediate Open Cut outflow [GS8150200 - (Point 5 + GS8150210)] are shown in Appendix A Figures 4.36 to 4.39 respectively.

Assurances that the load data were meaningful was provided in four instances where pollutant concentrations and flow data existed for the Intermediate Open Cut outflow water. Good agreement between the pollutant loads at GS8150200 and the summation of the loads at GS8150210, Point 5 and the Intermediate Open Cut out-flow was obtained. The following observations are made:

- The seasonal pollution load patterns at GS8150200 were similar for copper, manganese, zinc and sulphate and followed the pattern of the season's flow;

- The highest flow carried the highest loads at GS8150200;

- For the greater part of the season the Intermediate Open Cut outflow was the major contributor to pollutant loads at GS8150200; and

- The load contribution from the Diversion Channel was predominant in early season low flows and during flow recession.

The data is insufficient to warrant the calculation of seasonal loads transported via the Open Cuts, the diversion Channel and Wandering Creek. Nevertheless, it seems clear that in 1986-87 most of the pollutant loads appeared in the overflow from the Open Cuts. The question as to the source of the pollution should be addressed.

The East Finniss River flow to White's Open Cut carries only a small pollution load. The depth of water in White's Open Cut susceptible to flushing was thought to be approximately 15 metres (Henkel & Alcock 1987), which implied that the open cuts themselves could only contribute small loads of pollutant metals to the East Branch. However, if high flows in the East Finniss River disturb water at greater depth, where pollutant concentrations are much higher, White's Open Cut could be a significant source of pollution to the East Branch. This possibility requires investigation in 1987-88, and it is recommended that the open cuts, in particular, White's are profiled at close intervals before, during and after large flows from the East Finniss River.

In an endeavour to gain further quantitative knowledge of pollution sources it is recommended that in 1987-88 more detailed studies of the sample locations GS8150210, GS8150200, Point 5 the Intermediate Outflow and Copper Creek are made over significant flow events, preferably in conjunction with open cut profiles.

4.4.2 1987-88

In 1987-88 a more detailed sampling programme enabled a better understanding of the various pollution sources and their contribution to the East Finniss River, and beyond, was made possible. Percentage contribution allocations were made possible by having collected enough data to use statistics.

It was found that the open cuts, and particularly White's were responsible for about half of the dissolved pollution load at GS8150097, other than zinc.

Most of the zinc pollution originated from the diversion channel between GS8150209 and GS8150211, and Wandering Creek, which receive groundwater and water from springs from White's Overburden Heap and groundwater from Intermediate Overburden Heap. A schematic flow chart of the major sampling points is given in Figure 4.40. Figure 4.2 shows all mine site sampling locations.

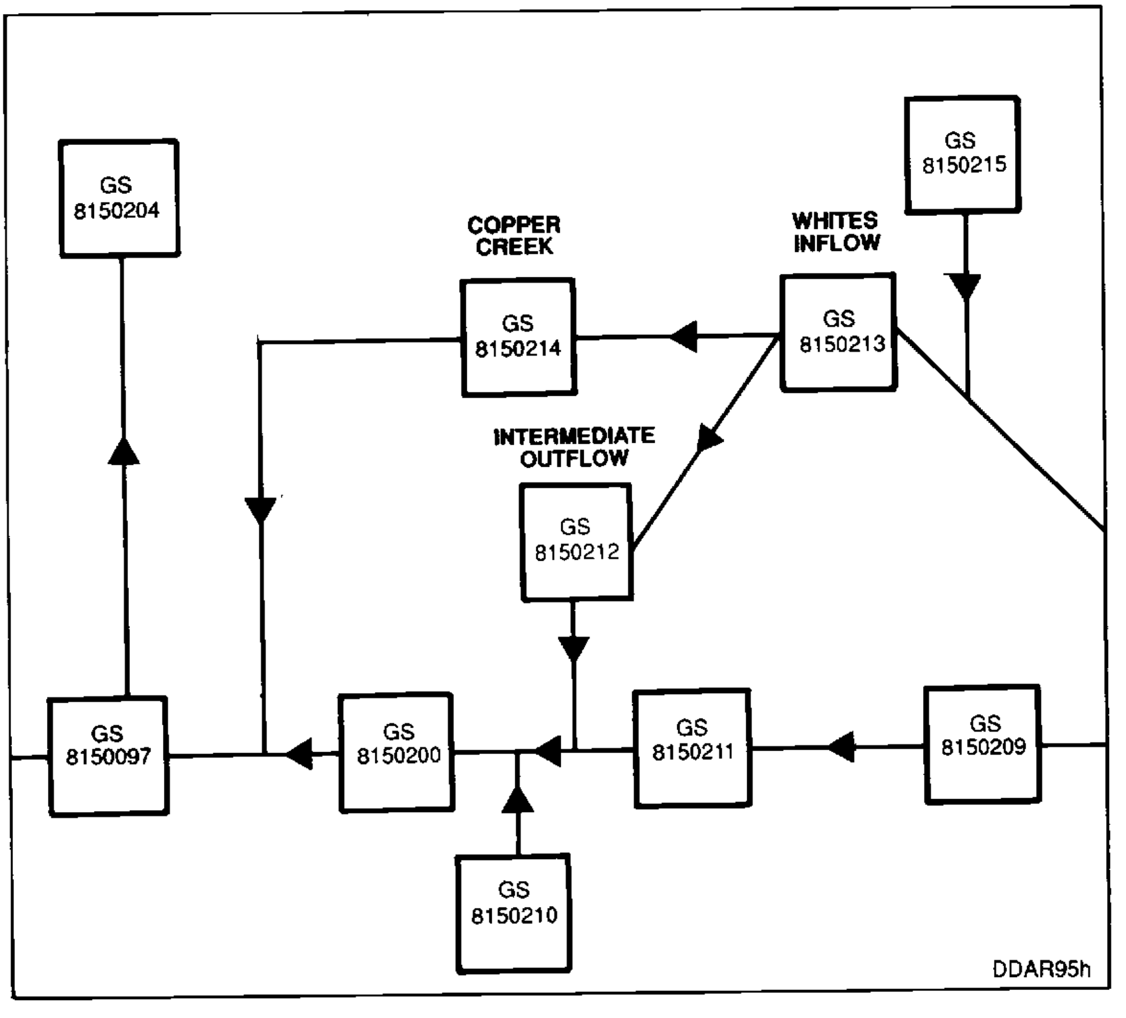

Figure 4.40 Flow chart of Rum Jungle sampling locations

Table 4.35 lists the gauging points and locations of the 1987-88 sampling programme for the East Finniss River system including Wandering Creek and open cut inflow and outflow sampling points.

Table 4.35 Gauging station locations

GS8150097	East Finniss River, downstream from mine
GS8150200	East Finniss River, downstream from road bridge
GS8150209	East Finniss River, start of diversion channel
GS8150210	Wandering Creek, above confluence with diversion channel downstream from Intermediate O/C outlet
GS8150211	Diversion Channel, downstream from GS8150209, upstream from Wandering Creek and Intermediate O/C outflow
GS8150212	Intermediate O/C outflow
GS8150213	White's O/C inflow
GS8150214	Copper Creek

MINE SITE POLLUTION LOADS

Table 4.36 lists calculated dissolved loads and flows. The results were obtained by calculating the average daily flow weighted load and multiplying this average by the total days of flow.

Table 4.36 1987-88 mine site pollutant loads

GS 8150	DAYS OF FLOW	NO. OF SAMPLES	% OF FLOW SAMPLED	FLOW ($m^3 x 10^6$)	Cu	Mn (tonnes)	Zn	SO_4
200	140	38	27	3.04	2.80	2.91	1.78	811
209	115	32	28	1.21	0.31	0.23	0.23	096
210	110	32	29	0.32	0.39	0.18	0.28	99
211	126	35	28	1.22	.69	0.73	1.10	232
212	72	22	33	1.50	1.79	1.94	0.30	473
213	94	27	29	3.99	0.62	0.65	0.51	219
214	101	30	30	2.28	0 .93	1.81	0.28	353
097	141	141	100	6.32	3.23	5.39	2.00	1 260

VALIDITY CHECK FOR MINE SITE LOAD CALCULATIONS

By comparing the flows and loads of the various mine site sampling points, and interpolating results obtained at GS8150097, it was possible to verify sampling and analytical methods.

For selected sampling points synthesized data was provided using calculated results for days no samples where taken. Table 4.37 compares results obtained by East Point Laboratory and the Hydrographic section. East Point Laboratory results are used in this report for the calculations of load and flow distributions.

Table 4.37 Comparison of synthesized and calculated dissolved pollutant loads

	FLOW (m^3x10^6)	Cu	Mn (tonnes)	Zn	SO_4
GS8150200 CALC.	3.04	2.80	2.91	1.78	811
GS8150200 SYNT.	2.97	3.02	3.11	2.10	814
GS8150209 CALC.	1.21	0.31	0.23	0.23	96
GS8150209 SYNT.	0.97	0.21	0.17	0.19	74
GS8150210 CALC.	0.31	0.39	0.18	0.28	99
GS8150210 SYNT.	0.29	0.41	0.18	0.29	96
GS8150211 CALC.	1.22	0.69	0.73	1.10	232
GS8150211 SYNT.	1.06	0.76	0.80	1.30	242
GS8150212 CALC.	1.50	1.79	1.94	0.29	473
GS8150212 SYNT.	1.36	1.50	1.71	0.27	405
GS8150214 CALC.	2.28	0.93	1.81	0.28	353
GS8150214 SYNT.	2.49	0.93	1.81	0.28	355

Table 4.38 shows that the combined calculated flows and pollutant loads found at GS8150210, GS8150211 and GS8150212 are in good agreement with those found at GS8150200.

The combined total flow and pollution load of GS8150200 and GS8150214 should be similar to that at GS8150097. Adjustments for flow and sulphates entering the East Finniss River beyond GS8150214 were made. It was calculated that an additional flow of approximately 900 000 m^3 entered the East Finniss River downstream of GS8150214 and GS8150200. A concentration of 15 mg/l for sulphate has been assumed as typical background concentration for the off mine site catchment area. Table 4.39 shows that a reasonable relationship exists between results obtained for these sampling points.

Table 4.38 Reconciliation of dissolved pollutant loads at GS8150200 with dissolved pollutant loads found upstream

	FLOW ($m^3 x 10^6$)	Cu	Mn (tonnes)	Zn	SO_4
GS8150210	0.31	0.39	0.18	0.28	99
GS8150211	1.22	0.69	0.73	1.10	232
GS8150212	1.50	1.79	1.94	0.30	473
TOTAL	3.03	2.87	2.85	1.68	804
GS8150200	3.04	2.80	2.91	1.78	811
DIFFERENCE	0.01	0.07	0.06	0.10	7

Table 4.39 Reconciliation of combined dissolved minesite pollutant loads with dissolved pollutant loads found at GS8150097

	FLOW ($m^3 x 10^6$)	Cu	Mn (tonnes)	Zn	SO_4
GS8150214	2.28	0.93	1.81	0.28	353
GS8150200	3.04	2.80	2.91	1.78	811
EXTRA FLOW	0.90	-	-	-	14
TOTAL	6.22	3.73	4.72	2.00	1 178
GS8150097	6.32	3.23	5.39	2.01	1 260
DIFFERENCE	0.10	0.50	0.67	0.01	82

INDIVIDUAL MINE SITE POLLUTION SOURCES

This section deals with the pinpointing and assessing of the magnitude of mine site pollution areas.

Results obtained at GS8150097 are an indication of the total dissolved load originating from the mine site.

The next sampling point upstream from GS8150097 is GS8150214. It carries part of the flushings from White's Open Cut. The remainder of White's Open Cut flushings discharges into Intermediate Open Cut. White's Open Cut inflow water is measured at GS8150213.

GS8150213 measured about 75 percent of the water flowing from the Acid and Sweetwater Dam area, which also drain the rehabilitated Dyson's sites. GS8150209 measured the remains water from upstream of White's Open Cut and the Diversion Channel. Approximately 83 percent of the flow measured at GS8150097 flowed through GS8150213 and GS8150209.

The pollution input between GS8150209 and GS8150211 is thought to originate mainly from groundwater input from White's and Intermediate Overburden Heaps, and was calculated by deducting flows and pollutant loads found at GS8150209 from those found at GS8150211. Table 4.40 shows the calculations.

Table 4.40 Pollutant input between GS8150209 and GS8150211

	FLOW ($m^3 x 10^6$)	Cu	Mn (tonnes)	Zn	SO_4
GS8150211	1.22	0.69	0.73	1.10	232
GS8150209	1.20	0.31	0.23	.23	96
INPUT	0.02	0.38	0.50	0.87	136
as percent at GS8150097	0.3	11.9	9.3	43.5	10.8

The combined total loads of GS8150209 and GS8150213 constitute the pollution originating from the Dyson's rehabilitation area, input from White's Overburden Heap from six subsoil drains, GS8150216 - GS8150221, and surface water run off.

Contributions from White's Overburden Heap to the East Finniss River above the Diversion Channel were calculated using the assumption that the water quality at GS8150209 should be similar to that measured at GS8150213. About 3.3 times more water flowed through GS8150213 than through GS8150209. The loads found at GS8150213 were divided by a factor of 3.3 to calculate the expected load at GS8150209. Table 4.41 shows the total loads found at GS8150209 and GS8150213. Table 4.42 shows the total calculated and expected loads at GS8150209 and the calculated pollution input from White's Overburden Heap to the East Finniss River above the Diversion Channel.

Table 4.41 Combined total dissolved pollutant loads found at GS8150209 and GS8150213

	FLOW ($m^3 x 10^6$)	Cu	Mn (tonnes)	Zn	SO_4
GS8150213	3.99	.62	.65	.51	219
GS8150209	1.20	.31	.23	.23	96
TOTAL	5.19	.93	.88	.74	315

Table 4.42 White's Overburden Heap pollutant input above GS8150209

		Cu	Mn	Zn	SO_4
			(tonnes)		
TOTAL	GS8150209	0.31	0.23	0.23	96
CALCUL.	GS8150209	0.19	0.19	0.16	66
WHITE'S O/B INPUT		0.12	0.04	0.07	30

Pollution originating from Dyson's rehabilitation area can also be calculated by using the calculated loads at GS8150209 and combining them with the loads from GS8150213. Table 4.43 shows the input from Dyson's area. No corrections were made for the input of White's subsoil drains GS8150216 to GS8150221, as they carried only small amounts of pollutants.

Table 4.43 Calculated dissolved loads from Dyson's Open Cut rehabilitation area

	FLOW ($m^3 x 10^6$)	Cu	Mn	Zn	SO_4
			(tonnes)		
GS8150213	3.99	0.62	0.65	0.51	219
GS8150209 CALCULATED	1.20	0.19	0.20	0.16	66
TOTAL	5.19	0.81	0.85	0.67	285
AS PERCENTAGE OF GS8150097	82.0	25.10	15.80	33.50	22.6

GS8150210 is at the confluence of Wandering Creek and the Diversion Channel. Pollution found here originates from Drain GS8150222 and groundwater from White's and Intermediate Overburden Heaps.

Pollution loads originating from White's and Intermediate Overburden Heaps can be estimated by combining the loads calculated for the input of White's Overburden Heap above the Diversion Channel and the input of White's and Intermediate Overburden Heaps to the Diversion Channel between GS8150209 and GS8150211 and GS8150210.

Table 4.44 shows the loads at GS8150210 and the total calculated pollution load estimated to have come from the White's and Intermediate Overburden Heap.

Table 4.44 Dissolved pollutant input from White's and Intermediate Overburden Heaps

	Cu	Mn (tonnes)	Zn	SO_4
GS8150210	0.39	0.18	0.28	99
INPUT ABOVE GS8150209	0.13	0.04	0.07	30
INPUT BETWEEN GS8150209 & GS8150210	0.38	0.50	0.87	137
TOTAL INPUT	0.90	0.72	1.22	266
AS PERCENTAGE OF GS8150097	28.10	13.40	61.00	21.0

The most significant source of pollutants in the East Finniss River other than zinc are the open cuts.

The treatment of White's Open Cut in 1985 with lime to a depth of approximately 22 metres, established a layer of relatively unpolluted water over highly polluted water. An annual flushing process, achieved by re-diverting the East Finniss River through the open cuts, affected the layer to an estimated depth of 30 metres. Profiling of White's Open Cut has revealed that some of the more polluted water may have been disturbed and mixed with water leaving White's Open Cut through Copper Creek and Intermediate Open Cut.

Intermediate Open Cut was treated in total and, at present, is only a minor contributor to the pollution regime in the East Finniss River. Most of its pollution is carry over from the water it received from White's Open Cut. Some polluted groundwater inflow and the dissolving of sludge not removed from ledges and crevasses during the treatment of the Intermediate Open Cut may be contributing.

The loads thought to originate from the open cuts were calculated by deducting the combined outflows from White's and Intermediate Open Cuts, GS8150214 and GS8150212, from White's Open Cut inflow, GS8150213.

Table 4.45 shows the loads coming from the open cuts and the percentage contribution to the total pollution load at GS8150097.

MINE SITE WATER QUALITY

Dissolved pollutant loads and concentrations measured at GS8150200 and GS8150209 to '214 are given in Appendix B Tables 4.46, 4.47 and 4.48 (a) to (g). White's and Dyson Overburden Heap drains will be discussed later.

No comparison can be made between previous years and the 1987-88 data, as in previous years insufficient data was collected.

Table 4.45 Dissolved Pollutant input from White's and Intermediate Open Cuts

	FLOW (m^3x10^6)	Cu	Mn (tonnes)	Zn	SO_4
GS8150214, WHITE'S O/C OUTFLOW	2.28	.93	1.81	.28	353
GS8150212, INTERMEDIATE O/C OUTFLOW	1.50	1.79	1.94	.30	473
TOTAL OPEN CUT OUTFLOW	4.03	2.72	3.75	.58	826
- GS8150213, WHITE'S O/C INFLOW	3.99	0.62	0.65	.51	219
POLLUTION INPUT BY OPEN CUTS	N/A	2.10	3.10	.07	607
AS PERCENTAGE OF GS8150097		65.0	57.5	3.5	48.0

WHITE'S OVERBURDEN HEAP SUBSOIL DRAINS

White's Overburden Heap has nine subsoil drains. Five flowed and are shown in Figure 4.2.

The calculated flow volume was significantly smaller for the 1987-88 season, as a result of low rainfall experienced. Of the five subsoil drains, GS8150222 flowed longest, whilst GS8150221 flowed only for a very brief period and was excluded from calculations for loads. As for 1986-87, drain GS8150222 remains the strongest flowing.

It was calculated that in 1987-88 a total of 2400m^3 of polluted water seeped from the drains, carrying 57 kg of copper, 57 kg of manganese, 56 kg of zinc and 23 tonnes of sulphate, as compared to 6400m^3 with 200 kg of copper, 150 kg of manganese, 240 kg of zinc and 67 tonnes of sulphate in 1986-87. Calculations of mean concentrations for copper and zinc showed reductions compared with 1986-87, while manganese and sulphate mean concentrations were similar.

When considering the accepted theory that low flows are conducive to high pollutant concentrations, significant improvement in water quality may have occurred at this source.

Table 4.49 shows comparison of loads calculated for 1986-87 and 1987-88 and percentage improvement for the 1987-88 season based on adjusted flow from 1986-87 to 1987-88 season. Table 4.50 shows the water quality as measured for the five drains as well as maximum and minimum concentrations measured in 1986-87 and 1987-88. Table 4.51 shows the loads calculated for White's Overburden Heap drains.

Table 4.49 Comparison of White's Overburden Heap subsoil drain's water quality 1986/87 to 1987/88

SEASON	FLOW (m^3)	COPPER	MANGANESE	ZINC (kg)	SULPHATE
1986-87	6 400	200	150	240	67 000
1987-88	2 350	57	57	56	23 000
		1987-88 ADJUSTED TO 1986-87 FLOW			
	6 400	160	150	150	62 000
% IMPROVEMENT		20	0	38	7

Table 4.50 White's Overburden Heap subsoil drains - pollutant concentrations

GS8150216

DATE	FLOW (l/s)	pH	SC (µs/cm)	Cu	Mn (mg/l)	Zn	SO_4
12-01-88	.004	3.4	2 900	9.5	4.5	7	2 100
10-02-88	.011	3.2	7 000	17	14	14	6 100
16-02-88	.438	3.5	10 000	18	23	28	6 100
23-02-88	.300	3.3	10 000	21	21	29	10 000
01-02-88	.250	3.1	12 000	21	24	35	12 000
07-03-88	.122	3.0	13 000	26	26	41	13 000
23-03-88	.056	2.9	16 000	33	33	54	17 000
28-03-88	.009	3.0	12 000	24	24	39	12 000
05-04-88	.032	2.8	15 000	29	31	52	17 000
12-04-88	.011	2.8	16 000	30	33	55	18 000
Max 1987-88				33	33	55	18 000
Max 1986-87				53	47	190	18 000
Min 1987-88				9.5	4.5	7	2 100
Min 1986-87				16	3	6	2 600
Mean 1987-88				12	15	23	7 700
Mean 1986-87				33	20	45	11 000

Table 4.50 Cont'd

GS8150221

DATE	FLOW (l/s)	pH	SC (µs/cm)	Cu	Mn (mg/l)	Zn	SO_4
16-02-88	.022	3.4	8 200	27	14	25	7 700
23-02-88	.016	3.4	8 400	28	15	27	7 900
Max 1986-87				48	27	36	11 000
Min 1986-87				29	11	22	6 600
Mean 1986-87				39	21	34	8 600

GS8150222

DATE	FLOW (l/s)	pH	SC (µs/cm)	Cu	Mn (mg/l)	Zn	SO_4
04-01-88	.093	3.2	11 000	37	35	27	12 000
11-01-88	.061	3.1	12 000	42	38	30	13 000
19-01-88	.056	3.1	12 000	37	37	28	12 000
25-01-88	.072	3.1	12 000	35	36	27	12 000
01-02-88	.130	3.1	13 000	44	38	31	14 000
09-02-88	.073	3.1	12 000	40	36	29	13 000
16-02-88	.316	3.2	8 800	25	26	17	8 100
23-02-88	.200	3.1	9 800	28	29	20	9 100
01-03-88	.156	3.0	10 000	30	31	22	10 000
07-03-88	.109	3.0	11 000	35	33	23	11 000
16-03-88	.058	3.0	12 000	40	36	26	13 000
23-03-88	.039	3.0	12 000	39	35	25	12 000
28-03-88	.039	3.0	11 000	34	32	23	11 000
05-04-88	.200	3.1	9 600	27	27	17	8 900
12-04-88	.112	3.0	11 000	30	30	20	10 000
20-04-88	.055	3.0	12 000	37	32	24	12 000
26-04-88	.044	3.0	12 000	37	33	25	12 000
03-05-88	.020	3.0	12 000	39	33	25	13 000
Max 1987-88				44	38	31	13 000
Max 1986-87				53	54	88	14 000
Min 1987-88				25	26	17	8 100
Min 1986-87				23	18	14	9 400
Mean 1987-88				33	32	23	10 000
Mean 1987-88				33	32	23	10 000
Mean 1986-87				33	28	25	9 400

Table 4.50 Cont'd

GS8150217

DATE	FLOW (l/s)	pH	SC (µs/cm)	Cu	Mn (mg/l)	Zn	SO_4
10-02-88	.011	3.6	5 100	18	8.5	6.0	4 200
16-02-88	.048	3.2	9 600	29	23	29	9 000
23-02-88	.041	3.2	8 700	26	20	25	8 300
01-03-88	.020	3.1	11 000	27	27	36	11 000
07-03-88	.004	3.2	11 000	26	27	36	11 000
16-03-88	.002	3.7	12 000	22	29	35	12 000
12-04-88	.001	3.6	11 000	22	27	28	11 000
Max 1987-88				29	29	36	12 000
Max 1986-87				31	25	55	13 000
Min 1987-88				18	8.5	25	4 200
Min 1986-87				27	10	13	5 400
Mean 1987-88				26	23	29	9 200
Mean 1986-87				28	19	42	11 000

GS8150218

DATE	FLOW (l/s)	pH	SC (µs/cm)	Cu	Mn (mg/l)	Zn	SO_4
10-02-88	.057	3.5	2 100	4.0	4.0	4.5	1 300
16-02-88	.083	3.2	8 600	19	20	6.0	7 800
23-02-88	.104	3.1	8 700	18	19	9.0	8 000
01-03-88	.076	3.1	10 000	18	22	35	9 600
07-03-88	.048	3.1	10 000	19	24	35	10 000
16-03-88	.016	3.1	11 000	18	24	34	10 000
23-03-88	.098	3.1	10 000	17	24	32	9 800
28-03-88	.030	3.1	9 600	18	21	27	8 900
05-04-88	.078	3.1	9 100	18	20	26	8 500
12-04-88	.039	3.1	9 700	16	22	27	9 200
20-04-88	.019	3.1	10 000	16	23	28	9 300
Max 1987-88				19	24	35	10 000
Max 1986-87				39	30	88	16 000
Min 1987-88				4	3	4.5	1 300
Min 1986-87				25	11	21	9 700
Mean 1987-88				17	20	22	8 200
Mean 1986-87				27	23	34	12 000

Table 4.51 White's Overburden Heap subsoil drain - pollutant loads

GS8150216

	FLOW (l x 10^6)	Cu	Mn	Zn	SO_4
			(kg/d)		
12-01-88	.001	.01	<.01	.01	2
10-02-88	.001	.02	.01	.01	6
16-02-88	.038	.68	.87	1.10	370
23-02-88	.026	.55	.55	.75	260
01-02-88	.022	.46	.53	.77	260
07-03-88	.011	.29	.29	.45	140
23-03-88	.005	.17	.17	.27	85
28-03-88	.001	.02	.02	.04	12
05-04-88	.003	.09	.09	.16	51
12-04-88	.001	.03	.03	.06	18
Calculated Load For Season	.910	14.60	14.60	22.80	7 800

Days of Flow: 91

GS8150217

	FLOW (l x 10^6)	Cu	Mn	Zn	SO_4
			(kg/d)		
10-02-88	.001	.02	.01	.07	4.2
16-02-88	.004	.12	.09	.12	36
23-02-88	.004	.10	.08	.10	33
01-03-88	.002	.05	.05	.07	22
07-03-88	.001	.03	.03	.04	11
16-03-88	.001	.02	.03	.04	12
12-04-88	.001	.02	.03	.03	11
Calculated Load For Season (kg)	.12	3.1	2.5	3.1	1 100

Days of Flow: 91

Table 4.51 Cont'd

GS8150218

	FLOW (1 x 10^6)	Cu	Mn (kg/d)	Zn	SO_4
10-02-88	.005	.02	.02	.02	6.5
16-02-88	.007	.13	.14	.04	55
23-02-88	.009	.16	.17	.08	72
01-03-88	.007	.13	.15	.25	67
07-03-88	.004	.07	.10	.14	40
16-03-88	.001	.02	.02	.03	10
23-03-88	.008	.14	.19	.26	78
28-03-88	.003	.05	.06	.08	26
05-04-88	.007	.13	.14	.18	59
12-04-88	.003	.05	.07	.08	27
20-04-88	.002	.03	.05	.06	19
Calculated Load For Season (kg)	.35	5.6	7.0	7.7	2 900

Days of Flow: 70

GS8150221*

	FLOW (1 x 10^6)	Cu	Mn (kg/d)	Zn	SO_4
16-02-88	.002	.05	.03	.05	15
23-02-88	.001	.04	.02	.04	11

* GS8150221 flowed only briefly during the sampling period. Pollutant loads were not calculated. Pollutants coming from this source are minimal and would not significantly effect calculations for the total loads at GS8150097.

Table 4.51 Cont'd

GS8150222

	FLOW (l x 10^6)	Cu	Mn	Zn (kg/d)	SO_4
04-01-88	.008	.30	.28	.22	96
11-01-88	.005	.21	.19	.15	65
19-01-88	.005	.19	.19	.14	60
25-01-88	.006	.21	.22	.16	72
01-02-88	.011	.48	.42	.34	150
09-02-88	.006	.24	.22	.17	78
16-02-88	.027	.68	.70	.46	220
23-02-88	.017	.48	.49	.34	150
01-03-88	.013	.39	.40	.29	130
07-03-88	.009	.32	.30	.21	99
16-03-88	.005	.20	.18	.13	65
23-03-88	.003	.12	.11	.08	36
28-03-88	.003	.10	.10	.07	33
05-04-88	.017	.46	.46	.29	150
12-04-88	.010	.30	.30	.20	100
20-04-88	.005	.19	.16	.12	60
26-04-88	.004	.15	.13	.10	48
03-05-88	.002	.08	.07	.05	26
Calculated Load For Season (kg)	.97	33.9	32.6	23.0	11 000

Days of Flow: 121

DYSON'S OPEN CUT DRAIN GS8150215

Dyson's Open Cut Drain GS8150215 was sampled eight times during the 1987-88 sampling programme. Only copper and radium-226 were measured.

Data collected during the 1986-87 wet season indicated that the integrity of the rehabilitation work may have been breached, as cracks and slumping were observed. It was calculated that for the 1986-87 season, 2300m^3 of highly polluted water carrying 670 kg of copper and 1.4 x 10^6 Bq radium-226 found its way into the East Finniss River system. In terms of percentage contribution of the total load measured at GS8150097, this was 12 percent, and made Dyson's Open Cut area a major source of pollution during the 1986-87 wet season.

During the 1987 dry season, Dyson's Open Cut was recontoured. Significant reductions in flow and copper concentrations were experienced in the 1987-88 wet season. The reduction of flow and copper concentration were almost certainly the result of the repairs carried out, and the poor wet season. Radium-226 concentrations were similar for both wet seasons.

The data obtained are presented in Table 4.52 and the location is shown in Figure 4.2.

Whilst eight samples may not provide sufficient data to engage in serious calculations, they give an indication of the magnitude of flow and copper and radium-226 originating from this source.

It was calculated that approximately 550m^3 of polluted water were carried by the drain, containing 11 kg of copper and 0.2 Bq x 10^6 of Ra-226.

Table 4.53 compares minimum and maximum concentrations of copper and radium-226 for the 1986-87 and the 1987-88 wet seasons.

4.52 Dyson's Open Cut drain GS8150215 - water quality

DATE	FLOW (lX10^6/d)	pH	SC (µs/cm)	Cu (mg/l)	Ra-226 (Bq/l)	Cu (kg/d)	Ra-226 (Bq/d)
10-02-88	0.043	3.4	920	1.45	0.120	0.06	5 160
17-02-88	0.002	2.8	7 000	26.00	0.860	0.05	1 720
24-02-88	0.006	2.9	6 300	22.00	0.760	0.13	4 560
09-03-88	0.004	2.8	9 500	48.00	0.770	0.19	3 080
24-03-88	0.009	3.0	3 970	17.95	0.280	0.16	2 520
31-03-88	0.002	3.2	2 800	10.20	0.210	0.02	420
06-04-88	0.008	2.8	7 800	71.00	0.780	0.57	6 240
12-04-88	0.003	2.8	9 300	83.00	0.680	0.25	2 040

Table 4.53 Dyson's Open Cut drain GS8150215 - 1986-87 and 1987-88 pollutant concentrations

Year	Copper Max	Copper Min (mg/l)	Copper Mean	Copper Load (kg)	Radium-226 Max (Bq/l)	Radium-226 Min ($Bq x 10^6$)	Radium-226 Mean	Radium-226 Load (kg)
1986-87	780	110	290	670	0.74	0.59	0.62	1.4
1987-88	83	2	35	11	0.86	0.12	0.55	0.2

4.5 CONCLUSIONS AND RECOMMENDATIONS

4.5.1 CONCLUSIONS

TOTAL FLOWS

The total flow volume for the 1986-87 wet season at GS8150097 on the East Finniss River was 13.2 x 10^6 m^3. This was similar to the total flow volumes of 1982-83, 1984-85 and 1985-86 (Section 4.3.4). Approximately half that flow was measured for the 1987-88 season which represented the lowest seasonal flow volume recorded since the inception of monitoring.

POLLUTANT LOADS

Pollutant loads for 1986-87 at GS8150097 were 5.6, 8.6, 2.7 and 2870 tonnes for copper, manganese, zinc and sulphate respectively. Comparable loads for 1987-88 were 3.2, 5.4, 2.0 and 1230 tonnes.

The agreement between the Commonwealth and NT Governments refer to a target load reduction of 70% for copper, 56% for manganese and 70% for zinc in comparison with the loads determined by the AAEC, based on the monitoring data obtained for the 1969-74 wet seasons.

In 1986-87 loads had reduced by 80% for copper and 60% for zinc, while the manganese load has not changed. The sulphate load increased by 140% in 1985-86 as a result of the rediversion of the East Finniss River through the Open Cuts. The sulphate load decreased to be 40% above pre-rehabilitation levels in 1986-87. (The sulphate load is expected to further decrease in the future as flushing of the Open Cuts continues.)

By 1987-88 all load reduction targets had been met. The percentage reductions were 90, 90 and 80 percent for dissolved copper, manganese and zinc. These percentages are based on the loads expected for a similar flow during the 1969-74 seasons (Verhoeven, pers. comm.).

Based on a non-adjusted flow, the reductions of dissolved loads from 1969-74 to 1987-88 were 95% for copper, 90% for manganese, 90% for zinc and 85 % for sulphate.

Decrease of dissolved loads in 1987-88 as compared with those in 1986-87 should be viewed in light of the greatly reduced total flow.

RADIUM-226

Radium-226 concentrations and loads at GS8150097 in 1986-87 were similar to those of 1985-86. On five early wet season low flow days the discharge based daily composite gave radium-226 concentrations slightly greater than the drinking-water criterion of 0.4 Bq/l. The maximum concentration recorded was 0.61Bq/l (Section 3.4.7).

The levels of radium-226 reduced significantly, however, in 1987 to less than half of those experienced in the previous season. The maximum level recorded was 0.09 Bq/l. The total Ra-226 load for the 1987-88 wet season was 350 x 10^6 Bq as compared with 800 x 10^6 Bq in 1986-87.

MAXIMUM DAILY POLLUTANT CONCENTRATIONS

Prior to rehabilitation, maximum daily concentrations were 182 mg/l for copper, 13 mg/l for manganese, 3.7 mg/l for zinc and 1290 mg/l for sulphate.

The maximum daily concentrations for copper, manganese, zinc and sulphate at GS8150097 for the 1987-88 season were 4.4, 4.0, 6.9 and 950 mg/l and for the 1986-87 season 3.4, 3.7, 3.5 and 600 mg/l respectively. Whilst the maxima represent a slight increase over those found for the 1986-87 season, all high concentrations were measured at the start of the wet season at very low flows.

Early wet season water quality at GS8150097 is highly dependent on the rainfall pattern and resultant flows. In 1987-88, the first 26 days of flow through GS8150097 came mainly from water which flowed through the Diversion Channel. The high values obtained during this period were the result of the dissolution of residual salts from the previous season and the rising of the polluted groundwater table.

As with previous wet seasons the highest concentrations occurred at lowest flows. Consequently, these high concentrations mean low loads.

DYSON'S OPEN CUT

Tailings and Copper Creek materials were buried in Dyson's Open Cut which produces small volumes of seepage containing concentrations of copper and radium-226.

During the 1987-88 season an estimated 560 m^3 of polluted water with a maximum concentration of 83 mg/l copper and 0.86 Bq/l radium-226 flowed from Dyson's Drain GS8150215 as compared to 1600 m^3 of water with a maximum of 780 mg/l copper and 0.74 Bq/l of radium-226 in 1986-87. The load reduced from 640 kg copper and 1.0 Bq X 10^6 radium-226 in 1986-87, to 11 kg copper and 0.2 Bq X 10^6 Ra-226 in 1987-88.

Dyson's Overburden Heap pollutes the East Branch of the Finniss River via springs at its base. The dominant pollutant is manganese (maximum recorded concentration in 1986-87 was 43 mg/l). Dyson's, however, is only a minor contributor to the pollution of the East Finniss River.

WHITE'S OVERBURDEN HEAP

White's Overburden Heap has seven subsoil drains. Five flowed during the past two years (1986-87 to 1987-88). The flows in the drains were characterized by high pollutant concentrations and low flow volumes. The water quality was similar to that of the last three seasons. During 1987-88 approximately 1500 m^3 of water from the drains carried 45 kg of copper, 45 kg of manganese, 35 kg of zinc and 16 tonnes of sulphate, as compared to 1986-87, when 6400 m^3 of water carried 200 kg of copper, 150 kg of manganese, 240 kg of zinc and 67 tonnes of sulphate.

This source of pollution could be either shallow groundwater entering from the south or minor infiltration of rainwater through the cover.

The drains were only minor contributors to the total dissolved loads at GS8150097. The percentage of loads contribution by the drains during the 1987-88 season to the total dissolved loads measured at GS8150097 were, 1.4% copper, 0.8% manganese, 1.8% zinc and 1.3% sulphate. This was lower than the 4% copper, 2% manganese, 9% zinc and the 2% sulphate found during the 1986-87 wet season. This reduction could be attributed to both the success of the rehabilitation works and the difference in seasonal rainfall.

POLLUTANT SOURCES

In 1987-88 the sampling program was extended in order to pinpoint the locations of pollution input to the East Finniss River and allocate percentages of pollution loads contributed to the total dissolved pollution load in the East Finniss River at GS8150097. This confirmed the opinions expressed in the 1986-87 report, i.e. that the open cuts were the major contributors. Approximate percentage contributions of the mine site sampling points are shown in Table 4.54.

Table 4.54 Mine Site Contribution Of Dissolved Pollutants to GS8150097

Area	Flow	LOAD Cu	Mn	Zn	SO_4
Open Cuts		65.0	58.0	3	48.0
GS8150210	4.9	12.0	3.3	14	7.9
GS8150213	63.0	19.0	12.0	26	18.0
GS8150209	19.0	9.7	4.3	12	7.6
Diversion Channel between GS8150209 and GS8150211	-	12.0	9.3	43	11.0

Units: Percent

Two different methods of synthesizing missing data were used to compare the minesite loads with the total loads at GS8150097.

The first method was to obtain a flow weighted daily average for the various sampling points and multiply these averages by the days of flow. As a validity check, flows and concentrations were synthesized for days no sampling was done.

The results of the two methods were in approximate agreement and in reasonable agreement with the results obtained at GS8150097.

The figures obtained by the first method are used throughout this report.

FINNISS RIVER WATER QUALITY

The minor fish kills noted in the past in the Finniss River should be diminishing with the lowering of dissolved heavy metals in general and of copper in particular.

The maximum soluble concentrations of heavy metals found in the Finniss River at GS8150204 were lower for the 1987-88 wet season than previously. Copper was 0.22 mg/l, manganese, 0.80 mg/l and zinc, 0.31 mg/l, as compared to 1986-87, when the maximum soluble concentrations were 0.85 mg/l for copper, 0.80 mg/l manganese and 0.50 mg/l zinc. The sulphate concentrations were similar for 1986-87 and 1987-88 being 140 and 150 mg/l respectively.

The maximum total concentrations, consisting of dissolved and particulate heavy metals, were erratic. For manganese, a reduction from a maximum of 0.921 mg/l in 1986-87 to 0.64 mg/l in 1987-88 was experienced. The maximum total copper concentration changed from 0.95 to 1.14 mg/l and the zinc from 0.53 to 0.09 mg/l.

As with the previous season, the highest concentrations coincided with the initial low flow of water from the open cuts.

Firm reasons cannot be determined for the difference in results of total and dissolved concentrations in 1985-86, 1986-87 and 1987-88, other than the differences in flow patterns and rainfall over the catchment area. This particularity applies to the 1987-88 season when rainfalls were highly localised.

An above average wet season is needed to test the integrity of the rehabilitated areas.

4.5.2 Recommendations

It is recommended that:

- The sampling programme at GS8150097 on the East Finniss River be maintained.

- The sampling programme at GS8150204 on the Finniss River below the confluence with the East Finniss River be maintained.

- Monitoring of the Open Cuts be intensified and modified to determine the extent to which flushing occurs in White's Open Cut, and whether pollutants are being transfered from the untreated water to the East Branch of the Finniss River.

- The on-site monitoring programme be revised, consistent with logistic and economic constraints, to determine the proportion of pollutant loads transported via the Open Cuts, the Diversion Channel and Wandering Creek.

- Monitoring of White's Overburden Heap sub-soil drains continue.

- The seepage from Dyson's Open Cut be monitored, particularly for copper and radium.

- Monitoring of ground-water levels and water quality continue.

- Monitoring of the Overburden Heap covers and the physical and chemical conditions within the heaps be continued through the agency of the Australian Nuclear Science and Technology Organisation.

5. GROUNDWATER STUDIES

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5.1 INTRODUCTION

A study has been made of the field data relating to groundwater collected as part of the monitoring of the Rum Jungle Uranium Mine rehabilitation project. This project commenced in 1983 and has been documented in several places (Bennett et al. 1989).

The groundwater of the Rum Jungle site in Northern Australia has been monitored since 1983 by about 70 boreholes (Figure 5.1), with some 35 being in the vicinity of White's Heap (Figure 5.2). The overburden heaps were among the principal sources of pollution before rehabilitation, so the largest of the heaps, White's, was made the focus of attention for the present groundwater studies. This heap also had the advantage that a borehole through it has allowed sampling of the water beneath the heap since 1983; in 1987 two more holes were drilled through the heap into the original soil below. Measurements of groundwater level and quality in the various boreholes have been made periodically since mid 1983, that is, from the time that White's Heap was covered with a layer of clay and soil. The measurements were made about once a month during the wet season; mostly only one or two were made during the dry. The water quality has been quantified by measurements of pH, electrical conductivity and concentrations of copper, zinc, manganese and sulphate.

Quite a large body of data has been collected and has been put into a file on the mainframe computer at the Lucas Heights Research Laboratories. Examination of various graphical displays of the measurements was found to be the most fruitful method of looking for overall trends in the relatively sparse and fluctuating data. A number of graph plotting programs have been developed to produce suitable diagrams. A representative sample of these diagrams will be presented to construct a picture of the behaviour of the groundwater.

The groundwater system has also been modelled mathematically. Because the overburden heaps are predominantly unsaturated, a model is needed which includes both unsaturated and saturated flow. The unsaturated flow is fundamental to the problem of pollutant release as a reservoir of pollutants is held in the pore water in the overburden heaps, high above the water table.

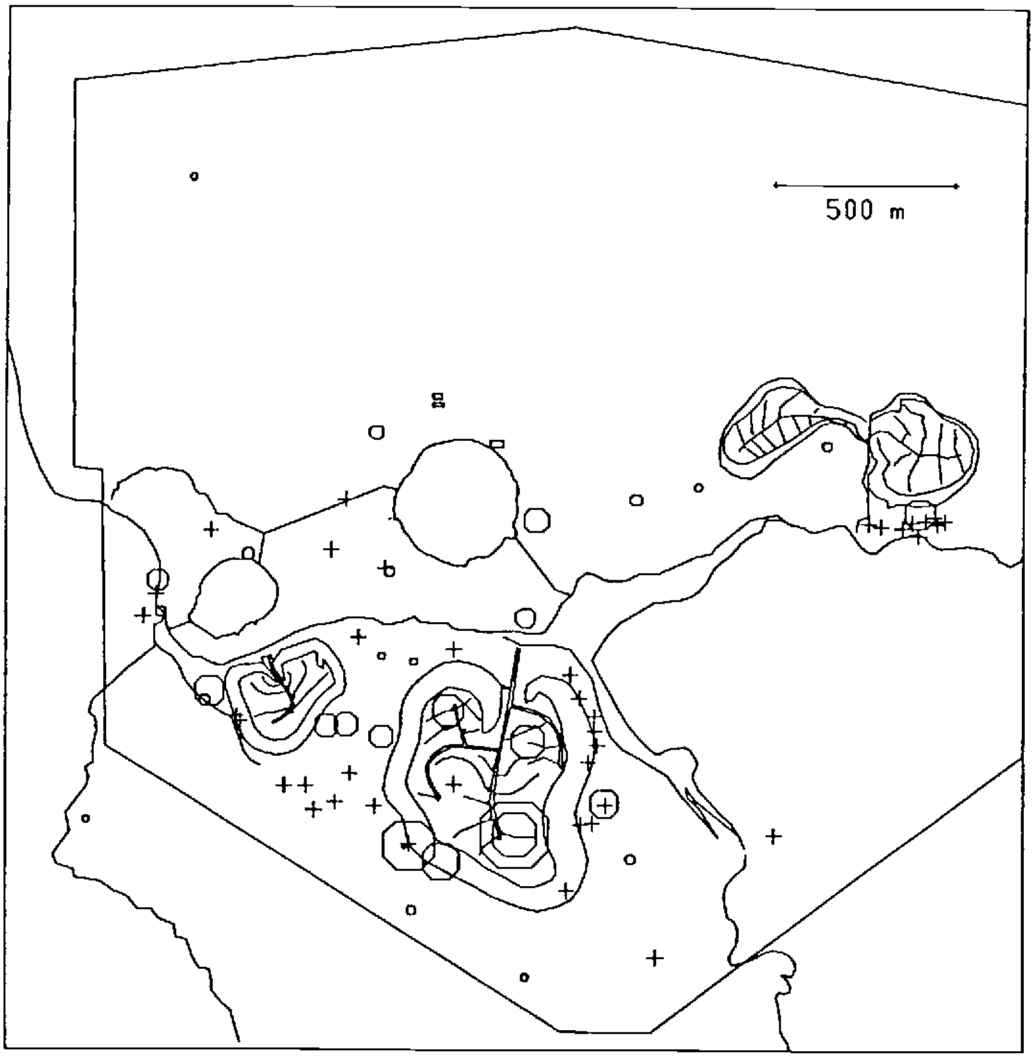


Figure 5.1 Map of region showing locations of all boreholes. The circles represent the sulphate concentrations measured during October 1987 (circle area is proportional to the concentration). The concentric circles represent sampling at two depths from one borehole.

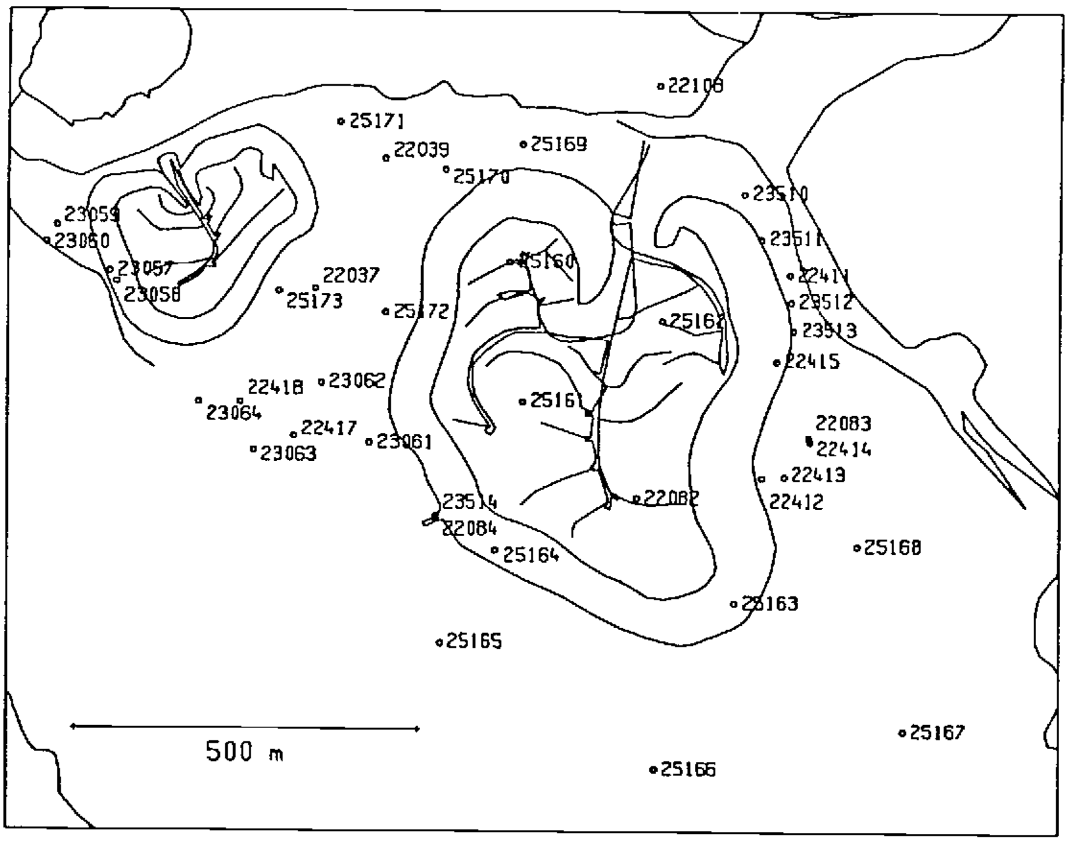


Figure 5.2 Map of White's Heap and environs showing locations and designations of boreholes.

5.2 EXAMINATION OF FIELD DATA

5.2.1 PLAN VIEW OF CONTAMINANT CONCENTRATIONS

The measurements are too sparse to permit the generation of meaningful contour maps of contaminant concentrations at specific times. However, if circles are drawn on a map of the site at the positions of the boreholes, and the area of each circle is made proportional to the concentration of a particular contaminant measured on a particular date, a good overview of the contaminant concentration distribution on that date is obtained. The distributions of sulphate, copper and manganese are shown by this method in Figures 5.1, 5.3 and 5.4. These diagrams are for measurements made in late 1987 because this is the only time that measurements are available for more than one borehole beneath White's Heap. Apart from this, they are typical of measurements made at other times. It is clearly seen that the pollution levels of the groundwater in the vicinity of the overburden heaps are markedly higher than the average. In view of the work carried out before rehabilitation, when the overburden heaps were identified as major sources of pollution, this is no surprise. However, it shows that there is a strong localisation of pollutants beneath the heap even after five years of reduced contaminant production following the capping of the heap. Measurements of copper concentration at February 1986, the end of the wet season, shows that the groundwater in the vicinity of the former spring sites, on the south-east and north-west of the heap, contains more than average contaminant (Figure 5.5). This reflects the predominant drainage pattern of the area, in which water entering the region below the heap from higher ground to the south tends to leave by the small gullies in the original ground surface which used to feed the springs.

Figure 5.1 shows that the water quality in the distant, or regional, boreholes has been unaffected by the mining, when it is understood that the smallest circles on the diagram correspond to sulphate concentrations of around 20 mg/l. This level can be expected to occur naturally in this region; for example, levels fluctuating about 20 mg/l have been measured in the East Branch of the Finniss River upstream of the mine site.

5.2.2 SEASONAL VARIATION IN WATER HEIGHT

Borehole RN22084, situated on the south-west side of White's Heap, has been used as a reference for the comparison of the seasonal rise and fall of groundwater levels, for no other reason than it has a fairly complete set of measurements. It is a deep borehole (18m) and is sealed at nine metres to exclude water from above this level. During the wet season, when the water table is high, its behaviour is very similar to that of a nearby very shallow hole, RN23514, which was dug by auger to a depth of two metres where weathered granite was struck (Figure 5.6). The seven low water levels recorded in the shallow hole should be viewed sceptically, as they correspond to times when the hole was almost completely dry. In other words, if this hole had been 1.5m deeper the variation in water level would have followed that of the deeper hole. Therefore, it would seem that the two boreholes are in fact sampling the same aquifer, or aquifers that are closely connected. The water level rises and falls past the weathered granite boundary without interruption, implying that the hydraulic conductivity of at least the top layer of this material does not differ markedly from that of the overlying soil.

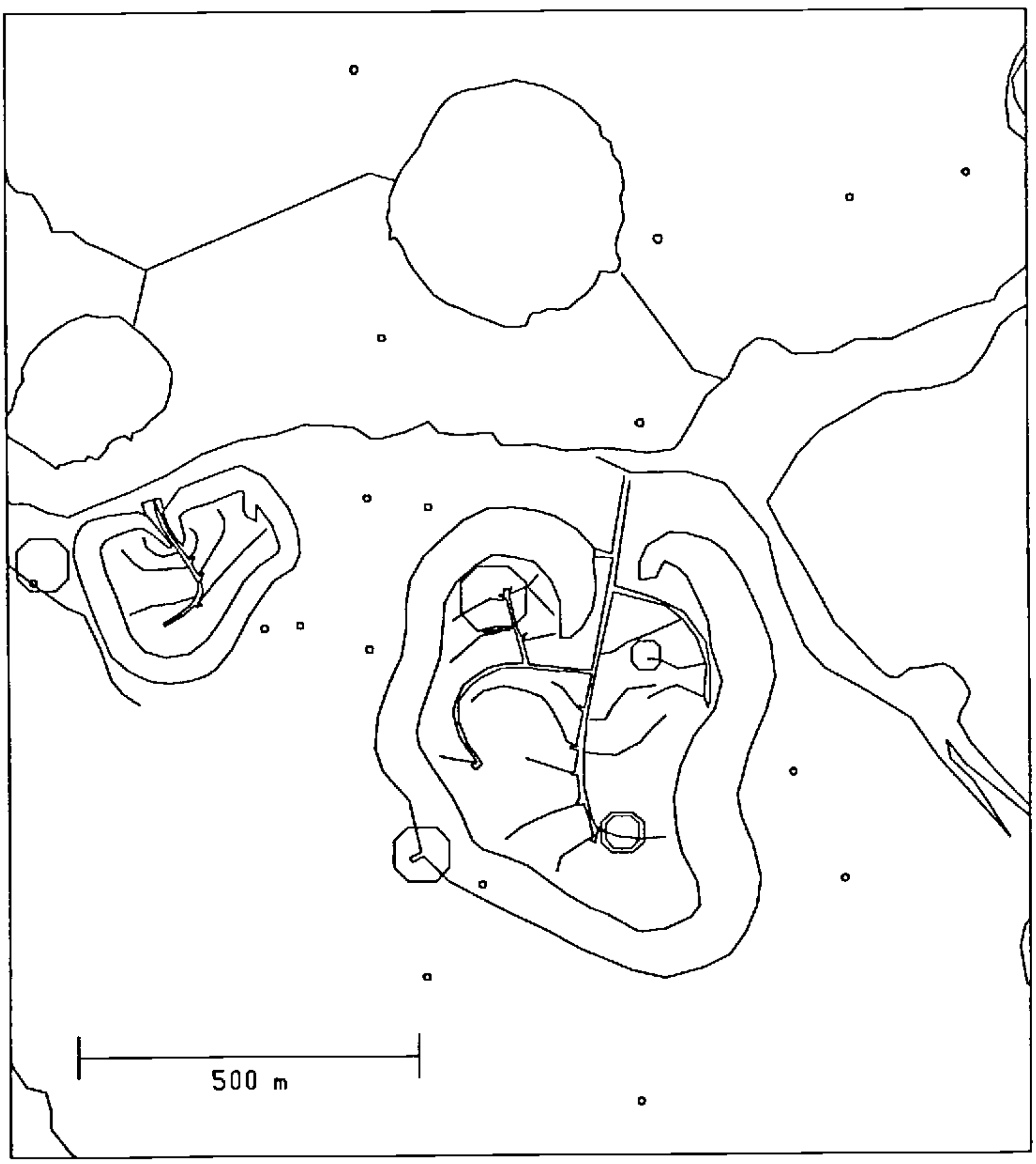


Figure 5.3 Copper concentrations in groundwater at various boreholes, measured September 1987 (circle area is proportional to the concentration). The maximum concentration is 64 mg/l. The concentric circles represent sampling at two depths from one borehole.

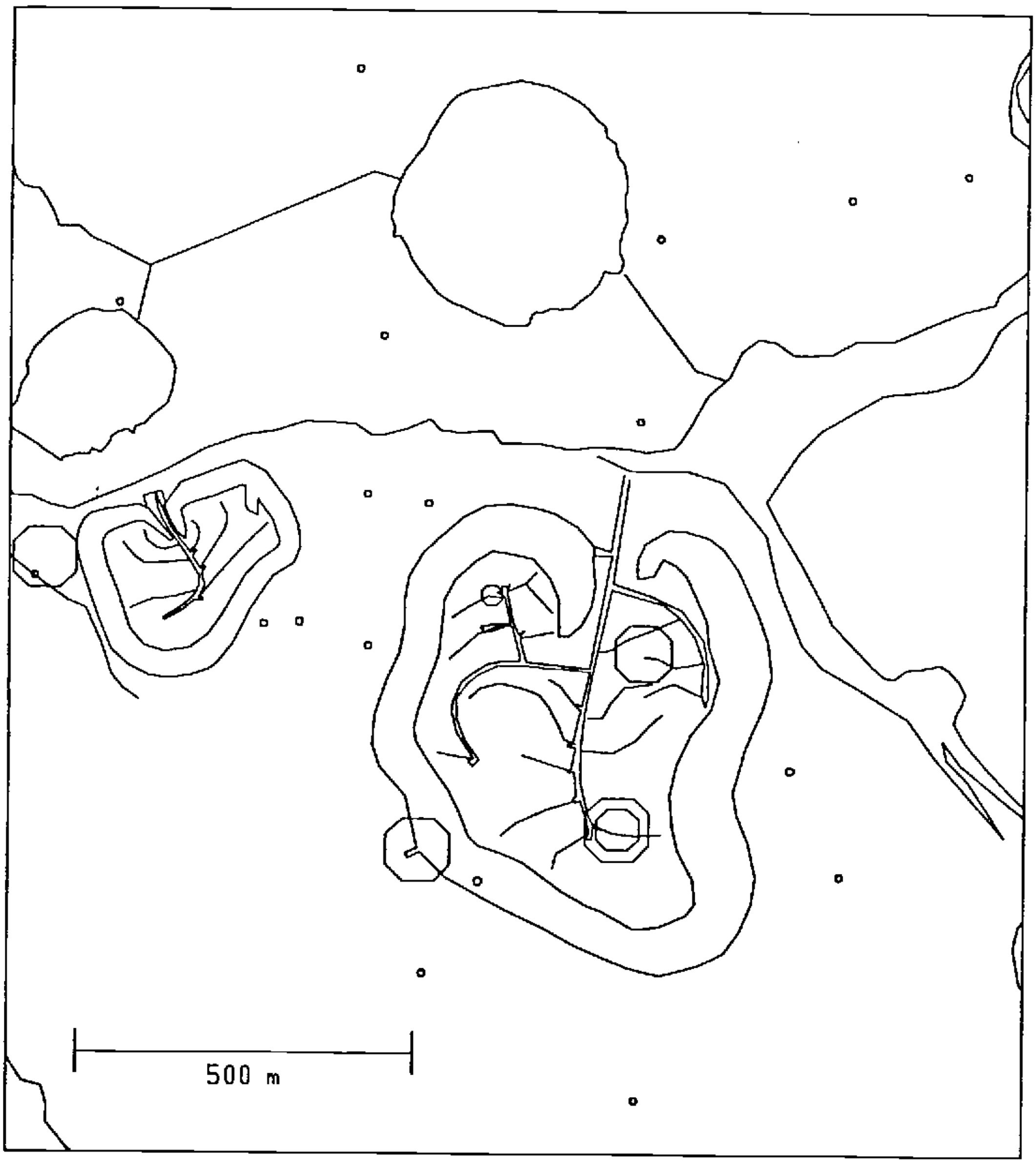


Figure 5.4 Manganese concentrations in groundwater at various boreholes, measured October 1987 (circle area is proportional to the concentration). The maximum concentration is 223 mg/l. The concentric circles represent sampling at two depths from one borehole.

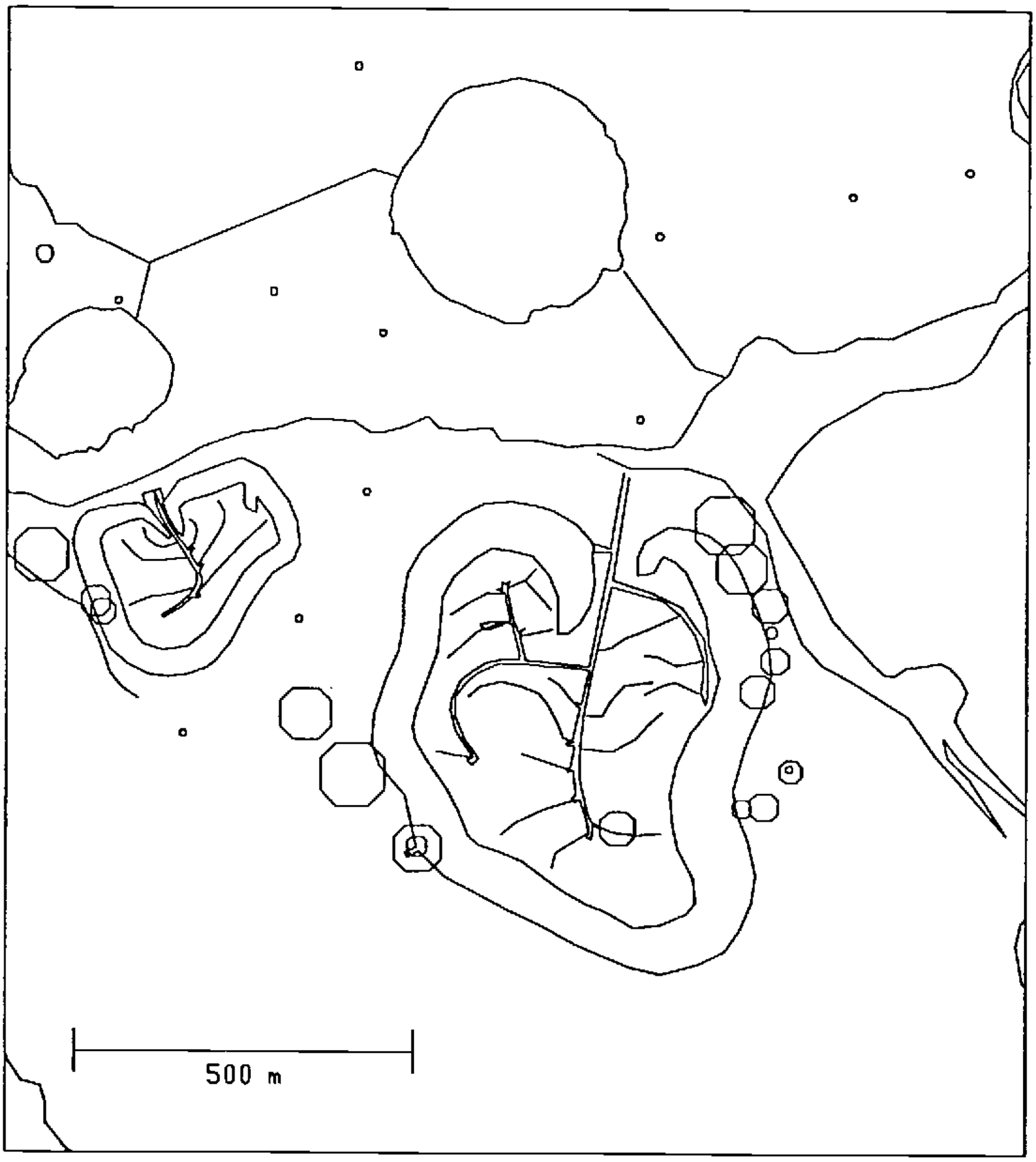


Figure 5.5 Copper concentrations in groundwater at various boreholes, measured February 1987 (circle area is proportional to the concentration). The maximum concentration is 76 mg/l.

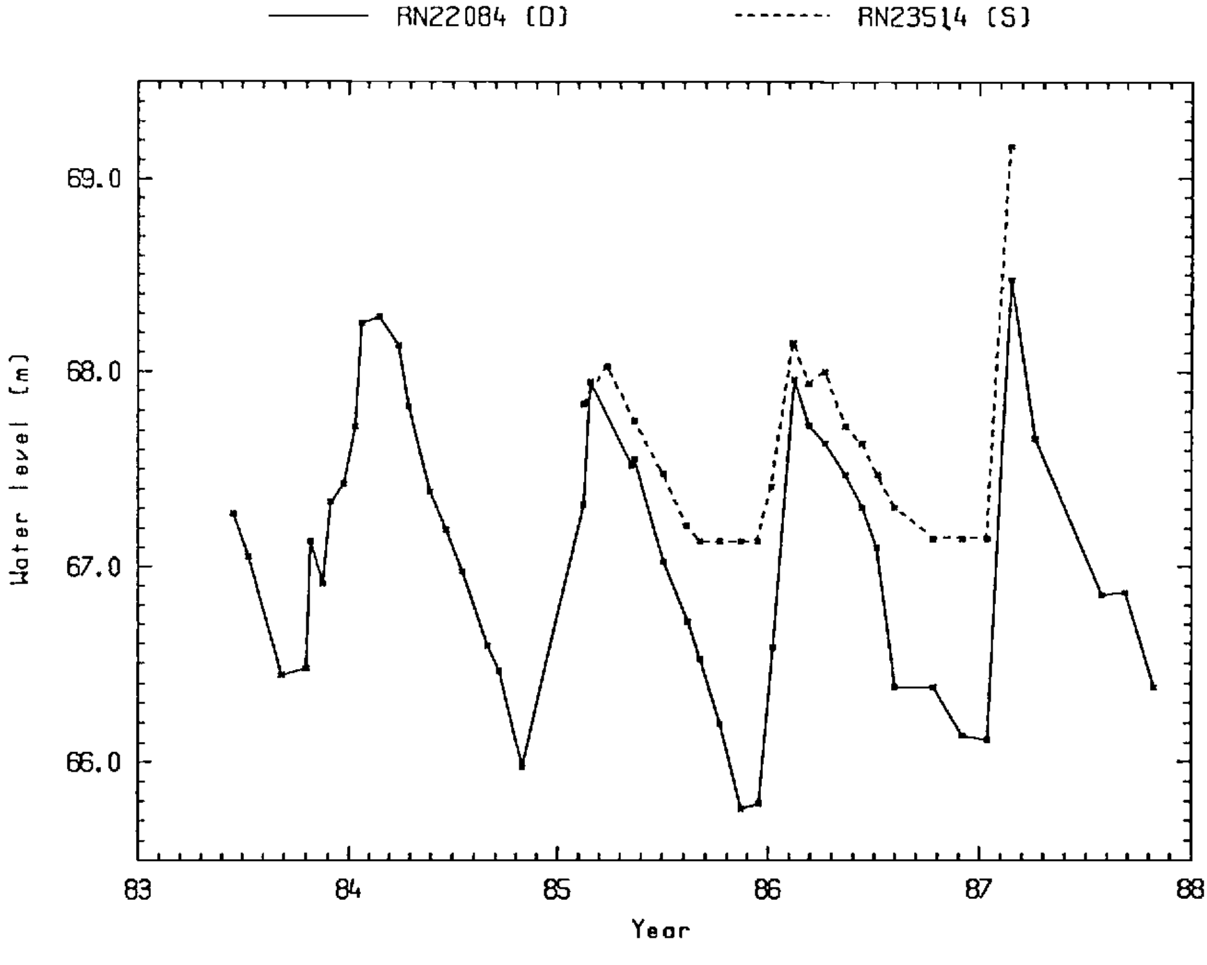


Figure 5.6 Comparison of water levels in deep and shallow boreholes close together on southwest edge of White's Heap.

Further evidence is gained from a pair of monitoring holes which were installed in one borehole drilled through the heap (RN22082). The liner of one hole passes through a cement plug some 15m below the original ground surface and proceeds on for a further 18m. The other hole penetrates 8.5m below the original ground surface. Figure 5.7 shows that the water levels of these two holes follow the same seasonal pattern, again indicating that the aquifers are closely connected. A third example is shown in Figure 5.8 where the deep reference borehole is compared with another deep hole, but one that is not sealed off from any shallow aquifer. The argument based on Figure 5.6 is again supported, but without the complication of a very shallow borehole.

As the water table varies seasonally from one to three metres below the ground surface it is inferred that the surface aquifer must be at least three metres thick. Borehole logs show that this aquifer is composed of sandy, gravelly soil lying on top of weathered granite. We have already shown that the boundary between these is rather indistinct from a hydrological point of view. The two metre seasonal rise and fall in the water table corresponds reasonably well with a rainfall of about 1.1m recorded over the last few years, an infiltration coefficient of 0.5 and a porosity of 0.3 ($\delta z = 1.1 \times 0.5/0.3 = 1.8$).

In Figure 5.9 the water levels below the heap are compared with the levels in the reference hole. The level of the water below the dump is higher than that in the reference borehole because it lies higher on the original ridge and is recharged from the higher ground to the south. The region around the reference hole will be recharged from local rainfall infiltration and seepage from higher ground, both from under and outside the heap. It is apparent that the rise and fall of the level below the heap lags behind the reference hole by about three months. As the infiltration through the capped heap has been reduced to five per cent, the only significant recharge for the groundwater below the dump comes from nearly horizontal flow and therefore a time delay is to be expected. However, it is somewhat surprising that the water table under the heap, on a ridge in the underlying ground, has a full two metres seasonal variation. It seems that the catchment area outside the heap that contributes to the influx of water must be large compared with the area lost through shielding by the heap. The close connection between the deep and shallow water movements may play a part in this process, with water being forced upwards during the wet season recharge.

5.2.3 SEASON VARIATION OF GROUNDWATER QUALITY

For further inferences about water movement we must look at the groundwater quality data. In Figure 5.10a the zinc concentrations in the two boreholes below White's Heap are compared; Figure 5.10b is a similar plot for sulphate. The concentrations in the deeper level do not vary greatly with season. They show some indication of an initial improvement in water quality in the first year or so after rehabilitation. The situation is reversed in the upper level, where there is strong seasonal oscillation of concentration but no evidence of a long term change. Figure 5.11 shows the contaminant concentration in the shallow hole falls as the water levels rises and vice versa.. Therefore the rise in water level must be due to an influx of relatively pure water, causing apparent dilution of the contaminated water. If the water rise was caused by a pressure induced rise in the water already under the heap this dilution could not occur.

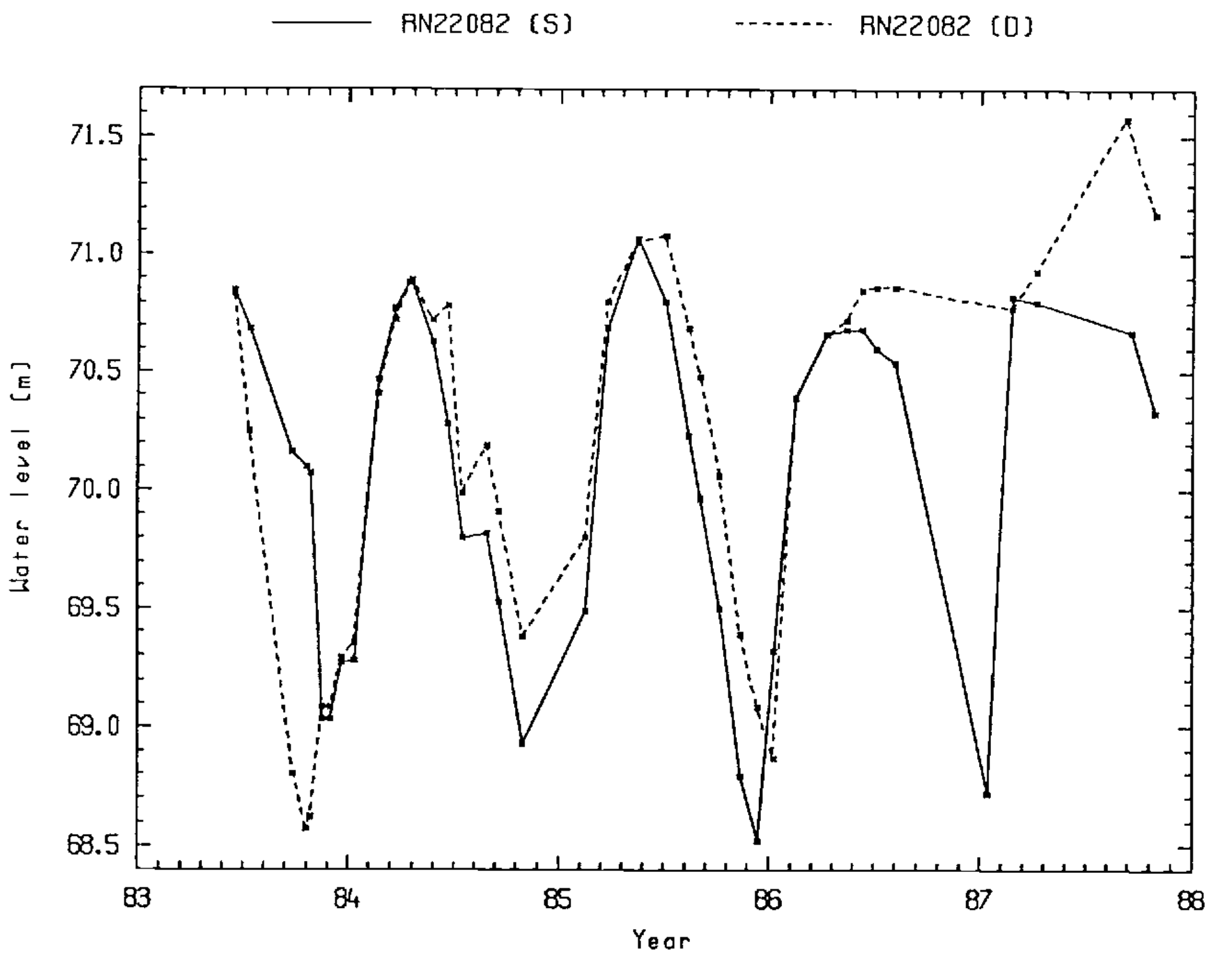


Figure 5.7 Comparison of water levels in deep and shallow boreholes at same point beneath White's Heap.

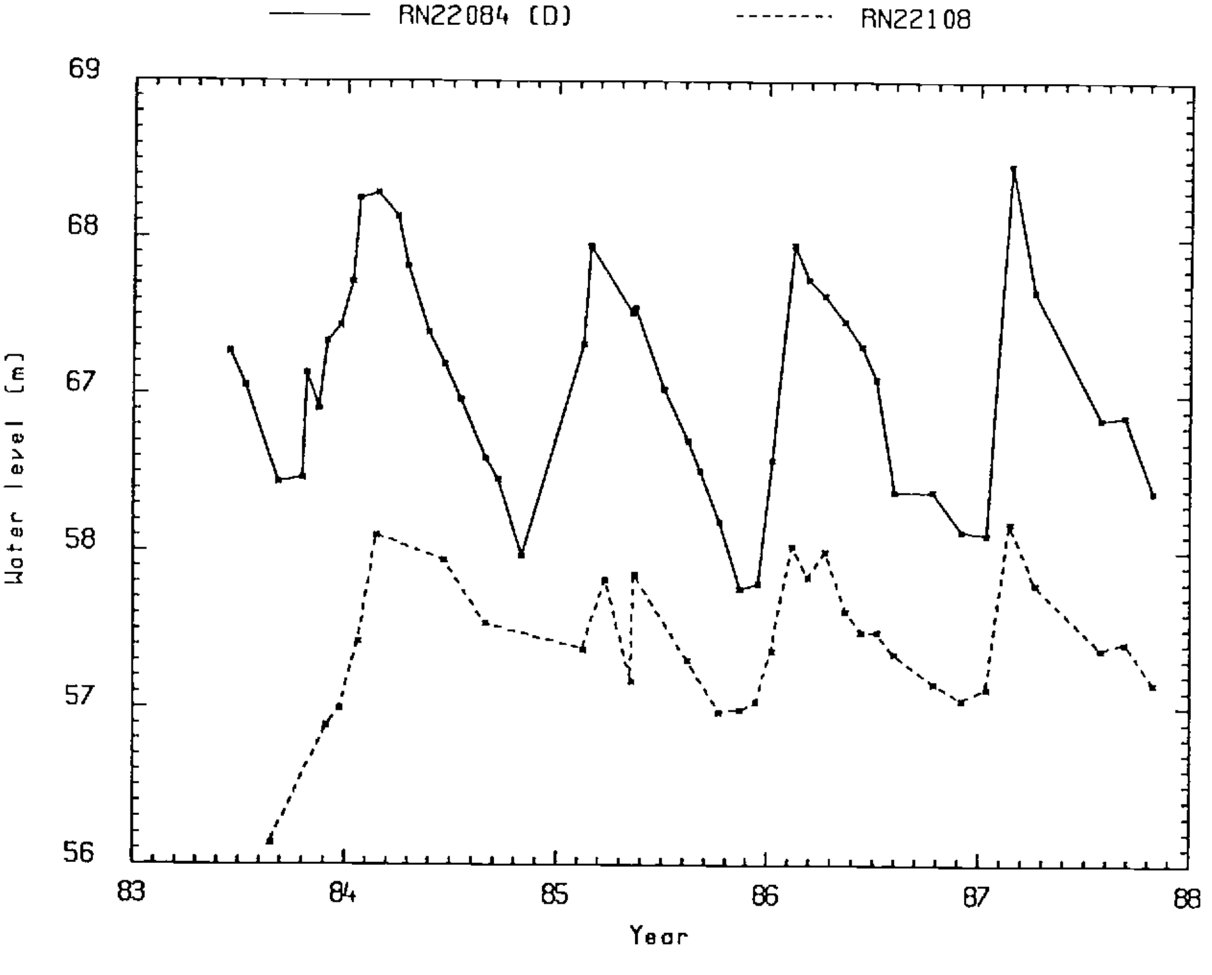


Figure 5.8 Comparison of water levels north of White's Heap with reference borehole.

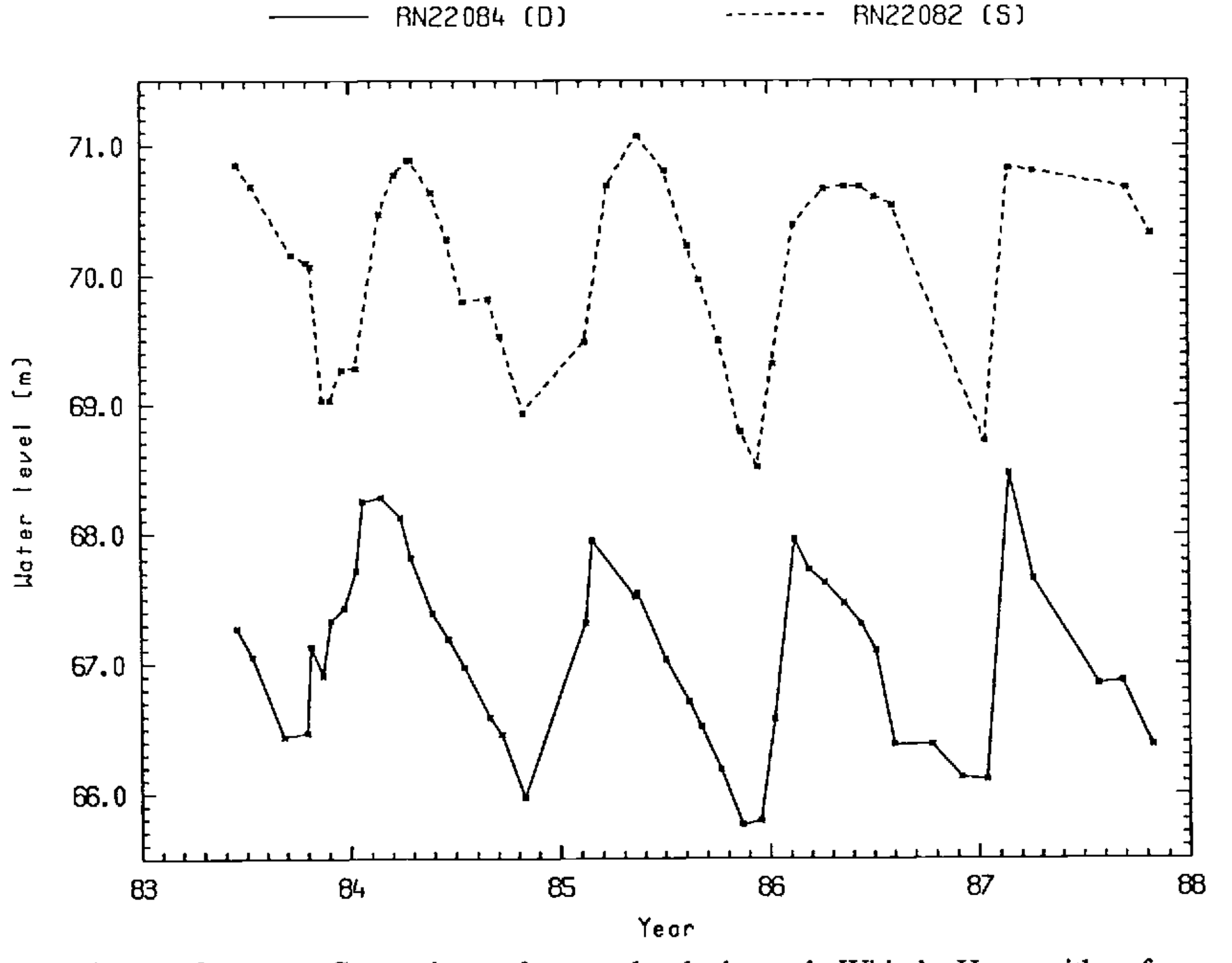


Figure 5.9 Comparison of water levels beneath White's Heap with reference borehole.

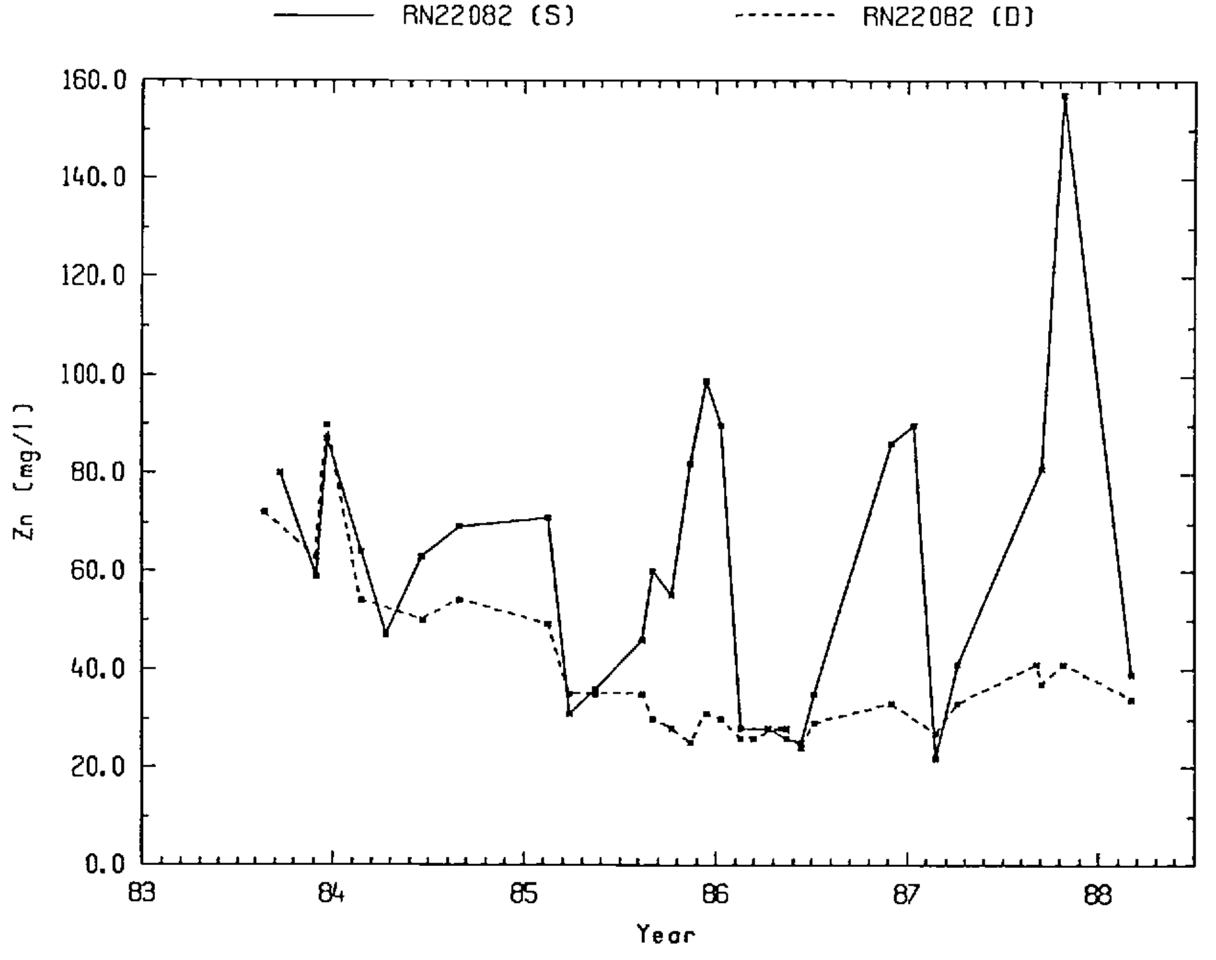


Figure 5.10a Comparison of zinc concentrations in deep and shallow boreholes beneath White's Heap.

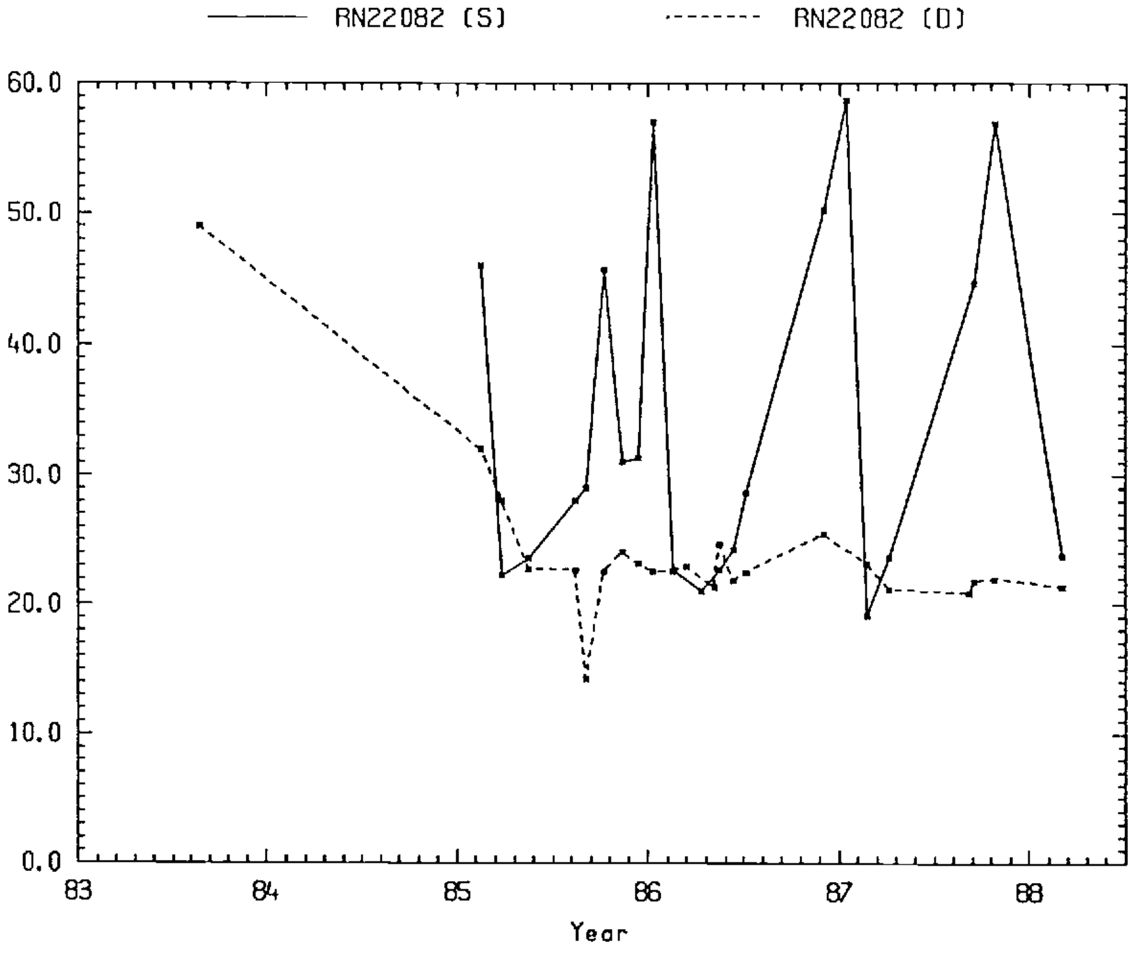


Figure 5.10b Comparison of sulphate concentrations in deep and shallow boreholes beneath White's Heap.

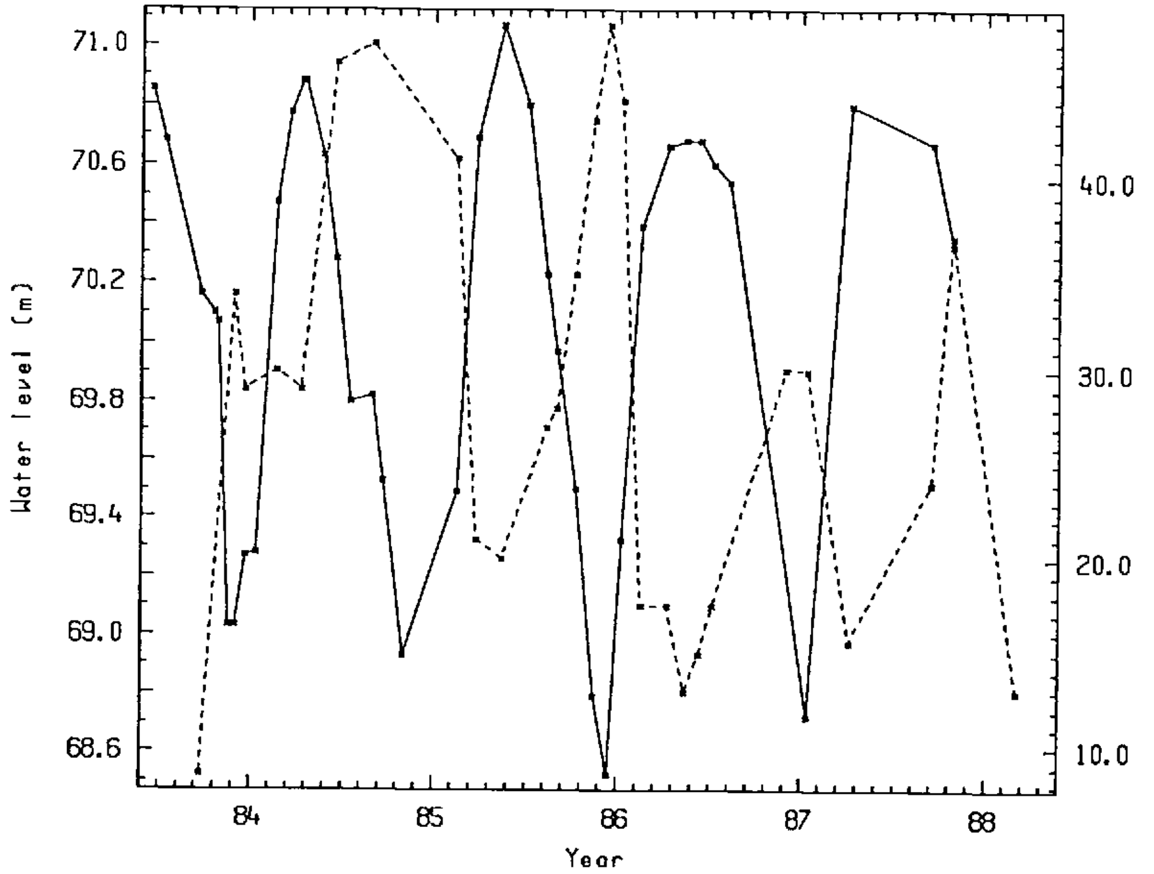


Figure 5.11 Data from shallow borehole beneath White's Heap (RN22082) showing the out of phase relationship between water level (solid) and copper concentration.

We have referred to an apparent dilution, as it appears that there is little mixing of the surface water with that lying below except during the sampling procedure. The evidence of the lack of mixing comes from the observation that the concentration returns to its original value as the water level falls during the dry season. The measured contamination levels are weighted means of those of the two water bodies. Likewise, the water sampled from the deep bore under the heap is probably a mixture of contaminated water lying below the heap and an input from a very deep aquifer (about 30m depth) noted as a plentiful source of water at the time of drilling. At present it can only be seen as a coincidence that the contaminant concentrations in the lower borehole are very similar to those in the upper hole each wet season. The fact that the deep groundwater has been contaminated by the overburden heap again shows that the two aquifers are not isolated from one another.

The concentration of sulphate in a borehole downslope of the heap is plotted against time in Figure 5.11. The Figure shows that the average concentration if anything has tended to increase over the five year period that has elapsed since rehabilitation of the heap. Clearly there has not yet been any reduction in pollution levels of the groundwater in response to the rehabilitation. Hence the field data support the results of modelling in that the timescale for significant changes to the groundwater quality will probably be long compared with this period (Gibson & Pantelis 1988).

5.3. MATHEMATICAL MODELLING

5.3.1 MATHEMATICAL BASIS

The horizontal extent of the aquifer at the Rum Jungle site is very large compared to the vertical distance between its highest and lowest points. Also we are interested in the long term movement of water through the system. The asymptotic approximation model, which describes the saturated-unsaturated flow in gently sloping, thin unconfined aquifers over a long time span (Pantelis 1987), is therefore well suited for a study of the site. The model gives sufficiently accurate details while considerably reducing the computational effort required and is relatively easy to set up even for complicated geometries. The water movement can be described by a three-dimensional specific discharge field, which can also be used to calculate the flow paths and travel times of contaminants.

Let D be the vertical distance containing the aquifer system, L be its horizontal extent and K_s the representative saturated hydraulic conductivity of the aquifer system. An analysis of the order of magnitudes of the various terms in the equations shows that the characteristic timescale for vertical mass transport over the aquifer's vertical length scale, D, is of the order of $L^2/(DK_S)$. This is the same as the characteristic timescale for horizontal mass transport over the horizontal length scale L. The vertical timescale is governed by the slow unsaturated flow, predominantly vertical, through the small height of the heap, D, whereas horizontally the flow is almost entirely via faster saturated flow, but the distance, L, that must be traversed is much greater.

5.3.2 COMPUTER MODEL

Simulations were carried out over a region of approximately one square kilometre which includes White's and Intermediate Overburden Heaps. Although the model can be extended to deal with a layered and heterogeneous aquifer system (Pantelis 1988b) the lack of hydrogeological data requires that some simplification be made. Therefore the overburden heaps and the underlying shallow aquifer are treated as a single unconfined aquifer. Data for the ground surface height were obtained from local survey maps. The contours of the lower impermeable bed of the aquifer was derived from the sparse geological data from the borehole logs and the few simple pump down and slug tests made at the site.

The pressure head was computed from a finite difference scheme of the water transport equation. Tracer flow paths emanating from several selected points near the upper surface of the heaps were obtained using the pressure heads to compute the interstitial velocities (Pantelis 1988a, b).

5.3.3 RESULTS OF SIMULATION AND DISCUSSION

The computations were carried out over a simulation time of several years for two cases. In the first simulation there was normal infiltration of rain into the overburden heaps but for the second the infiltration into the heaps was restricted, as by clay covers. Before rehabilitation the infiltration rates were estimated by measurements of rainfall, runoff and evaporation to be about 0.5. After rehabilitation lysimeter measurements showed that the infiltration had been reduced to less than 0.05 by the clay covering (see Chapter 7). The values of 0.5 and 0.05 were therefore used for the pre and post-rehabilitation infiltration rates in the calculations. The rainfall rates were the average of the mean monthly falls of the last 20 years.

The pressure heads and total horizontal discharges before and after rehabilitation, and at two seasonal extremes, are shown in Figures 5.13 to 5.16. The heads and flow directions are significantly changed by the rehabilitation. The heads largely appear to follow the contours of the original ground surface but are slightly perturbed below the heaps. There is no evidence of a water table mound developing below the heaps as was suggested by Salama (1986). However, other simulations using larger recharge rates do show evidence of mounds developing under the heaps.

Figure 5.17 shows flow paths which would be followed by conservative tracers starting from near the tops of two heaps, for the pre and post-rehabilitation regimes. The flow paths are terminated when they intersect the ground surface; at this point the water is transported by surface flow and the tracer enters the river system either directly or by overland flow from a spring. The tracer depths at regular intervals are shown in metres A.H.D. (Australian Height Datum). Arrow heads appear at yearly intervals along the flow paths. It can be seen that the longest flow path from White's heap to the nearest waterway is about five years before rehabilitation and 15 years after rehabilitation. If we assume that the oxidation of pyrite ceased immediately after the placing of the clay covers, so the only contaminants to be considered are those stored in the unsaturated and saturated zones of the heaps, then

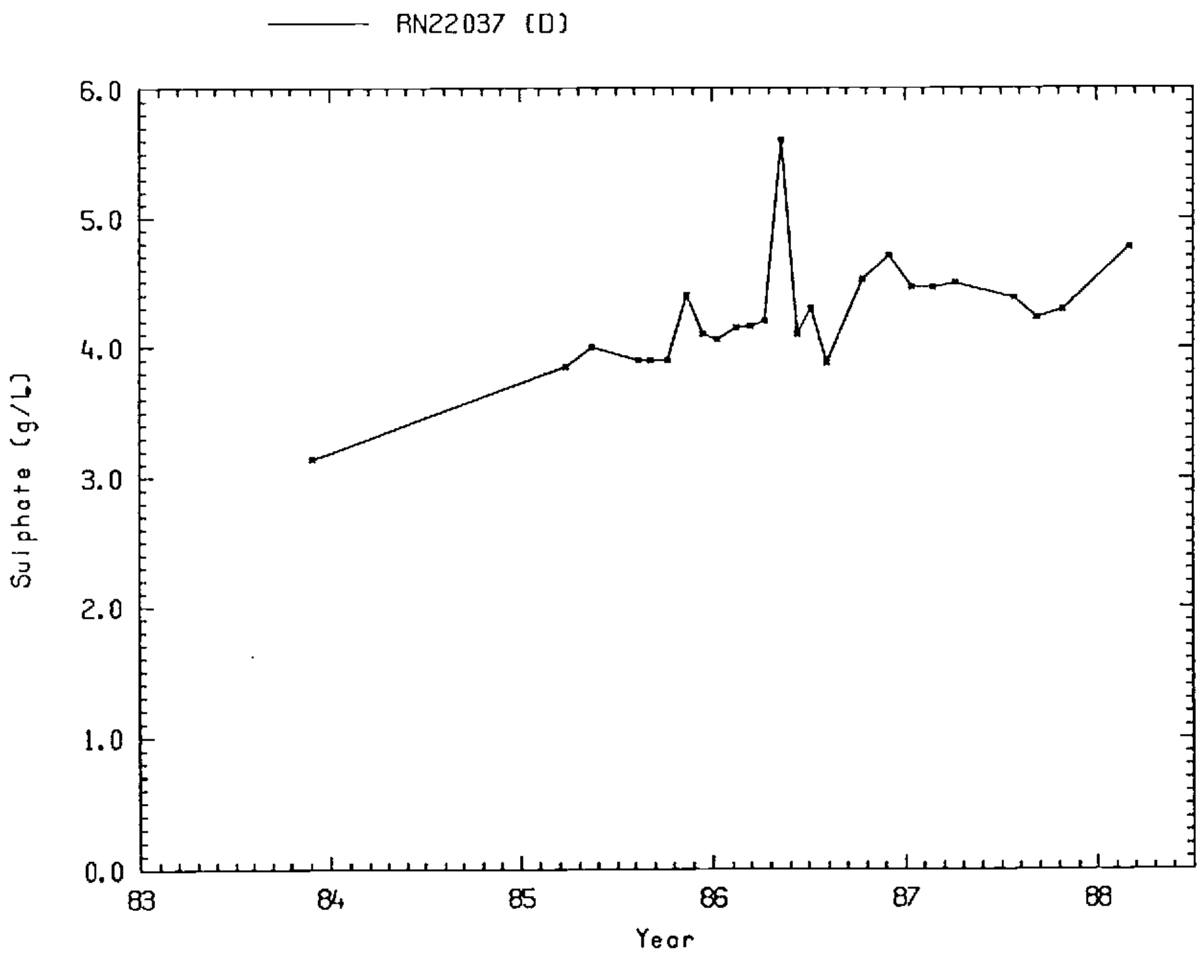
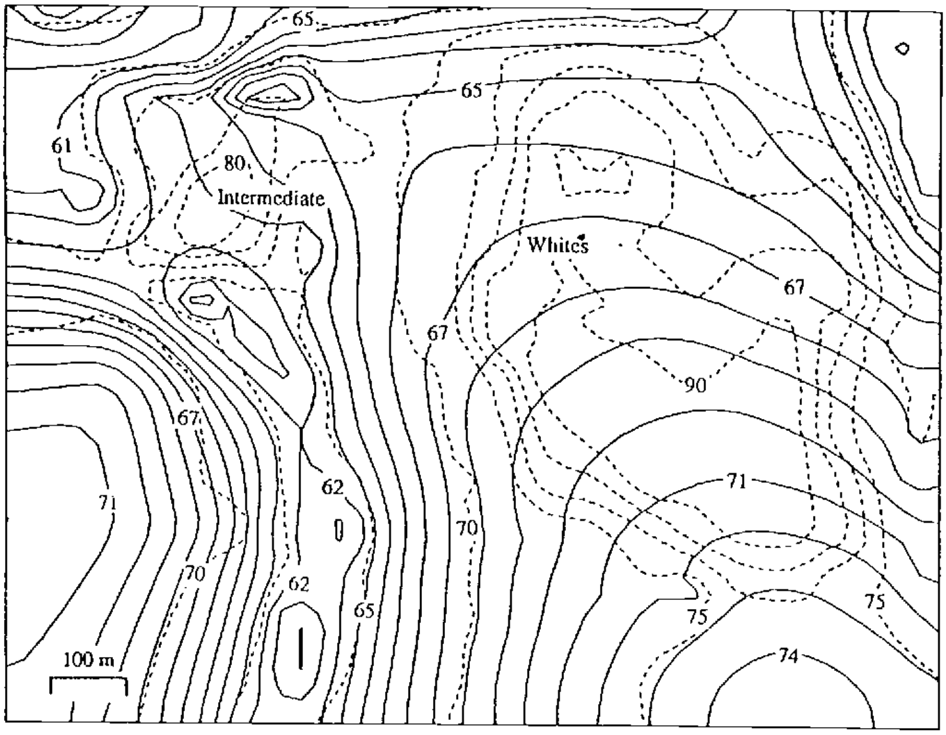
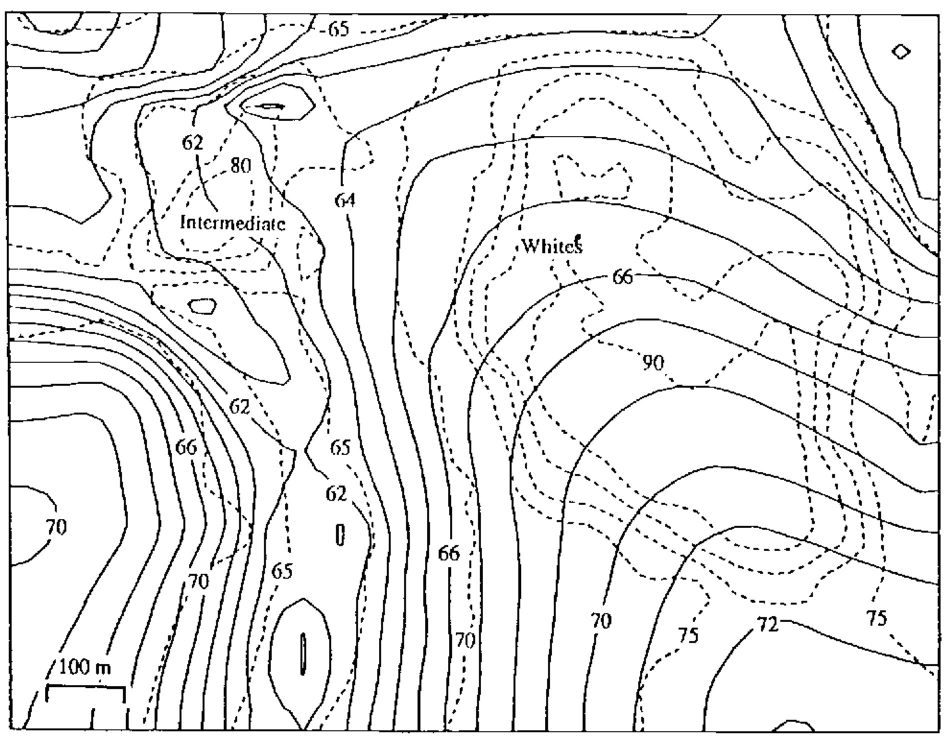


Figure 5.12 Seasonal variation of sulphate concentration at RN22037 to the north-west of White's Heap.

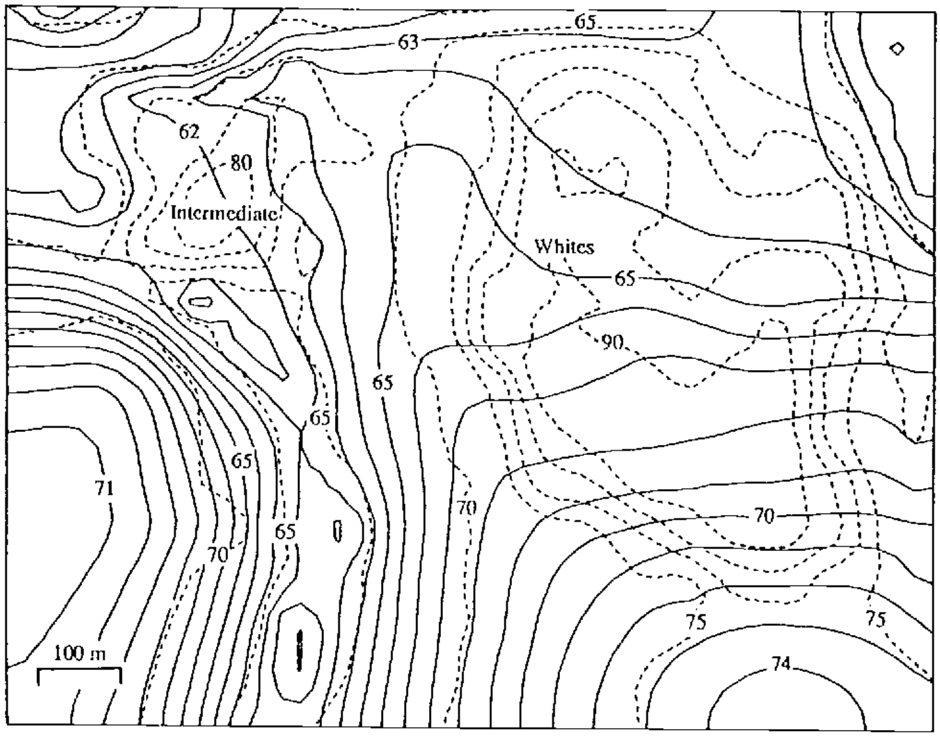


(a) End of wet season

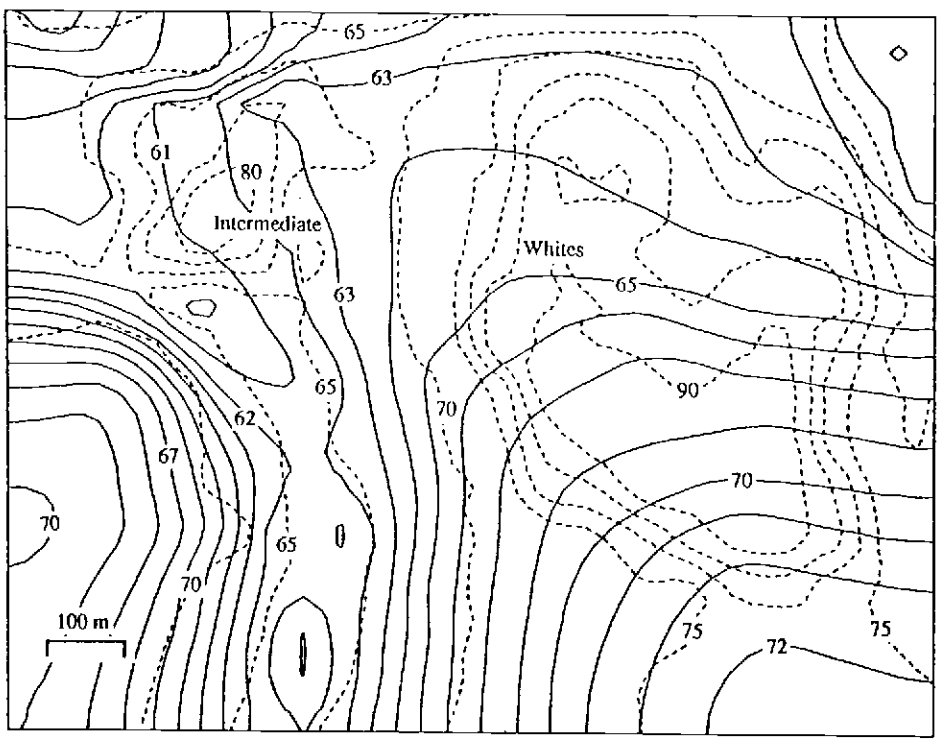


(b) End of dry season

Figure 5.13 Pre-rehabilitation pressure head contours (one metre interval) shown on contour map of environs of White's and Intermediate Heaps (five metre contour interval, dashed).

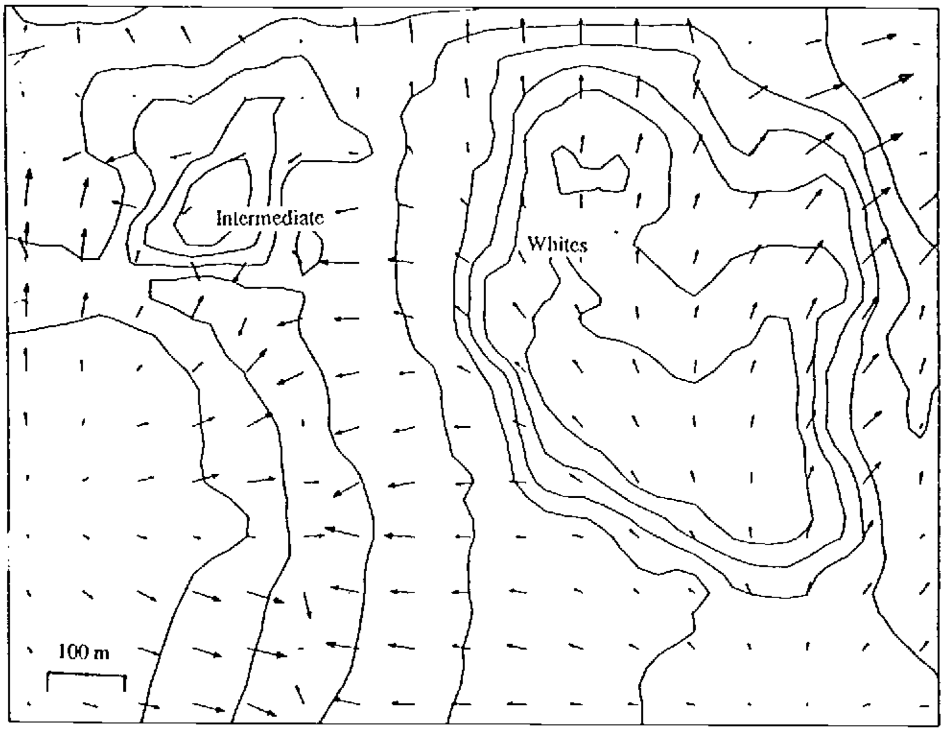


(a) End of wet season

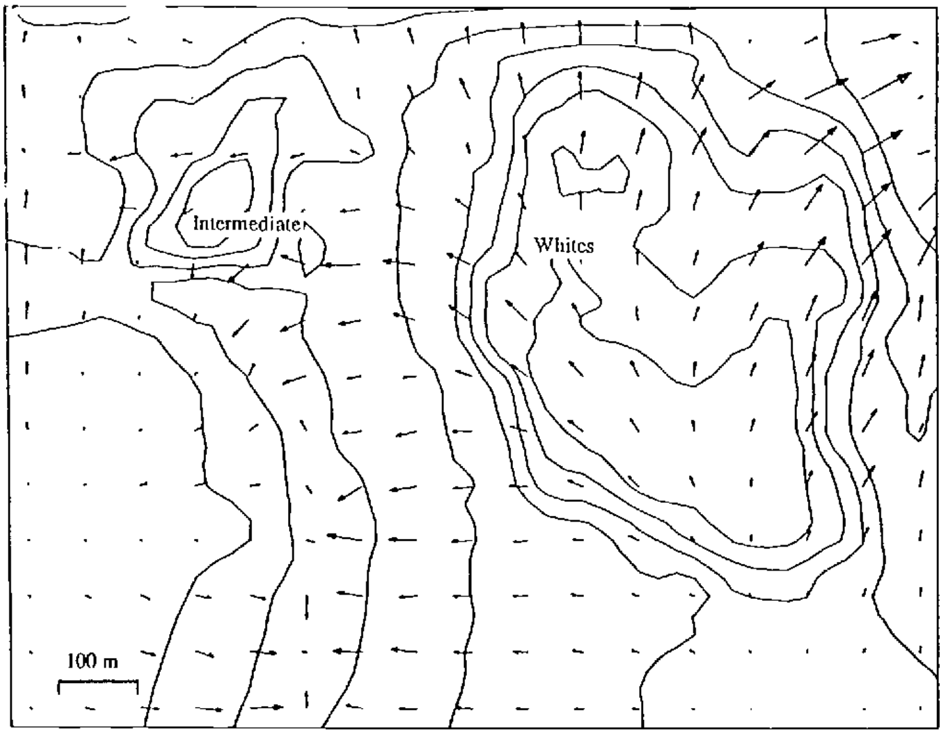


(b) End of dry season

Figure 5.14 Post-rehabilitation pressure head contours (one metre interval) shown on contour map of environs of White's and Intermediate Heaps (five metre contour interval, dashed).

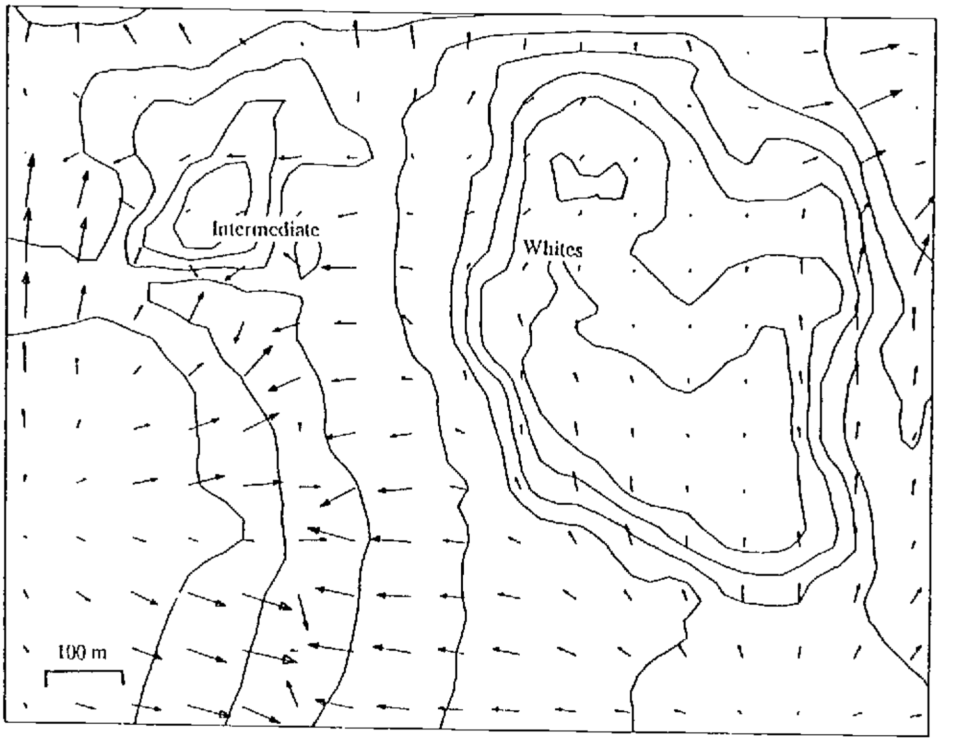


(a) End of wet season

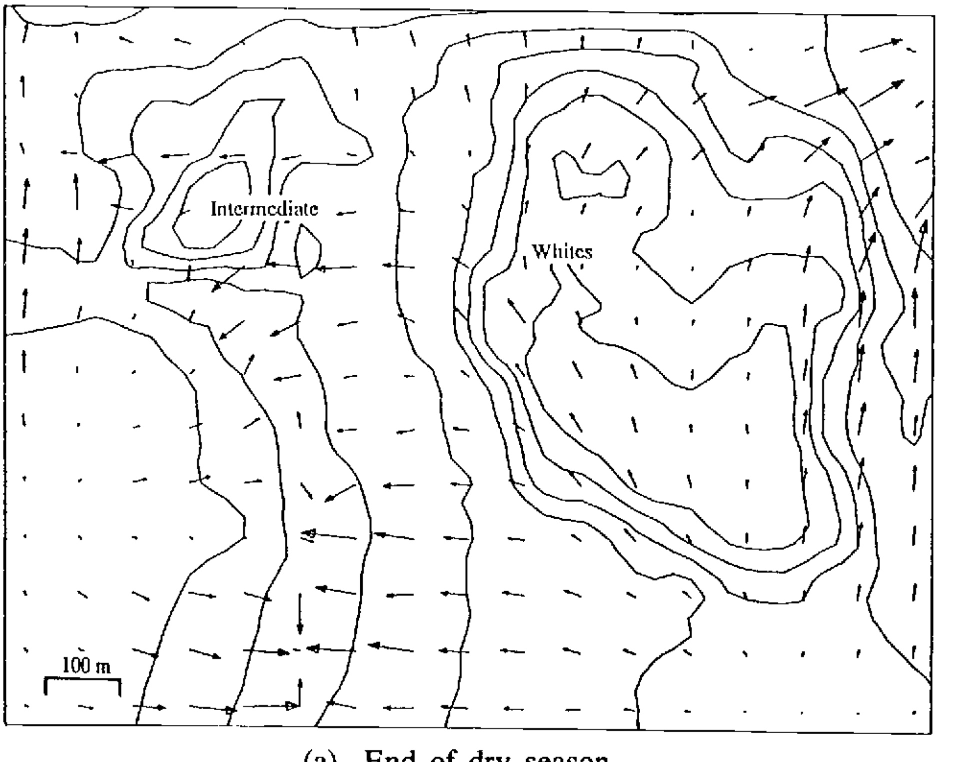


(b) End of dry season

Figure 5.15 Pre-rehabilitation total horizontal discharge vectors shown on contour map of environs of White's and Intermediate Heaps (five metre contour interval). The maximum vector length corresponds to (a) $1.5m^2$ /day and (b) $1.0m^2$ day.

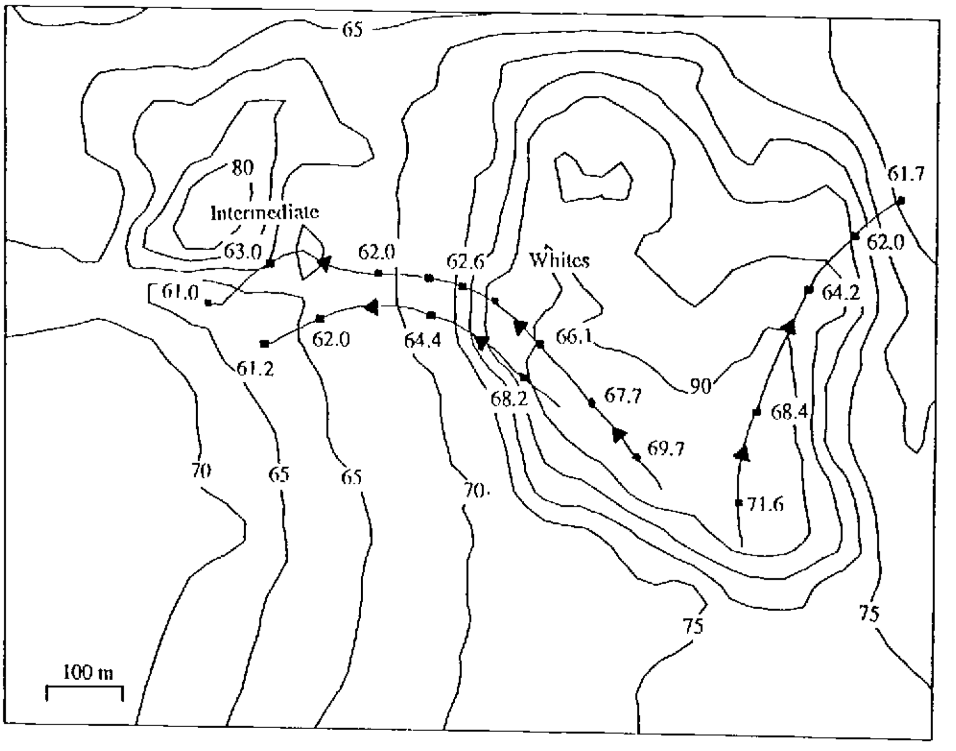


(b) End of wet season

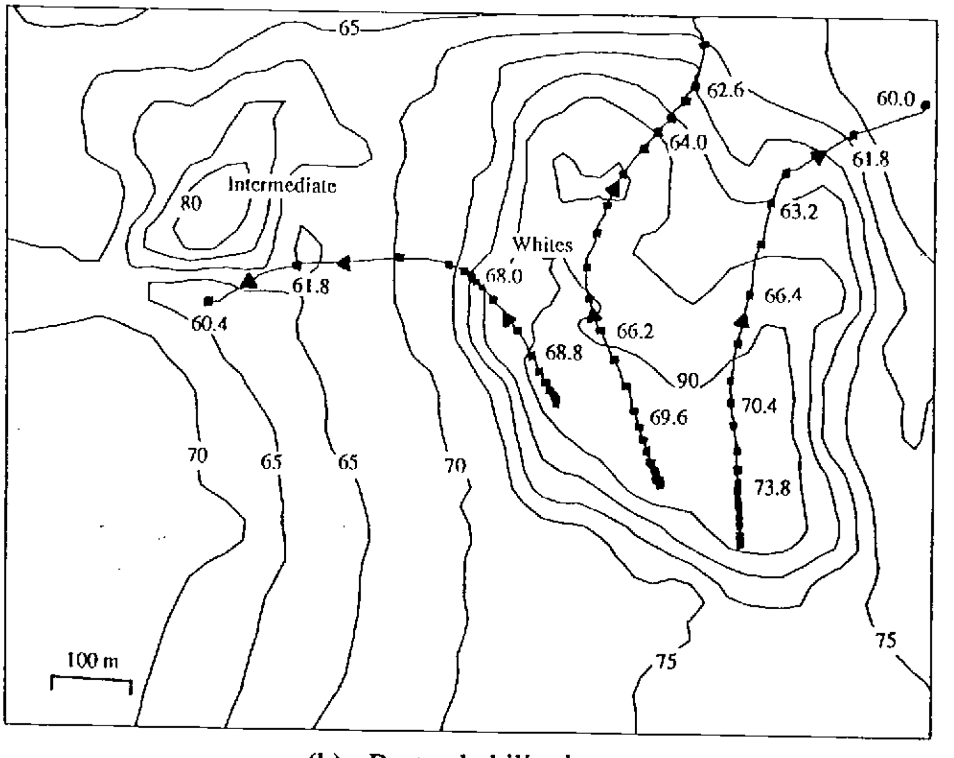


(a) End of dry season

Figure 5.16 Post-rehabilitation total horizontal discharge vectors shown on contour map of environs of White's and Intermediate Heaps (five metre contour interval). The maximum vector length corresponds to (a) 1.1m^2 /day and (b) 0.5m^2 day.



(a) Pre-rehabilitation



(b) Post-rehabilitation

Figure 5.17 Selected flow paths starting from various points on White's and Intermediate Heaps. the arrowheads indicate yearly intervals; the current heights of the paths are shown in m A.H.D (Australian Height Datum).

the travel times of the tracer flow paths give some indication of the timescale associated with flushing the contaminants into the local river system.

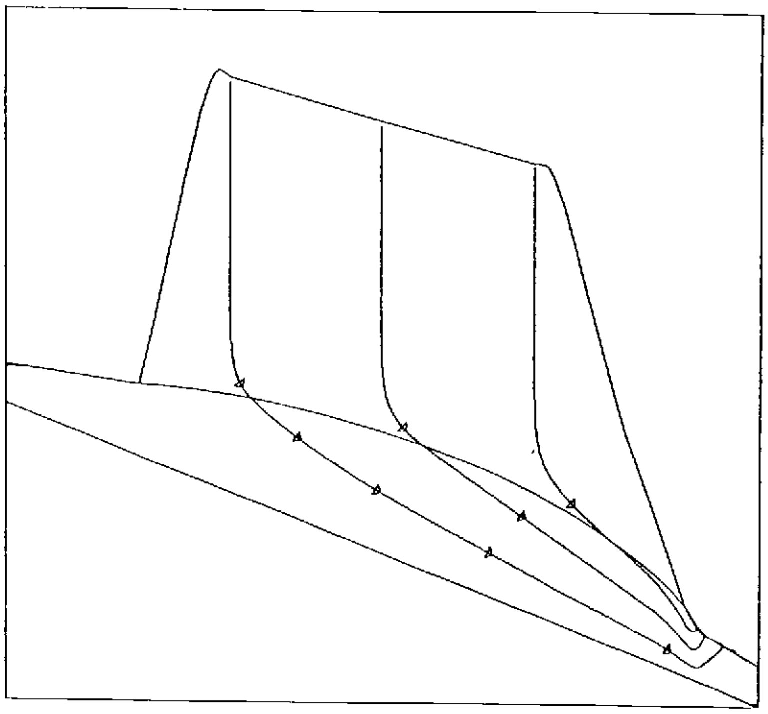
An alternative approach has been followed using a vertically averaged convection dispersion equation (Pantelis 1987). The results suggested a flushing-out period of about 20 years after rehabilitation. In this work it was assumed that the clay covers were completely impervious to rainfall, so that the vertical transport was severely reduced at the top of the heaps. It is therefore implied that the five percent infiltration through the clay significantly influences the flushing-out time.

An analysis of the chemical transport equation (the convection-dispersion equation) has been carried out for general unconfined aquifer systems. It is shown by Pantelis (1988b) that while vertical advection is numerically much smaller than the horizontal advection, the vertical advection plays a significant role in the long-term transport of solutes in aquifer systems of a kind considered at Rum Jungle. It is also shown that transverse dispersion is also important in vertical mixing where horizontal flows are significant while longitudinal dispersion need not be included.

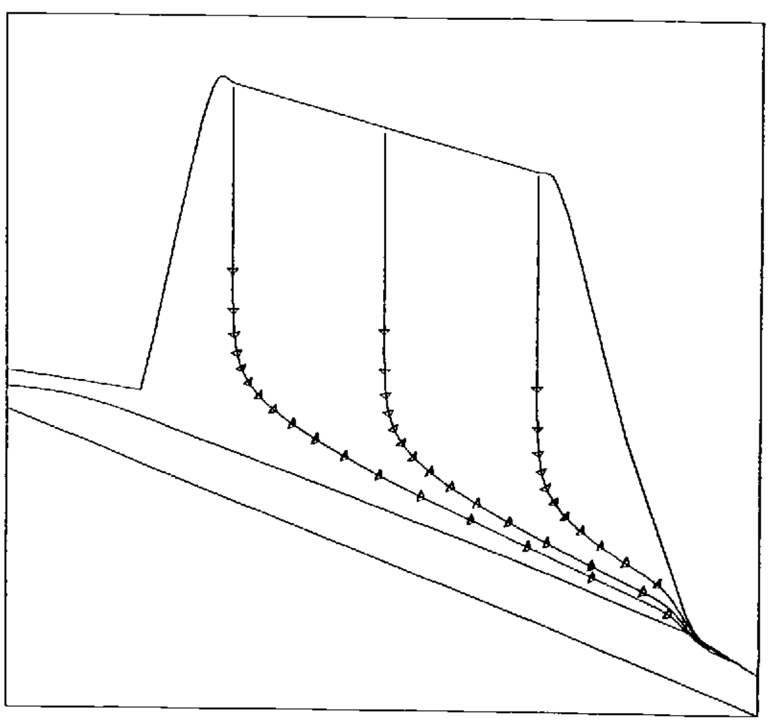
Simulations using a simplified vertical slice to represent a cross section of White's heap illustrate the importance of vertical advection at the top of the heap in determining the transit time of pollutants from the top to the water table. Figure 5.18 shows the vertical discharge fields, and Figure 5.19 the flow paths, before and after rehabilitation, assuming steady state conditions. It is seen that horizontal flows high in the heap are always extremely small. This means that the action of transverse dispersion in this region is small which leaves vertical advection as the only significant means of contaminant transport. Thus it is obvious that the clay cover increases the travel time. Close to the water table horizontal flows are large and transverse dispersion is important.

It must be stressed that these simulations are based on certain parameters which we have inferred from the scarce hydraulic information that is available. It was evident that the reruns for slight changes in the topography of the impermeable bed of the shallow aquifer can significantly change the flow directions in certain areas. Also the parameters associated with the capillarity of the soils strongly influence the travel times of the tracers, especially in the overburden heaps. For instance it was found that the flushing-out times were shortened by increasing the capillarity of the soil, for a fixed value of saturated hydraulic conductivity. This was evident in the larger horizontal flows in the unsaturated zone for soils of higher capillarity.

The above results are instructive since they give an idea of the direction and travel times of contaminants being released high in the overburden heaps. However, many major mechanisms have been omitted. First, in applying flow paths to contaminant transport it is assumed that the contaminants are conservative. Also, it has been impossible to isolate a few dominant chemical reactions and the many reactions that must be considered are not necessarily fast. This means that the local equilibrium assumption cannot be made, and makes modelling difficult due to the unavailability of reliable rate constants which describe the chemical kinetics.

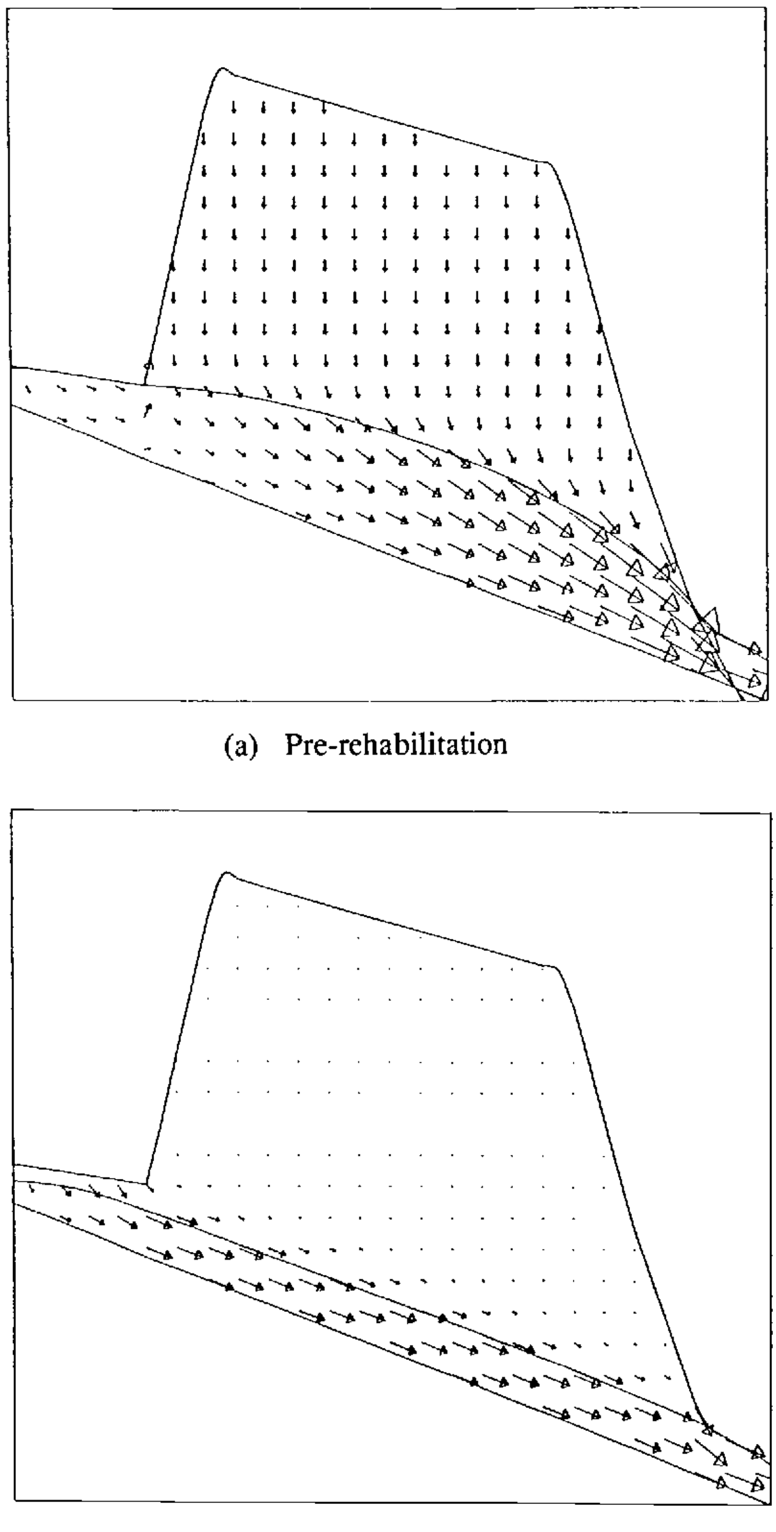


(a) Pre-rehabilitation



(b) Post-rehabilitation

Figure 5.18 Flow paths in a two-dimensional vertical section of an overburden heap and underlying shallow aquifer. The x axis represents one km and the y axis 25m. The arrowheads indicate yearly intervals.



(a) Pre-rehabilitation

(b) Post-rehabilitation

Figure 5.19 Specific discharge vectors in a two-dimensional vertical section of an overburden heap and underlying shallow aquifer. The x axis represents km and the y axis 25m.

5.4. PICTURE OF GROUNDWATER MOVEMENT

The following picture of the groundwater system in the region of White's Heap is a synthesis of the conclusions derived from the field data and the results of calculations. Below the heap there is a body of contaminated water (e.g. [Cu] ~ 50mg/l) extending from 3m below the original ground surface to possibly 20-30m depth. Each wet season there is an influx of clean water, from rainfall infiltration upslope of the heap, over the top of this water. Owing to density differences and also perhaps to low hydraulic conductivity at the deeper levels there is little mixing of these two lots of water. During the dry season the top water layer drains off, leaving the contaminated reservoir largely unchanged. Calculations show that, with the 0.5 rainfall infiltration into the heap which occurred before rehabilitation, the unsaturated water flow through the heap would have carried contaminants downward into the saturated zone (Figure 5.18a). This process would have produced the body of contaminated water below the heap. However, when the infiltration is reduced to 0.05 by the clay cover, the calculations show that the unsaturated flow has a strong lateral component, especially in the capillary fringe one -two metres above the water table. The water in this unsaturated flow reaches the edge of the heap before entering the saturated zone and therefore does not contaminate the upper water layer below the heap (Figure 5.18b). At the heap boundary it adds to spring water, if the water table so dictates, or else is washed into the groundwater by the normal rainfall infiltration applying outside the heap's perimeter. The contaminants stored in the pore water within the heap are leached out by this mechanism.

In the above argument, which implies that there is little mixing of the surface and deeper waters, there is, however, some conflict with theoretical considerations which suggest that there would be rapid vertical dispersion of the contaminants to the groundwater (Pantelis 1988a). Here is should be emphasised that the arguments against mixing are based on measurements from one borehole situated near the high end of the heap and that future measurements from the more recent holes at lower points on the heap may show otherwise. These uncertainties suggest that an informative extension of the monitoring program would be the installation of several boreholes with multiple sampling ports to measure the vertical distribution of the contaminant concentration.

The concentration of pollutants in the seepage water appears to be substantially the same before and after rehabilitation, which would be expected as it is governed by the pore water contamination level. However, rehabilitation will have reduced the annual output of pollutants from the heap tenfold, proportional to the reduction in infiltration rate. Thus annual releases of one tonne of copper and 250 tonnes of sulphate can be expected, from scaling the estimates of Daniel et al. (1982). Such a reduction in contaminant load is consistent with the observed improvement in surface water quality.

5.5 CONCLUSIONS

The borehole monitoring data show that the groundwater quality close to the waste rock heaps at the Rum Jungle site continues to be affected by pollutants which have emanated from the overburden heaps. The overall contaminant concentration of the groundwater has not changed since the rehabilitation, despite good evidence that oxidation of the pyrite in the heap has been virtually halted. Calculations show that there is a large store of pollutants held in the pore water in the unsaturated regions of the heap. The time taken for this store to be noticeably depleted has been calculated to be in the order of 10 to 20 years. It is therefore most desirable to capitalise on the monitoring work done at the site by continuing the programme until these changes can be verified.

6. WATER QUALITY OF OPEN CUTS

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6.1 WATER QUALITY 1986-87

6.1.1 INTRODUCTION

The treatment of water in White's and Intermediate Open Cuts and the subsequent rediversion of the East Branch of the Finniss River has been documented in a previous report (Henkel & Alcock 1987).

The main reason for rediverting the East Branch of the Finniss River to flow through the open cuts was to ensure annual flushing. It was anticipated that the design would ensure that at least the top few metres of water in the open cuts would be flushed on an annual basis. The re-routed river is shown in Figure 6.1.

The open cuts were studied in detail prior to treatment, and closely monitored during the treatment process. After treatment was completed a sampling programme was initiated to monitor the seasonal and annual variation of water quality in both open cuts. Henkel & Alcock (1987) describe the water quality in the open cuts on five occasions from November 1985 to August 1986. It was concluded that the water treatment was a success and the strategy of rediversion was also successful, resulting in improved water quality on an annual basis. It was anticipated that water quality would continue to improve with further flushing during successive wet seasons. The influence of inflow water was initially thought to be around five metres depth in both open cuts (Allen & Verhoeven 1986). However, it was later shown to be in the order of 15 metres (Henkel & Alcock 1987).

This report is a record and discussion of monitoring from August 1986 to November 1987.

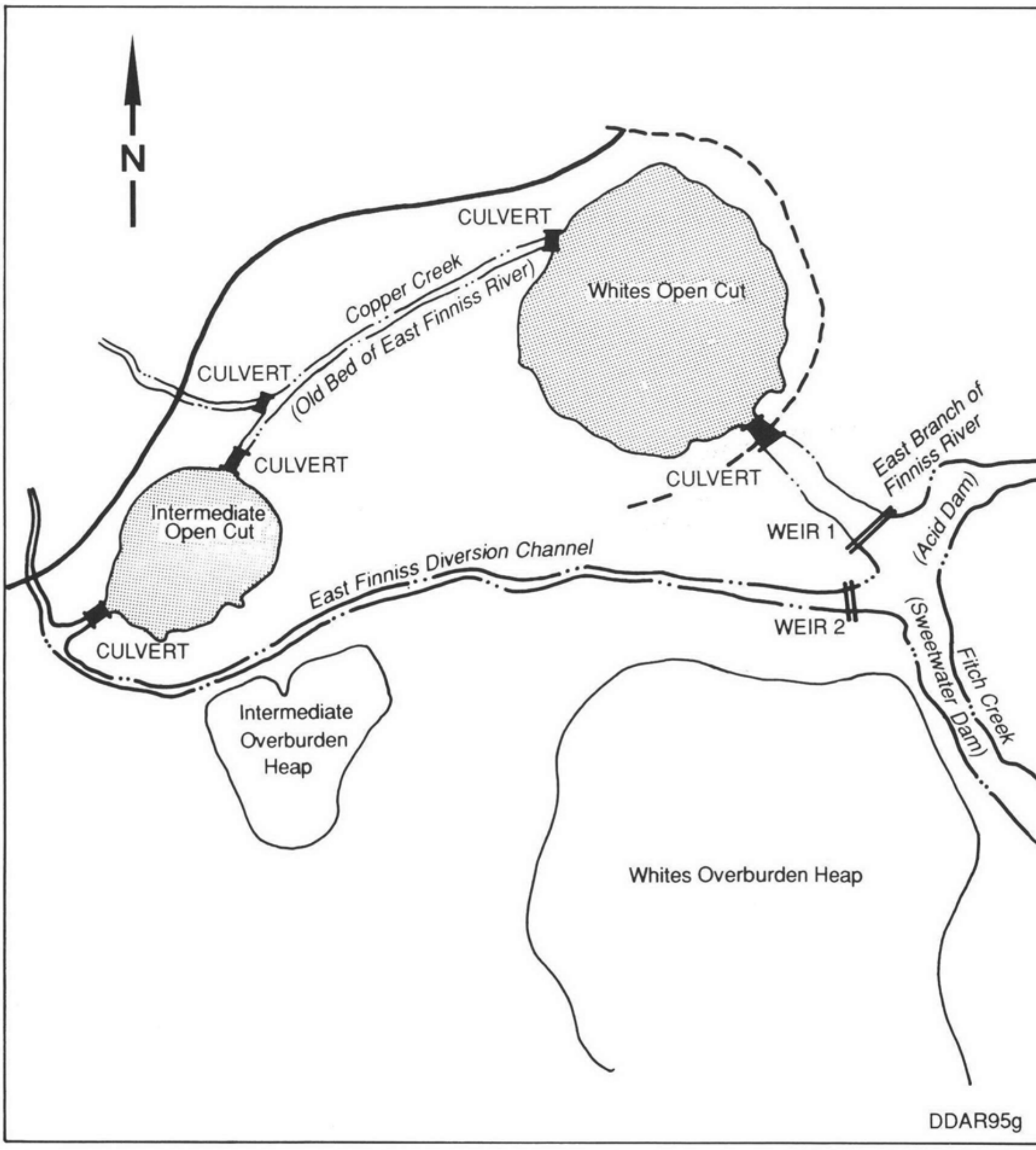

Figure 6.1 The rediversion of the East branch of the Finniss River

6.1.2 WHITE'S OPEN CUT

The pH, specific conductance, copper, manganese, zinc and sulphate concentrations for six sampling profiles from the 27th August 1986 to the 9th November 1987 are shown in Appendix C, Figures 6.2 to 6.7. The data are in Appendix D, Table 6.1. The following observations are made:

- The 1986-87 wet season flush caused an increase in pH above approximately AHD 30m. pH decreased as the 1987 dry season progressed. Generally, for a given profile, pH was fairly consistent to 45m AHD, and then decreased over approximately the next 12m to approximately 3.0, which is the pH of the untreated water.

- For a given profile the specific conductance was fairly consistent from the surface to 44-46m AHD, then increased to about 8000 µS/cm, at about 30m AHD which is the specific conductance of the untreated water. Specific conductance decreased during the 1986-87 wet season because of the flushing by river water. The specific conductance of water above 45m AHD in November 1987 was approximately 700 uS/cm, which was a considerable improvement on the water quality of November 1986 when the specific conductance was 1400 µS/cm.

- The specific conductance results mainly from alkaline earth sulphates. Thus the sulphate profiles were similar to those for specific conductance.

- Comparison of the copper, manganese and zinc profiles with the corresponding pH profiles show that metal concentrations increase as the water becomes more acidic. The lowest concentrations of metals measured in the treated water were after the wet season flush. Concentrations increased during the dry season as the water became more acidic.

6.1.3 INTERMEDIATE OPEN CUT

Seven profiles were measured from the 26th August 1986 to the 9th November 1987. The pH, specific conductance, copper, manganese, zinc and sulphate profiles are shown in Appendix C, Figures 6.8 to 6.13. The data is in Appendix D, Table 6.2. The following observations are made:

- The pH profiles generally showed several highs and lows. The most notable and consistent feature was increased pH at 27 m AHD. Above this is the fresh water input. Below this layer there is more acidic water with higher concentrations of metals.

- pH decreased steadily during the dry season over the interval from the surface to approximately 38m AHD. The surface waters are poorly buffered, typical of the wet season river water flow.

- The specific conductance profiles show that water quality above 37m AHD was markedly affected by inflow water. The 1986-87 wet season was the second time that the open cuts were flushed by flow from the East Finniss River. This resulted in a further decrease in the specific conductance of the water in the Intermediate Open Cut. Specific conductance increased during the 1987 dry season.

- As with White's Open Cut, the specific conductance was largely a result of sulphate salts. The sulphate profiles were similar to those of specific conductance.

- Comparison of the copper, manganese and zinc profiles with the pH profiles showed that lower metal concentrations were evident at 27m AHD where a layer of relatively high pH water exists. Below 27m AHD metal concentrations steadily increased. This may be the result of polluted groundwater inflow or pyritic oxidation, and redissolution of metal hydroxides residual from the in-situ water treatment. There were some anomalous profiles which could not be explained; these include the profile for manganese of November 1986.

6.1.4 DISCUSSION AND CONCLUSIONS

The 1986-87 East Finniss River and Finniss River monitoring report suggested that the open cuts were a greater source of pollutants to the East Finniss River than previously suspected (Henkel & Alcock 1987a). It was suggested that high flow conditions into White's Open Cut flushed polluted water from depths greater than 15m.

This report recommended that the open cut monitoring be increased and refers to the monitoring prior to the adoption of the more detailed 1987-88 programme.

The 1987-88 programme of sampling should result in less ambiguous data. Questions which arise from the 1986-87 data and which require resolution are:

- What is the depth to which White's Open Cut is affected by flushing and what are the implications for pollution of the East Finniss River?

- What will be the effect of above average flow years?

  The data in this report suggests that flushing occurs to a depth of at least 30m AHD, where untreated water was encountered. The depth of flushing would depend primarily on the energy of the inflow water, and would presumably be more extensive if the water density was lowered because of previous flushing. To date, the open cuts, and in fact the entire rehabilitation works have been tested only by well below average flow years.

- How stable are the bottom waters in the Intermediate Open Cut?

  The data suggest that metal concentrations increased in 1987 below 27m AHD. The decrease in pH could result from oxidation of a pyrite surface or input from an acidic groundwater. Both of these mechanisms combined with the dissolution of residual sludge would lead to an increase in metal contamination.

- What is the origin and stability of the higher pH water at 27m AHD in the Intermediate Open Cut?

  This water is a buffer between the bottom and top waters and is thought to be the residual of the initial treated water.

- What is the mechanism by which polluted concentrations in the upper water levels increased during the dry season?

The mechanisms previously proposed were thermal density differences, energy from winds and diffusion across concentration boundaries. However, the profiling was not sufficiently detailed to prove that mixing was the predominant mechanism, and the possibility of polluted groundwater inflow was not precluded.

Successful prediction requires a greater knowledge of the open cuts' hydrology. This report is confined to a record of the water quality in the open cuts over the study period (Appendix D, Tables 6.1 and 6.2). As expected, the overall quality of the water subject to annual flushing in the Intermediate Open Cut is inferior to that in White's Open Cut. The overall quality of the water subject to annual flushing is a major improvement on the quality of water before treatment (Henkel & Alcock 1987a, Allen & Verhoeven 1986).

6.2 WATER QUALITY 1987-88

6.2.1 INTRODUCTION

The following is a record of the monitoring of White's and Intermediate Open Cuts from November 1987 to October 1988 and shows the deepening of the fresh water layers in the open cuts beyond design expectations (Allen & Verhoeven 1986).

6.2.2 WHITE'S OPEN CUT

Fresh water entering White's Open Cut during the wet season as a matter of planned annual flushing, affected the water quality to a depth of about 31m AHD (29m from surface).

Three distinct zones have become evident since treatment and annual flushing commenced. These are the relatively unpolluted top layer of 16 metres, the mixed layer from 16 metres to 23 metres consisting of fresh water mixed with polluted water from depth, gradually increasing in contaminant concentrations with increasing depth, and the untreated layer, from 23 metres to the bottom consisting of water not treated during the rehabilitation of White's Open Cut.

At the start of the 1987-88 wet season in December 1987, profiling showed the layer of fresh water to be at 44 metres AHD, and the mixing zone from 44 to 37 metres AHD, (Appendix C, Figure 6.14).

The data for the profiling of White's Open Cut from November 1987 to October 1988 are shown in Appendix D, Table 6.3.

The 1986-87 report on the open cuts, (Henkel & Alcock 1987b), mentioned the likelihood that the untreated layer in White's Open Cut may be disturbed when flow velocities of water entering the open cut from the Diversion Channel are increased in times of heavy rains.

This has been proven, since profiling carried out during and after days of high flow-through showed that the fresh water and the mixed water layer deepened by two metres. Figure 6.14 (Appendix C) shows the changes of depth of the layers that took place between November 1987 and October 1988.

It is estimated that on that occasion, approximately five tonnes of copper and 20 tonnes of manganese were brought up into the mixing and fresh water layers.

Two mechanisms are put forward to explain the lowering of heavy metal concentrations in the top layer, the first being the action of flow-through of relatively uncontaminated water. The second is the action of water with a pH of greater than 6.0 entering the open cut during times of high flows. The velocity of the in-flowing water causes turbulence at greater depth and disturbs the polluted bottom layer, thus bringing heavy metals to the surface, where precipitation takes place. This precipitate sinks back into the low pH layer and redissolves.

The theory for the first mechanism is obvious.

The validity of the second action is borne out by the fact that at the beginning of the 1987/88 wet season (measurements taken 21/12/87) 21,000 kg of copper and 83,000 kg of manganese were measured in the top 29 metres of White's Open Cut. At the end of the wet (13/5/88), one month after flow-through ceased, 13,000 kg of copper and 57,000 kg of manganese were found to be present in the top 30 metres.

About 8,000 kg of copper and 26,000 kg of manganese were removed from the top 30 metres.

As only 3,200 kg of copper and 5,000 kg of manganese were found to have passed GS8150097, of which 2,000 kg of copper and 2,500 kg of manganese were thought to originate from the open cuts (Henkel 1989) about 5,000 kg of copper and 21,000 kg of manganese may have been precipitated and sunk to below 31 metres AHD in the open cut where they were redissolved.

The mechanism of settling is clearly shown by comparing results obtained for the 20/4/88 and the 13/5/88 measurements (Appendix C, Figure 6.16). Between those two measurements flow had ceased and movement in the water was minimal.

Another indication that precipitated heavy metals are transported into the untreated layer is the increase of copper at depth. Prior to the treatment, the copper concentration had been stable for ten years at approximately 60 mg/l.

Since treatment, the copper concentration has risen significantly and was analysed as 84 mg/l at 24 metres AHD (35 metres from the surface) in October 1988.

During the same period, the manganese concentrations increased from 210 mg/l to 240 mg/l.

The increase of heavy metal concentrations between wet seasons in the top of White's Open Cut is due to mixing of highly polluted water from greater depth by thermal and wind actions, entry of polluted ground water, and to a lesser degree by evaporation at the surface. Figures 6.17 to 6.24 (Appendix C) show the changes of copper and manganese concentrations from the start of the 1987-88 wet season to the end of the 1988 dry season.

The water quality in the top of White's Open Cut deteriorated during the dry season, indicating that the open cut may be receiving significant amounts of contaminated ground water, (Anon 1978). It is estimated that approximately 89,000 m^3 of polluted groundwater entered White's Open Cut. This figure was obtained by calculating the difference in volume between the estimated loss of water by evaporation, of rainfall and the difference in the surface water level.

This estimate does not include a seepage loss which is thought to occur through a fault line and could be significant.

6.2.3 INTERMEDIATE OPEN CUT

Water in Intermediate Open Cut to a depth of 38 metres AHD (20 metres from surface), has been replaced by relatively unpolluted water from White's Open Cut. This represents a deepening of the fresh water layer by approximately two metres when compared to the profilings carried out on the 15/11/87 and the 27/10/88. Figure 6.25 (Appendix C) describes the gradual deepening of the fresh water layer since August 1966. Table 6.4 (Appendix D) shows the data obtained for profilings from November 1987 to October 1988.

Using 38 metres AHD as a cut off, the calculated pollution load contributed by Intermediate Open Cut to the East Finniss River was small when compared to the total pollution load carried at GS8150097.

At the beginning of the 1987/88 wet season about 800 kg of copper, 900 kg of manganese and 170 kg of zinc were present in the top twenty metres of Intermediate Open Cut. This was reduced to 430 kg copper, 840 kg of manganese and 80 kg of zinc at the end of the wet season in May 1988, when all surface flow ceased.

Most heavy metals found in the top layer of Intermediate Open Cut at the beginning of the 1987/88 wet season were the result of heavy metals transported from White's Open Cut, pollutants picked up from the channel connecting White's and Intermediate Open Cuts, and the input from contaminated ground water.

This occurred during periods of heavy rainfalls when the water table rose, and water, contaminated with copper was released into the connecting water course, and consequently transported into the Intermediate Open Cut.

It is reasonable to assume that a similar precipitation action took place in the Intermediate Open Cut as described for White's Open Cut, but with reduced effect as the prevailing pH values were generally lower than in White's Open Cut, and precipitation especially for manganese would have been less. This is shown by the small difference in manganese found at the start of the wet and the end of the wet season.

Contaminated ground water entered the Intermediate Open Cut during the whole year. This was manifested in the decrease of pH and the gradual increase of heavy metals in the top layer as the dry season progressed.

The increase of pollutant concentrations at the surface of the top layer of Intermediate Open Cut is largely due to evaporation.

The quality of water in the Intermediate Open Cut should improve with time as the measures taken during the rehabilitation of the Rum Jungle Mine Site will take full effect and the residual pollutants will have diminished.

6.2.4 CONCLUSIONS

Sampling of the open cuts was carried out throughout the 1987-88 wet season, giving a better understanding of the behaviour of the open cuts since treatment.

Results obtained show that:

- The relatively unpolluted top layer in White's Open Cut deepened by two metres, from 44 metres AHD to 42 metres AHD and the mixing zone deepened by three metres, from 37 metres AHD to 34 metres AHD.

- The open cuts are major contributors of copper and manganese to the East Finniss River, (Henkel 1989).

- The zinc contribution from both open cuts was minimal when compared to the total load measured at GS8150097.

- The Intermediate Open Cut contributions of pollutants are not as great as initially thought (Henkel 1989).

- The water course connecting White's and Intermediate Open Cuts is the original bed of the East Finniss River, and passes through the rehabilitated Copper Heap Leach area.

  Although much of the highly contaminated material has been removed from this area and was securely buried, and the surface capped with clay and neutralised with lime, pollutants which have seeped to greater depth in the soil and to the water table were not removed during rehabilitation. When the water table rose during the wet season, these pollutants were mobilised and entered the water course. This could be the reason for the water in the top layer of Intermediate Open Cut containing consistently higher heavy metal concentrations than White's Open Cut, (Allen & Verhoeven 1986).

- The increase of heavy metal pollutant concentrations in the top layer of White's Open Cut is also attributed to the mixing with polluted water from greater depth, evaporation and input of contaminated groundwater. (Anon 1978).

- The increase of heavy metal concentrations in Intermediate Open Cut is due to the input of groundwater, the carry-over of pollutants from White's Open Cut and the pick-up of pollutants from the water course connecting the open cuts. Heavy metal concentrations in Intermediate Open Cut at depth remained low, but are gradually increasing.

7. CHEMICAL ACTIVITY AND WATER BALANCE OF THE OVERBURDEN HEAPS

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7.1 INTRODUCTION

The waste rock dumps were major sources of heavy metal and acid pollution at the Rum Jungle site before rehabilitation. It was estimated that about 50% of the copper, 21% of the manganese and 99% of the zinc released from the site in the 1973/74 wet season came from White's and Intermediate dumps (Allen & Verhoeven 1986,Table 3.2). A further 32% of the copper came from the Heap Leach Pile which was removed during rehabilitation and dumped into Dyson's Opencut. Hence the objective of reducing pollutants in the East Branch to the desired levels could only be achieved if the release of pollutants from the waste rock dumps was greatly reduced. This chapter describes the program to monitor the effectiveness of rehabilitation work carried out on the waste rock dumps.

The monitoring of the waste rock dumps was carried out by the Australian Nuclear Science and Technology Organisation (Ansto), previously known as the Australian Atomic Energy Commission (AAEC). Ansto had investigated the waste rock dumps before rehabilitation began and collected data which formed a basis for evaluating the effectiveness of the rehabilitation project.

Pollutants were generated in the waste rock dumps by the bacterially catalysed oxidation of pyritic material. The main pollutants were sulphuric acid and soluble salts of copper, manganese and zinc.

Studies on the unrehabilitated dumps showed that ground water provided the main pathway for the release of pollutants. These were leached by infiltrating rainwater to the base of the dumps and transported thence to the local river system by groundwater. Pollutants in seepages from the side of the dumps and run off were visually obvious pathways but they were less important than groundwater. The main characteristics of the waste rock dumps are summarised in Table 7.1.

Table 7.1 Characteristics of waste rock dumps before rehabilitation

	White's	Intermediate	Dyson's
Area (ha)	26	6.9	8.4
Volume (m^3)	$4x10^6$	$0.8x10^6$	$1.2x10^6$
Mass (Mt)	8	1.6	2.3
Sulphur (g/kg)	32.7	30.6	-
Copper (g/kg)	0.86	2.0	-

7.2 REHABILITATION WORK CARRIED OUT ON THE DUMPS

The rehabilitation strategy adopted for the waste rock dumps was to minimise the ingress of water by covering the dumps with a low permeability layer. As well as reducing the transport of pollutants from the dumps, this cover was also expected to reduce the supply of oxygen to oxidation sites within the dumps and hence limit the further production of pollutants.

The following is a brief description of the work carried out on the waste rock dumps. For a detailed description of the design criteria and implementation see Allen & Verhoeven (1986).

The dumps were reshaped to create a stable landform . The slopes of the side of the dumps were reduced to a maximum slope of one-in-three horizontal and on White's dump a berm was constructed at mid-height to enable greater control of stormwater run off. The tops of the dumps were graded towards central drainage channels with gradients between one and ten degrees. Erosion control banks were constructed on the top surface to divide the surface into relatively small sub-catchments and control overland flow velocities. The top surface of Intermediate dump, which was believed to be more reactive than the other dumps, was limed to reduce acidity.

A three-layer cover was then spread over the dumps. On the top surface the cover consisted of a layer of compacted clay (minimum thickness 225 mm) as a moisture barrier, a layer of sandy clay loam (minimum thickness 250 mm) as a moisture retention zone to support vegetation and prevent the clay layer drying out, and, on top, a layer of gravelly sand (minimum thickness 150 mm) to provide erosion protection and to restrict moisture loss by evaporation in the dry season. A similar three-layer cover was spread on the sides of the dumps, but the layers were thicker (minimum thickness 300 mm of compacted clay and minimum thickness 300 mm of sandy clay loam) and crushed rock was used for the erosion barrier Engineered runoff channels were constructed on the tops and sides of the dumps. The design life of the rehabilitation works applied to the dumps is 100 years. Vegetation was established to stabilise the dump surface against the long-term effects of erosion.

White's dump was rehabilitated in 1983/84, almost two years before Intermediate and Dyson's dumps were rehabilitated. Hence the results of monitoring White's dump provided early confirmation of the success of the rehabilitation techniques applied. If major problems had been evident on White's there would have been time to modify the planned work for Intermediate and Dyson's dumps.

7.3 WATER BALANCE

The infiltration of water through the cover layers was monitored using lysimeters installed in the reshaped White's and Intermediate dumps before emplacement of the clay layer. The lysimeters, Figure 7.1, consisted of 200 l drums with tubes to allow collected water to be extracted and measured. The bottom of each drum was filled with 300 mm of gravel to make a water collection zone, the gravel was covered with graded sand layers and the rest of the drum was filled with dump material. Ten lysimeters were installed in White's dump and eight in Intermediate, two at each of the locations shown in Figure 7.2.

As the bottom of the lysimeters is effectively a perched water table in the unsaturated dump some water that enters the top of the lysimeter will be transported out of the lysimeter to the water table at the base of the dump rather than collect at the bottom of the lysimeter. An estimate of the magnitude of this effect has been obtained for lysimeters in different soil types by using steady state and time dependent water flow models. The results show that the

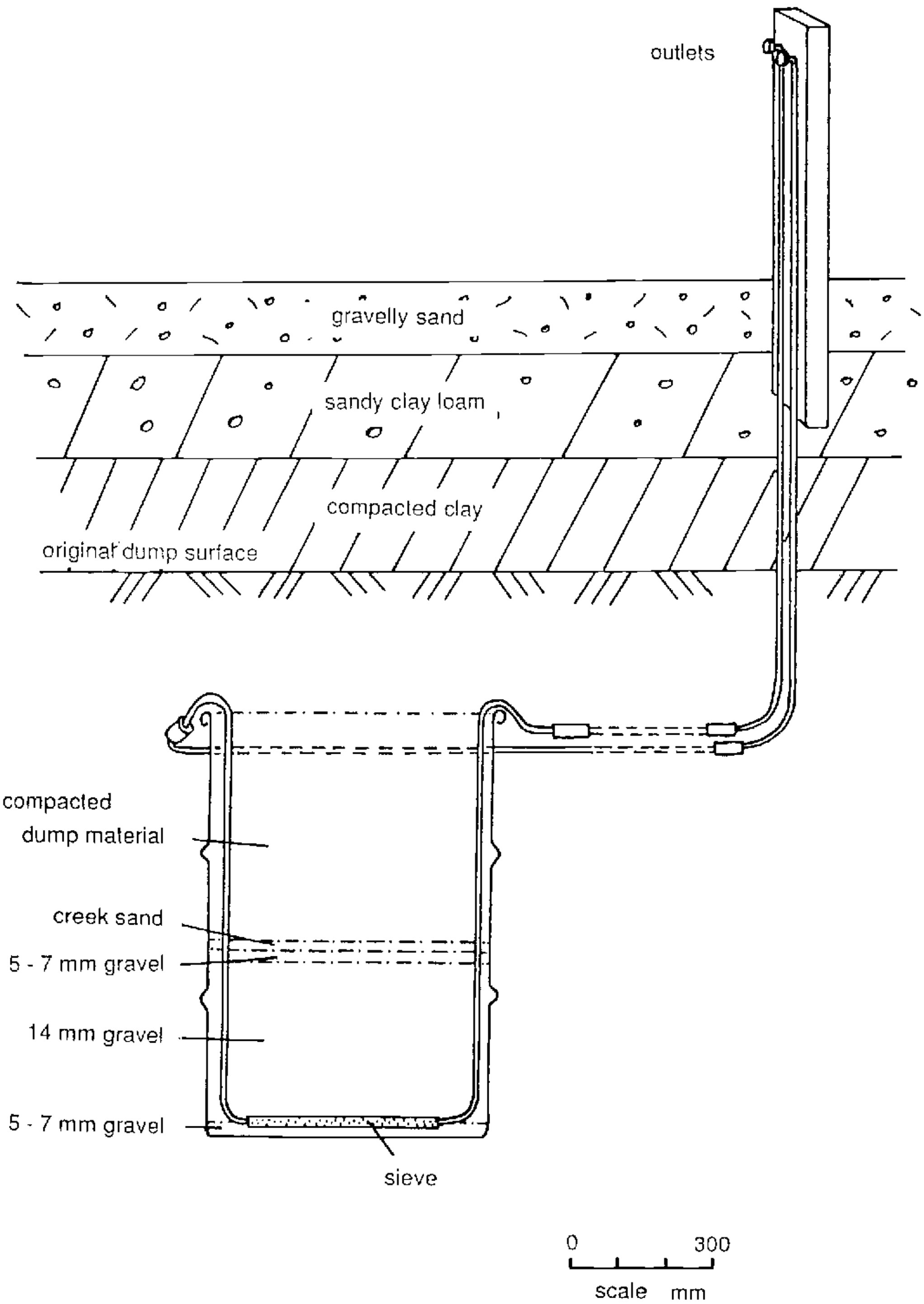


Figure 7.1 Lysimeter construction and placement.

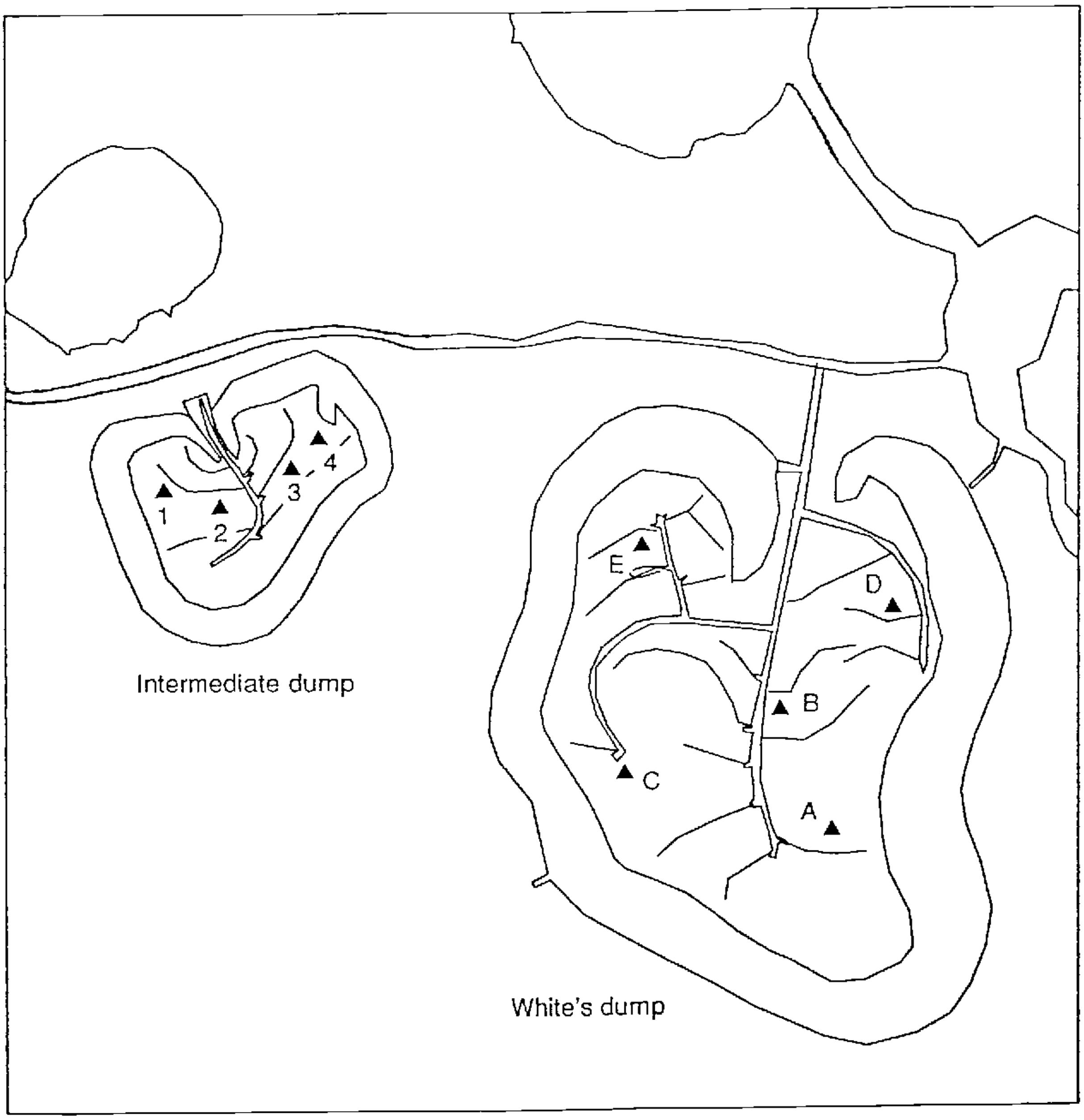


Figure 7.2 Lysimeter positions; two lysimeters are located at each position marked by a triangle.

lysimeters have a high collection efficiency in loamy sand materials such as are found between the boulders in the Rum Jungle dumps but would not work in soils containing significant amounts of clay (Gibson 1987).

The lysimeters were pumped at regular three-monthly intervals to measure the amount of water collected. The results from all ten lysimeters were averaged to obtain an estimate of the rainwater that infiltrated the covers. Figure 7.3 shows the cumulative volume collected by one of the lysimeters at each of the five locations from June 1986 to June 1987 (one mm rain corresponds to 0.246 l of water collected in a lysimeter). Also shown in Figure 7.3 is the cumulative rainfall over the same period.

There was a loss of water from the lysimeters due to wicking, and the amount of wicking was estimated from the loss of water during the dry season. The wicking averaged over all lysimeters corresponded to seven mm of rainfall per year. The estimated amount of rainwater, corrected for wicking, collected in the lysimeters in White's and Intermediate dumps is shown in Table 7.2. The amount was equivalent to less than 5% of the incident rain for both dumps. This indicates that the compacted clay cover achieved the desired reduction in water ingress. Before rehabilitation, it was estimated that about 50% of the incident rain percolated through the dumps (Daniel *et al.* 1982).

Table 7.2 Infiltration derived from the quantity of water collected in lysimeters as a percentage of rainfall (corrected for wicking).

Dump	Dates	Rainfall (mm)	Infilt. (%)
White's	Nov 84 - May 85	1072	2.5
	May 85 - May 86	1087	2.0
	May 86 - Jun 87	1289	2.3
	Jun 87 - Jun 88	1057	1.4
Intermediate	Dec 85 - May 86	935	3.5
	May 86 - Jun 87	1399	4.8
	Jun 87 - Jun 88	1057	3.6

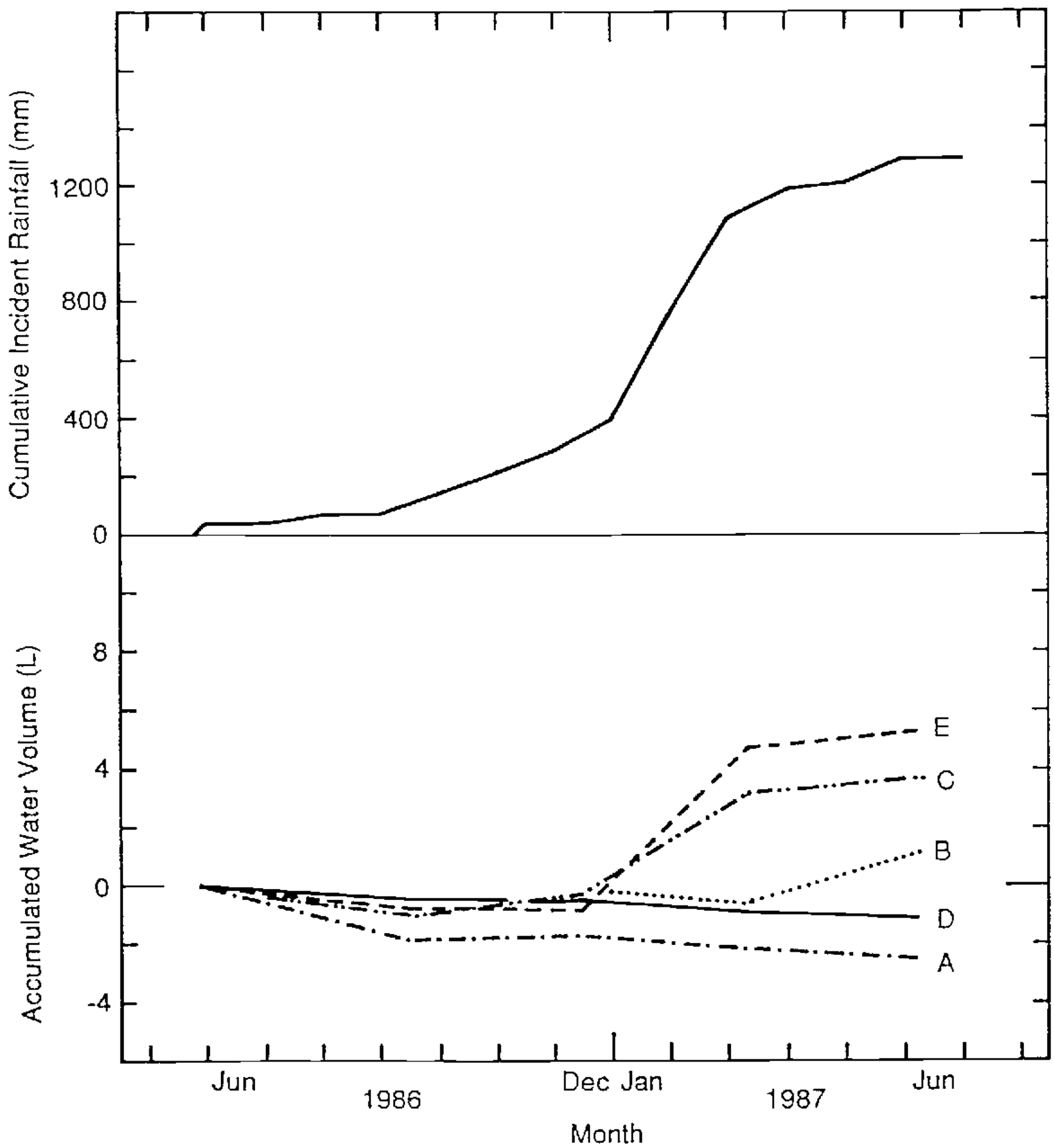


Figure 7.3 Accumulated water in five of White's lysimeters, June 1986 - June 1987.

7.4 PROBE HOLES

Probe holes drilled down to the original ground surface in White's and Intermediate dumps have been used to monitor temperature, gas composition and water content within the dumps. Early data were obtained using holes installed by Ansto before the rehabilitation project began. Holes drilled since 1983 were installed as part of the monitoring program for the Rum Jungle Project.

The first drilling program in the Rum Jungle waste rock dumps was in 1976 when six holes were installed in White's dump. These holes were lined with a 50 mm i.d. polyethylene pipe and sealed at the bottom to exclude water (type "n" holes). In 1982 three holes were drilled in White's dump to enable the interstitial gas to be sampled. These holes had gas ports inset into the liner at depths of 0.5, 1.0, 1.5, 2.0, 3.0, 5.0 m and then at 2.5 m intervals to the bottom of the hole (type "g" holes - Ag, Bg, Dg). The locations of the pre-rehabilitation holes in White's dump are shown in Figure 7.4.

The holes in White's dumps were preserved during the rehabilitation earthworks which were carried out between August 1983 and June 1984, although the liners of most holes had to be lengthened to reach the top of the cover layers. An additional ten holes were installed in White's dump in June 1987. These holes have pairs of gas sampling tubes attached to the outside of the polyethylene liner to directly sample the gas in gravel back-filled zones at each metre down the hole (type "p" holes), Figure 7.4.

The first drilling program in Intermediate dump was carried out in 1982 when four g-holes and two n-holes were installed. An additional nine g-holes were drilled in 1984 to provide additional information about pre-rehabilitation conditions. The location of the holes in Intermediate dump before the earthworks began is shown in Figure 7.5.

All the pre-rehabilitation holes in Intermediate dump were lost when it was rehabilitated between August and December 1985. Nineteen new p-holes were installed in Intermediate dump in November and December 1985 after the earthworks on the dump were completed (Figure 7.5.).

7.5 TEMPERATURE PROFILES

Temperatures within the dumps were measured using thermistor probes lowered down the probe holes. Temperature profiles were measured at approximately three-monthly intervals before and after rehabilitation. Before rehabilitation, the temperatures at several locations within both White's and Intermediate dumps exceeded 50°C. The temperatures have decreased since rehabilitation and the highest temperature in either dump in June 1988 was 41°C. Figures 7.6 and 7.7 show the temperature distribution in White's and Intermediate dumps before and after rehabilitation. The temperatures in hole A were already decreasing before rehabilitation and there was a more rapid decrease following rehabilitation in late 1983, Figure 7.8. Subsequently, the rate of decrease has slowed but the rate of approach to the ambient temperature continued to be more rapid than it was before rehabilitation.

The elevated temperatures in the dumps were caused by heat released by the oxidation of sulphidic materials. The heat production is principally due to the oxidation of pyrite to sulphuric acid and ferrous sulphate which is exothermic and releases 1440 kJ $mol^{-1}(FeS_2)$.

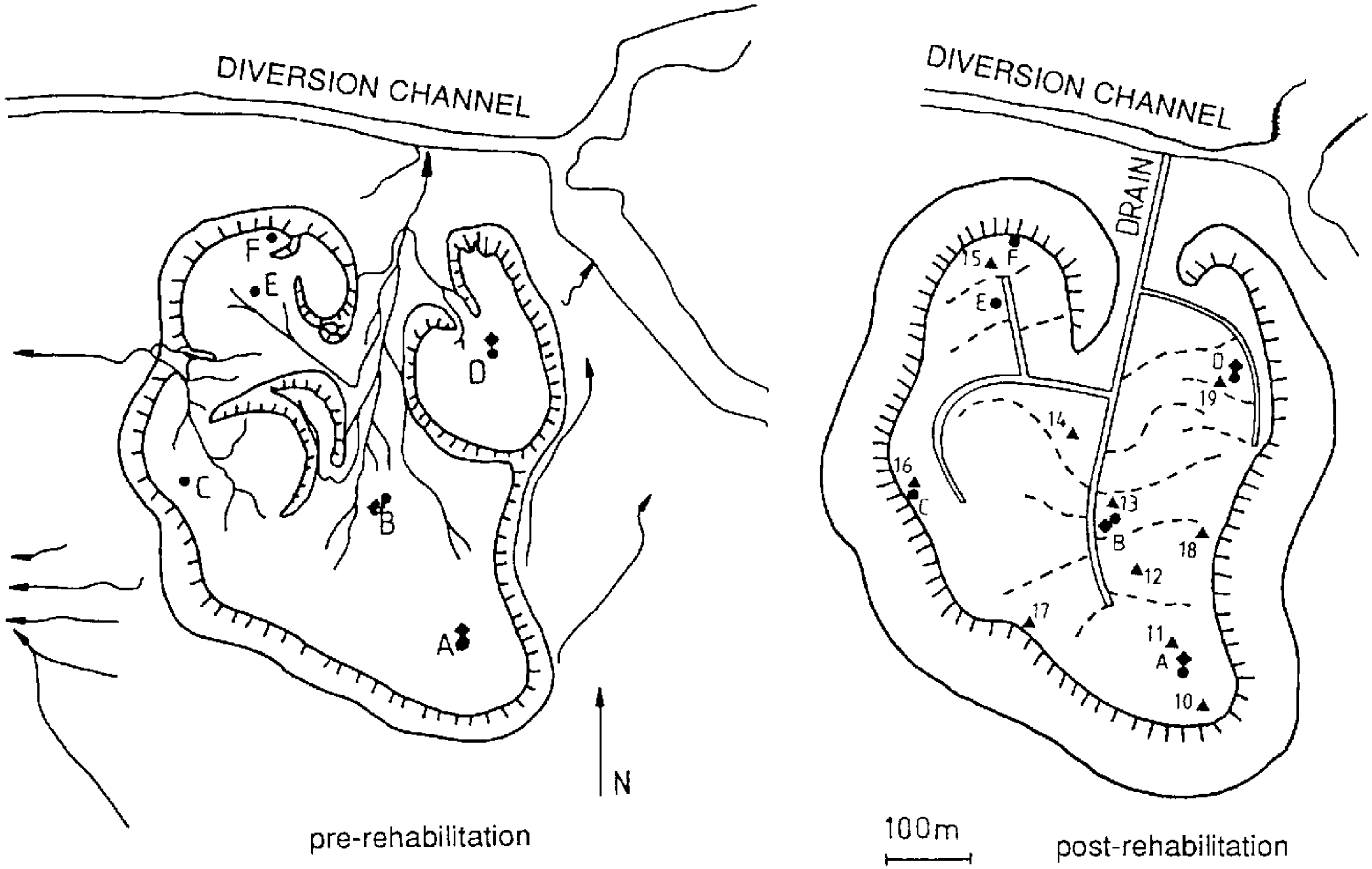
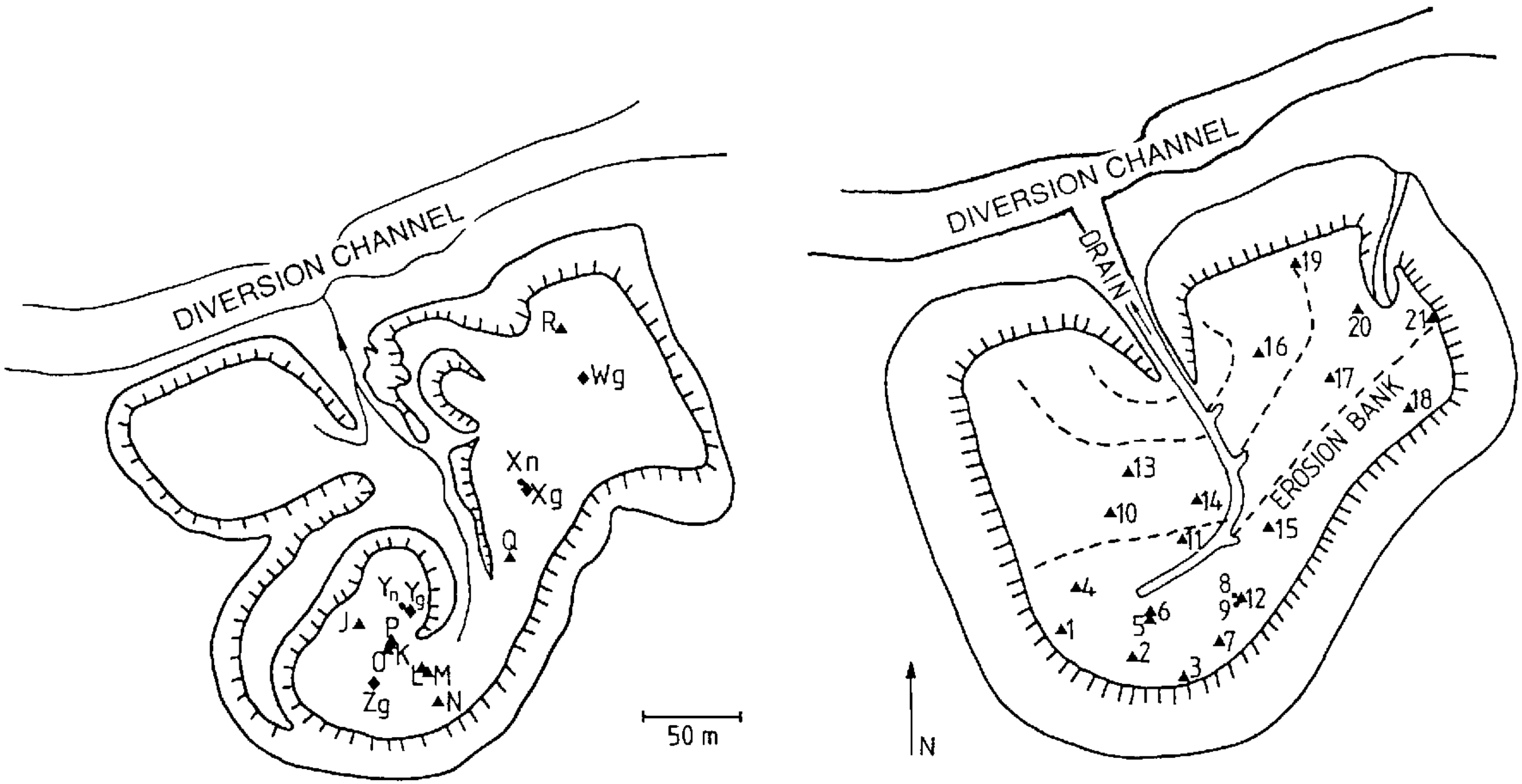


Figure 7.4 Locations and identifications of probe holes in White's dump, type 'n' holes ( ), 'g' holes ( ) and 'p' holes ( ).



pre-rehabilitation

post-rehabilitation

Figure 7.5 Locations and identifications of probe holes in Intermediate dump, type 'n' holes ( ), 'g' holes ( ) and 'p' holes ( ).

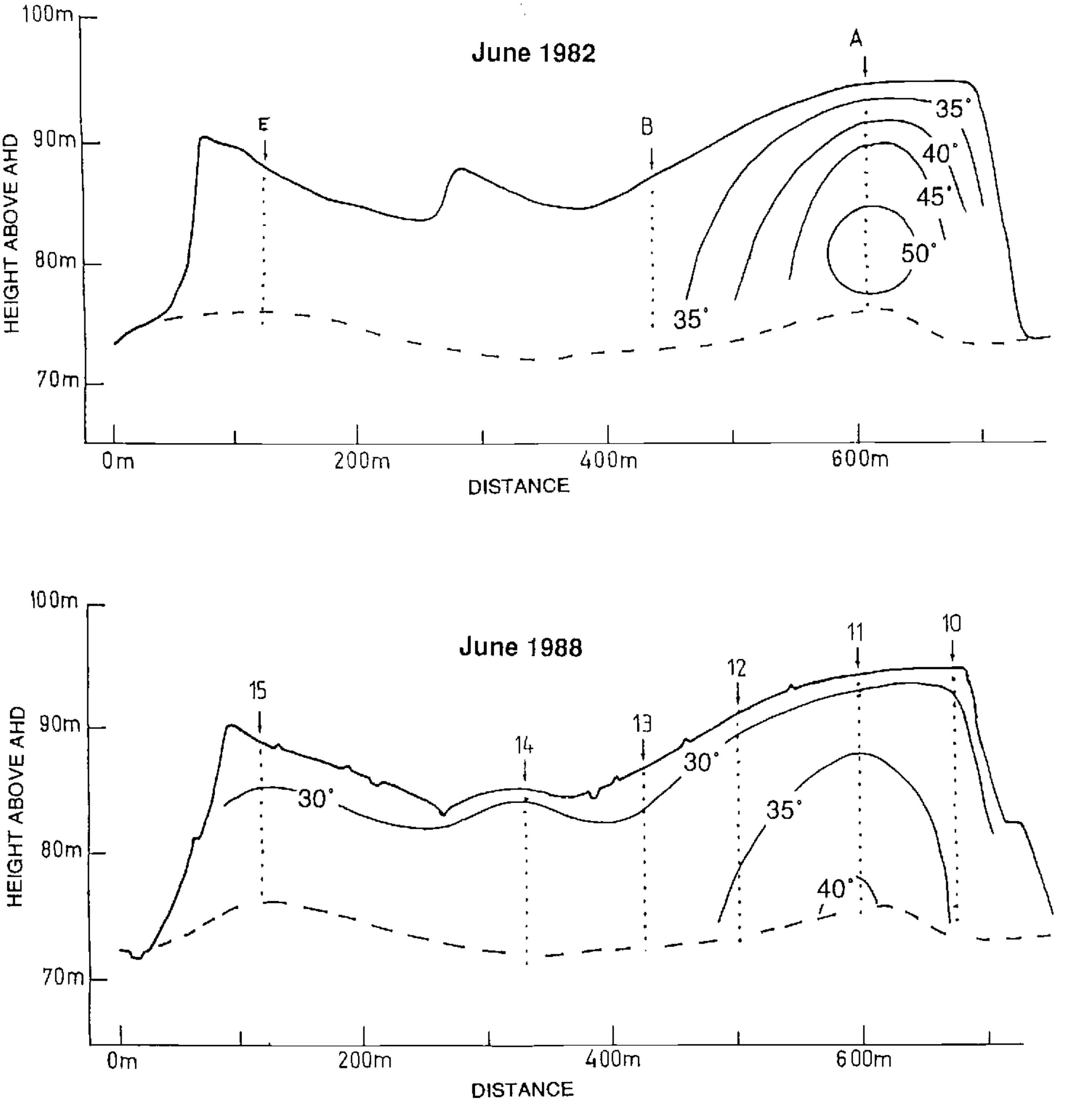


Figure 7.6 Temperature distributions in White's dump before and after rehabilitation. Numbers identify holes in which temperatures were measured (see Figure 7.3).

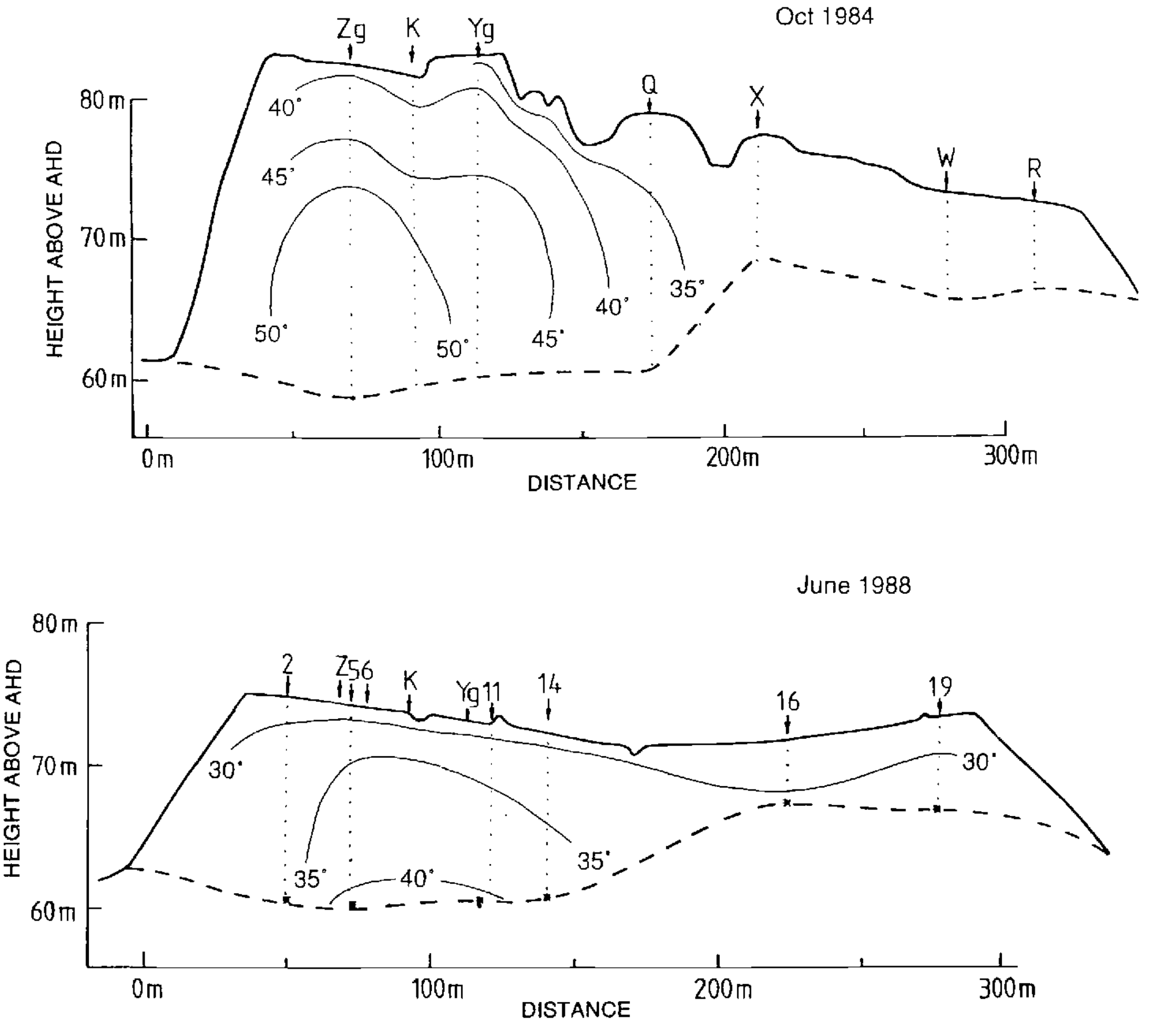


Figure 7.7 Temperature distributions in Intermediate dump before and after rehabilitation. Numbers identify holes in which temperatures were measured (see Figure 7.4).

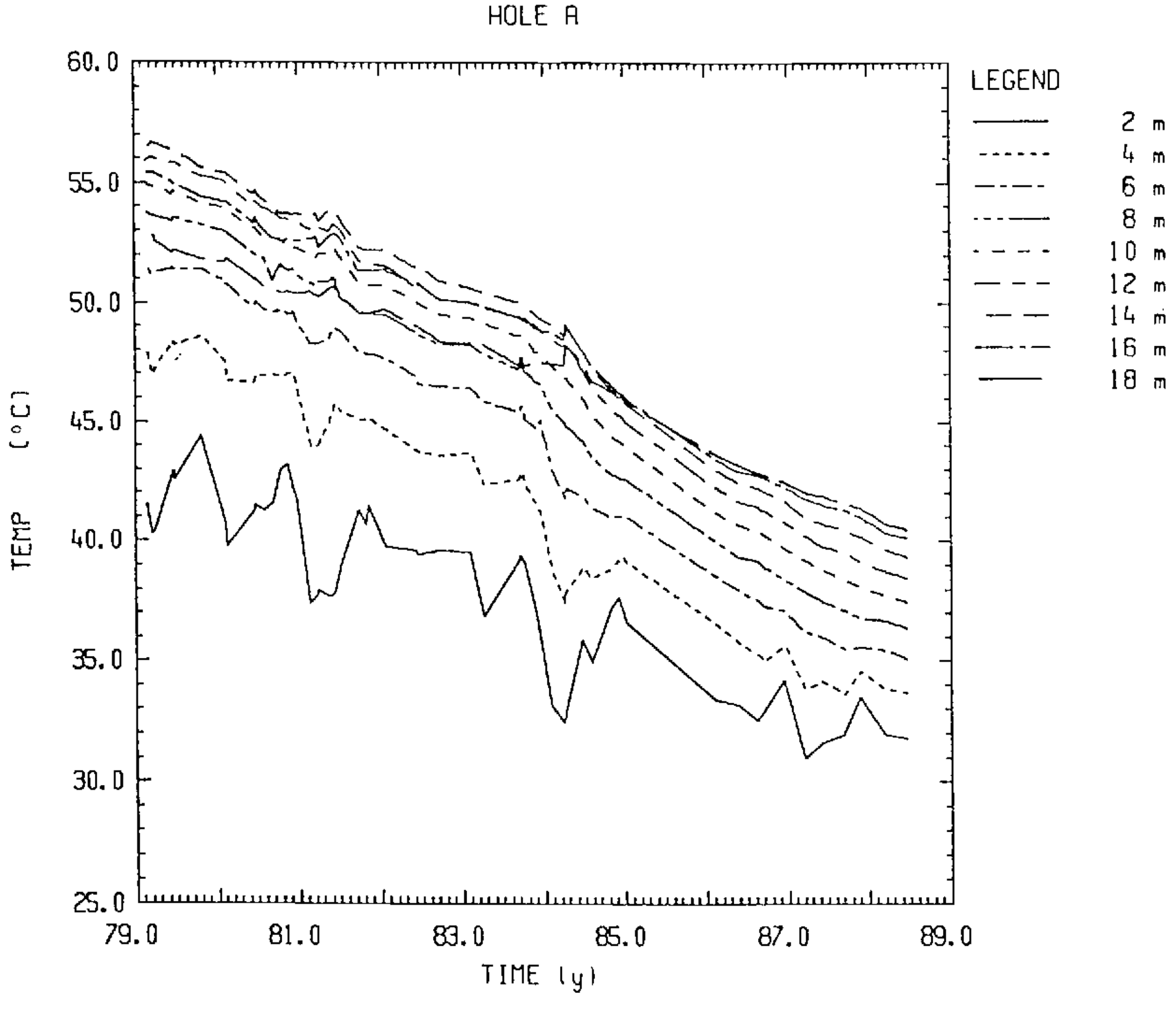


Figure 7.8 Temperatures at different depths in hole A in White's dump.

The heat production necessary to produce the observed temperature profiles was derived using a one-dimensional heat transfer model (Harries & Ritchie 1980, 1987). This calculation required estimates of the thermal conductivity, heat capacity and density of the dump material. Thermal conductivity was determined by measuring the rate of temperature rise produced in the probe holes by a known heat source. The rate of oxidation of pyrite is directly related to the heat production by the heat of reaction.

The derived heat production distributions showed that the heat production that was occurring at depth in holes A, C, D and F in White's dump before rehabilitation was effectively stopped by rehabilitation (Figure 7.9). The analysis of the Intermediate dump temperature distribution is complicated by the large amount of dump material that was moved when the dump was reshaped. Even so, it is clear that there was heat production before rehabilitation in some parts of the dump and effectively none after rehabilitation.

7.6 PORE GAS COMPOSITION

7.6.1. BEFORE REHABILITATION

The distribution of oxygen in the dumps showed some regions where the oxygen concentration decreased monotonically with depth, and other regions where the oxygen increased at depth, Figures 7.10 and 7.11. The monotonic decrease with depth is characteristic of oxygen transport by diffusion from the top surface. The oxygen concentrations increased at depth in those regions where there were high temperatures in the dump and this indicated thermal convection was transporting air in from the sides of the dumps and up through the hot regions. The atmospheric air entering at the side has an oxygen concentration of 20.9 vol. % and the oxygen would be removed as the air flow encountered material containing unoxidised pyrite. The supply of oxygen was the main process limiting the rate of oxidation in the Rum Jungle waste rock dumps before rehabilitation (Harries & Ritchie 1985).

At some locations the oxygen concentrations varied over time scales of less than a day. These short-time variations are caused by advection of the interstitial gas driven by variations in atmospheric pressure. At tropical locations like Rum Jungle, the main atmospheric pressure variations are atmospheric tides which have two maxima and two minima per day. Increasing pressure causes air to flow into the pore space and, because the incoming air has a higher oxygen content than air already in the dump, the oxygen concentration measured at a given point increases. Decreasing atmospheric pressure caused air from which oxygen has been used to flow out of the dump. Hence the atmospheric tides cause the oxygen concentration at a given point in the dump to have maxima and minima twice daily.

Carbon dioxide concentrations in the pore gas were anticorrelated with the oxygen concentrations. This suggests that the controlling process was the rate of exchange between the pore gas and the atmosphere; the lower the exchange rate between the pore gas and the atmosphere the greater the time for the oxygen to be used in the oxidation process and the smaller the opportunity for carbon dioxide to escape into the atmosphere. It was surmised that high carbon dioxide levels in the dumps resulted from acid reacting with dolomitic material in the dumps.

The air permeability of the dump material has been measured using a two-tube technique. The permeability was found to range between 1×10^{-11} and 2×10^{-10} m^2 and at some locations there was a higher permeability zone at the base. A permeability of 10^{-10} m^2 is typical of dry fine sand.

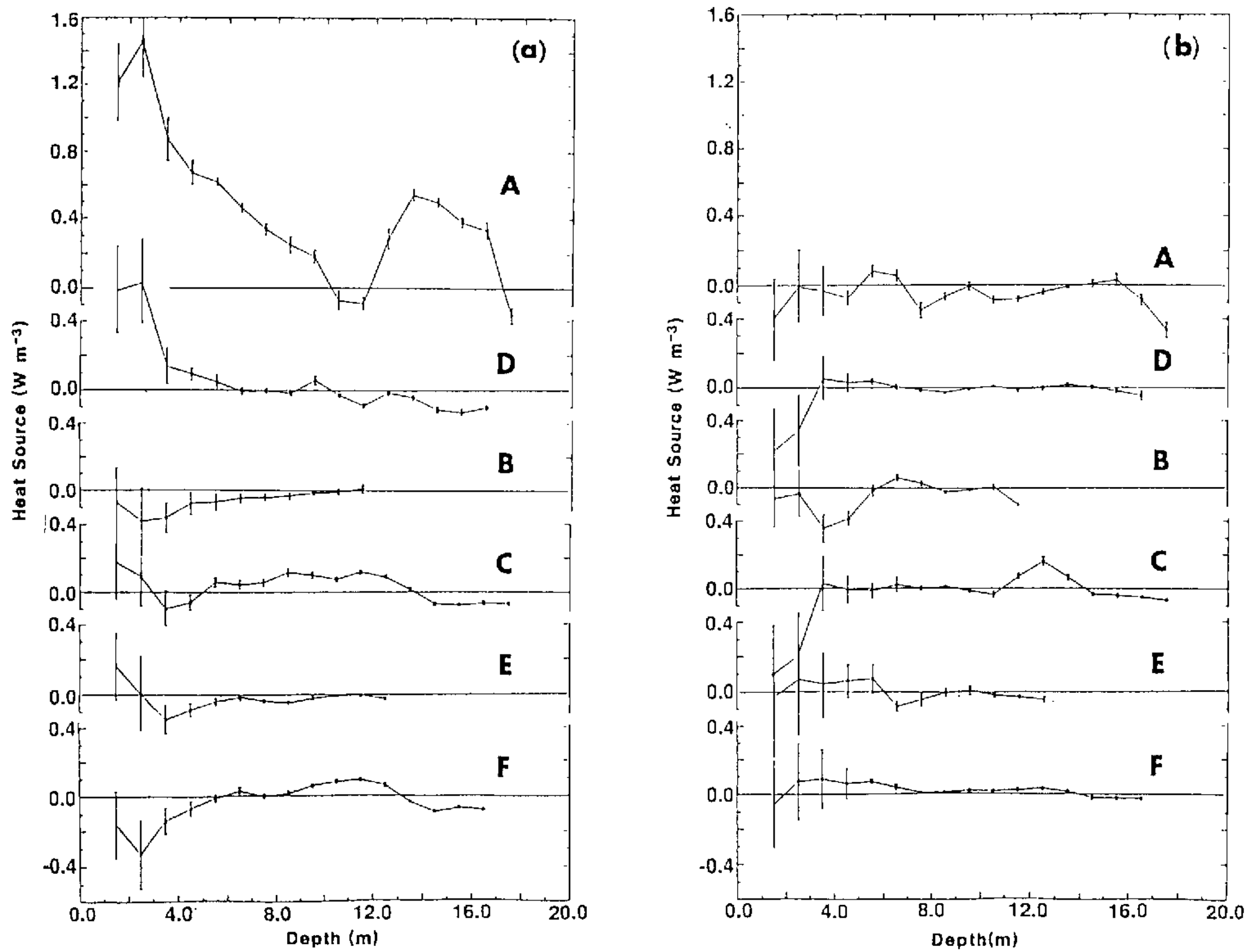


Figure 7.9 Heat production at hole locations A, C, D, and F in White's dump (a) before and (b) after rehabilitation.

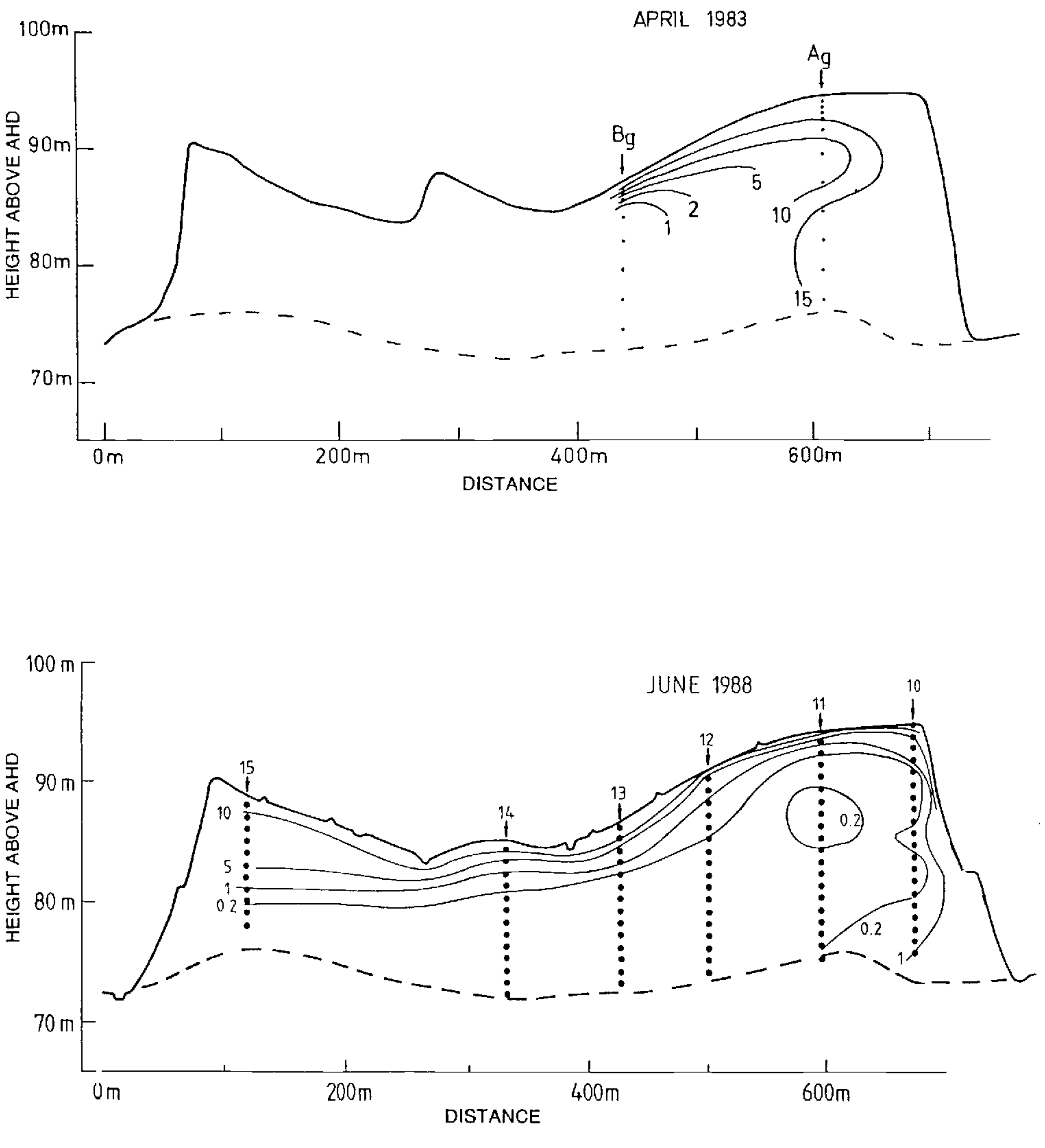


Figure 7.10 Oxygen distribution in White's dump before and after rehabilitation. The hole positions along the sections are as shown in Figure 7.4. The contours indicate pore gas oxygen concentration (vol%).

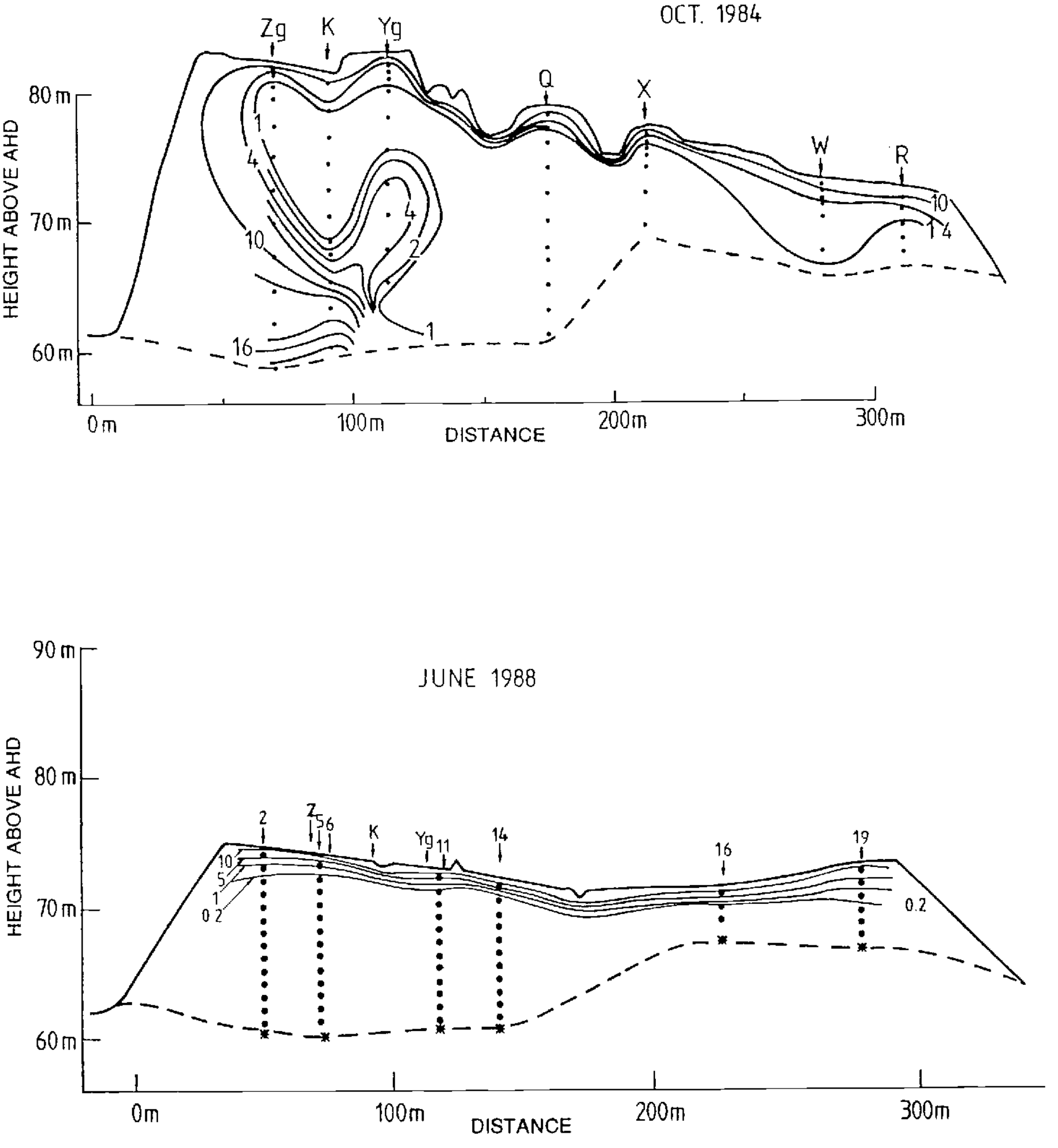


Figure 7.11 Oxygen distribution in Intermediate dump before and after rehabilitation. The hole positions along the sections are as shown in Figure 7.5. The contours indicate pore gas oxygen concentration (vol%).

7.6.2 AFTER REHABILITATION

The emplacement of the compacted clay covers on the dumps greatly reduced the level of oxygen in most regions of the dumps, Figures 7.10 and 7.11. Since rehabilitation, the oxygen concentrations at depth have been low at all measuring points except in the northwest corner of White's dump where there were very low levels of pyrite. The clay cover effectively stopped oxygen transport by thermal convection. After the covers had been in place for about a year, the oxygen concentrations in the top few metres were found to increase in the morning and evenings in the wet season. This diurnal behaviour was similar to that observed before rehabilitation and was due to advection driven by variations in atmospheric pressure. These elevated oxygen concentrations were present only in the wet season and this can be explained by the effect of seasonal changes in the permeability of the compacted clay cover. If the clay near the holes was not as well compacted as the clay further from the holes, air flow produced by variations in the atmospheric pressure would tend to be concentrated in the higher permeability material near the holes. This would cause the diurnal variation seen in the wet season.

The low oxygen concentrations and the lack of diurnal variation in the dry season indicate that there was cracking of the clay layer in the dry season, and that the cracks provide paths over the whole dump surface for advection of air by atmospheric pressure variations. The reappearance of the diurnal variations in the oxygen concentrations early in the wet season shows that most of the cracks closed as the moisture content of the clay increased, but the clay near the holes did not seal as well as that further away. Oxygen concentrations at depth in the dumps continue to be much less than they were before rehabilitation. The compacted clay cover appears to have stopped oxygen transport by thermal convection.

7.7 CONCLUSIONS

Monitoring the waste rock dumps at Rum Jungle has shown that rehabilitation by reshaping and covering with compacted clay was effective in greatly reducing the ingress of water, the rate of oxidation of pyrite and the transport of oxygen. The lysimeters and gas composition measurements provided early evidence of the success of the rehabilitation strategy. The reduced ingress of water and the low or zero oxidation rate (pollution generation rate) gives confidence that the release of pollutants from the waste rock dumps has decreased, although it will be some years before improvement is evident in groundwater quality (see Chapter 5). Further monitoring will be necessary to show that the low oxygen levels and oxidation rates continue in the long term and to confirm that the leaching of heavy metals and acid has been reduced to acceptable levels.

8. REVEGETATION, EROSION CONTROL AND COVER STABILITY

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8.1 INTRODUCTION

Assessments of several aspects of minesite rehabilitation at the Rum Jungle minesite were conducted by Australian Groundwater Consultants Pty Limited (AGC) in August 1987 and May 1988 on behalf of the Power and Water Authority (PAWA). An interim report was presented in September 1987. This report presents more complete findings and conclusions of the monitoring and assessment works as a result of site inspections conducted on all rehabilitated surfaces in May 1988 (Figures 2.1 and 2.2). Aspects addressed include drainage works stability, pasture status, slope stability, tree growth, maintenance works, and land use recommendations.

8.2 RESULTS AND RECOMMENDATIONS

8.2.1 SURFACE DRAINAGE STRUCTURES

White's Heap

Since construction in September 1984, the rip rapped section (Drain B) of the main runoff drain on White's Heap has experienced instability. The probable causes of instability of rip-rap used in the main drain on Whites Heap were addressed in the interim report (AGC 1987) and can be summarised as being:

(i) short, over-steep sections of channel;

(ii) rip-rap particle sizing and wide tolerance in the 100 mm range; and

(iii) possible less than optimum layer thickness.

The interim report (AGC 1987) recommended the mattressing of damaged sections of rip rap, in addition to extensions to the mattressed outfalls from erosion control drains which discharge surface runoff into the main drain. These works and, in particular, the outfall mattressing, were substantially successful in stabilising active sections of rip-rap. However, two significant zones of instability developed during the 1987/1988 wet season (Plates 8.1 and 8.2). These zones appear to relate to the location of mitigation works carried out in 1987, whereby mattressing or low gabion structures were to be constructed on previously active zones of rip-rap. These works were carried out, with the addition of the construction of gabion weirs across the drain (Plate 8.1). Movement of rip-rap and damage to the drain occurred downstream (and in one case upstream) of the gabion weirs.

Inspection of the damaged sections of drain was conducted with the assistance of Conservation Commission soil conservation specialists in May 1988. There was general agreement that at least one of the gabion weirs had been constructed too high and the downstream mattressed section too short, leading to significant flood damage downstream (Plate 8.2). In the remaining zones of damage, the precise cause of failure was more difficult to define and the separation of damage attributable to mitigation works from historical (i.e. construction and design works) causes was not possible.

As a result of the site inspections, it is recommended that the damaged sections of rip-rap be repaired with mattressing, and the two gabion weirs be substantially lowered. Loose pieces of geotextile fabric should be removed from the drain to minimise the potential for blockage to flow in the drain (Plate 8.1).

Elsewhere on White's Heap, surface runoff drains appeared stable and future problem areas were not evident.

Dyson's Open Cut

Corrective earthworks conducted in 1987 have resulted in shedding of runoff to the main drain. Previously, the low area had accumulated water. The main drain continues to pond water along a 20 metre section of subsidence. Remedial measures are not considered economically feasible, or warranted in terms of the potential (low) impact of allowing seasonal ponding to occur.

A small amount of leachate or "groundwater" was observed emanating from the base of the drop structure beneath the main drain (Plate 8.4). Details of this leachate are discussed in the report by Henkel & Alcock (1988).

Dyson's Heap

The rip-rapped and mattressed sections of drains on Dyson's Heap remain stable.

The soil conservation works conducted on the approach track to Dyson's in 1987 have been successful in preventing further gullying of the soil covers.

Intermediate Heap

The rip-rap drains of Intermediate Heap are stable and have been colonised in patches by stands of pasture grass. The mattressed sections of drain appear quite stable, with no further slumping evident at the drop structure above the outfall of the main drain.

Minor sheeting of the 2A soil covers either side of the drop structure has occurred. Elsewhere, vegetation and the rock mulch are providing adequate protection of soil covers from surface drainage, and significant zones of erosion are not evident.

Plate 8.1 White's Heap Drain B looking downstream. Gabion weir constructed 1987.

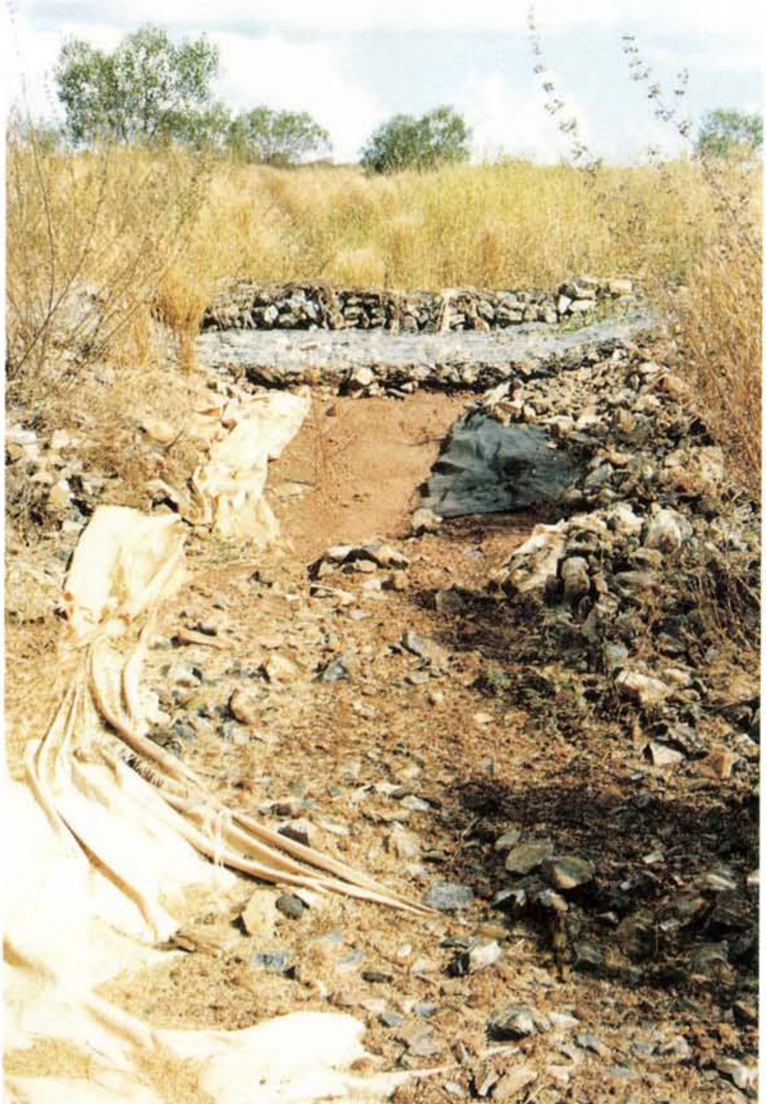

Plate 8.2

Damaged section of rip-rap downstream of gabion weir. May 1988.

Plate 8.3 Subsidence and backfall in mattressed drain on Dyson's Open Cut. Created by settlement of fill. May 1988.

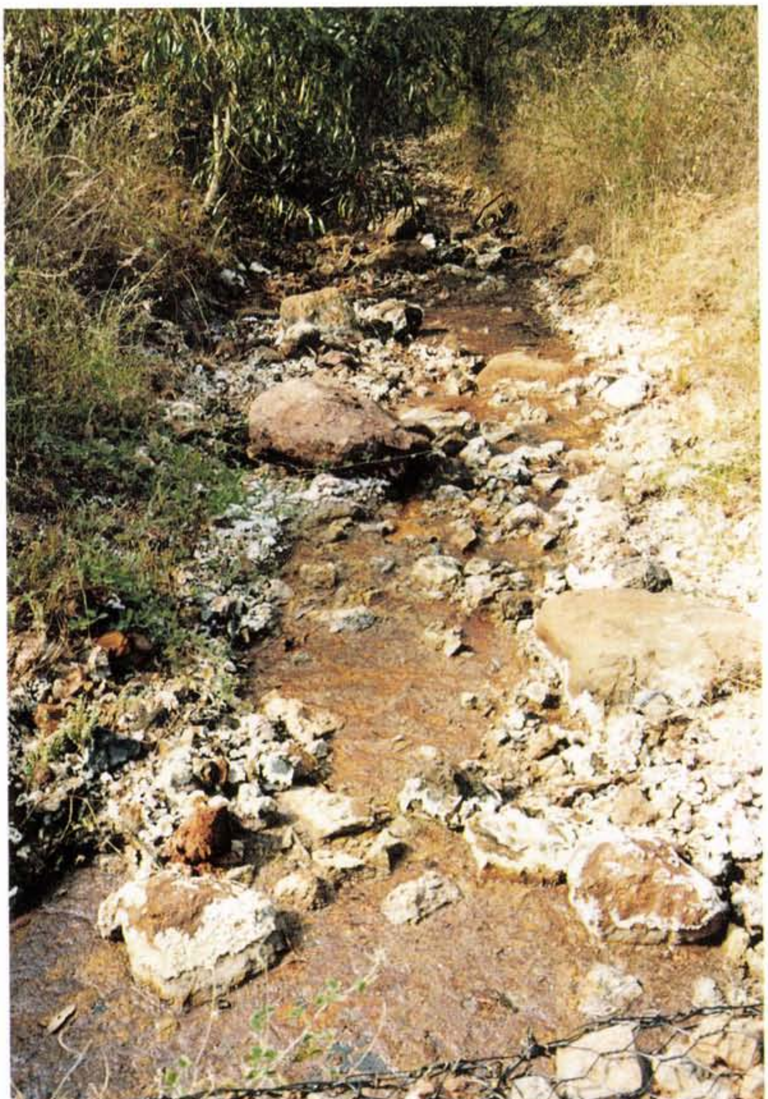

Plate 8.4

Precipitated salts and leachate. Dyson's Open Cut. May 1988.

White's North and Copper Heap Leach Area

The contour drainage and outfall systems established on White's North appear to have been operating effectively. Minor sheeting on the flank of White's North at the East Finniss channel to White's Open Cut has occurred. Drainage banks on the old Copper Heap Leach area are stable and performing to expectations.

Tailings Dam Area

The main rip-rap channel draining the Tailings Dam area is essentially stable. Fine gravels and sands are gradually infilling voids between the rip-rap particles, providing a form of cementing matrix (Plate 8.8). A single point of scour has developed at the confluence of the rip rap drain and the western channel. No remedial action is recommended at this stage. Contour drain outfalls to the drain are stable and performing effectively.

The developing tree belts lining the main rip rap drain are also providing additional stability to the drain surrounds and batters (Plate 8.8). Relatively minor sheet erosion of the soil cover is occurring in the western sector of the tailings dam, at the break in slope between the pasture covered surface and the western channel batters.

Treatment Plant and Stockpile Area

Drainage structures on these areas consist of a main rip rap channel, contour drain outfalls and contour drains. All structures remain essentially stable and grass cover in the drains is increasing.

The remedial soil conservation works conducted on the old Treatment Plant site have repaired the runoff backfall problems that previously existed. However, some runoff along the vehicular track will inevitably continue to occur. Runoff will probably continue to channel at one side of the track, maintaining the small gully that exists on the track.

Filter Cake Disposal Area

Remedial erosion control works conducted on the Filter Cake Disposal area have been largely successful. The previously existing scour channel in the centre of the site has been successfully stabilised with rip-rap and a low mattress outfall.

Minor sheeting is taking place on the northern boundary, however remedial action is not considered necessary at this stage.

Borrow Pits

Attention by the Conservation Commission to ensure effective drainage and recontouring of borrow pits during the operational phases between 1984 and 1986 has resulted in a high standard of borrow pit rehabilitation.

Two borrow pits to the south west of White's Heap continue to display some batter erosion. These particular pits were sources of 1B material and were located in highly erodible, weathered granitic material. However, there are signs that vegetation and slope lowering will gradually reduce the degree of erosion.

8.2.2 PASTURE STATUS

White's Heap

A high standard of vegetation cover has developed on the surface of White's Heap (Plate 8.5). Pastures are dominated by *Urochloa mozambicensis* (Sabi grass), *Stylosanthes hamata* (Verano stylo) and *Chloris gayana* (Rhodes grass). The previously dormant *Paspalum notatum* (Bahia grass) has made some advances in the past 12 months. The creeping legume *Macroptilium atropurpureum* (Siratro) is advancing from the batters into the top surface pasture sward.

Overall, the appearance of the pasture is good and an effective erosion cover has been established due primarily to the provision of a soil medium and follow-up maintenance fertilisation and slashing.

The naturalised grass *Pennisetum pedicellatum* (Pennisetum) is a common species on sections of White's Heap, particularly in the main drain (Drain B). *Cynodon dactylon* (Couch grass) continues to dominate barren areas, and is often present beneath the taller, more visible grasses. *Acacia holosericea* shrubs are slowly colonising the top surface and are mostly confined to contour drainage banks and alongside drains. Some 50 specimens were counted.

Vegetation cover over the rock-mulched batters continues to increase. Siratro is the dominant species, in association with annual Sorghum and Heteropogon species. Numerous shrubs of *Acacia holosericea* have established.

Dyson's Open Cut

Pastures are dominated by Sabi grass, Verano stylo and Rhodes grass. The wet season annuals, *Alysicarpus vaginalis* (Alyce clover) and *Digitaria ciliaris* (Summer grass) are also common. Couch grass appears to dominate minor low-lying areas. Significant amounts of Pennisetum grass have established in the main runoff drain.

The batters of Dyson's Opencut exhibit gradually increasing cover by Siratro and an assortment of naturalised and native annual grass species.

Dyson's Heap

Pasture development on Dyson's Heap has progressed satisfactorily and, in general, a good protective cover exists. The sward is dominated by Sabi, Rhodes and Bahia grasses, with amounts of *Brachiaria decumbens* (Signal grass). Sections of the drains and outfalls continue to support a cover of *Paspalum plicatulum* (Bryan plicatulum) and *Brachiaria mutica* (Para grass).

Plate 8.5 White's Heap; view to the northwest, showing good quality pasture cover and colonisation by *Acacia holosericea*. May 1988.

Plate 8.6 Intermediate Heap; view to the west showing a dense pasture sward dominated by *Brachiaria decumbens* (Signal grass). May 1988.

Patches of native spear grasses are evident in the pastures and on contour bank surfaces. Some colonisation by Siratro, presumably from Dyson's Opencut batters, has also occurred.

Intermediate Heap

The pasture sward on Intermediate Heap is noticeably different to other surfaces, being dominated almost exclusively by a dense cover of Signal grass (Plate 8.6). Verano stylo is present in lesser amounts, and Rhodes grass occurs consistently but in low densities. Trees have not colonised the surface or batters. Batter vegetation is dominated by Siratro, and the naturalised species *Eriachne glauca* (Pan Wanderrie Grass).

White's North and Copper Heap Leach Area

Pasture cover on both these areas is of a good standard and primarily dominated by Sabi and Rhodes grasses and Verano stylo. Significant amounts of Signal grass occur in the southeastern sector of White's North. Colonisation by other species has been minimal.

The native shrub and tree species sown as seed along the northern flank of the Copper Heap Leach area have established well. They should continue to provide stability to the discharge channel from White's Opencut.

Tailings Dam Area

A healthy cover of pasture generally dominated by Sabi, Bahia and Rhodes grasses and Verano stylo, has established on the Tailings Dam site (Plate 8.7). Noticeable advances by Bahia grass have been made in the past 12 months, particularly in the southern sector.

The tree belts and clumps continue to develop and a dense line of trees, dominated by *Acacia holosericea*, has established on both sides of the main runoff drain (Plate 8.8). Isolated specimens of *Mimosa pigra* continue to appear in the drainage bank outfalls on the Tailings Dam site (Plate 8.8 and Section 8.2.3).

Treatment Plant and Stockpile Areas

Pasture cover on these areas remains somewhat retarded in comparison to the surfaces discussed above. The degree of soil compaction and consequent moisture infiltration rates are the likely reasons. However, the lighter cover does not appear to be detrimental to the erosion status of the surfaces and may be expected to increase with time and favourable seasons.

Sabi and Rhodes grasses dominate, with lesser amounts of Verano stylo. Couch grass occurs in isolated patches and as a common ground cover beneath the taller grasses.

Plate 8.7 Tailings Dam area viewed from the old plant site, showing pasture cover and developing tree belts. Slashing in progress, May 1988.

Plate 8.8 Close up view of main drain on the Tailings Dam area, showing developing tree belts and infilling of rip- rap voids with fine material. May 1988.

Plate 8.9 Mature specimens of *Mimosa pigra* on the Tailings Dam area. May 1988.

Filter Cake Disposal Area

Vegetation cover on the disposal area has improved considerably over the 1987/1988 wet season. The site was sown in December 1986 with an extensive mixture of remaining available pasture grass and legume species, and the resultant cover reflects this mixture. The dominant species include Rhodes, Sabi and Couch grasses, and the legumes Verano stylo and *Stylosanthes scabra* (Seca stylo). Significant numbers of invader species have colonised including Pennisetum grass, native Couch, spear grasses, Wanderrie grass and the common weeds *Hyptis suaveolens* (Hyptis) and lesser amounts of *Sida acuta* (Sida). Trees and shrubs have not yet colonised the site.

Borrow Pits

Attention to drainage, recontouring and topsoil respreading aspects during borrow pit operations has resulted in high standards of revegetation (Plate 8.10). Minor exceptions are generally confined to sections of batter, particularly on the pits located in granitic soil profiles southwest of White's Heap.

8.2.3 WEEDS

The commonly occurring weeds, Hyptis and Sida are present to varying degrees on all rehabilitated surfaces. Competition from the pasture grasses has been strong to date, resulting in a general restriction of weed species to the contour drainage banks, and the edges of the rehabilitated heaps. This situation can be expected to continue whilst the vigour of the pasture species (both sown and colonising species) is maintained. This is related to a variety of factors, including soil nutrient levels, seasonal climatic variables, fire, and vegetation density.

Isolated outbreaks of *Mimosa pigra* continue to occur in consistent locations. These are the drainage outfalls on the Tailings Dam site, the ripped area in front of the sheds/workshops, Borrow Area 3 (immediately east of workshops), and Drain B on White's Heap. Inspection and eradication of outbreaks at six monthly intervals is strongly recommended.

8.2.4 ROCK MULCH STABILITY

Detailed monitoring of the stability transects established in 1985 on White's Heap was not conducted, since gross movement or failure of the mulch has not occurred on any of the Heaps.

Movement, however, continues to occur in discrete particles. Conversely, vegetation cover across the batters continues to increase, adding stability to the mulch.

Future potential avenues of gross failure of rock mulch, such as failure of sections of 1A clay, or widespread windthrow of colonising trees were not investigated because their occurrence is considered remote.

Plate 8.10 Borrow pit near Mt Fitch gate, May 1988. Recontoured December 1985. Unassisted re-vegetation.

Plate 8.11 Original sward of pasture, Tailings Dam area, May 1988. The plot has remained un-mown since planting in December 1984.

8.2.5 SOIL FAUNA

Several species of ants and one species of termite continue to be active on the rehabilitated surfaces. The surface of White's Heap displays the most diverse array of species and activity, with an active soil fauna in the surface litter layer.

The grass-eating termite *Nausitermes triodeae* occupies at least 20 mounds, mostly in the northwestern sector of White's Heap surface. The mounds are generally less than 350 mm high and appear to be increasing more in number than individual size. Observation (by eye) of the particle size and quartz particle content of the mounds, and their colour, would indicate that the 1A clay material is not being targeted as a construction material.

8.2.6 OPEN CUT SURROUNDS

A small proportion of the hand-sown native shrub and tree seed spread around White's and Dyson's Open Cuts has established. *Acacia holosericea* dominates the successful species. A gradual increase over time in the development and diversity of cover is predicted.

8.2.7 TREE COLONISATION

An extensive search of literature pertaining to the effects of tree roots upon the integrity of compacted clay layers has revealed surprisingly little data. Reference is often made in the literature to potential effects, however, quantification or case studies are absent.

On the basis of the trials conducted on site for 18 months between 1985 and 1986, regional observations, and an analysis of tree removal costs/benefits versus stability/aesthetic benefits, some comments are presented:

(i) Endemic trees have the ability to penetrate the 1A clay seal. Whilst the Eucalypts on trial maintained their habit to deep root, they confined many major roots to a lateral habit, following the planes of weakness created by compacted lift layers. Acacia species on trial maintained their habit to confine the great bulk of roots in the less compacted, surface layers. However, rootlets were able to penetrate the 1A clay.

(ii) Competition from pasture species and Acacia shrubs will delay the colonisation of surfaces by Eucalypt species for an unknown period of time, perhaps several years.

(iii) Colonising trees will need to expend considerable energy penetrating compacted layers, severely retarding their physical development.

(iv) Volumetrically, the pore spaces (and therefore potential pathways) created by tree roots in the 1A clay can only constitute a small percentage of the total amount of seal afforded by the 1A clay layer.

(v) Windthrow of colonising trees is not considered to be a significant factor on the rehabilitated top surfaces. Windthrow on the batters could potentially lead to local erosion.

(vi) The annual removal of trees entails an annual, permanent maintenance cost estimated to be of the order of $5,000 to $10,000, and increasing with increased tree numbers.

(vii) Gradually, trees and shrubs will take on some of the erosion protection role currently undertaken by the pastures. Removal of trees will place a greater requirement for pasture maintenance works, and therefore costs.

(viii) In terms of floral and faunal population dynamics, the available literature on rehabilitated landforms suggests the attainment of a vegetation community incorporating grasses, shrubs and trees is a more desirable goal.

Consequently, it is recommended that trees not be removed. The characteristics of colonisation and the effects of trees upon the integrity of the covers at Rum Jungle should be specifically addressed, again, within the next two years.

8.2.8 PASTURE MAINTENANCE

Soil Chemistry and Implications

From an agronomic point of view, the soils at Rum Jungle in which pastures are establishing have a low nutrient status (Table 8.1).

The analytical results for the common nutrients required for plant growth (nitrogen, phosphorus, potassium and sulphur) for May 1988 (Table 8.1) show the available nutrient levels for a soil profile through the Tailings Dam soil cover system. Levels of N, P and K are low whilst S is adequate. Comparison of these levels, however, with those recorded from the same site in November, 1986 show the benefits of maintenance fertilising between 1986 and 1988 whereby the more stable nutrients, P and K, have built up from extremely low to low levels.

Soil pH and conductivity remain at stable and desirable levels, whilst the levels of specific elements in Table 8.1 do not indicate abnormal migration of elements from the old tailings subsoil into the overlying soil covers. The recorded level of 150 ppm Cu at depth is, however, an indication of the presence of metals in the old subsoil and probably reflects some mixing of soil cover with subsoil.

The higher pH of the lower-most layer of soil covers (400 mm depth) is a reflection of the residual lime that is still visible in soil samples from depth.

In terms of the natural soil systems surrounding the rehabilitated surfaces at Rum Jungle, the levels of soil nutrients are not abnormal. Thus, discussion of the nutrient status of Rum Jungle soil covers should be made only in conjunction with discussion of the intended land use of the site.

Land Use Options and Recommendations for Pasture Maintenance

With regular maintenance fertilisation, the rehabilitated surfaces at Rum Jungle are currently capable of supporting light forms of primary production, such as grazing or annual hay cutting. Without maintenance, soil nutrient levels are insufficient to support such land use.

Additional land use options fall in the more passive category, and include light visitor use, research and rehabilitation monitoring, and simply leaving the site alone.

Primary production is not a recommended form of land use at Rum Jungle, unless a commitment to maintenance fertilisation is guaranteed. Given the decreasing financial commitment to the site, this would appear to be an unlikely development. Activities such as hay cutting and grazing without fertilisation will remove large amounts of available nutrient, to the detriment of vegetation cover. Commonly, about 180 kg of nitrogen per hectare is removed in clippings from maintained pastures.

If funds permit, fertilisation of pastures with a compound (NPK) fertilizer in the 1988/1989 or 1989/1990 wet season is recommended. A similar recommendation for an annual slashing towards the end of the wet is also made.

Without maintenance, and in particular, slashing, pastures will gradually develop a thicker, taller habit with increasing colonisation by native and neutralised species (Plate 8.11). Species used in the rehabilitation of batters such as Siratro, will also tend to colonise for the first few years. Fires will burn "hotter" due to the increased amount of combustible matter, and native Acacia shrubs Acacia holosericea, in particular, will probably tend to be replaced over time with the fire-favourable species such as the eucalypts.

Thus, a balance between the currently maintained pastures and a no-maintenance policy is recommended. Slashing and fertilising on an ever reducing frequency should allow the phasing in of a no-maintenance policy.

It is strongly recommended that the pasture status and maintenance issues be reviewed in 12 months time. Fire breaks should be re-instated around the site. This will not exclude fires, but should reduce their frequency and extent.

Table 8.1 Tailings Dam Area Soil Cover - Selected Analyses[1].

	SOIL DEPTH (mm)			
	0-100	100 - 250	250 - 325	325 - 400
<u>GENERAL PARAMETERS</u>				
Saturated Paste				
pH (May 1988)	6.82	6.45	6.58	7.24
EC mS/cm (May 1988)	0.09	0.07	0.08	0.15
<u>NUTRIENTS</u> (ppm)				
Available				
N*	56			
P*	< 5	N/R	N/R	N/R
K*	22			
N**	2	2	2	2
P**	11	5	2	14
K**	120	70	80	80
S**	29	25	24	10
<u>SPECIFIC ELEMENTS</u> (ppm)				
Total (by ICP) (May 1988)				
Cu	15			150
Pb	< 5			< 5
Zn	15			< 5
Fe%	11.8	N/R	N/R	8.64
Mn	5 300			5 750
Mg	1 650			3 200
K	1 000			8 400
P	950			500
S	30			30

1. Located adjacent to the southern grazing/mowing exclosure (TD1).
* Department of Primary Production, Darwin. November, 1986
** SGS Quantum Brisbane. May 1988.
N/R Not recorded.

8.3. SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

8.3.1 LAND USE/MAINTENANCE

Primary production without a guaranteed commitment to fertilisation and activities supervision is not recommended.

A decreasing level of current maintenance practices is recommended. Review in 12 months is recommended.

Controlled visitor use of the site, with the provision to visitors of an accurate summary of the project's history (i.e. an official handout sheet), is recommended.

Unrestricted vehicular use of the site is not recommended.

Regular eradication of *Mimosa pigra* outbreaks is recommended. The Department of Industry and Development may be able to provide assistance with control.

Tree eradication programmes are currently not considered necessary. However, a review of the situation within the next 12 months is recommended.

A low level of monitoring of the issues investigated in this report is strongly recommended. This could be simply achieved, and take the form of inspections at 12 monthly intervals.

8.3.2 PROVISION OF MONITORING RESULTS

The rehabilitation of Rum Jungle will continue to provide both government legislators and the mining industry with valuable data with respect to more effective mine regulation and decommissioning.

Assessment of the success of the project in the form of revegetation, and surface stability monitoring is therefore recommended at an appropriate and economically practical level. Also, as part of Project assessment, it is understood that the appropriate agencies will be seeking a continuance to water quality monitoring programmes. The dissemination of the results of monitoring programmes to the appropriate authorities and industry personnel is an important adjunct to monitoring programmes.

9. SITE MAINTENANCE

9.1 INTRODUCTION

Annual inspections are conducted at the Rum Jungle site to ascertain the requirement for maintenance. The maintenance program was outlined in The Final Project Report (Allen & Verhoeven 1986) and is reproduced below.

9.2 MAINTENANCE PROGRAMME

9.2.1 COVERS

Maintenance of the cover system comprises the detailed inspection of the covers during and at the end of the wet season and the repair of any significant erosion damage, particularly gully erosion, during the ensuing dry season. Repairs to the covers should be made with material similar to that which has eroded from the area, sourced from one of the previously established borrow pits from around the site and placed in a similar manner as the original material. Reasons for damage should be ascertained to enable design of approximate remedial works and repairs.

9.2.2 VEGETATION

This comprises the inspection and re-seeding at the start of the wet season of any significant areas where seeding has failed during the previous dry season, the re-seeding of any repaired areas and the subsequent fertilising and slashing of all revegetated areas of the site. Re-seeding should utilise seed mixes similar to those used for the original seeding.

Fertilising and slashing should be carried out twice during the wet season, the first being early February and again during April, the exact timing will be dependant on seasonal weather conditions. Selection of a suitable fertiliser should be based on an analysis of vegetation at the time of application and should take into account any recognised soil deficiencies. Details are described by Ryan, 1986.

Unfortunately, the two year period may not be sufficient time to ensure successful site revegetation to a point where maintenance fertilisation and slashing can cease. Nor may it be sufficient time to conclude that revegetation works have been totally successful in the longer term. These issues will need to be carefully considered before the works cease.

9.2.3 REDIVERSION WORKS

Maintenance of the rediversion works should be limited to the inspection of culverts and weirs during and at the end of the wet season, the removal of any accumulated debris from the structures, and the repair of any damage to the structures or their foundations before the next wet season.

9.2.4 DRAINAGE

This programme comprises inspection (formally on an annual basis after the wet season but also during the wet season when appropriate) and rectification as described below.

(a) Inspect all erosion control drains and repair any damage, particularly the drain outlet area.

(b) Inspect all rip-rap lined drains for signs of movement of lining material and any other damage, and repair as necessary.

(c) Inspect all mattress lined drains for signs of deterioration of wire mattresses, movement of fill material and any other damage, and repair as required.

(d) Inspect all half round pipes (berm drain and drop down drains on White's heap) for signs of deterioration or erosion of drain foundations and repair as required.

(e) Inspect all drainage structures (gabion drop structures, manholes, energy dissipaters, culverts etc) and carry out repairs as necessary.

(f) Inspect subsoil drains and repair as required.

9.2.5 OTHER

- Inspect and repair the designated road pavements to maintain serviceability, to the standard of gravel all weather roads.

- Inspect the cattle proof fences around the site and around the filter cake disposal area annually after the wet season and carry out repairs as required.

- Inspect all buildings remaining on the site and repair as required to maintain their serviceability.

- Inspect all monitoring facilities (gauging stations, pluviometer stations, etc) prior to the start of and during the monitoring season and repair as required.

- Inspect the site water supply facilities and repair as required.

- On completion of repairs to fencing (item above), eradicate feral buffalo from within the site.

- Inspect and maintain the fire break around the site perimeter fence annually. Exclusion of fire from the site is necessary to ensure the survival of the introduced pasture species.

- Under the Noxious Weeds Act 1985 certain plant species must be controlled or removed. Other species are undesirable in terms of the Project aims.

Inspect at six monthly intervals, and keep at tolerable levels by the use of herbicides and mowing, weeds including *Hyptis sauveolens*, *Sida acuta* and *Mimosa pigra*.

This maintenance program is the responsibility of, and to be co-ordinated by the Water Resources Division of the Department of Mines and Energy.

9.3 MAINTENANCE CONDUCTED

Fertilisation and slashing of pastures, weed control and minor repairs to drainage structures were conducted and are described in detail in Chapter 8.

10. FINANCE

Expenditure on the Rum Jungle Rehabilitation Project up to June 1986 totalled $18.6 million. This is summarised in Table 10.1.

Tables 10.2 and 10.3 show expenditure for the following years 1986-88, as reported at the ninth and eleventh meetings of the Monitoring Committee.

The surplus identified at the eleventh and final committee meeting in June 1988 was $11 310. Revenue from sales of assets and recoveries from other accounts after this date provided an additional $22 277.90. A total of $33 587.90 was therefore held in the Trust Account and was transferred to the Conservation Commission of Northern Territory when it assumed responsibility for the site.

Table 10.1 Summary of Project Expenditure 1982 - 86

CATEGORY DESCRIPTION		EXPENDITURE UP TO 30 JUNE 1986
CATEGORY A. EARTHWORKS ETC		
A1	Copper Heap Leach	3 539 670
A2	Tailings Dam	138 157
A3	Dyson's Open Cut	8 098
A4	White's Open Cut	320 268
A5	Intermediate Open Cut	240
A6	Dyson's Overburden Heap	262 047
A7	White's Overburden Heap	1 376 783
A8	White's North Overburden Heap	696 771
A9	Intermediate Overburden Heap	491 396
A10	Acid/Sweetwater Dams	204 231
A11	Other Areas	379 981
A12	Site Establishment Including Protective Fence	1 194 932
Sub Total		**8 612 574**
CATEGORY B. CONSTRUCTION WORKS		
B1	Water Treatment Plant	2 016 228
B2	Pipeline	1 012
B3	Construction Camp	227 065
Sub Total		**2 244 305**
CATEGORY C. PROJECT MANAGEMENT, SITE SERVICING, MONITORING		
C1	Camp Services - power, water, sewerage	52 493
C2	Camp Generator, Fuel and maintenance	161 587
C3	Camp Accomodation	1 617
C4	Monitoring	322 346
C5	Engineering and Management	3 028 293
C6	Site Services	0
Sub Total		**3 566 389**
CATEGORY D SUPPLY OF CHEMICALS FOR WATER TREATMENT PLANT		**2 824 581**
CATEGORY E OPERATION OF WATER TREATMENT PLANT		**1 392 400**
CONTINGENCY		**600 000**
GRAND TOTAL (Not including Contingency)		**18 640 249**

Table 10.2 Revenue and Expenditure for 1986/87

REVENUE	**$**
Previous Balance	194 103.13
C'wealth grant 86/87	480 000.00
Sale of assets	398 819.00
TOTAL	**1 072 922.13**
EXPENDITURE	
Administration	421 763.54
Maintenance	582 667.72
Monitoring	63 706.53
TOTAL	**1 068 137.79**
SURPLUS	**2 285.10**

Table 10.3 Revenue and Expenditure for 1987/88

REVENUE	$
Brought forward from 86/87	2 285
Commonwealth funding 87/88	231 000
RECEIPTS - SALE OF ASSETS TO MAY	14 805
- ADDITIONAL DISPOSALS	8 000
TOTAL	**256 090**

EXPENDITURE $

ITEM	ESTIMATED	AT 31.5.88	REMAINING	SUB-TOTAL
Monitoring				
ANSTO bores	23 700	40 700	9 500	50 200*
ANSTO monitor	21 700			
PAWA	26 400	34 000	2 000	36 000*
Consultancy	11 800	6 700	9 000	15 700
Final Report	5 000	-	5 000	5 000
Maintenance				
Vegetation	20 000	27 800	2 000	29 800
Covers	30 000	18 100	2 000	20 100
Rediversion Works	10 000	-	-	-
Drainage	20 000	28 400	1 000	29 400
Roadworks	10 000	-	-	-
Fencing	1 000	-	-	-
Build. maint.	2 000	600	400	1 000
Buffalo control	500	-	-	-
Other	-	500	-	500
Contingency	17 900	-	-	-
Thiess	-	14 700	-	14 700+
Tax H & K	-	-	33 000	33 000+
1986 Report	-	9 200	-	9 200*
MPES	-	-	-	-
TOTAL	**200 000**			**244 600**

SURPLUS	**11 310**

Notes: * Total includes revote items from 86/87 not allowed for in estimates.
\+ Items not allowed for estimates.

11. SITE MANAGEMENT PLAN *

T.J. Verhoeven

Formerly Power and Water Authority
PO Box 1921, Darwin NT 0801, Australia.

11.1 INTRODUCTION

Under an Agreement between the Commonwealth and Northern Territory Governments (O'Donovan 1983), the Rum Jungle mine site has been undergoing rehabilitation since 1982. The Agreement provided for scheduled works to be undertaken over a period of four years, together with a monitoring program for a further period of two years, with an all up cost to the Commonwealth Government of $16.2 million (1982 value). The work has been undertaken by the Northern Territory Government. The Agreement contains several important provisions including its operation, rehabilitation of the site, liaison and finance (described in detail in the Final Project Report (Allen & Verhoeven 1986)).

The program of works and monitoring as defined by the Agreement will be completed by August 1988. To ensure the lasting integrity of the rehabilitation measures after completion of the works, it is necessary to properly manage the site and to maintain the rehabilitation measures. This is recognised in the Agreement.

This chapter describes the nature and extent of ongoing management measures and land use restrictions needed at the site, to ensure Northern Territory public safety requirements are met and to protect the Commonwealth's investment in the rehabilitation structures. These matters need to be the subject of an agreement between the Northern Territory and the Commonwealth in mid 1988.

* *This plan was developed in June 1988. Since that time many of the recommendations have been implemented and are outlined in Chapter Two.*

11.2 LEGISLATION AND ADMINISTRATION

11.2.1 OWNERSHIP OF THE SITE

The land concerned is within Sections 1090, 1091 and 2890 Hundred of Goyder. It is owned by and therefore controlled by the Northern Territory, subject only to two matters:

(i) Finniss River Land Claim (Claim No. 39). All of these sections are subject to this claim which has yet to be determined (discussed in Section 2.4).

(ii) Any continuing role by the Commonwealth in rehabilitation, maintenance and monitoring of the land pursuant to the Agreement.

11.2.2 LEGISLATION AND ADMINISTRATION UNDER THE AGREEMENT

Legislative control has been exercised via the Mines Safety Control Act, the responsibility of the Minister for Mines and Energy. This Act will not appropriate to the administration of the site after termination of the Agreement. The site is also a declared Fire Protection Zone.

For the period 1983 to mid 1986, the rehabilitation work was managed by a special Project Unit. The Unit was first located within the Department of Transport and Works, and then transferred in late 1984 to the Department of Mines and Energy. The Project Unit was disbanded in mid 1986, the work then being managed by staff who are now within the Power and Water Authority (PAWA).

The project team's main objective was to implement the program of rehabilitation within both the approved time and limit of grants provided. The team sought to minimise the management costs of the project by drawing on resource and expertise provided by other government authorities and private consultants where necessary. Project management, including control, financial administration, and public information, is described in Allen & Verhoeven (1986).

Three committees were involved in the oversight and co-ordination of various matters relating to the project; the Liaison Committee, the Monitoring Committee, and the Technical Committee. Their composition, objectives and functions are described in Allen & Verhoeven (1986).

11.2.3 LEGISLATION AND ADMINISTRATION BEYOND THE AGREEMENT

The Final Project Report (Allen & Verhoeven 1986) identified that beyond mid 1988 an adequate degree of control of the site would still be required, but that the Mines Safety Control Act currently providing such control would no longer be applicable. In particular, the Report concluded that abuse of the rehabilitated mine site may result in damage to the cover systems employed to prevent the further spread of pollution. As noted in Section 11.3, the potential for soil erosion thus jeopardises the integrity of the whole rehabilitation.

The report concluded that a legislative framework was still required to maintain adequate control. It recommended that this control be achieved by applying the provisions of the Soil Conservation and Land Utilization Act (1980).

A Working Group of PAWA and Conservation Commission (CCNT) staff has examined possible appropriate legislation. It recommended to the Soil Conservation Advisory Council that it recommended to the CCNT that the mine site within the fenced boundary be declared a Restricted Use Area as defined in Clause 20 of the Soil Conservation and Land Utilization Act (1980). The various conditions listed in Clause 20(C) (see Appendix E) will form an important tool to help manage the site and to restrict erosion.

The above recommendation is currently under consideration by the CCNT.

With the change in controlling legislation, the administration of the site, and hence of programs of monitoring and maintenance, should transfer to the CCNT. The main administrative tasks would include:

. Management of the Rum Jungle site (described in Section 11.3).
. Co-ordination of the monitoring program (described in Section 11.4).
. Administration and supervision of the maintenance program (described in Section 11.5).
. Maintenance of video and photographic records of the site beyond mid 1988.
. By liaison with the Department of Primary Industries and Energy, advise the appropriate Commonwealth and Territory Ministers of progress.

Any administrative activities beyond August 1988 which pertain to the period 1986 to 1988 (such as compilation of a comprehensive report) remain the responsibility of PAWA to complete.

11.2.4 FINNISS RIVER LAND CLAIM

Ownership

The Rum Jungle rehabilitation site area as defined in the Aboriginal Land Commissioner's Report on the Finniss River Land Claim (1981) is within the boundaries of 'Area 4' as defined (shown in Figure 11.1).

Title of this land is vested in the NT following proclamation of the NT Self Government Act (1978) Section 69 (2). The Land Commissioner has recommended that 'Area 4' including the Rum Jungle site be granted to an Aboriginal Land Trust (Allen & Verhoeven 1986, p. 40) and noted at paragraph 310 that "..... it appears that the Commonwealth would suffer no detriment by the sites becoming Aboriginal Land".

Status of Land Claim

Finalisation of this claim by the Minister for Aboriginal Affairs is dependent on the resolution of a number of detriment issues. It is understood that it may take a few months before those issues in respect to 'Area 4' are resolved. This has been the status of the land claim since mid 1985.

Protection of Commonwealth/NT Interests

Although the Land Commissioner has indicated that the continuation of the Rum Jungle rehabilitation project could be permitted under Section 14 of the Land Rights Act there are doubts that this section of the Act provides sufficient protection for essential Commonwealth/NT interests. The traditional owners have been in favour of the project but there may be a need for a more formal arrangement to protect ongoing Commonwealth/NT maintenance and monitoring activities. For example the exclusion of the Rum Jungle access road from any grant cannot be assumed.

Conditional Grants

Morison's report in 1985 stressed that the key objective for the Commonwealth/NT is to ensure that any grant of land to an Aboriginal Land Trust subsequent to the Government's consideration of the Finniss River Land Claim is conditional upon Commonwealth/NT identified land use restrictions and other measures deemed necessary for public safety and to protect the integrity of the rehabilitation work. Justice Toohey in his review report (1983) on the 'Aboriginal Land Rights (NT) Act 1976 and Related Matters' (paragraphs 164-169) recommended that conditional grants as envisaged above could be made. However, as the concept of conditional grants has not been tested, there is no guarantee that it can be applied.

Alternatives to the 'conditional grants' concept include:

(i) Propose an amendment to the Land Rights Act for Rum Jungle as was the case for Ranger and Kakadu National Park.

(ii) Effect a grant conditional on a lease-back arrangement to the NT. This has special attractions for the Rum Jungle site since it has the advantage of enabling the NT to exercise appropriate land use management controls. The lease back arrangement would need to be negotiated between the NT Government and the traditional owners.

It was decided by the Liaison Committee in 1985 (Morison, 1985) that before a determination is made with respect to a grant of site land to an Aboriginal Land Trust, that Commonwealth/NT formulate land use controls based on long term assessments of the site. These would include an assessment of health risks for people at or near the site, from residual pollutants, and identification of measures needed to protect rehabilitated areas from excessive wear as a result of man and nature. The basic objective of such restrictions and management controls would not vary, regardless of future ownership of the site, but their detailed character would have to be tailored to the nature of activities contemplated by the owners. Provisions are available within the Land Rights Act to defer the grant of land subject to the resolution of these requirements.

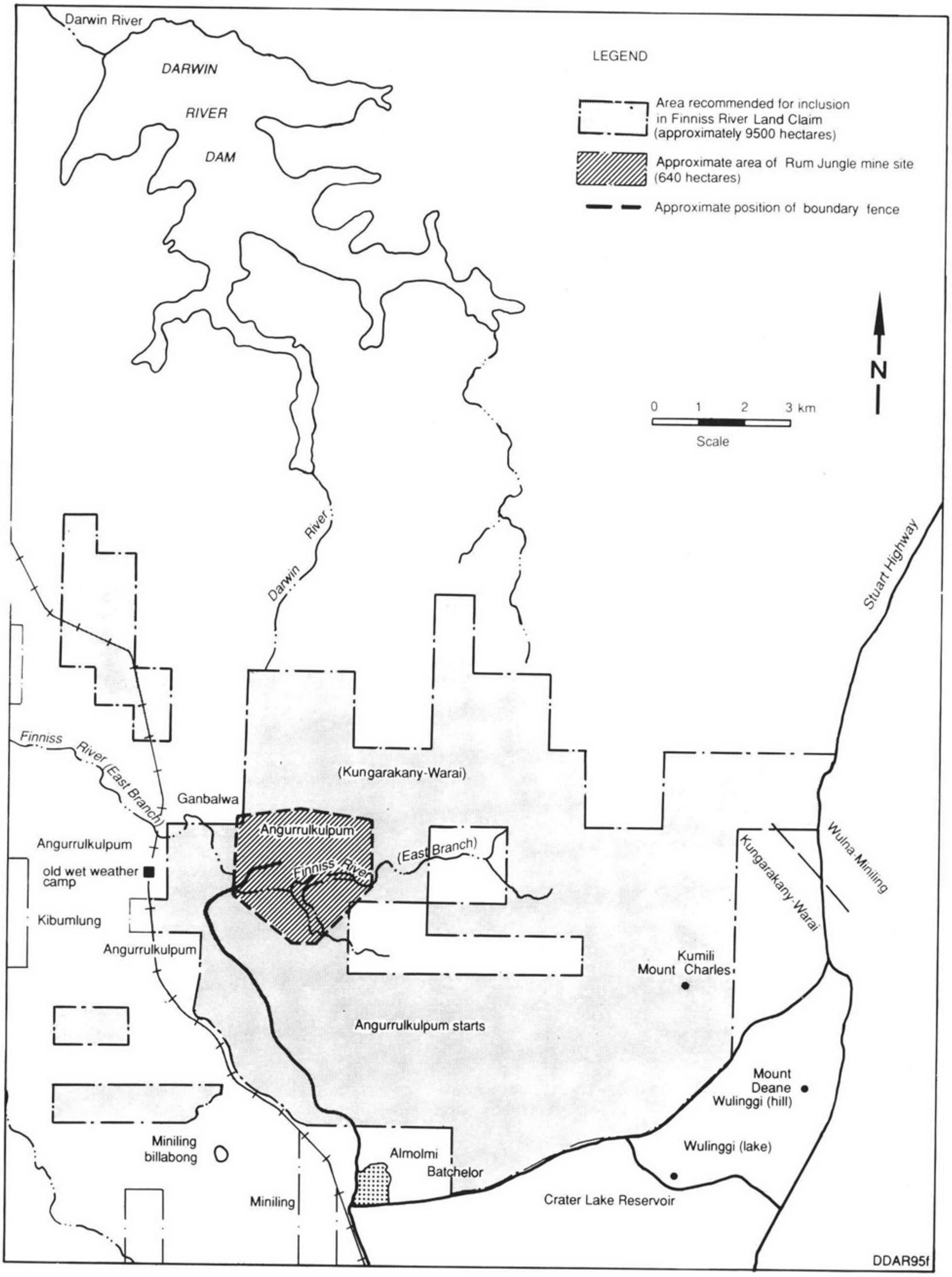

Figure 11.1 Finniss River land claim 'Area 4'

Conditions of Grant

The Department of Aboriginal Affairs (DAA) were advised in 1985 of the following preliminary conditions to be attached to the grant, to safeguard Commonwealth/NT interests:

(i) adequate rights to complete works covered by the Rum Jungle Agreement, and to carry out any further rehabilitation work which may be deemed necessary;

(ii) rights of access to carry out environmental monitoring and any remedial work; and,

(iii) restraints as necessary in land management and usage consistent with public health and environmental protection requirements (including protection and maintenance of the integrity of the rehabilitation work).

Other identified conditions included:

(i) rights of access restricted to authorised personnel during the life of the rehabilitation program;

(ii) rights to erect and maintain prominent long-standing markers with relevant information engraved thereon;

(iii) endorsement of appropriate Rum Jungle site information (irrespective of ownership) on local and national land survey plans and title deeds and placement of covenants on future land use;

(iv) indemnity against liability on the part of the NT or Commonwealth arising from previous use of the site; and,

(v) rights to apply and vary land use restrictions and management controls.

In addition to the above conditions, the land use restrictions listed in Morison's paper (1985) were agreed to as appropriate for further advice to DAA on site management controls:

. Restriction of activity on waste containment sites and overburden covers so that damage does not result.

. Restriction on the use of open cut pit water if unfit for recreation following treatment.

. Restriction on flora intrusion to those varieties which would be unlikely to damage the rehabilitation works.

. Restriction on access of fauna to those types which would be unlikely to damage the rehabilitation works.

. Restriction of mining operations to those consistent with agreed site management requirements.

. Restriction of tourism/recreation activities consistent with determined site management controls.

11.3 LAND USES AND RESTRICTIONS

11.3.1 CONSTRAINTS

As indicated in Section 11.2 and in the Final Project Report (Allen & Verhoeven 1986), the long term effectiveness of the rehabilitation measures depends on the integrity of the works. Whilst these works have been designed to withstand the impact of animals and a wide range of weather conditions, their integrity could be compromised as a result of human activities.

In particular, the integrity of the above-ground structures can only be maintained if their impervious covers are not breached. The Liaison Committee (Morison 1985) stated that there should be no activity permitted on waste containment sites or other areas where the resulting mechanical action could accelerate the removal of soil covers and the reviewed release of containment material. These areas are located throughout the site and include White's, Intermediate and Dyson's Overburden Heap, the infilled Dyson's Open Cut, rehabilitated slopes and earth banks (Figure 11.2). In addition, the banks and beds of watercourses, channels and dams should be protected.

Turning to the open cuts, the objective in the Agreement was to reduce pollution. This was interpreted by the Liaison Committee to mean that, after treatment, the water in the open cuts should be of a quality suitable for recreational use (Morison 1985). Following completion of water treatment, the East Branch of the Finniss River was rediverted through the open cuts as described in the Final Project Report (Allen & Verhoeven 1986). Thus at the end of each wet season the water quality in the upper layers of the pits is of riverine quality. However, the behaviour of the water bodies is complex. Water quality changes seasonally and with depth, responding alternately to the impact of groundwater hydrology and surface water mixing. At this stage there is insufficient information to develop a sound policy on the use of the open cuts.

11.3.2 TOURISM/RESEARCH

Public awareness, general educational interest, and research (both national and international) interest in the site are high, and will continue to be so for a number of years. Whilst limited supervised public access is considered to be an important part of site management, unsupervised access is not recommended at any stage as this will result in damage from vehicles with resulting soil erosion.

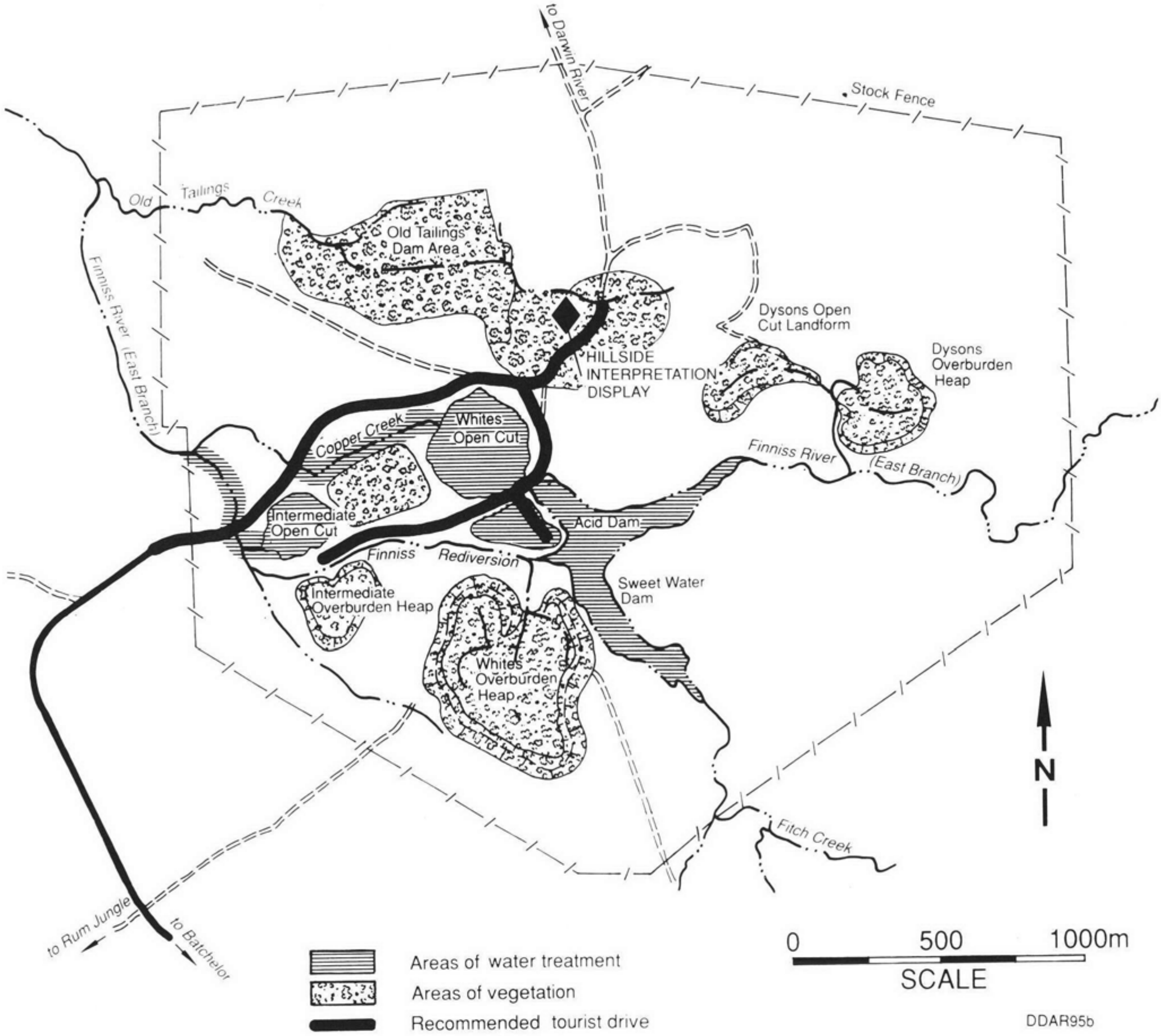

Figure 11.2 Site plan after completion of rehabilitation

Access should cater for two groups:

(i) The public, including tour groups and school children. An offer was made in 1987 by the Batchelor-Adelaide River Tourism Development Association to conduct guided tours. This offer has recently been restated to the CCNT. Such an arrangement has the advantages of:

- Guided, restricted access with tight control on areas inspected.
- Minimal maintenance costs associated with public access.
- A local sense of responsibility for the upkeep of the site, helping in site management.
- Generation of income to help the local community and to help maintain the major access roads.

Figure 11.2 shows possible tour areas. (The cost of construction of the proposed hillside interpretation display should be negotiated with the Commonwealth this year). This route is used for current tours arranged through PAWA.

(ii) Researchers (both national and international) with a bona-fide interest in the site. These could have less restrictive access to the site, with written authorisation from a delegated officer of CCNT. At present such 'do it yourself' access is arranged through PAWA; it has proven a successful working arrangement.

11.3.3 GRAZING

Maintenance of the stock proof fence erected around the mine site area should serve to control its use by animals. The earlier (Morison 1985) recommendations of the Liaison Committee have been modified with time as vegetation has become established. Fauna in the area should be restricted generally to those types which would be unlikely to damage the rehabilitation works. While it is almost impossible to exclude buffaloes totally, their numbers on site should be kept to a minimum, both now and in the future.

11.3.4 MINING

A number of companies hold mining and exploration rights within the region. However, within the boundaries of the site there are no current mining leases. The site is covered by an exploration licence application (EL 4880).

If a mining operation was to be undertaken the NT would need to ensure that such operations were consistent with agreed site management requirements as well as with normal requirements under NT Government mining regulations. Associated rehabilitation measures are a matter for the NT Government and the companies.

11.3.5 OTHER LAND USES

The above described uses of the site take into account the site constraints, community requirements and the costs of managing the site for the specified uses.

Similarly, future land uses (for example using the pastures as a source of mulching hay) will need to be considered on the basis of:

(i) the site constraints identified in Section 11.3.1; or restated, what the land surface is capable of withstanding without detriment; and,

(ii) the overall costs of ongoing site management.

11.4 MONITORING

Results of the monitoring program show that as an indicator of short term success the objectives as set out in the agreement appear to have been achieved. While pollution still exists, it is important to emphasise that the rehabilitation works were never intended or expected to eliminate all of the pollution sources. Minor sources will remain, but the effect will be very small by comparison with that prior to rehabilitation (Allen & Verhoeven 1986).

However, there are two areas of concern:

(i) The four wet seasons during and after rehabilitation (1984/85 to 1987/88) have all been of below average rainfall and run off. Total annual run off in the East Branch of the Finniss River in each year has been approximately one third that of the median annual flow. As a consequence, the rehabilitation works have not been sufficiently stressed by an average or above average wet season to enable analysis of the long term behaviour of the works.

(ii) The environmental response to the rehabilitation of some elements on site has predictably been relatively slow. The longer term effects on groundwater hydrology and water quality of the open cuts, for example, cannot yet be quantified.

When examining the question of the need for and scope of further monitoring, it was considered important to separate the monitoring required to verify the continuing success and integrity of the rehabilitation works from monitoring required for other research purposes (using the site as a laboratory to monitor population dynamics, slope stability, etc).

Monitoring to date has tended to extend over the whole site, and at relatively frequent intervals in time. The Monitoring committee has identified key indicators to obtain an early warning of negative changes/trends on site, and has redefined sampling frequencies.

The recommended monitoring program includes:

(i) Monitor Water Quality of the East Branch of the Finniss River

This is required in order to safeguard the water resources of the Finniss River system. The change in the water quality of the river is the prime indicator of the effects of rehabilitation measures adopted under the Agreement.

The current extensive surface water monitoring program over the site is to be markedly reduced to the measurement of water quantity and chemical quality at one gauge station GS 8150097 downstream of the main site. To further reduce costs, daily grab samples are to be taken using the installed automatic sampler, with the station visited only every 24 days to change the carousel. Samples are to be analysed for Specific Conductance, pH, Copper, Manganese, Zinc and Sulphate.

Rainfall information should be collected on site so that streamflow and pollution levels can be related to storm intensity and duration, and to the seasonal total. The rainfall monitoring network is to be cut back to the operation of one pluviometer R815205 located at Whites Overburden Heap. Rainfall information thus collected can also be used by other monitoring agencies in their studies:

(i) Australian Nuclear Science and Technology Organisation (Ansto) monitoring water balance in the overburden heaps, and groundwater behaviour.

(ii) CCNT monitoring vegetation, drainage and erosion.

The implementing agency PAWA has estimated the total cost of the above to be $17,500 per annum (including salaries). While it is intended that this work be carried out for five years to 1993, the work proposed should be reviewed annually against results obtained.

(ii) Monitor Water Quality and Temperature Profiles in Whites and Intermediate Open Cuts

Monitoring to date has shown complex behaviour of water quality in the open cuts, seasonally and with depth. Further monitoring is required to assess the long term quality stability of the open cut pits.

The frequency of monitoring can be reduced from weekly to half yearly. Sampling runs should be made toward the end of the wet season, and at the end of the dry season, with water quality at its best and worst respectively. Monitoring is required in 1988/89, to help assess long term stability. Beyond that, no monitoring is required until a wet season of average or above average rainfall and streamflow is experienced. Sampling runs for that year should then be made toward the end of the wet season, and at the end of the dry season.

For each sampling run, water samples should be collected at two metre intervals, and analysed for Specific Conductance, pH, Copper, Manganese, Zinc, Sulphate, Dissolved Oxygen and Temperature.

The implementing agency PAWA has estimate the cost of this work to be $6,400 per annum, for two years.

(iii) Monitor the Water Balance and Chemical Activity of Whites and Intermediate Overburden Heaps

This is required to confirm long term trends for chemical activity and groundwater pollution. Programs include:

Water balance. Lysimeters, rainfall data (from PAWA), groundwater monitoring bores. Water levels and quality are currently measured in 83 bores. This can be reduced to field measurement of water level, Specific Conductance and pH in 16 bores (four on Whites Overburden Heap and 12 surrounding it) with complete chemical analysis of water from five of these bores. Sampling should be carried out in November, February and April each year.
Chemical activity. Measurement of oxygen, moisture content and temperature within the heaps. The frequency of monitoring can be safely reduced from quarterly to half yearly for the two years 1988/89 and 1989/90, and thereafter to once annually.

The implementing agency is Ansto; the estimated cost of the above chemical activity and lysimeter monitoring is $6,000 per monitoring trip (excluding salaries). The PAWA are able to carry out bore monitoring work for Ansto at a cost of $1,200 per annum, including salaries. It is intended that this work be carried out for five years to 1993, with annual reviews of the results.

(iv) Monitor the General Integrity of the Site

This is required to confirm long term trends, and to program annual preventative maintenance requirements.

One annual visual inspection (recorded with photographs) is required at the end of the wet season to monitor vegetation condition, the introduction of weeds, erosion of cover systems and drains, streambed and embankment conditions. It also includes a visual inspection of the infill of Dysons Open Cut (renewed slumping, settlement or cracking are to be quantified by survey using the existing grid of permanent marks).

The implementing agency is CCNT; the estimated cost of the work is $1,500 per annum, including salaries. It is intended that this work be carried out for the five years to 1993.

(v) Flora and Fauna Survey

This survey was recommended to be carried out (Allen & Verhoeven 1986), five years after the completion of rehabilitation and associated programs. It is required when the above monitoring programs show there is little change to the site.

It is not intended that the extensive surveys reported by Davy (1975) be repeated. However, a fauna/flora survey of the East Branch of the Finniss River should be conducted in 1993 to establish the effects of rehabilitation. The results should be compared with relevant sections of the pre-rehabilitation survey (Davy 1975). Costs have not yet been estimated.

The above costs for various monitoring programs includes the preparation of annual reports by the three agencies. Costs are summarised in Section 11.6, Table 11.1.

The question of who funds the monitoring program should be resolved by negotiation between the Commonwealth and Northern Territory Governments. The Rum Jungle Liaison Committee noted that "In order to terminate the Agreement, it is almost a condition precedent that some arrangements be put in place relating to funding of monitoring and maintenance." Morison has previously suggested a recurring grant or annual appropriation.

11.5 MAINTENANCE

Maintenance entails considering three issues:

(i) The rehabilitation works have a minimum engineered design life of 100 years, and so a certain amount of (unquantified) deterioration is to be expected (Allen & Verhoeven 1986).

(ii) A basic amount of regular 'preventative' maintenance is required to preserve the integrity of rehabilitation (Allen & Verhoeven 1986). The maintenance program is aimed at achieving this, and meeting the minimum requirements imposed by the land use plan described in Section 11.2.

(iii) Reinstatement of damaged structures or badly eroded covers, etc resulting from unusual and/or unforeseen events. These large scale failures threaten the integrity of the rehabilitation works, and would require special, one-off attention by the Commonwealth and Northern Territory Governments.

The program of regular maintenance is to be defined as a result of the annual site inspections carried out by CCNT staff, described in Section 11.4. The maintenance program will include:

(i) Maintenance of vegetation

The two year period of maintenance to 1988 has not permitted sufficient time to ensure site revegetation to the point where maintenance fertilisation and slashing can cease. One more fertilisation is probably required in 1990 (cost $25,000), the need for this to be assessed in 1989. Slashing is still required, but can be reduced from half yearly to yearly (cost $3,000). Slashing should be carried out at the end of each wet season, after seed set. The need for slashing should be reviewed annually, for the five years to 1993.

(ii) Maintenance of rediversion works

This entails the removal of any accumulated debris from the culverts and weirs.

(iii) Fencing and fire breaks

At the end of the wet season, inspect and repair the cattleproof fences around the site and around the filter cake disposal area. Inspect and maintain the fire break around the site perimeter fence. Cost is estimated to be $500 annually. The need for this work is to be reviewed annually.

(iv) Roadworks

Inspect and repair the designated road pavements to maintain serviceability, to the standard of gravel all weather roads (cost $1,000 annually).

(v) Fauna control

On completion of repairs to fencing assess the presence of problem fauna such as feral buffalo. Eradicate from within the site if numbers become high.

(vi) Weeds

Inspect annually and keep at tolerable levels by the use of herbicides and mowing, weeds including *Hyptis sauveolens*, *Sida acuta* and *Mimosa pigra* (cost $500 in 1988/89, to be reviewed annually).

As with monitoring, the Liaison Committee has recognised the need for maintenance, with its funding being by a recurring grant or annual appropriation (Rum Jungle Liaison Committee, 1985). Costs are summarised in Section 11.6, Table 11.2.

11.6 CONCLUSIONS AND RECOMMENDATIONS

Future use of the Rum Jungle mine site is subject to determination of the Finniss River Land Claim and joint Commonwealth/Northern Territory requirements for appropriate site management.

To ensure the lasting integrity of the rehabilitation measures it is necessary to properly manage the site and to maintain the rehabilitation measures by:

. Declaring the site a Restricted Use Area as defined in Clause 20 of the <u>Soil Conservation and Land Utilisation Act 1980</u>.

. Having the site administered by the Conservation Commission of the NT.

. Implementing the land uses and restrictions described in Section 11.3.

. Monitoring agencies PAWA, Ansto and CCNT carrying out the reduced program of monitoring as described in Section 11.4.

. CCNT administering the carrying out of the 'preventative' maintenance program described in Section 11.5.

The programs for monitoring and maintenance should be reviewed annually, with the view to further reductions, and possible phasing out the monitoring by 1993.
The total costs (including salaries) are summarised in Table 11.1. Funding of the work is subject to negotiation between the Commonwealth and Northern Territory Governments.

Table 11.1 - Cost sharing for Rum Jungle monitoring and maintenance programme 1988/89 - 1992/93

	ACTIVITY	1988/89	1989/90	1990/91	1991/92	1992/93
	* MONITORING					
(i)	Water quality rainfall -					
	- salaries (P.A.W.A.)	12 300	12 300	12 300	12 300	12 300
	- operational (Commonwealth	5 200	5 200	5 200	5 200	5 200
	TOTAL	17 500	17 500	17 500	17 500	17 500
(ii)	Open Cuts					
	- salaries (P.A.W.A.)	3 400		3 400		
	- operational (Commonwealth)	3 000	--	3 000	--	--
	TOTAL	6 400		6 400		
(iii)	Overburden Heaps					
	- salaries (A.N.S.T.O.)	12 000	12 000	6 000	6 000	6 000
	(P.A.W.A.)	700	700	700	700	700
	- operational (Commonwealth)	12 500	12 500	6 500	6 500	6 500
	TOTAL	25 200	25 200	13 200	13 200	13 200
(iv)	Site Integrity					
	- salaries (C.C.N.T.)	1 000	1 000	1 000	1 000	1 000
	- operational (Commonwealth)	500	500	500	500	500
	TOTAL	1 500	1 500	1 500	1 500	1 500
(v)	Flora & Fauna Survey C.C.N.T.	--	--	--	--	To be estimated
	TOTAL MONITORING					
	- Agencies	29 400	26 000	23 400	20 000	20 000
	- Commonwealth	21 200	18 000	15 000	12 200	12 200

Table 11.1 Cont'd

ACTIVITY			1988/89	1989/90	1990/91	1991/921992/93
MAINTENANCE						
(i)	Vegetation					
	- fertilising	--	25 000	--	--	--
	- slashing	3 000	3 000	3 000	3 000	3 000
(ii)	Rediversion works	--	--	--	--	--
(iii)	Fencing and fire breaks	500	500	500	500	500
(iv)	Roadworks	1 000	1 000	1 000	1 000	1 000
(v)	Fauna control	--	--	--	--	--
(iv)	Weeds	500	?	?	?	?
TOTAL MAINTENANCE						
	- Agencies	--	--	--	--	--
	- Commonwealth	5 000	29 000	4 500	4 500	4 500
TOTAL						
	- Agencies	29 000	26 000	23 400	20 000	20 000
	- Commonwealth	26 200	47 700	19 700	16 700	16 700

* Salaries contributed by agencies (P.A.W.A, C.C.N.T., A.N.S.T.O.). Operational costs funded by Commonwealth

** All maintenance costs funded by Commonwealth.

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APPENDIX A

SURFACE WATER HYDROLOGY
(Chapter 4)

FIGURES

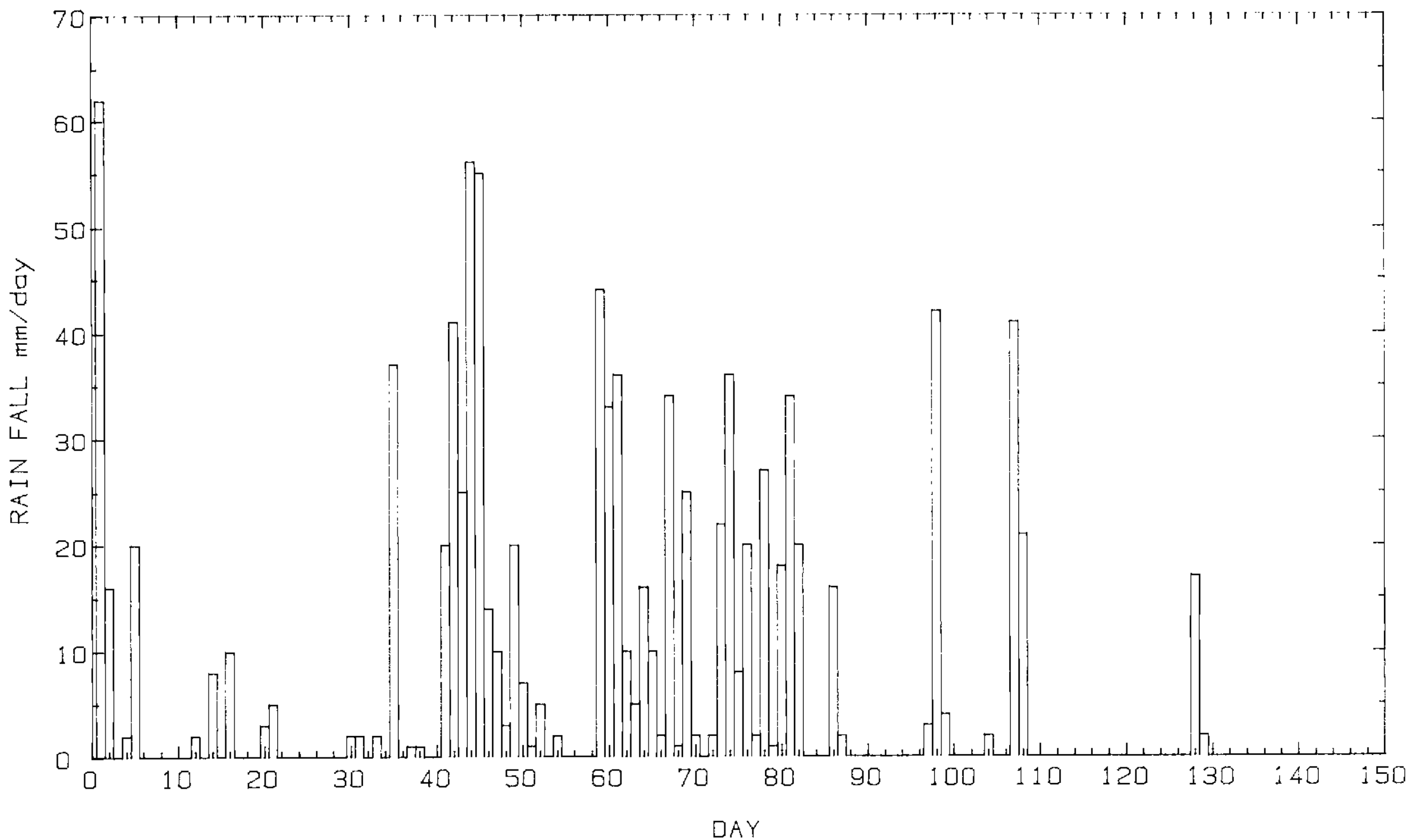

Figure 4.3 1986-87 Mine site rainfall at pluvio R815202A

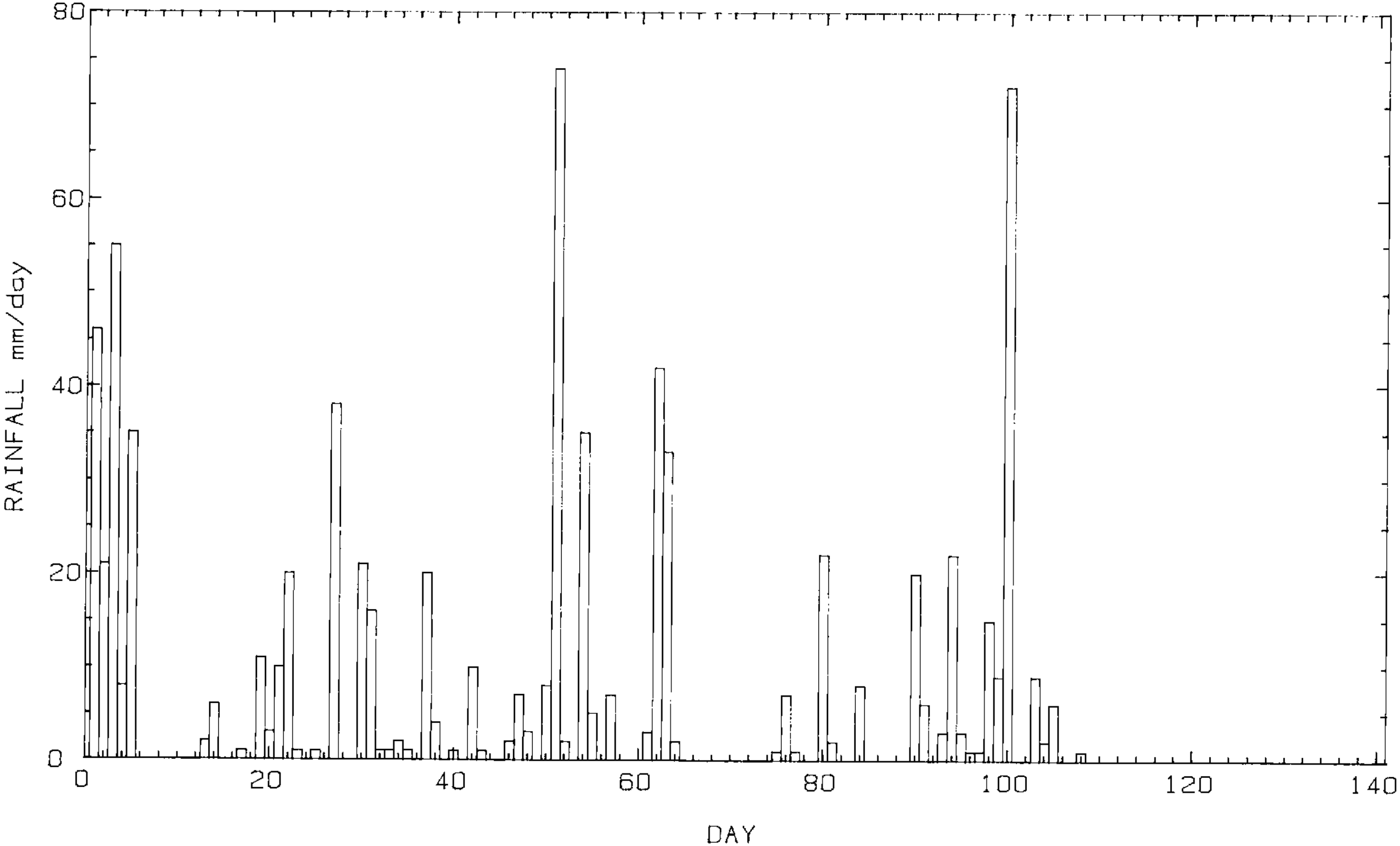

Figure 4.4 1987-88 Mine site rainfall at pluvio R815202A

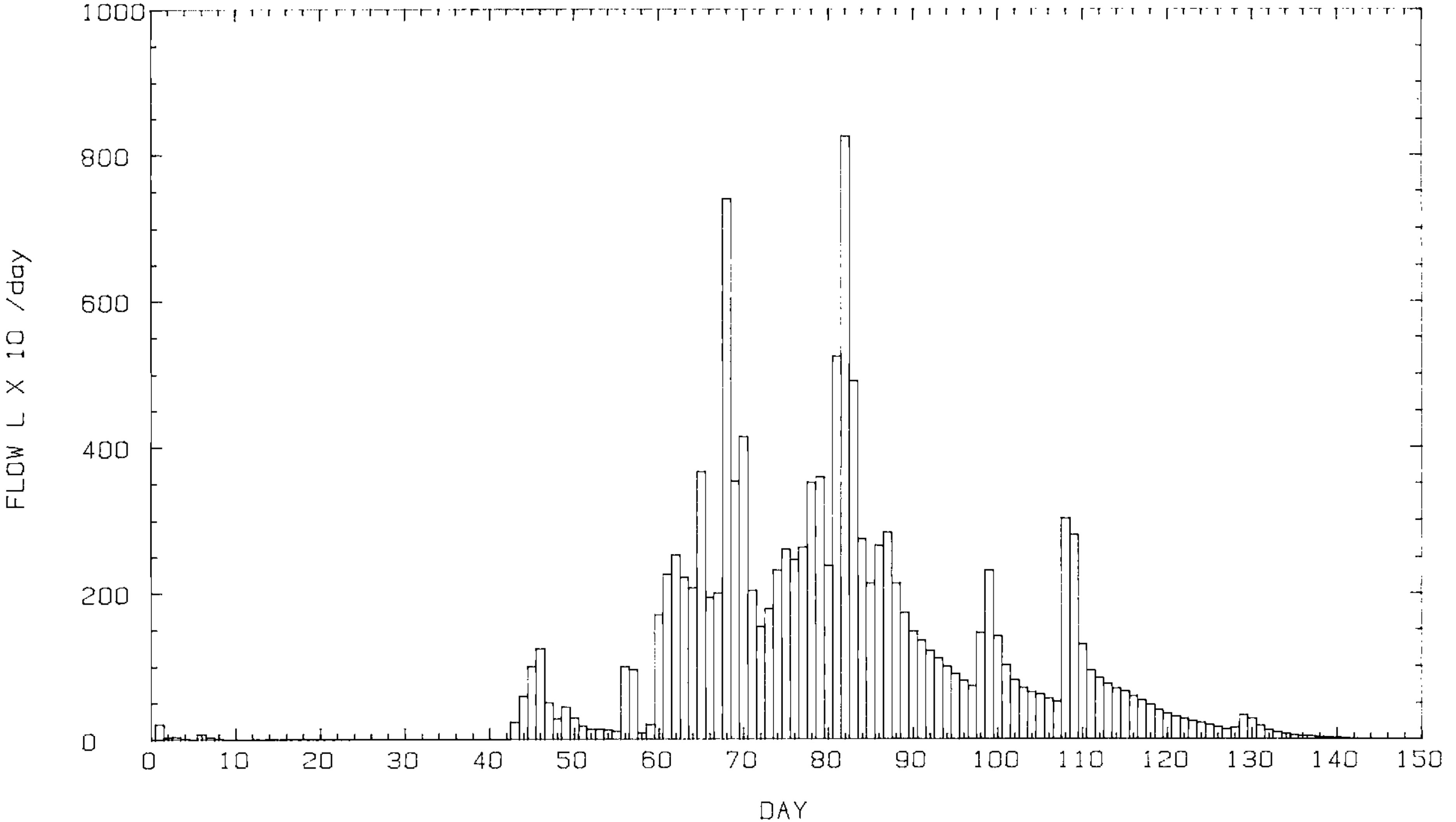

Figure 4.5 1986-87 East Finniss River flow volume at GS8150097

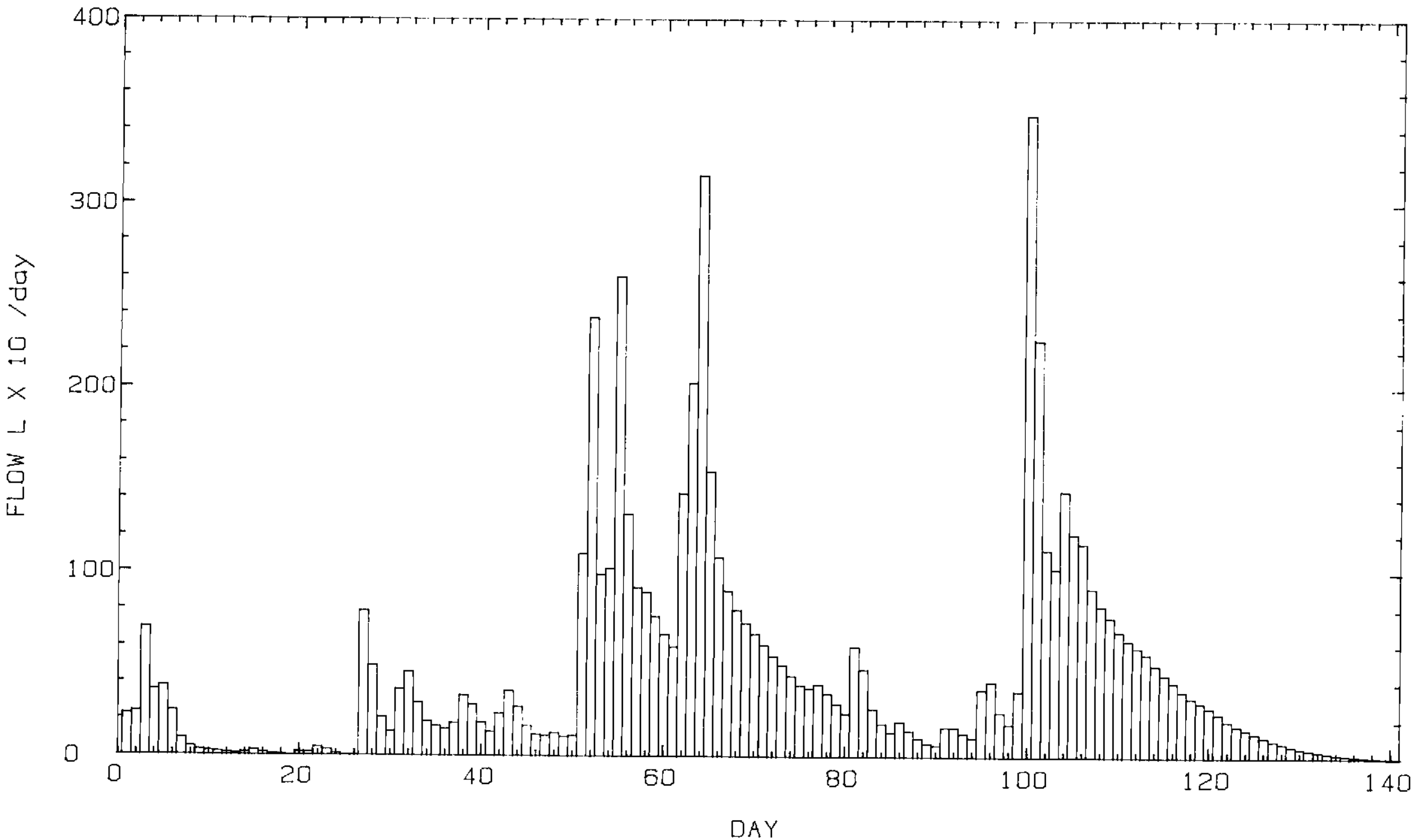

Figure 4.6 1987-88 East Finniss River flow volume at GS8150097

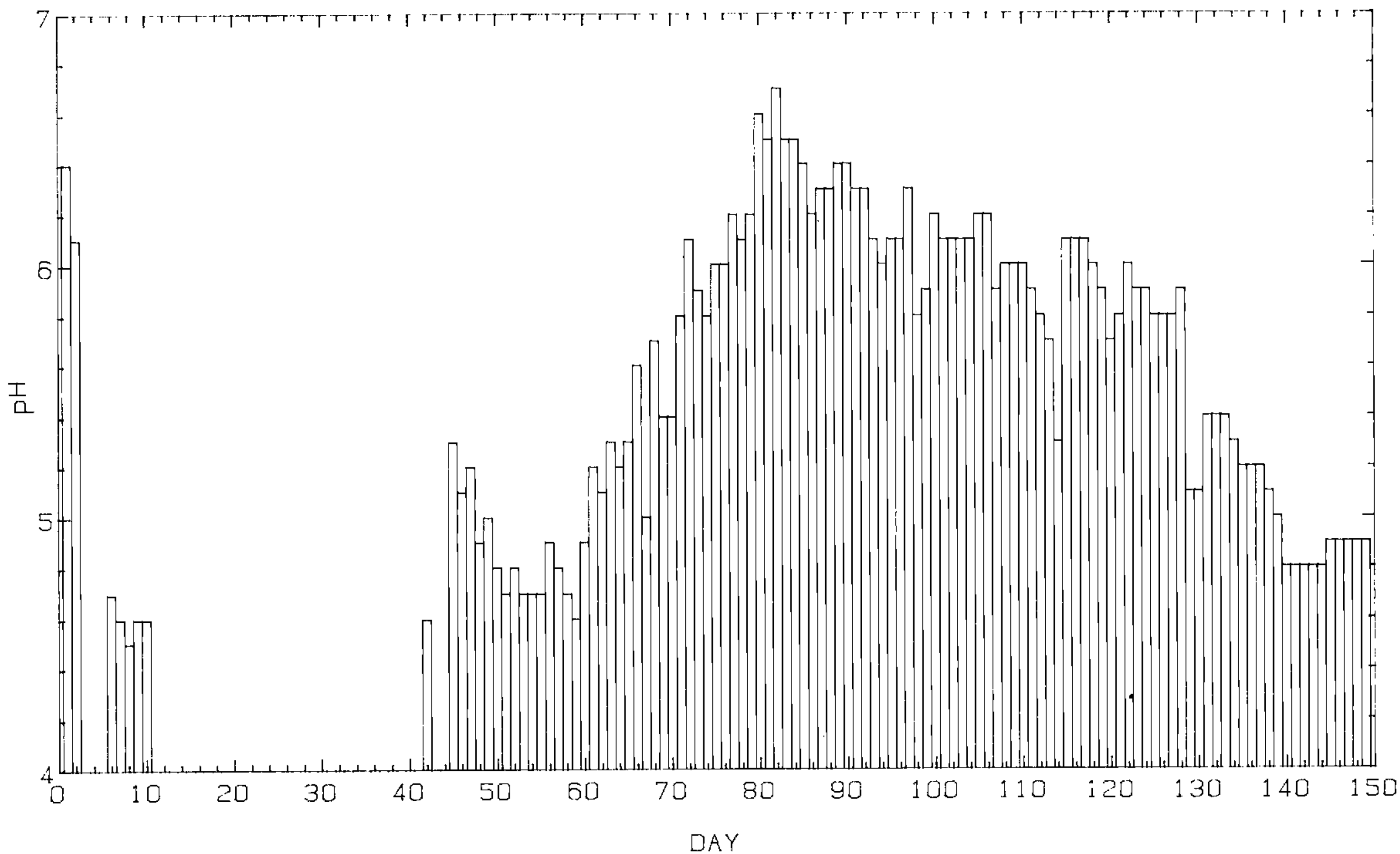

Figure 4.7 1986-87 East Finniss pH at GS8150097

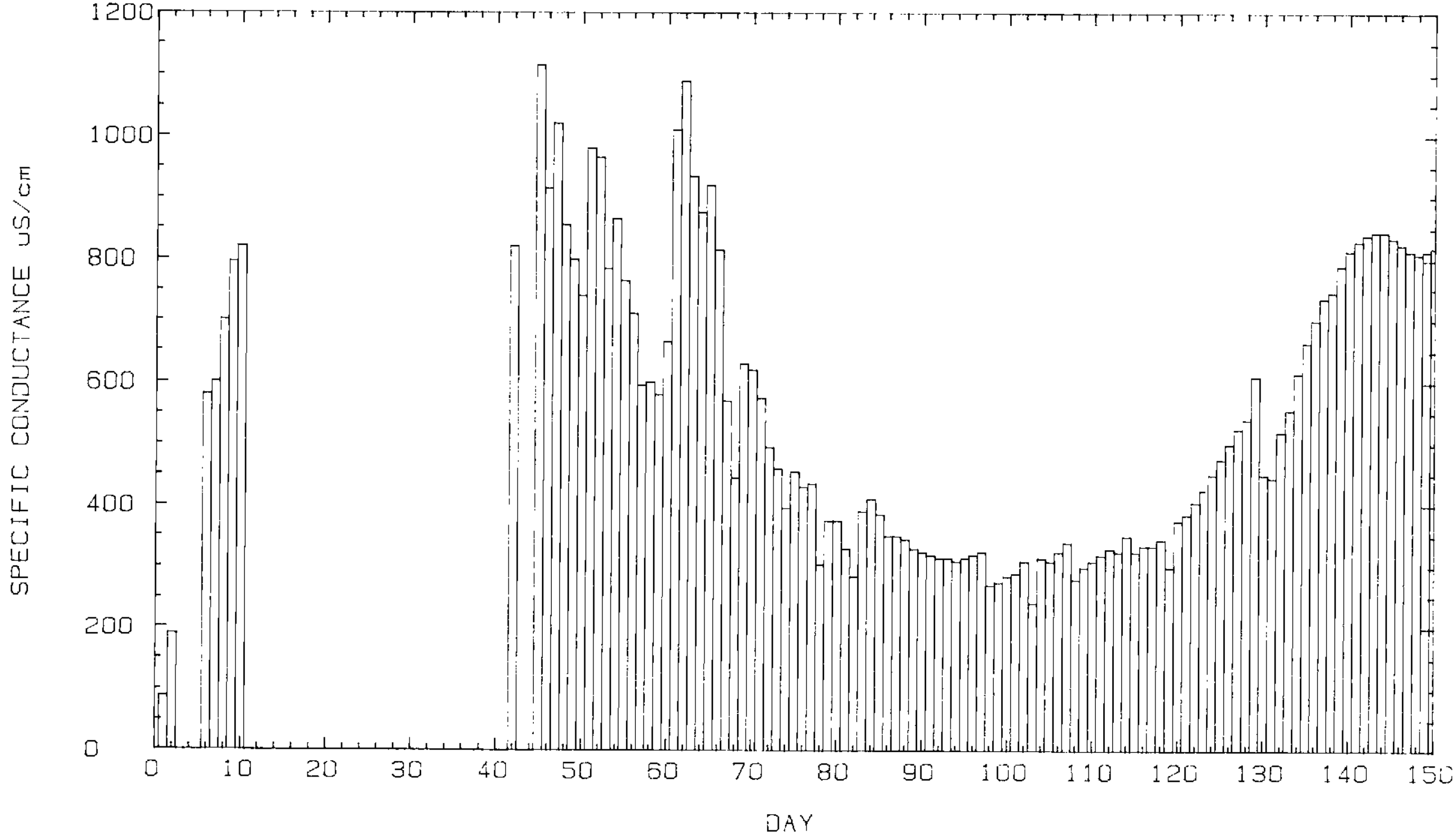

Figure 4.8 1986-87 East Finniss River specific conductance at GS8150097

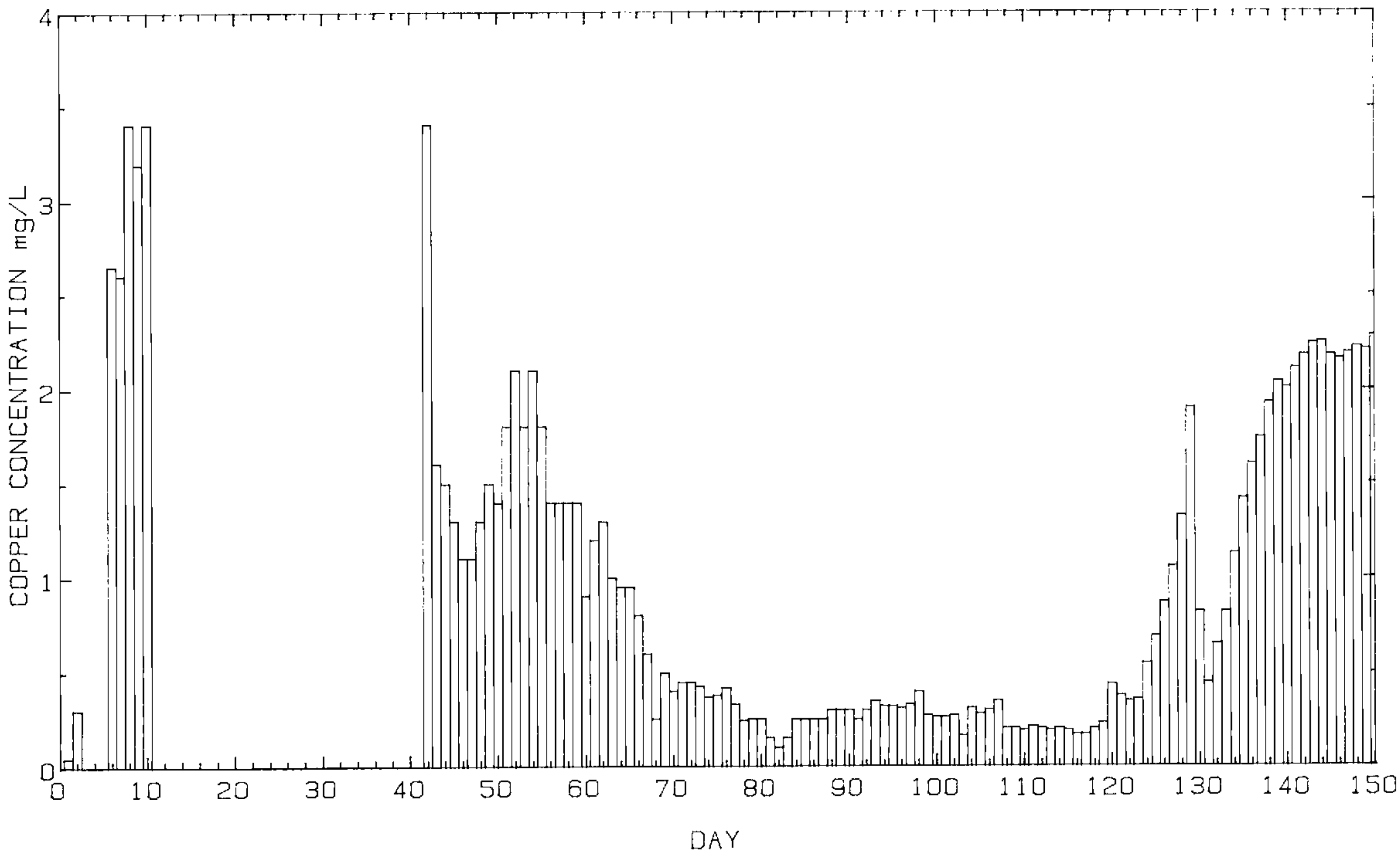

Figure 4.9 1986-87 East Finniss River copper concentration at GS8150097

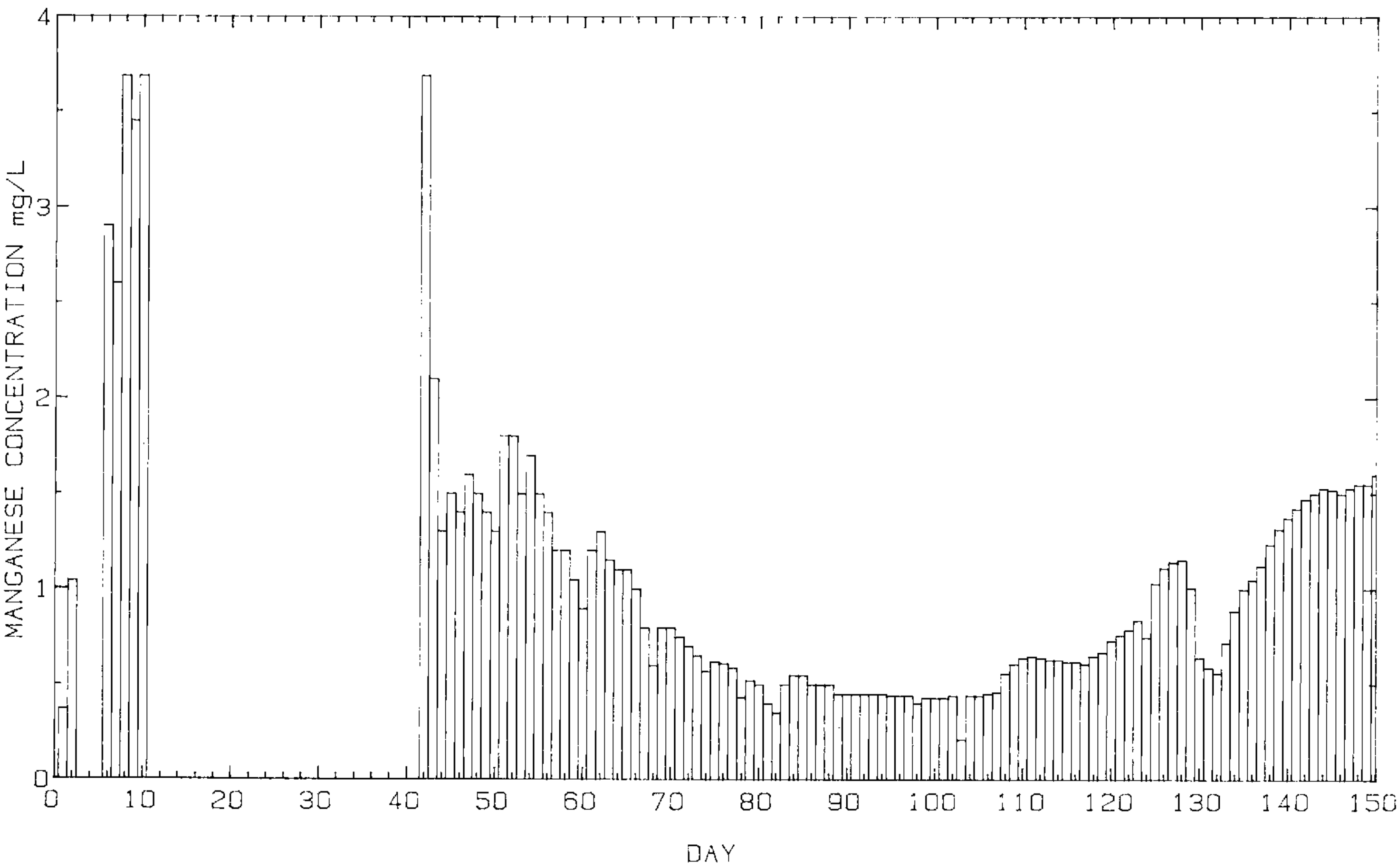

Figure 4.10 1986-87 East Finniss River manganese concentration at GS8150097

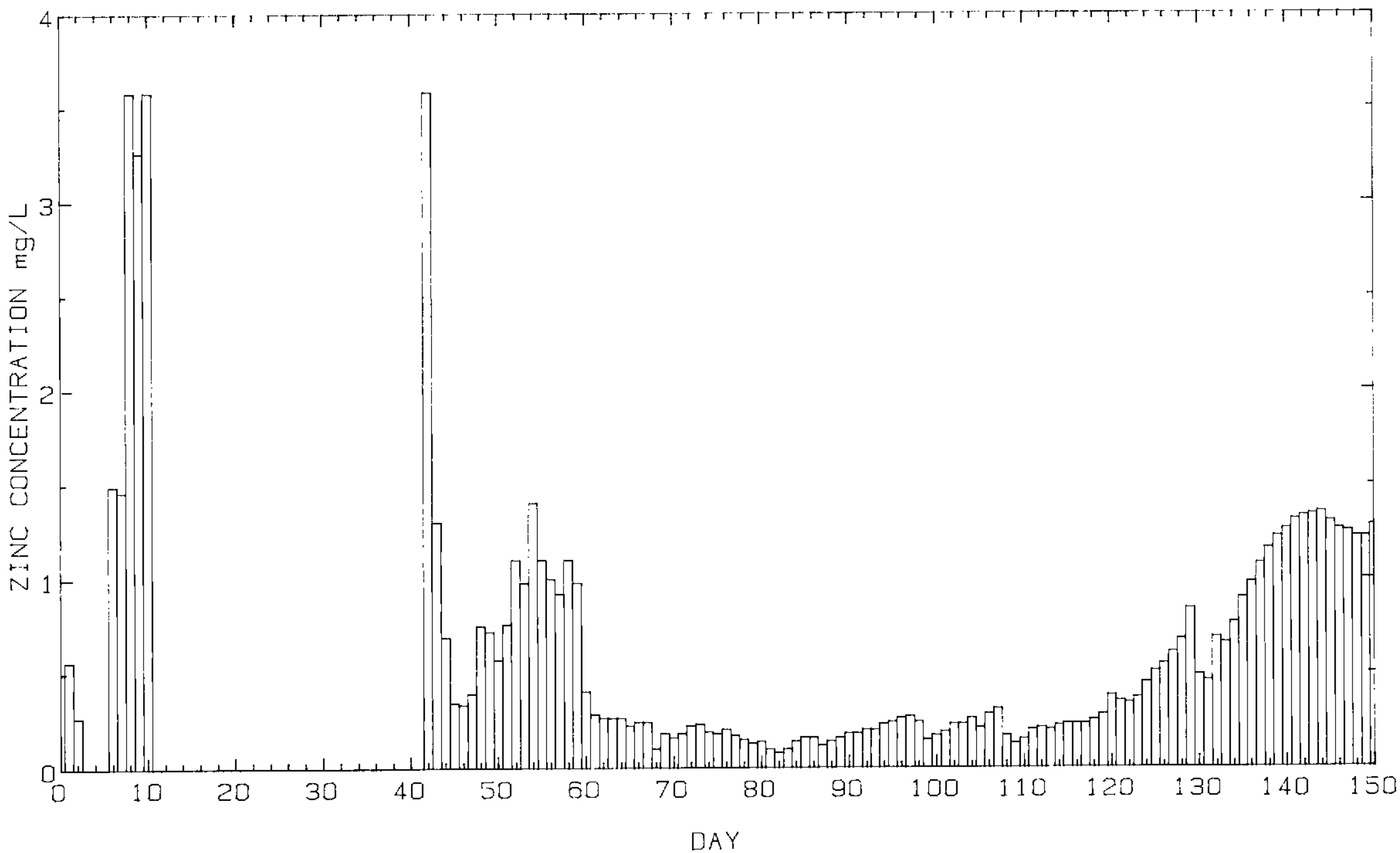

Figure 4.11 1986-87 East Finniss River zinc concentration at GS8150097

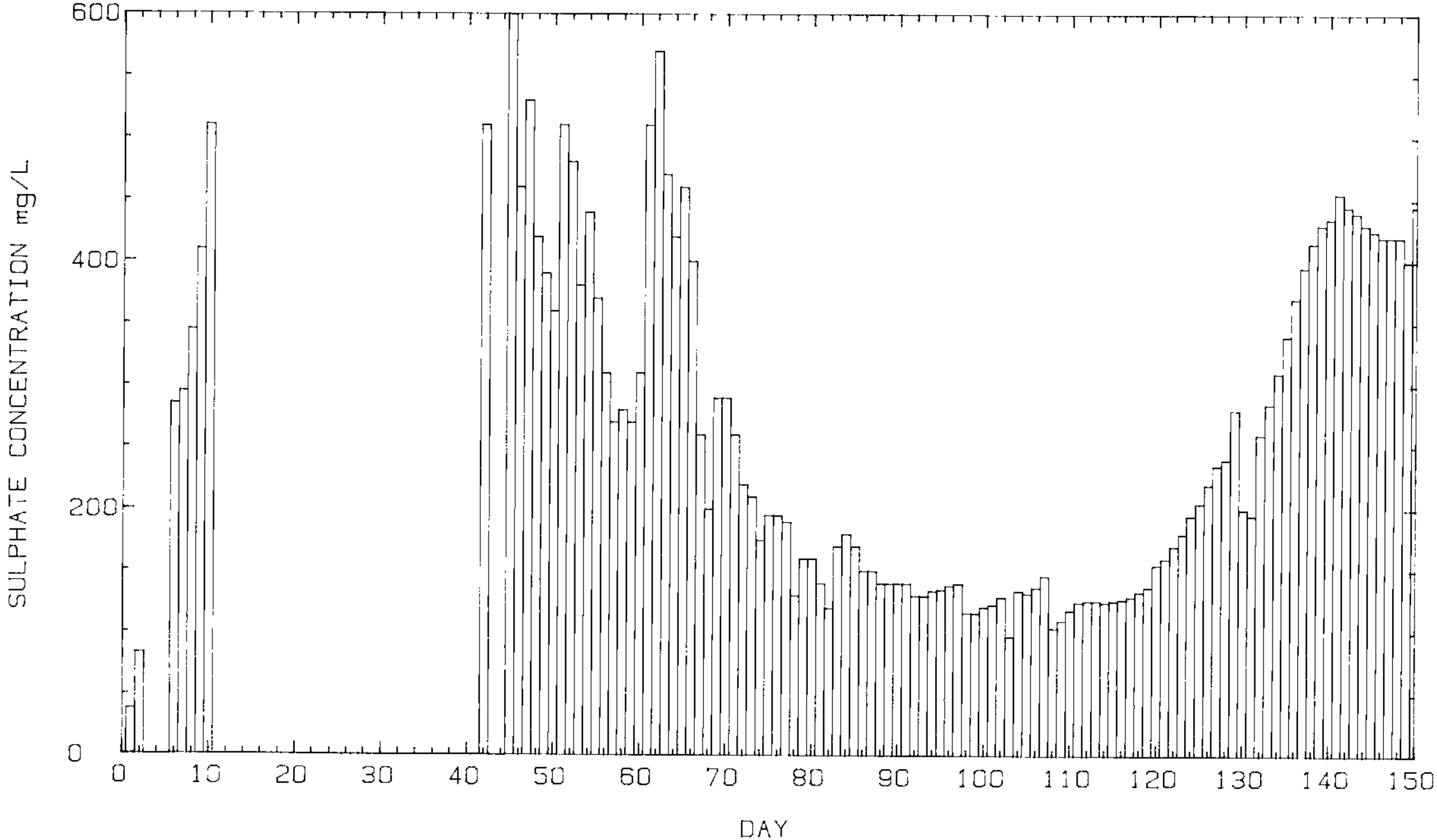

Figure 4.12 1986-87 East Finniss River sulphate concentration at GS8150097

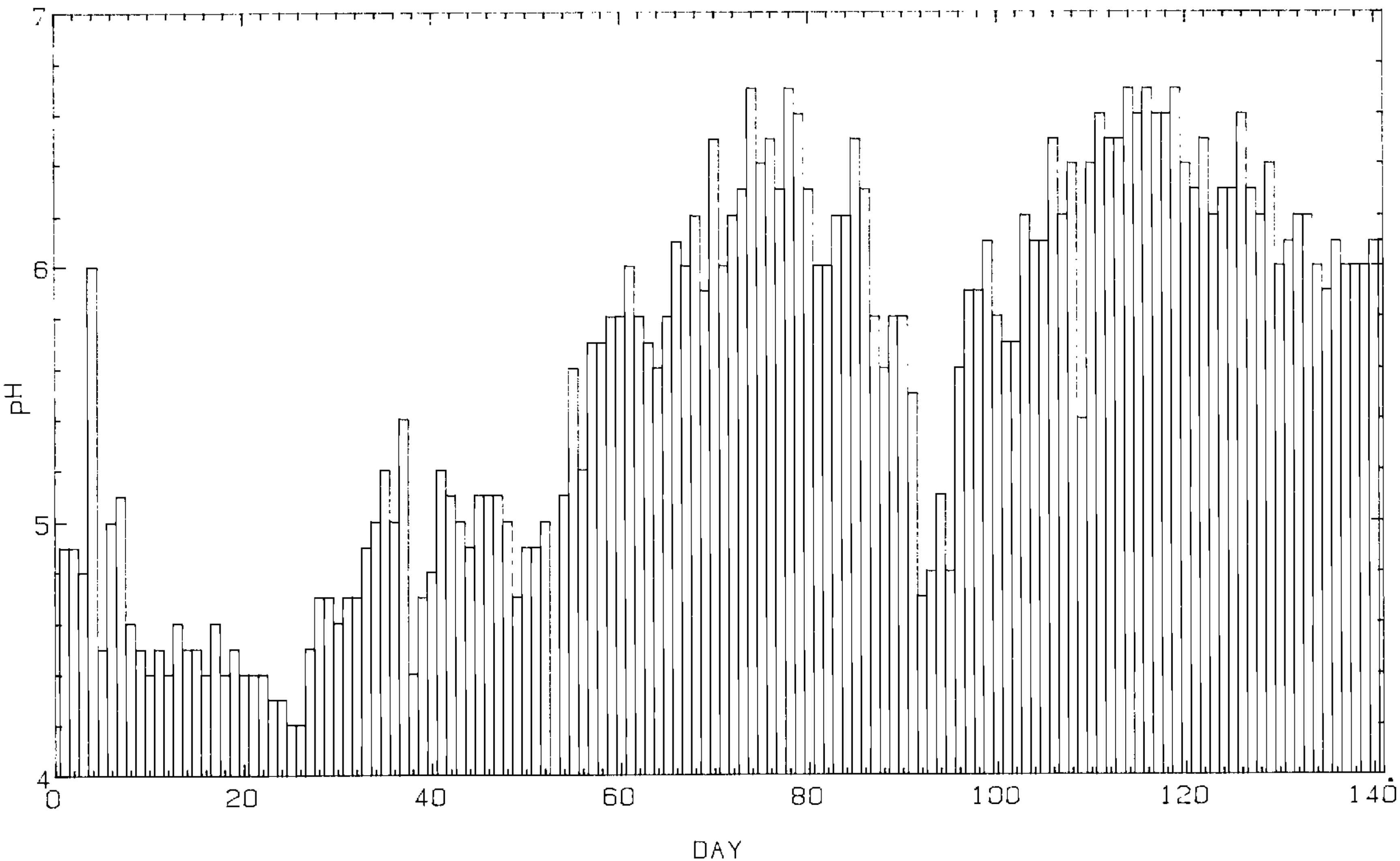

Figure 4.13 1987-88 East Finniss River pH at GS8150097

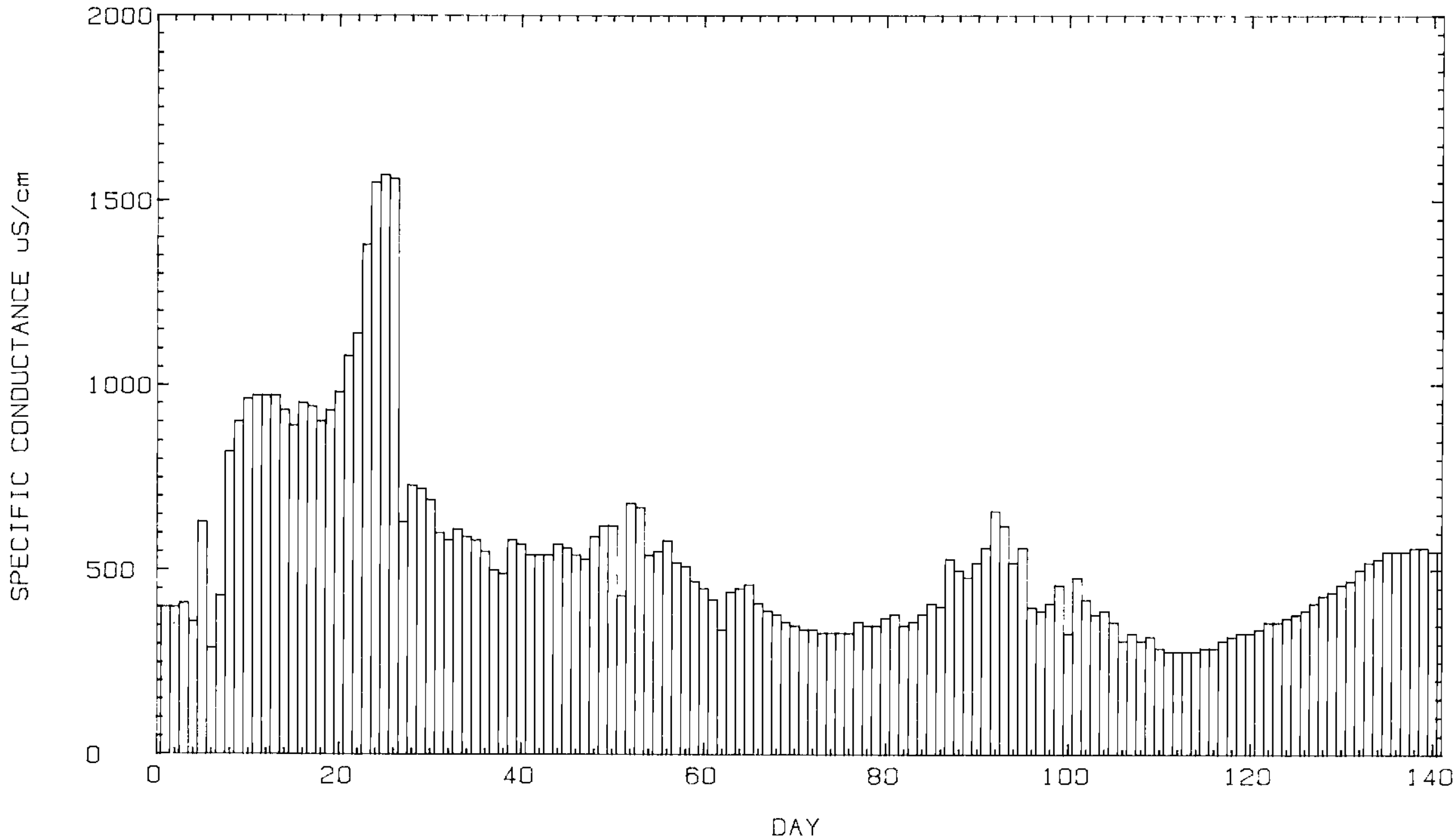

Figure 4.14 1987-88 East Finniss River specific conductance at GS8150097

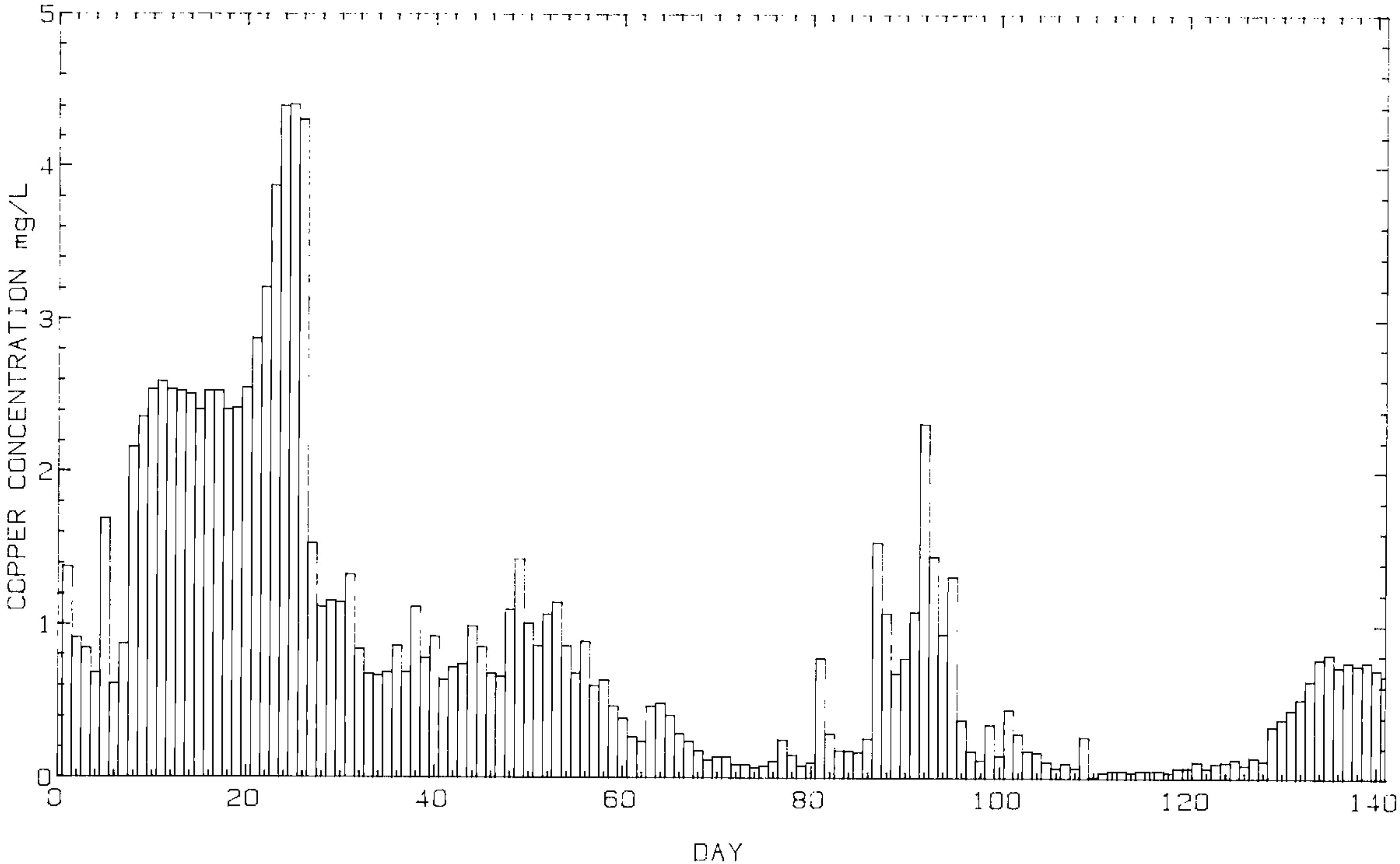

Figure 4.15 1987-88 East Finniss River copper concentration at GS8150097

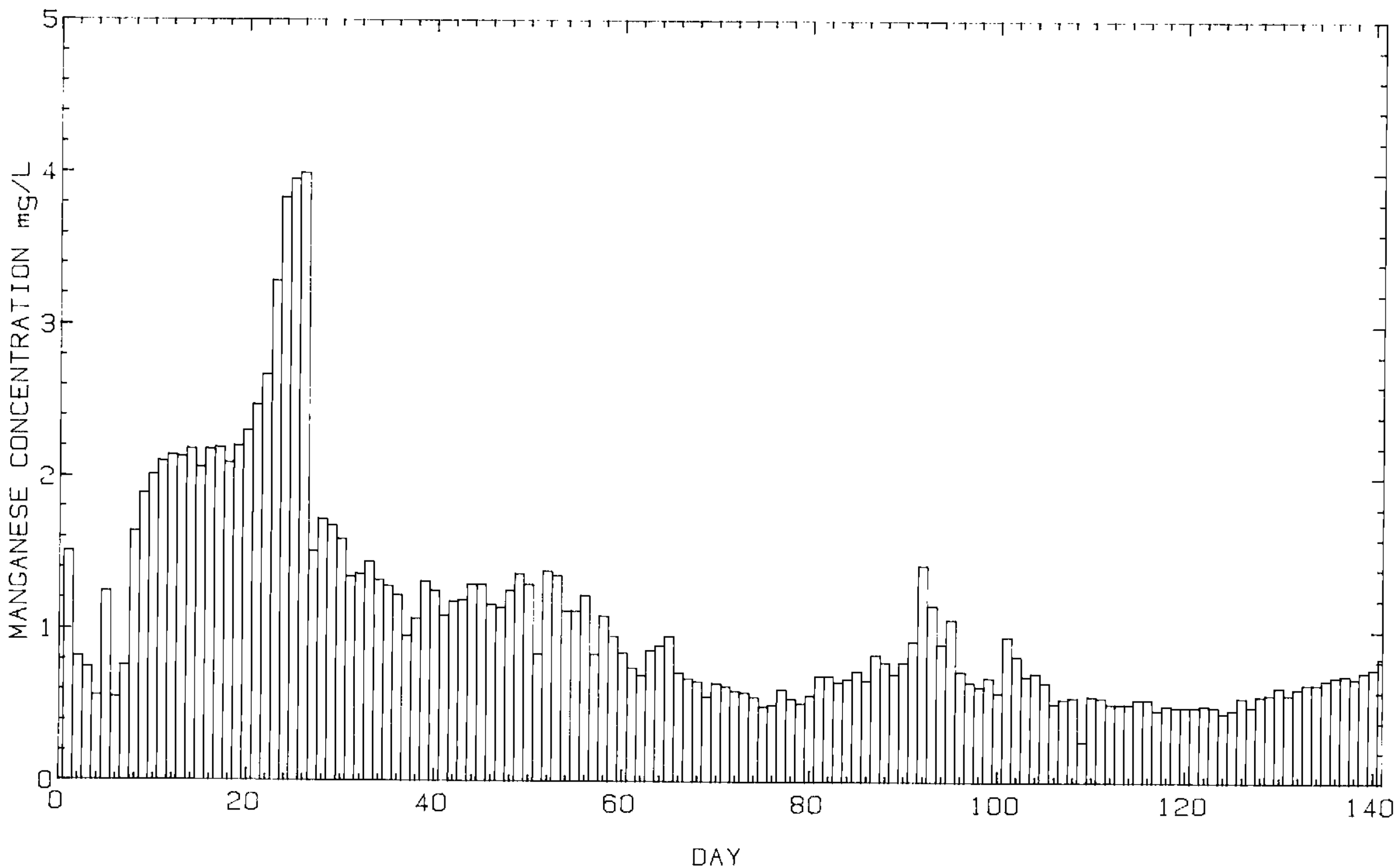

Figure 4.16 1987-88 East Finniss River manganese concentration at GS8150097

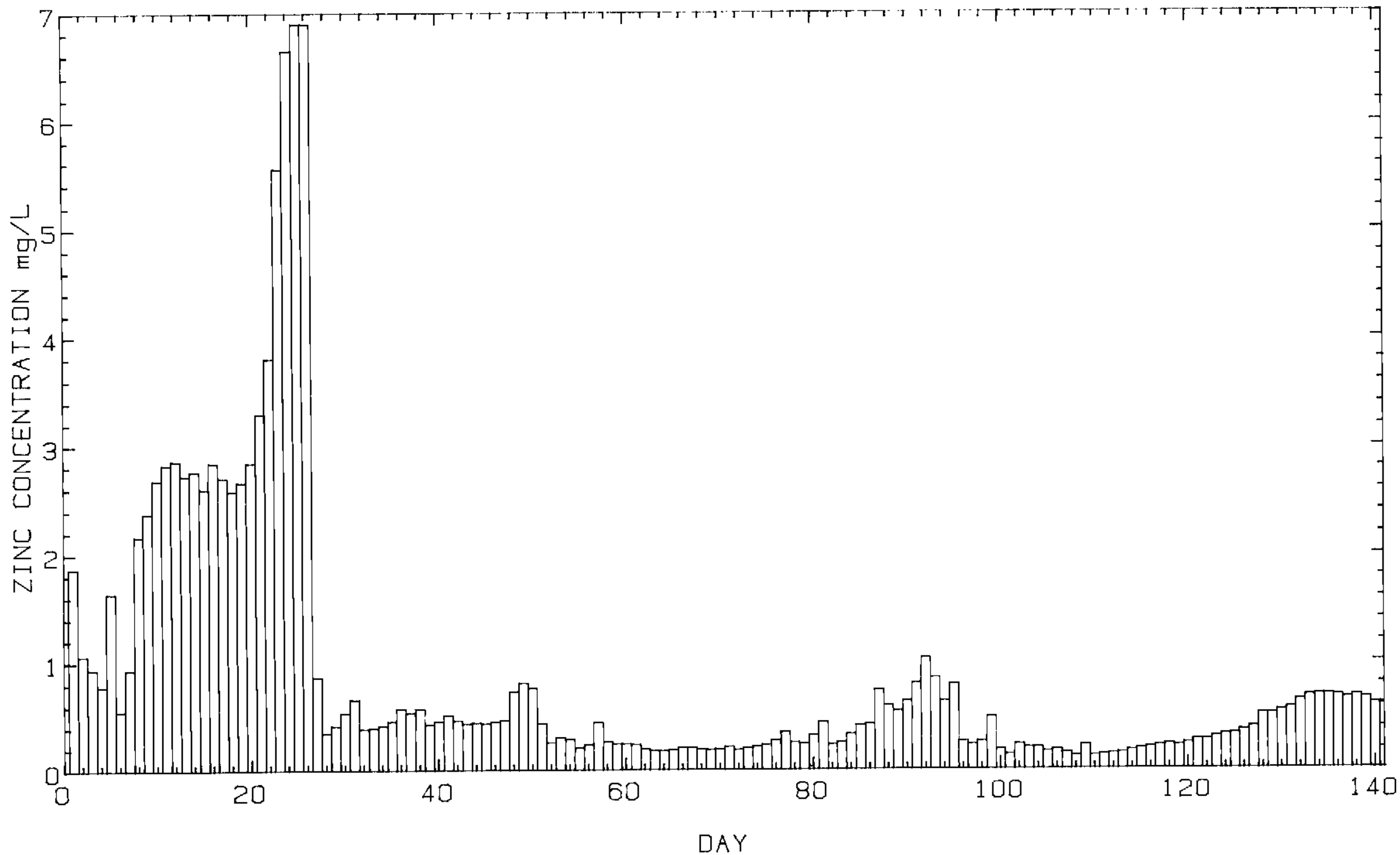

Figure 4.17 1987-88 East Finniss River zinc concentration at GS8150097

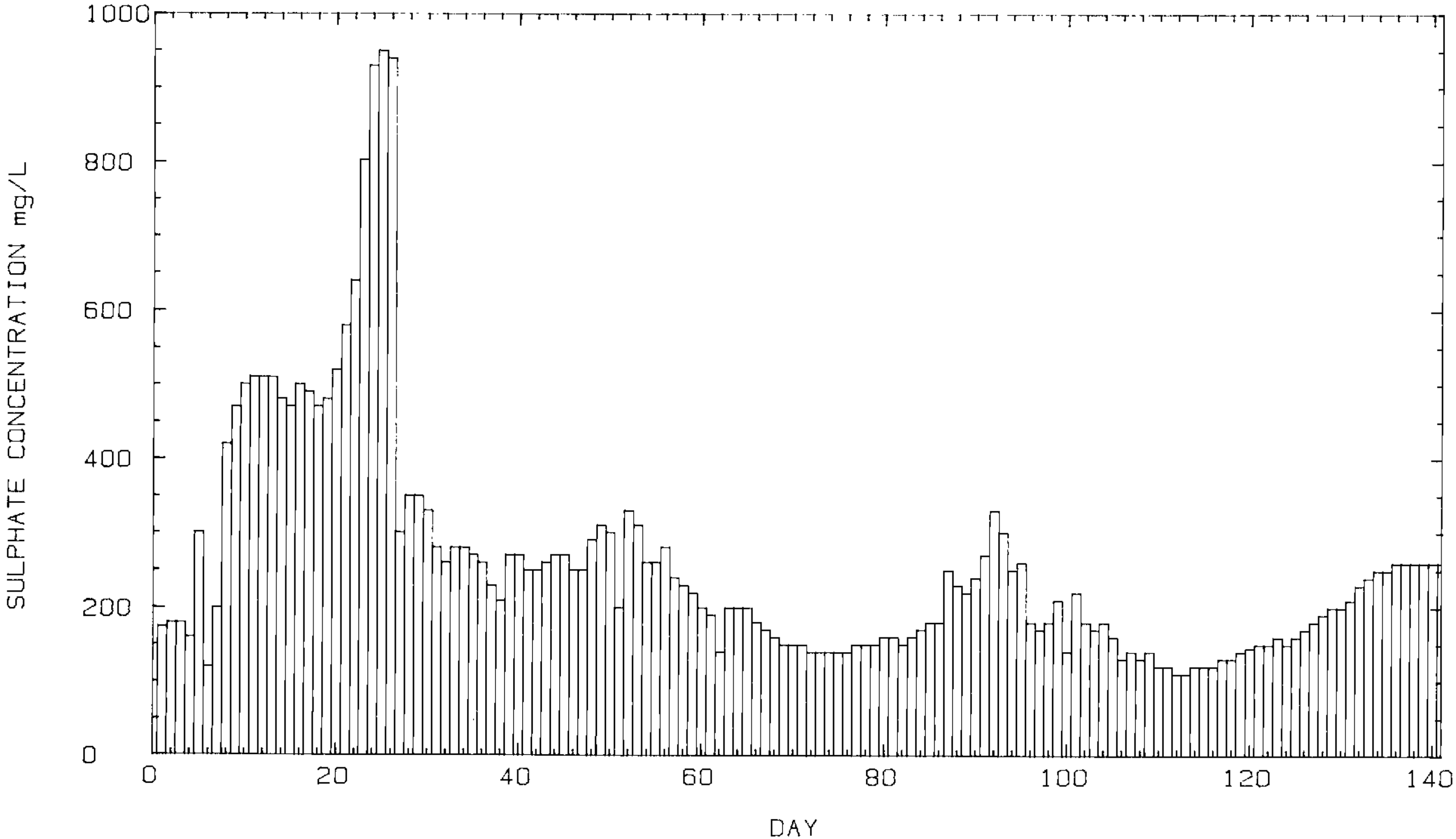

Figure 4.18 1987-88 East Finniss River sulphate concentration at GS8150097

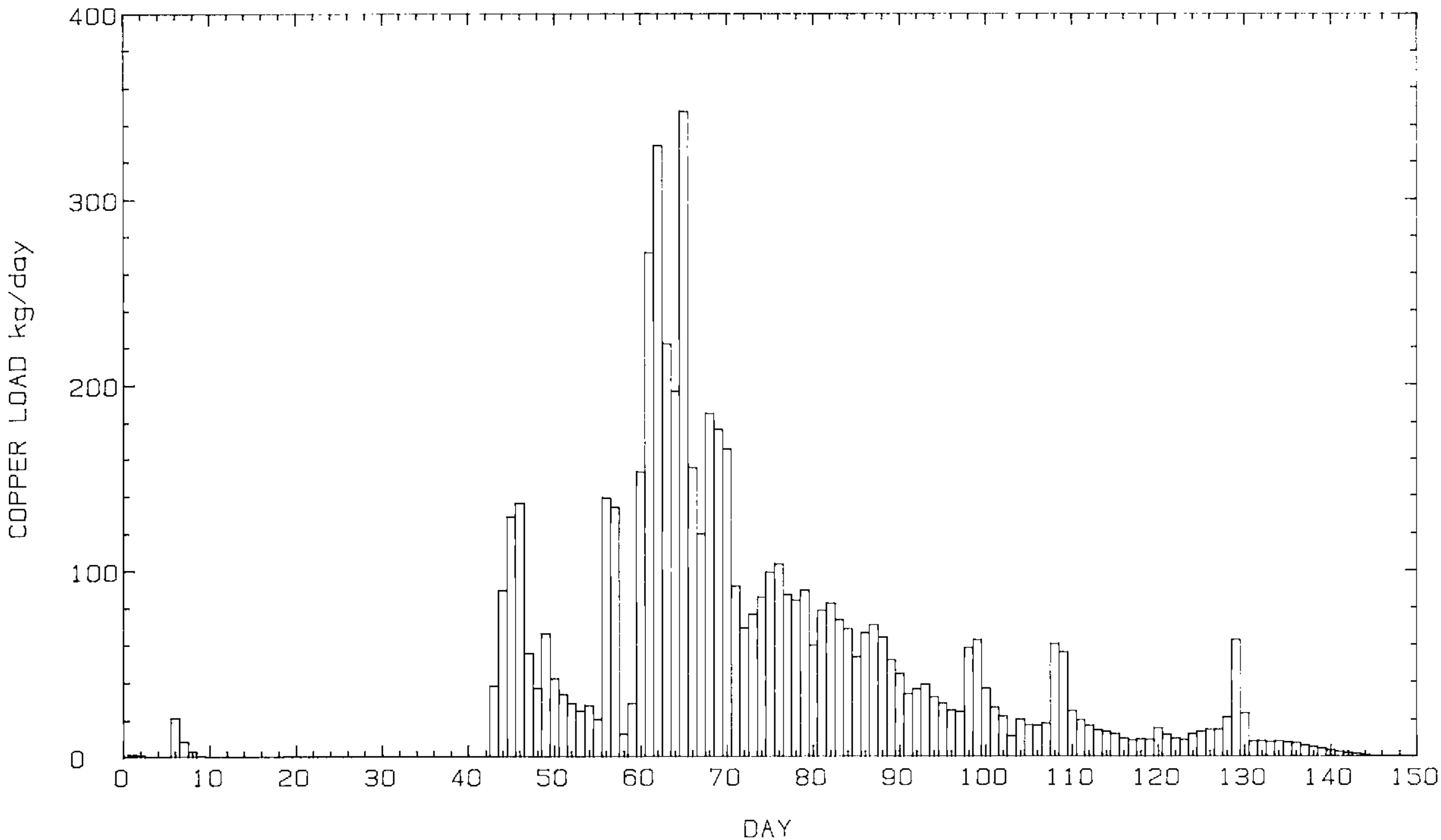

Figure 4.19 1986-87 East Finniss River copper loads at GS8150097

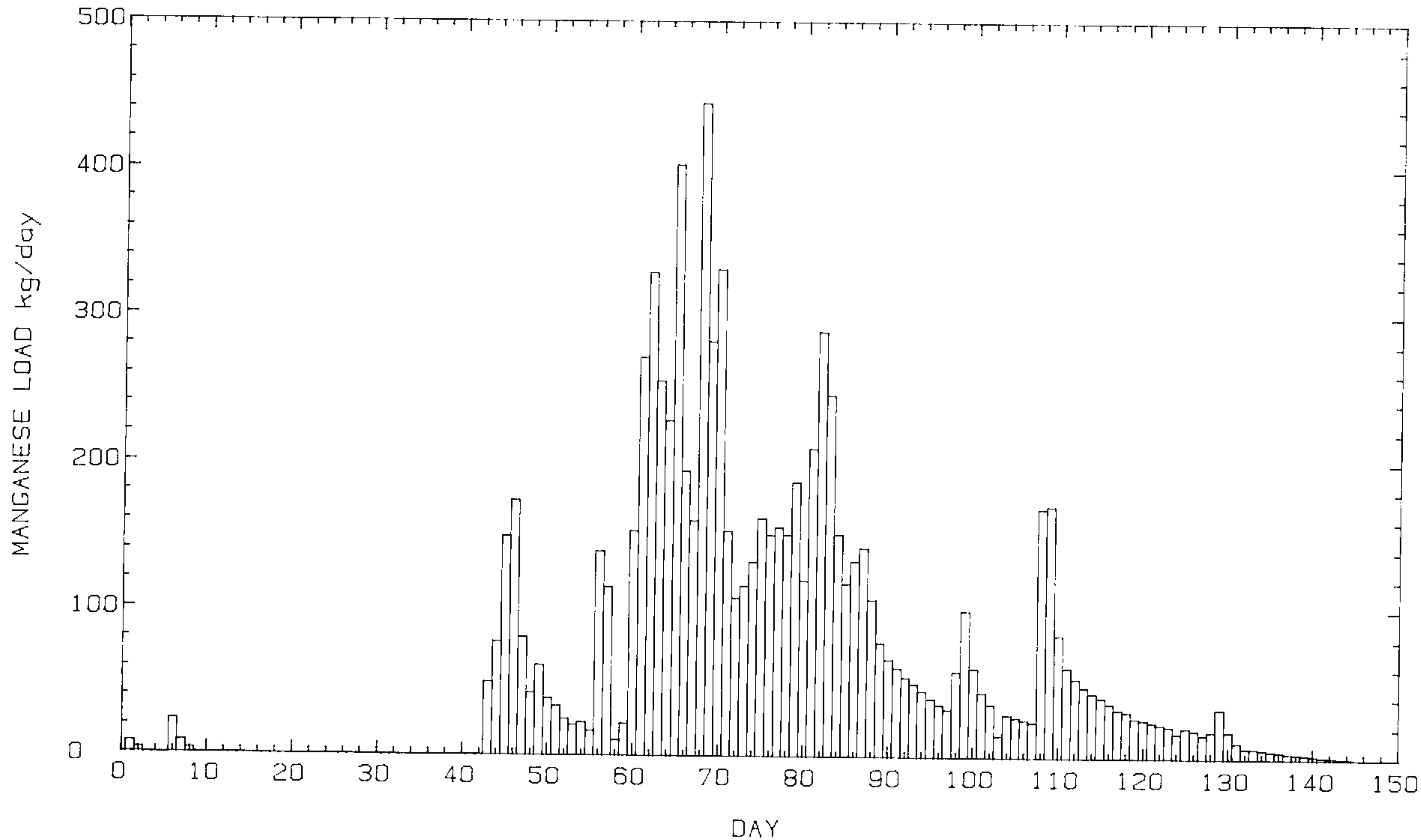

Figure 4.20 1986-87 East Finniss River manganese loads at GS8150097

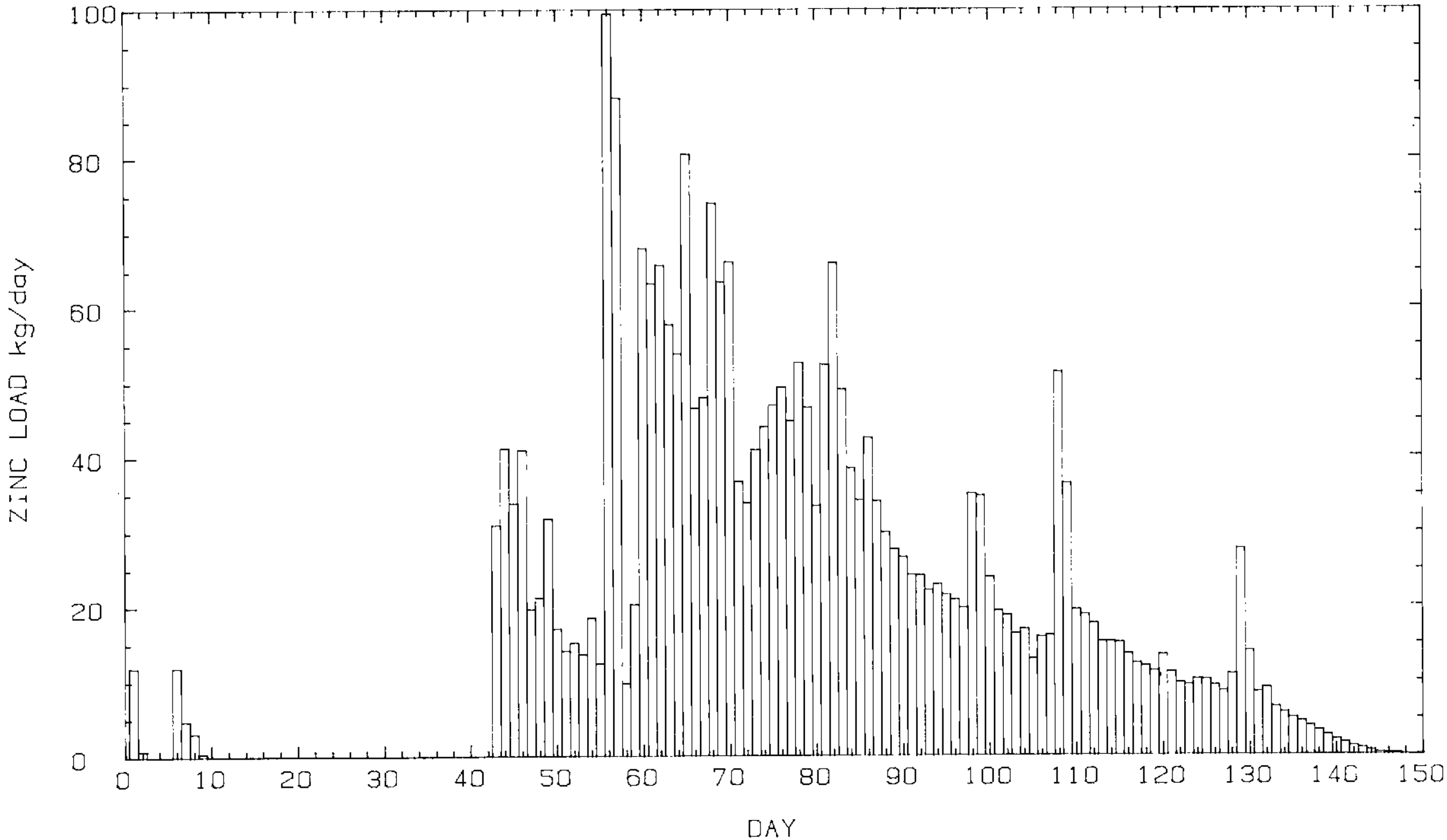

Figure 4.21 1986-87 East Finniss River zinc loads at GS8150097

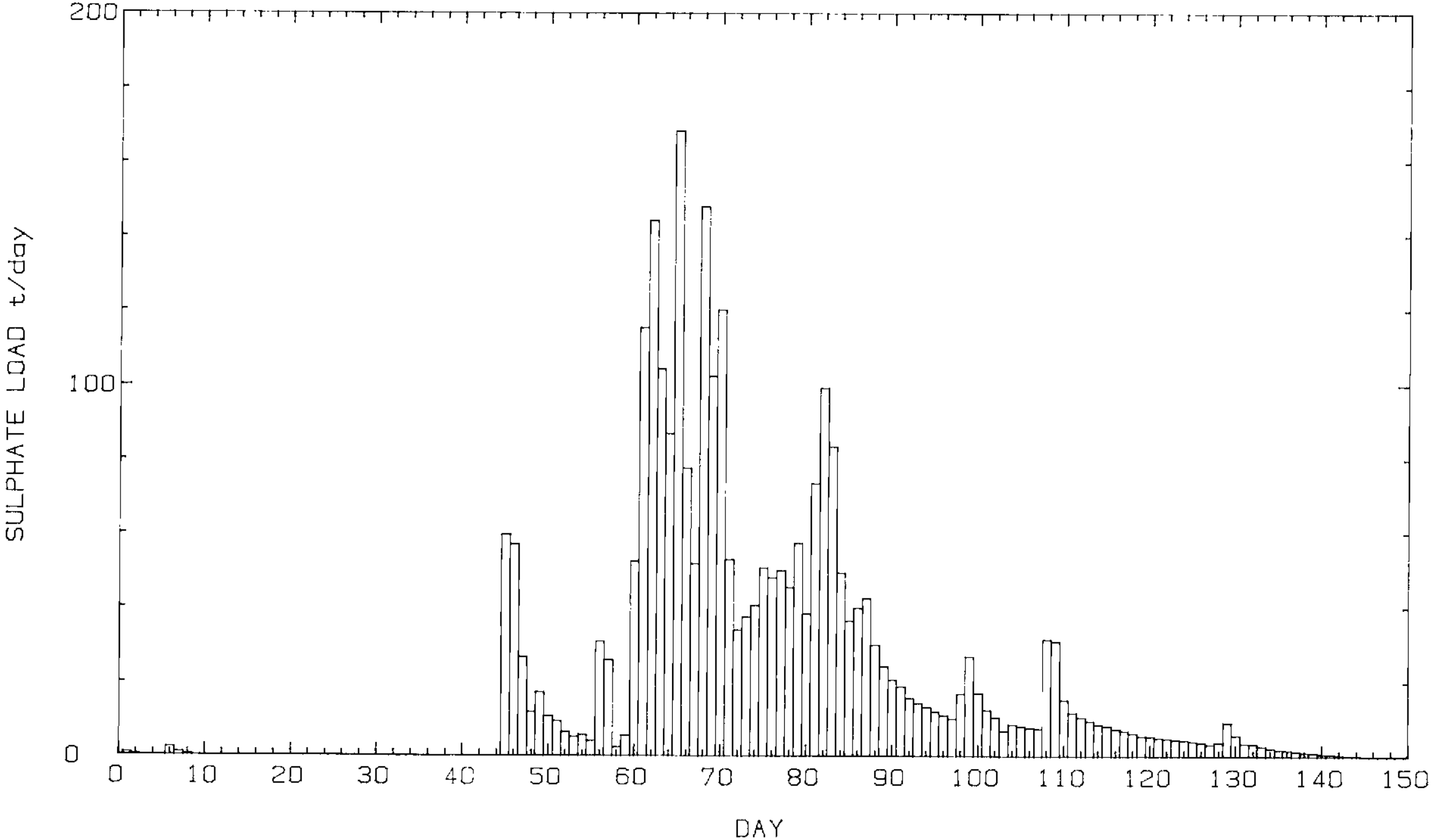

Figure 4.22 1986-87 East Finniss River sulphate loads at GS8150097

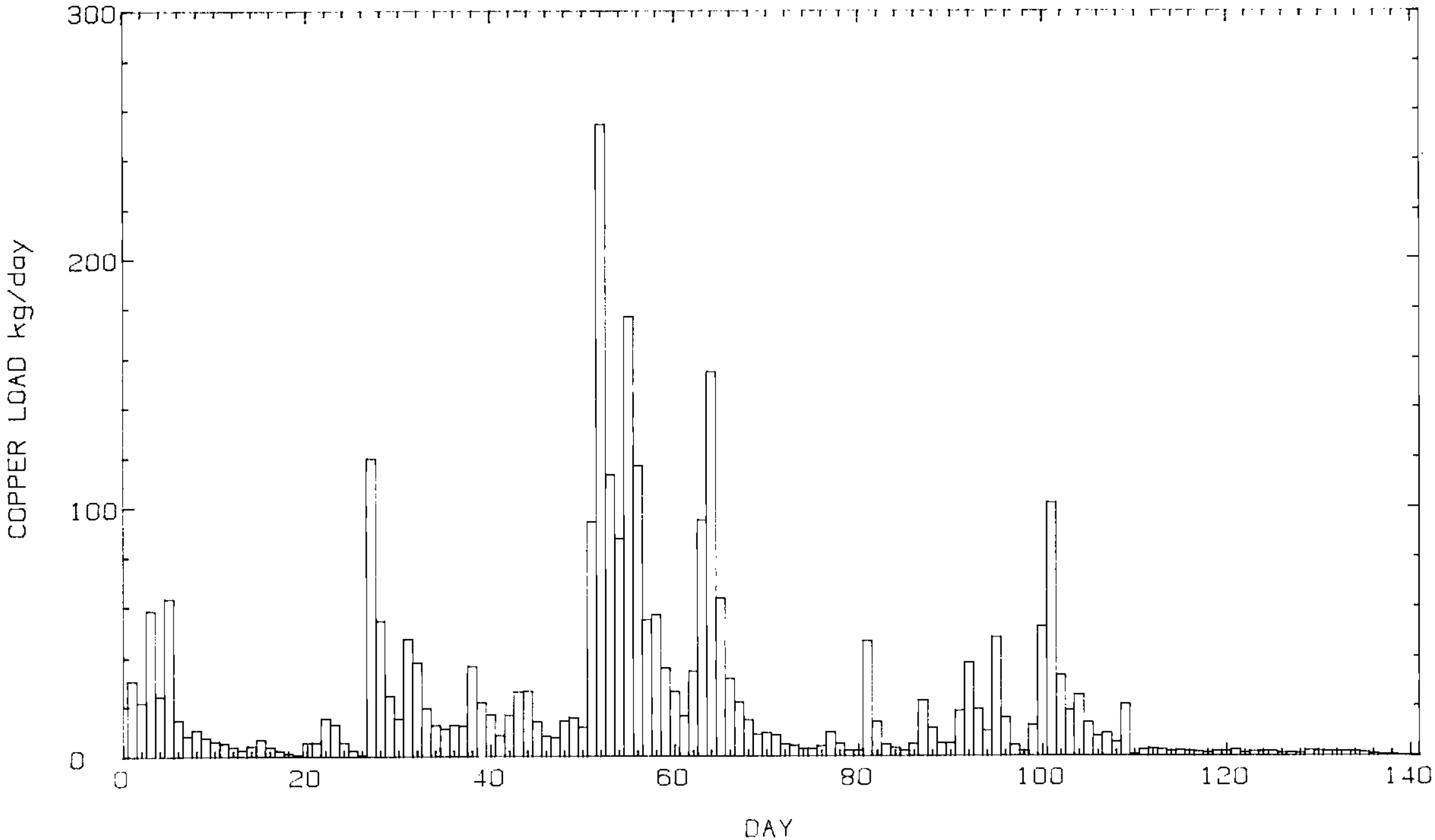

Figure 4.23 1987-88 East Finniss River copper loads at GS8150097

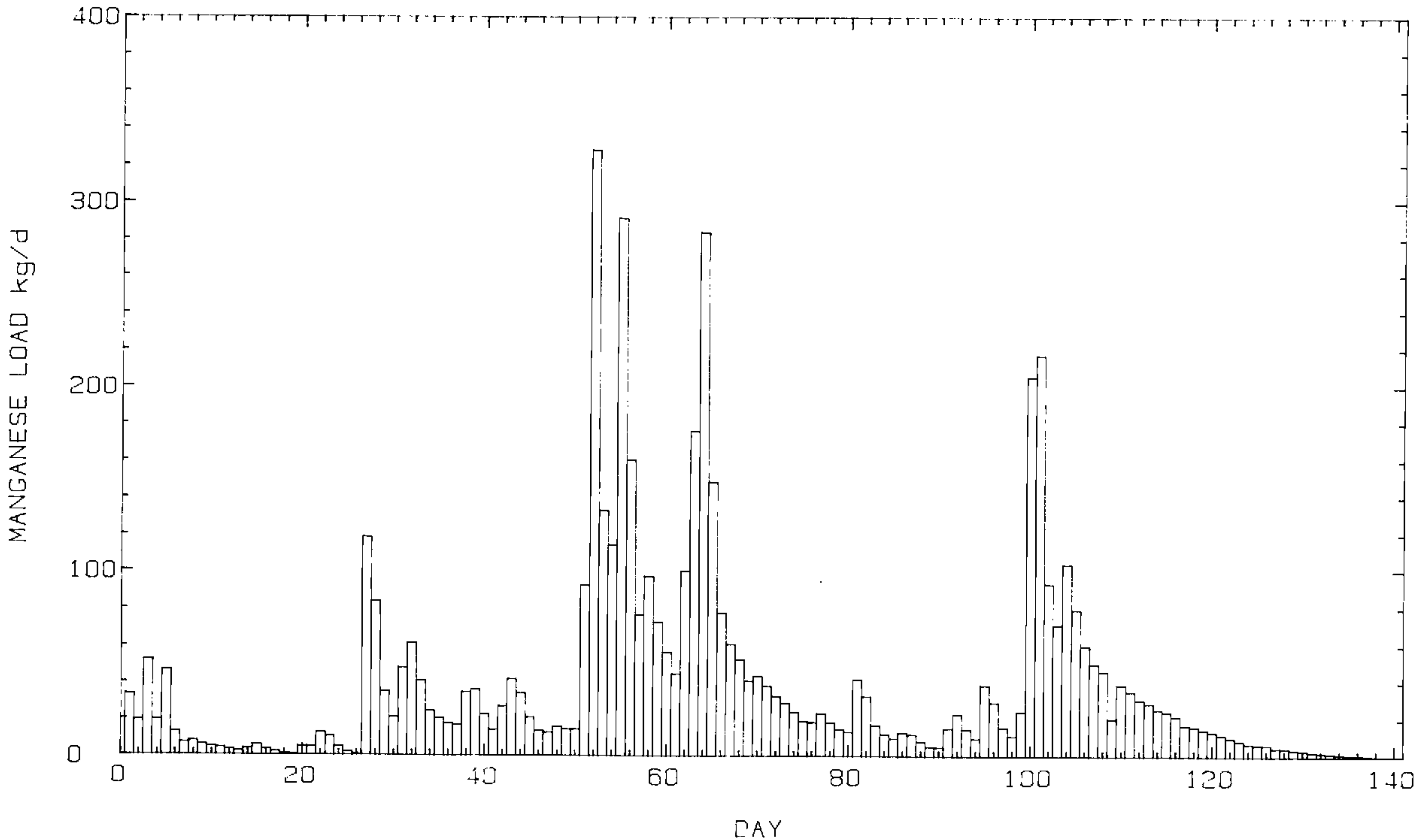

Figure 4.24 1987-88 East Finniss River manganese loads at GS8150097

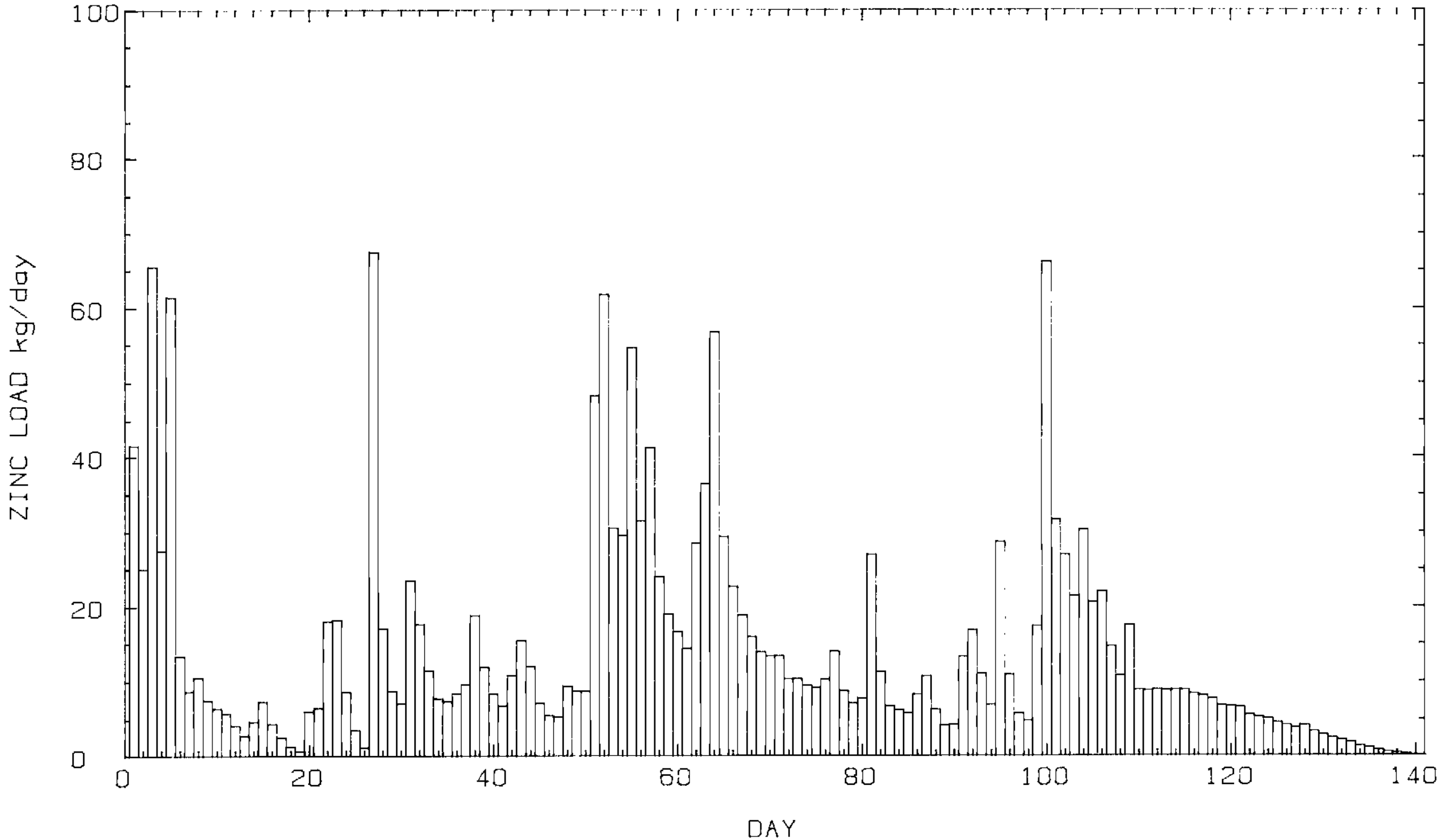

Figure 4.25 1987-88 East Finniss River daily zinc loads at GS8150097

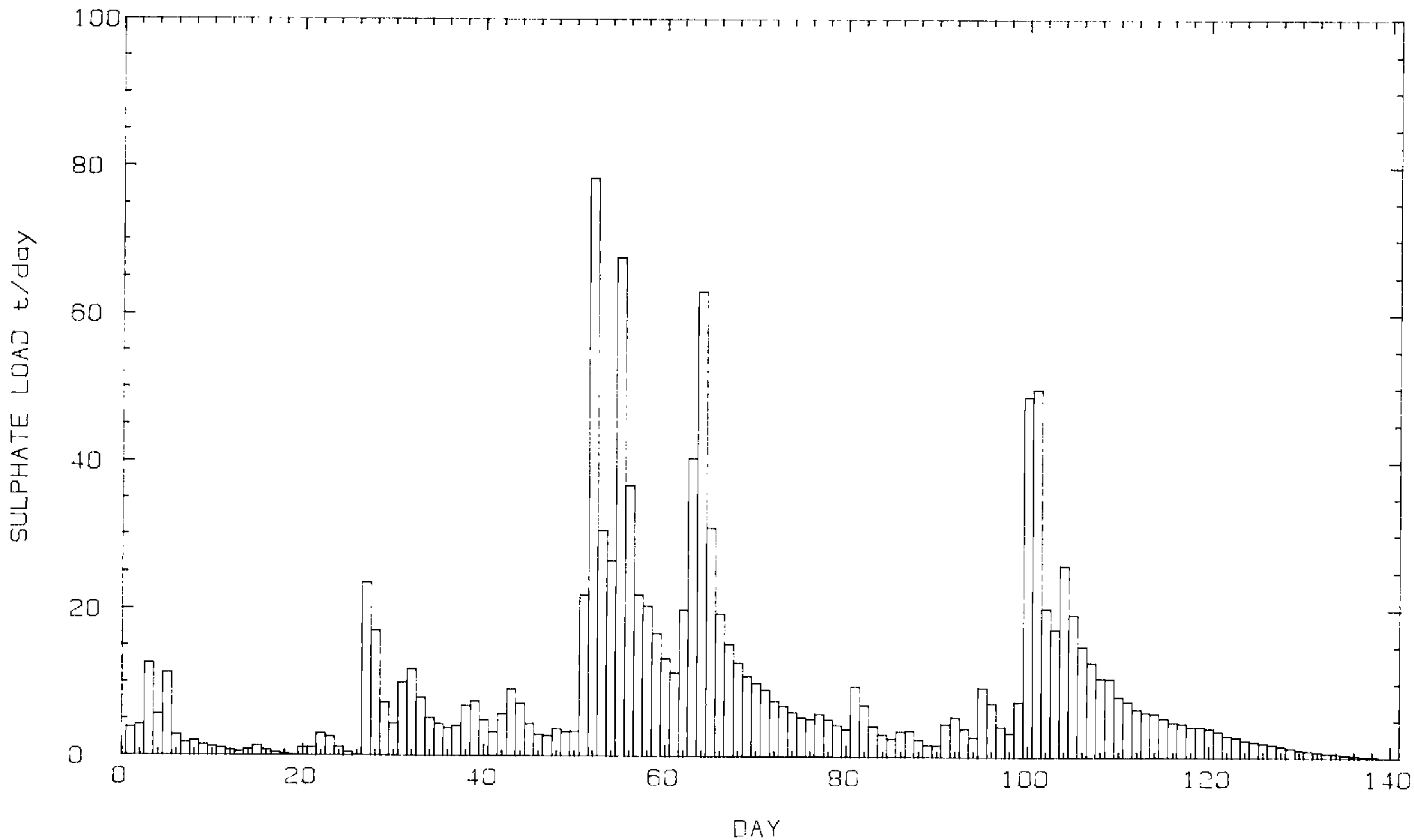

Figure 4.26 1987-88 East Finniss River sulphate loads at GS8150097

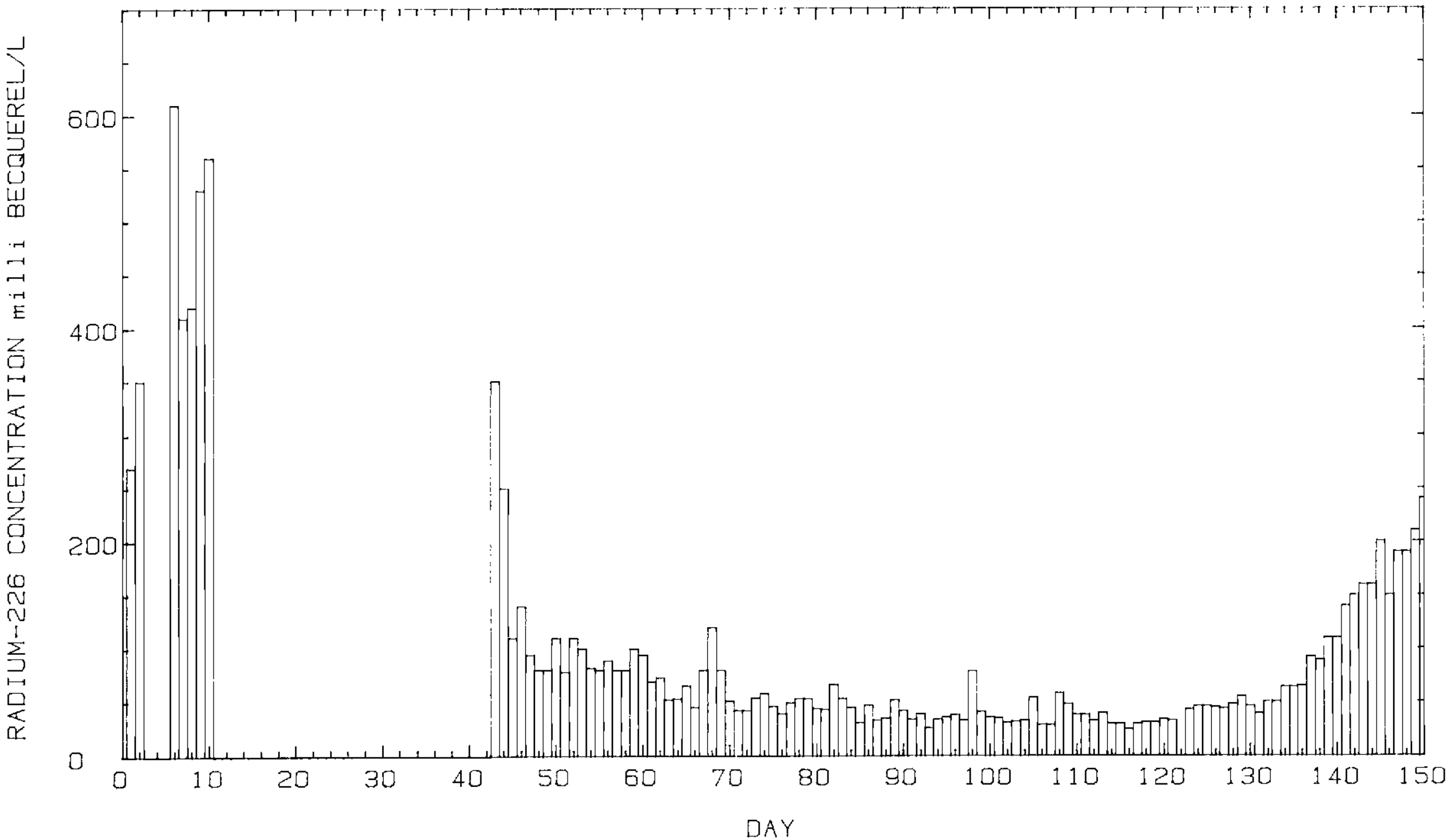

Figure 4.27 1986-87 East Finniss radium-226 concentrations at GS8150097

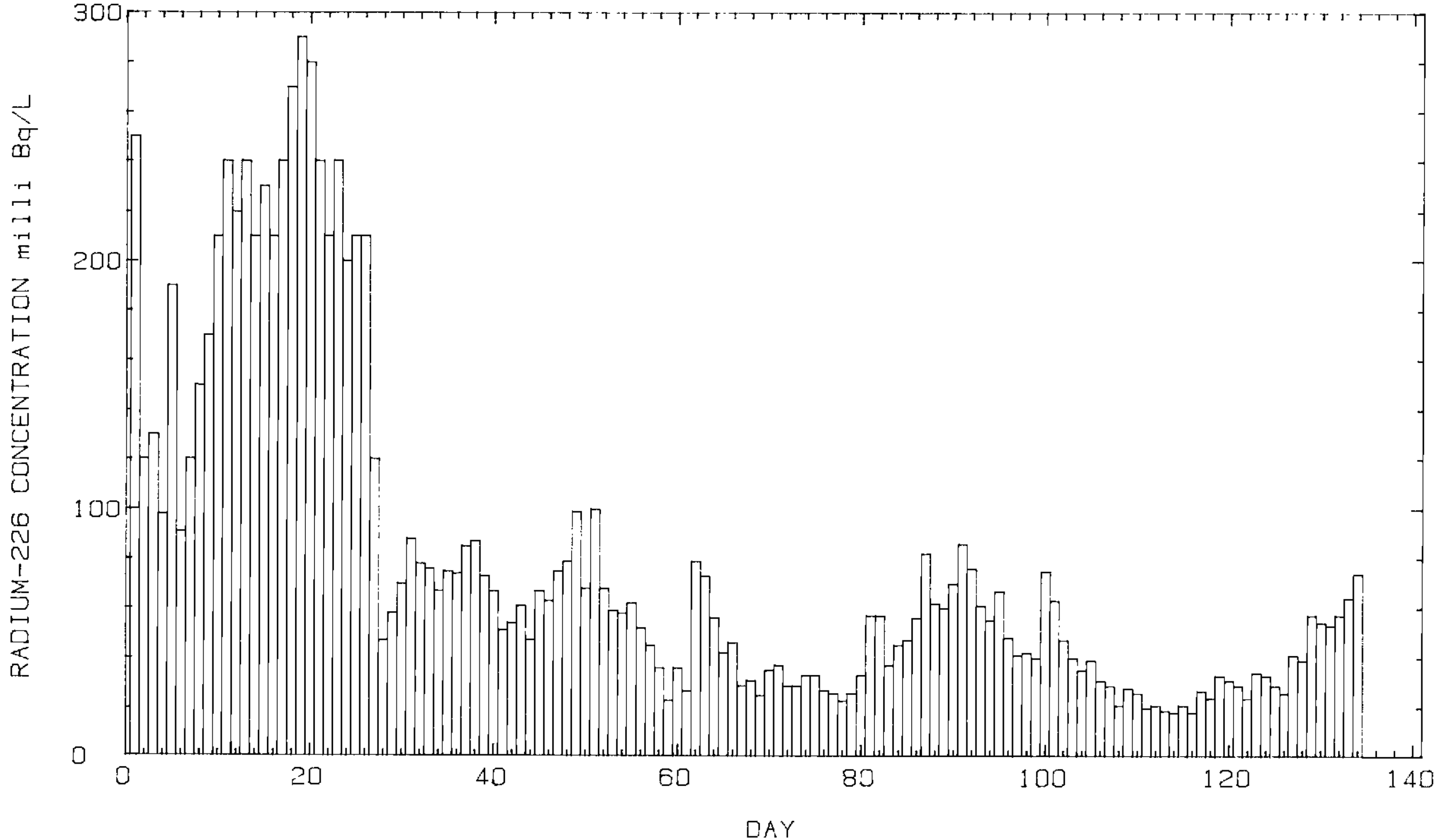

Figure 4.28 1987-88 East Finniss River radium-226 concentrations at GS8150097

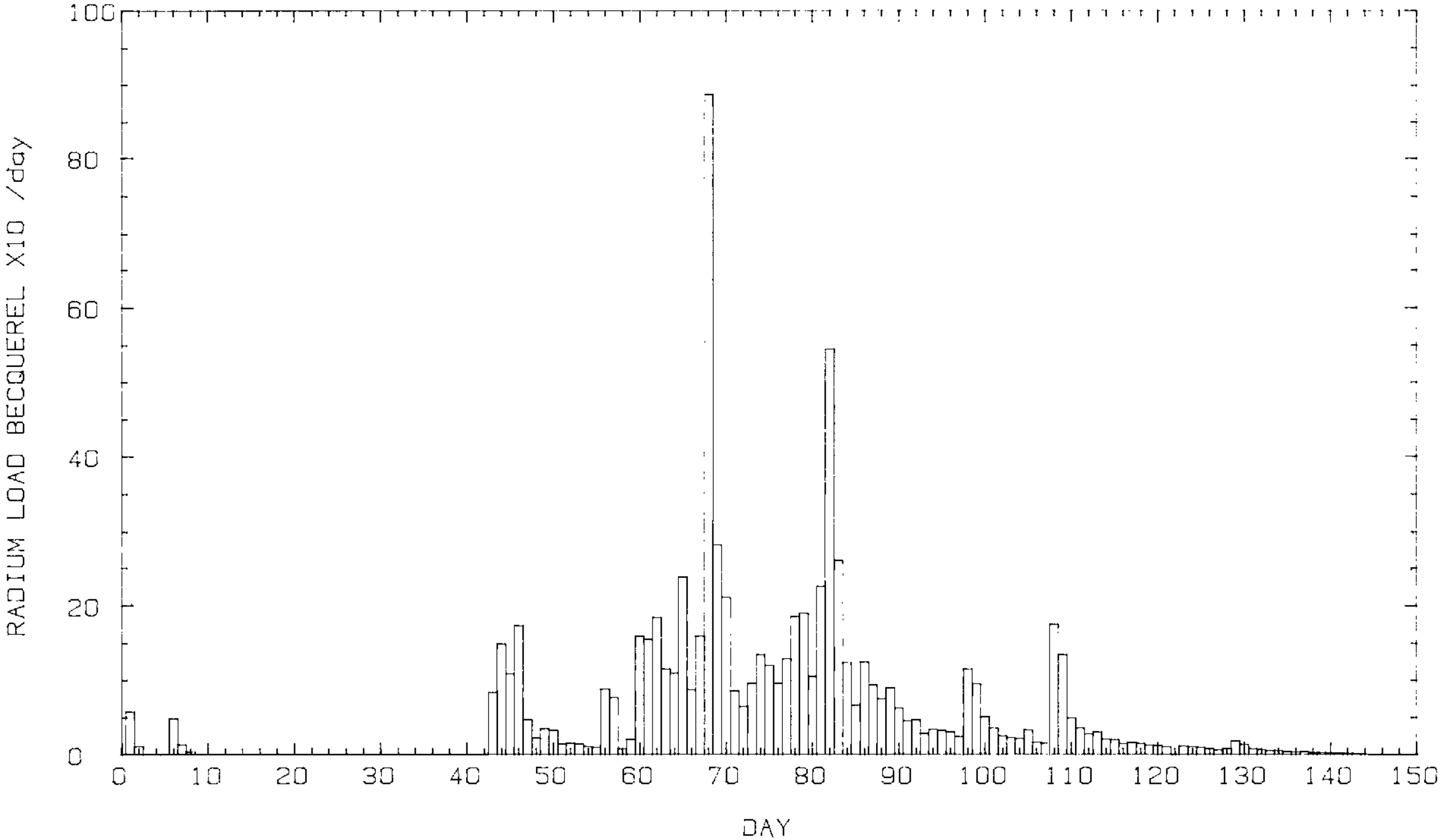

Figure 4.29 1986-87 East Finniss River radium-226 loads at GS8150097

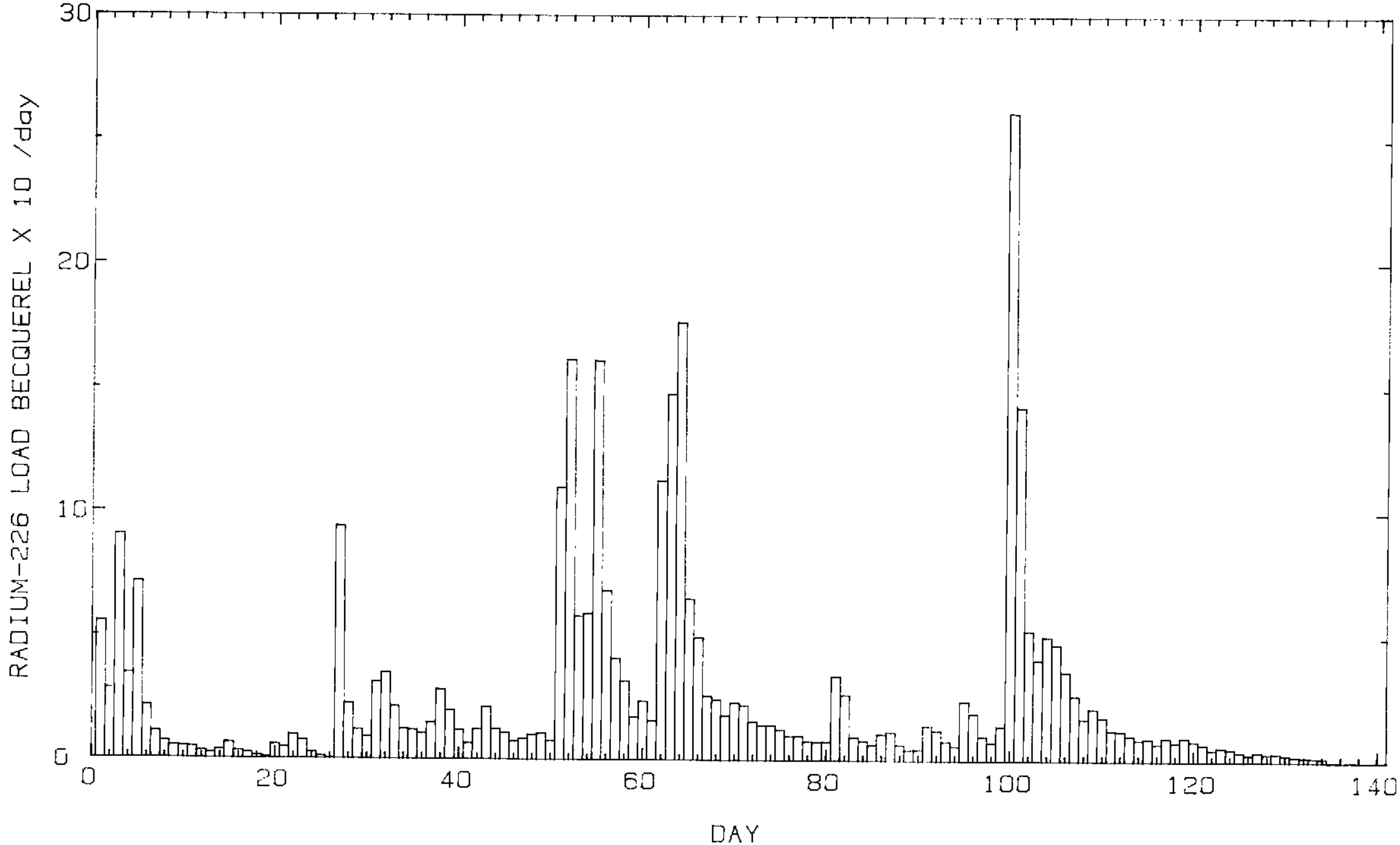

Figure 4.30 1987-88 East Finniss River radium-226 loads at GS8150097

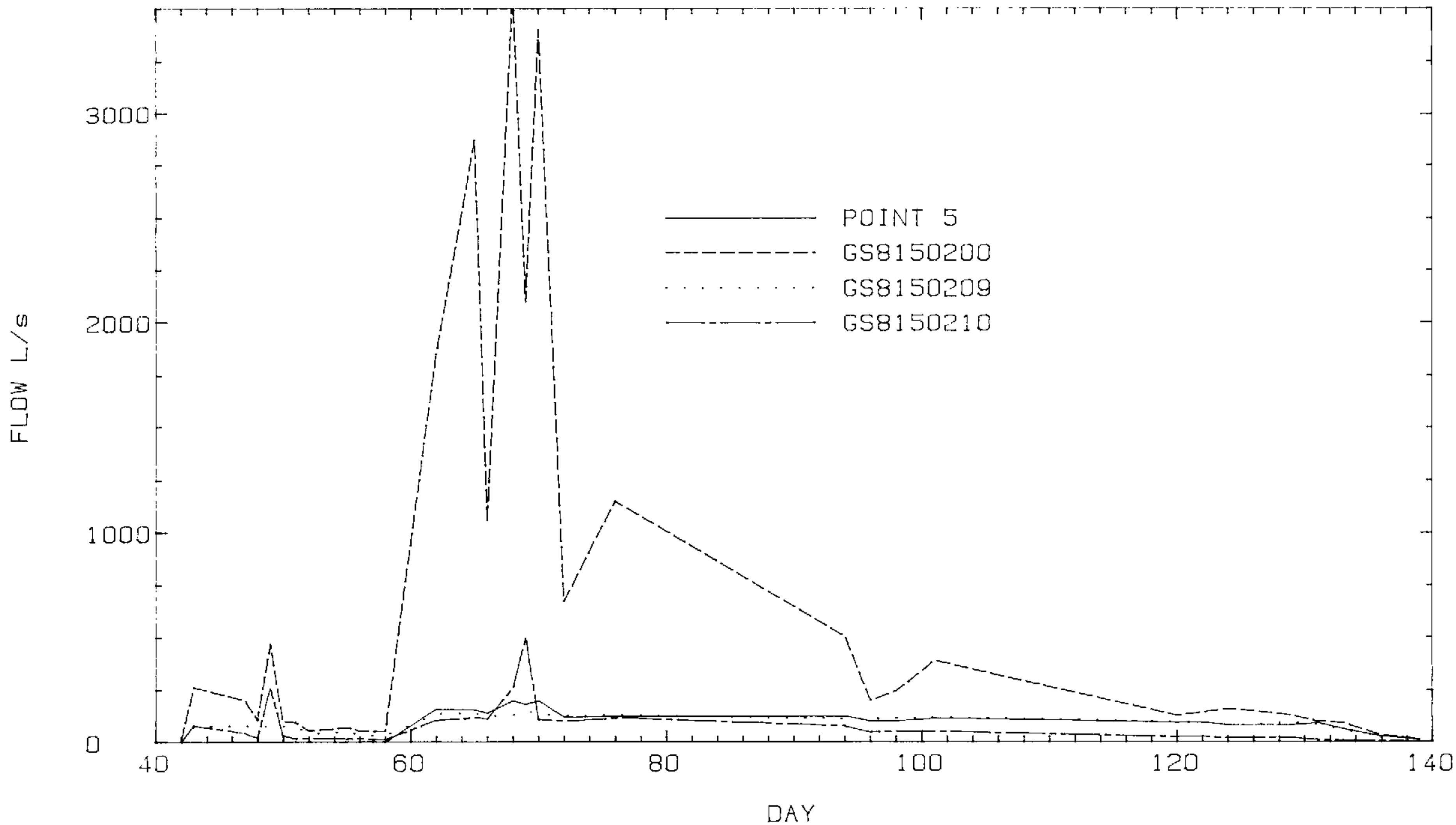

Figure 4.31 1986-87 mine site flow measurements

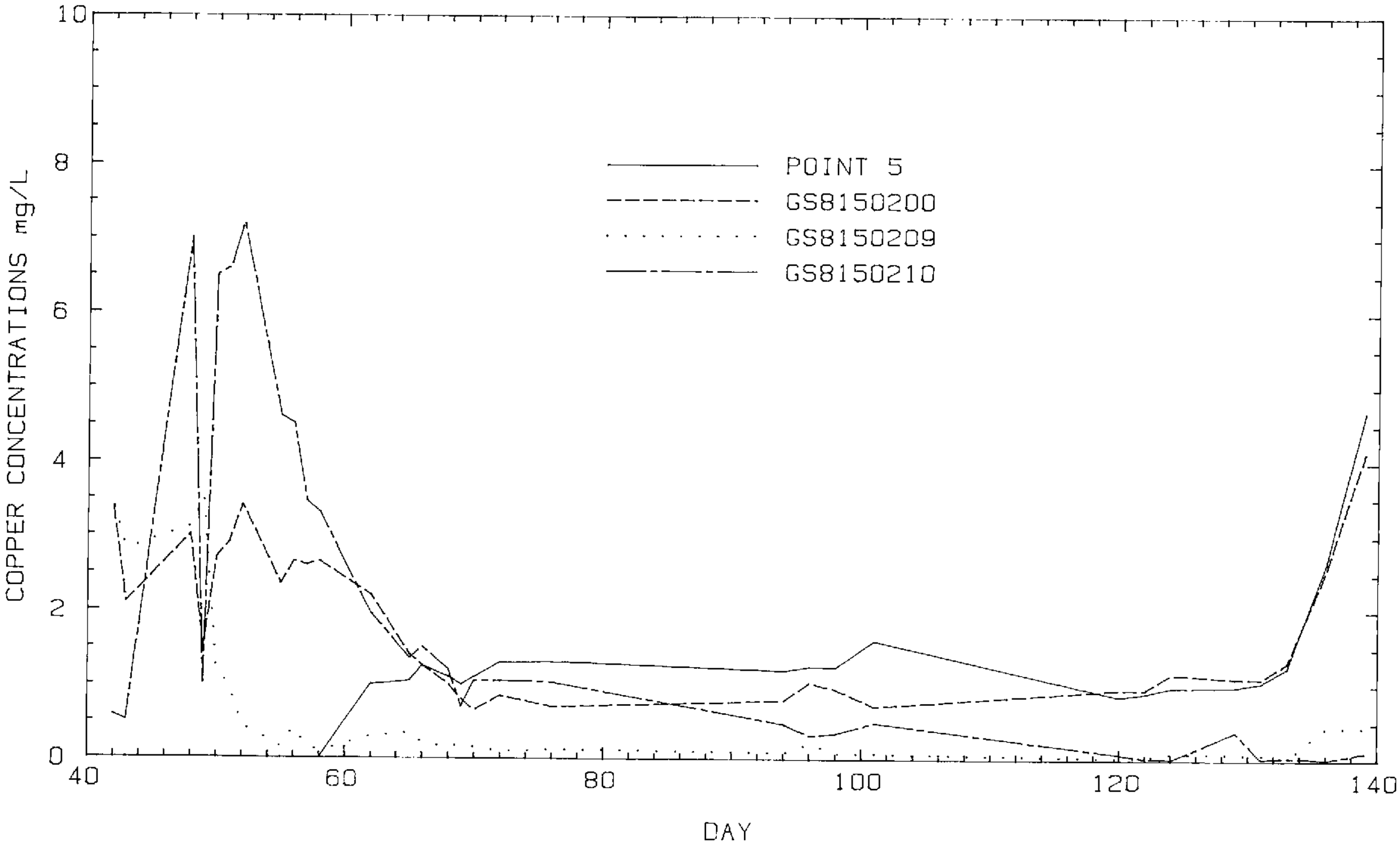

Figure 4.32 1986-87 mine site copper concentrations

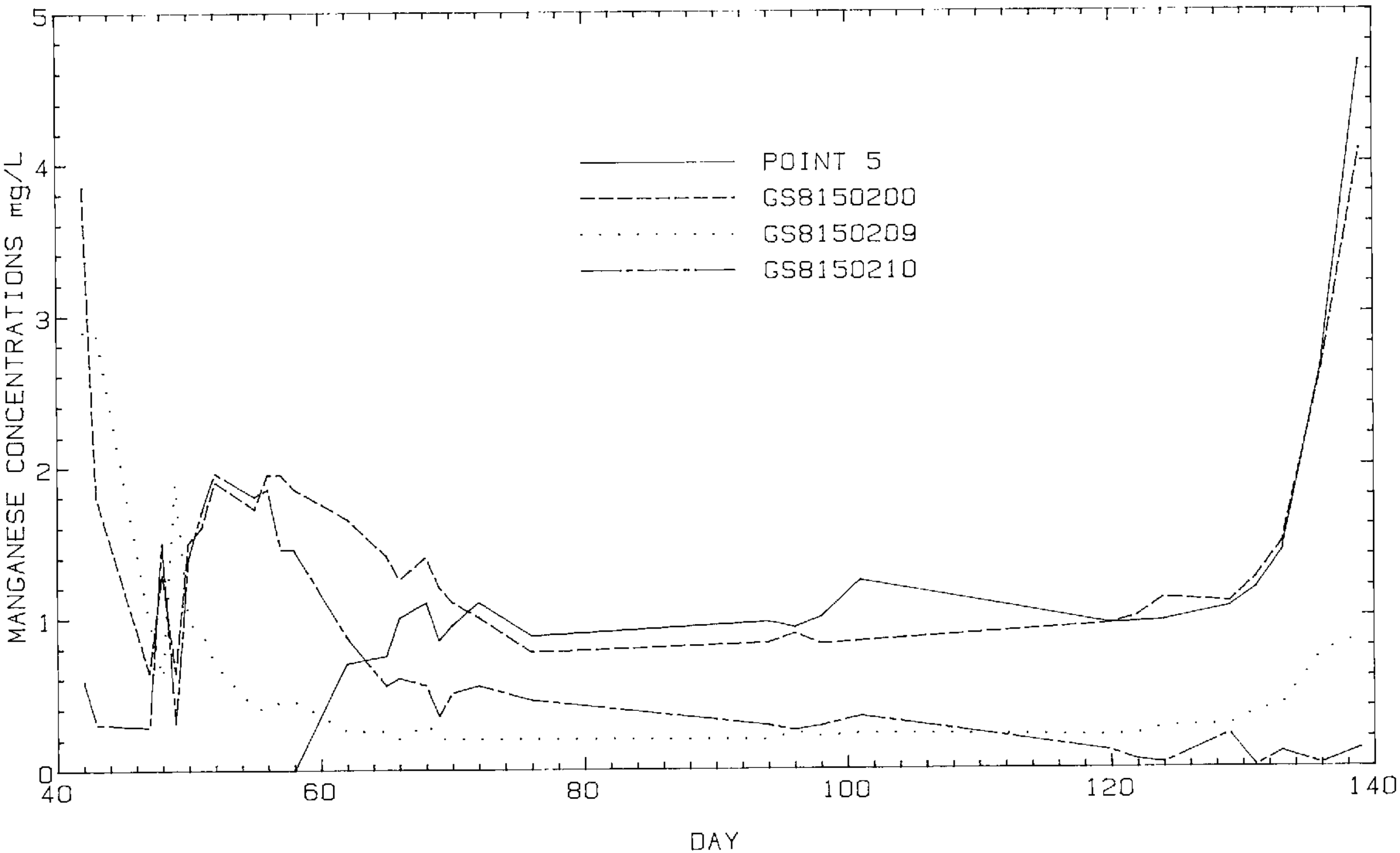

Figure 4.33 1986-87 mine site manganese concentrations

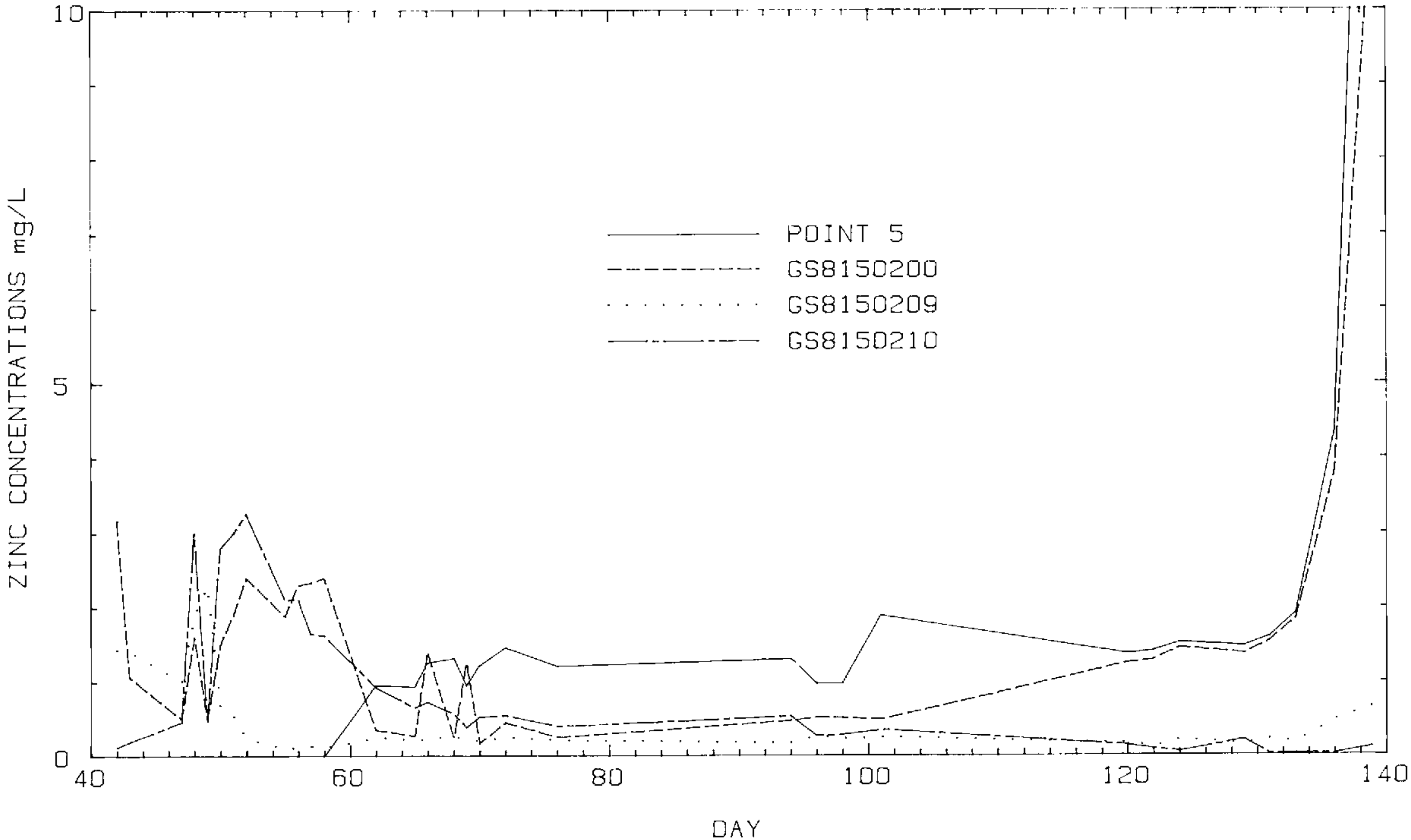

Figure 4.34 1986-87 mine site zinc concentrations

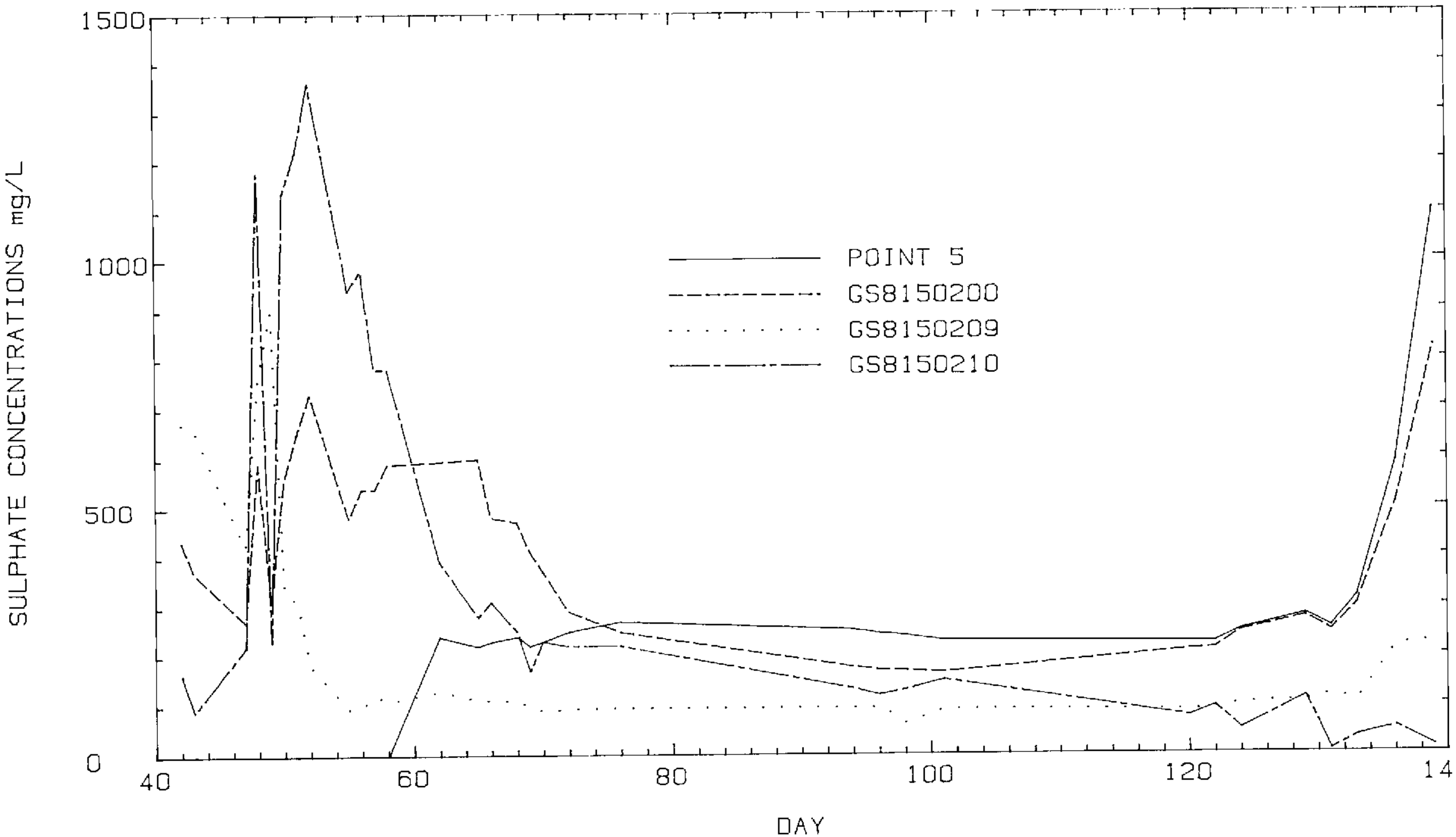

Figure 4.35 1986-87 mine site sulphate concentrations

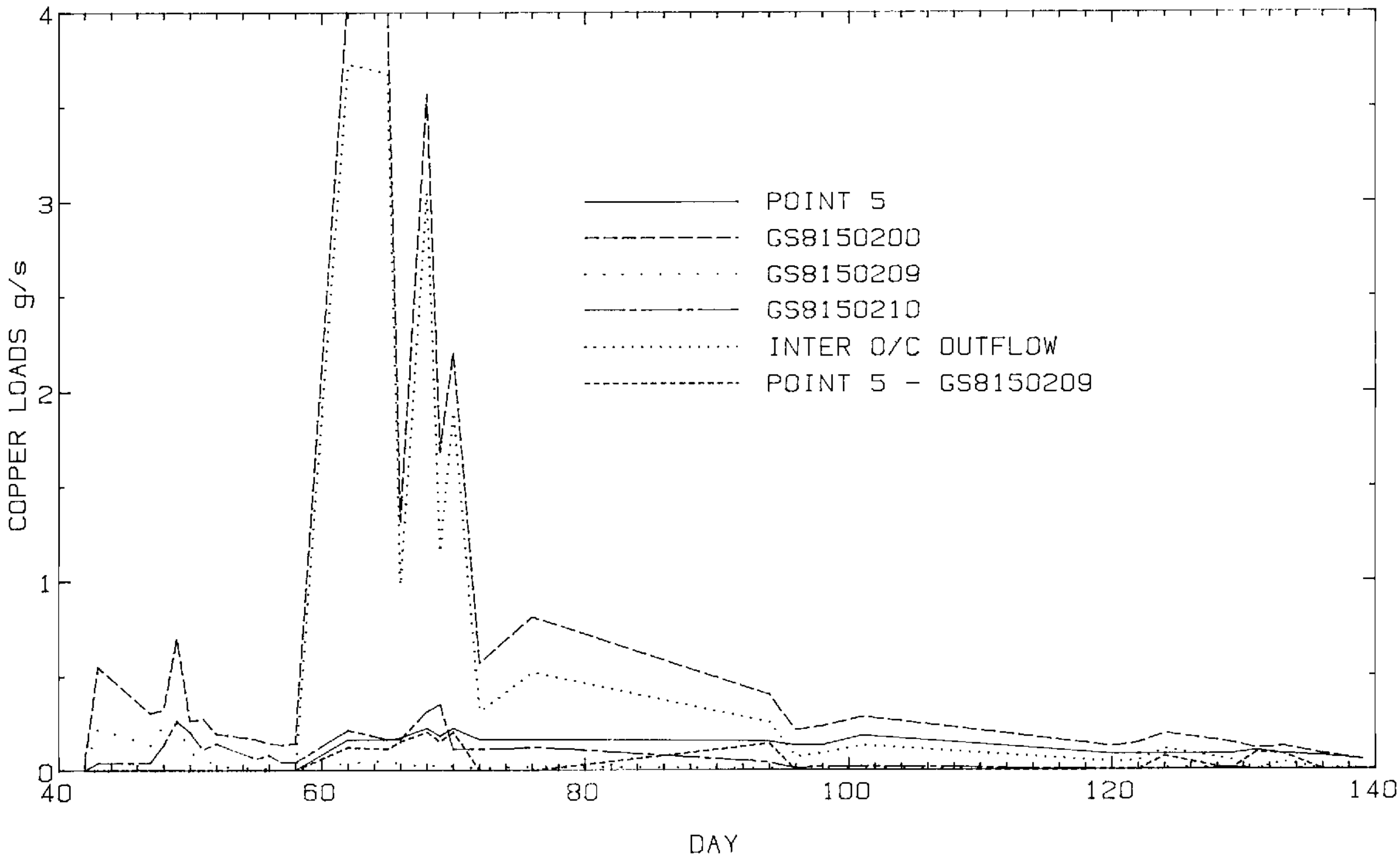

Figure 4.36 1986-87 mine site copper loads

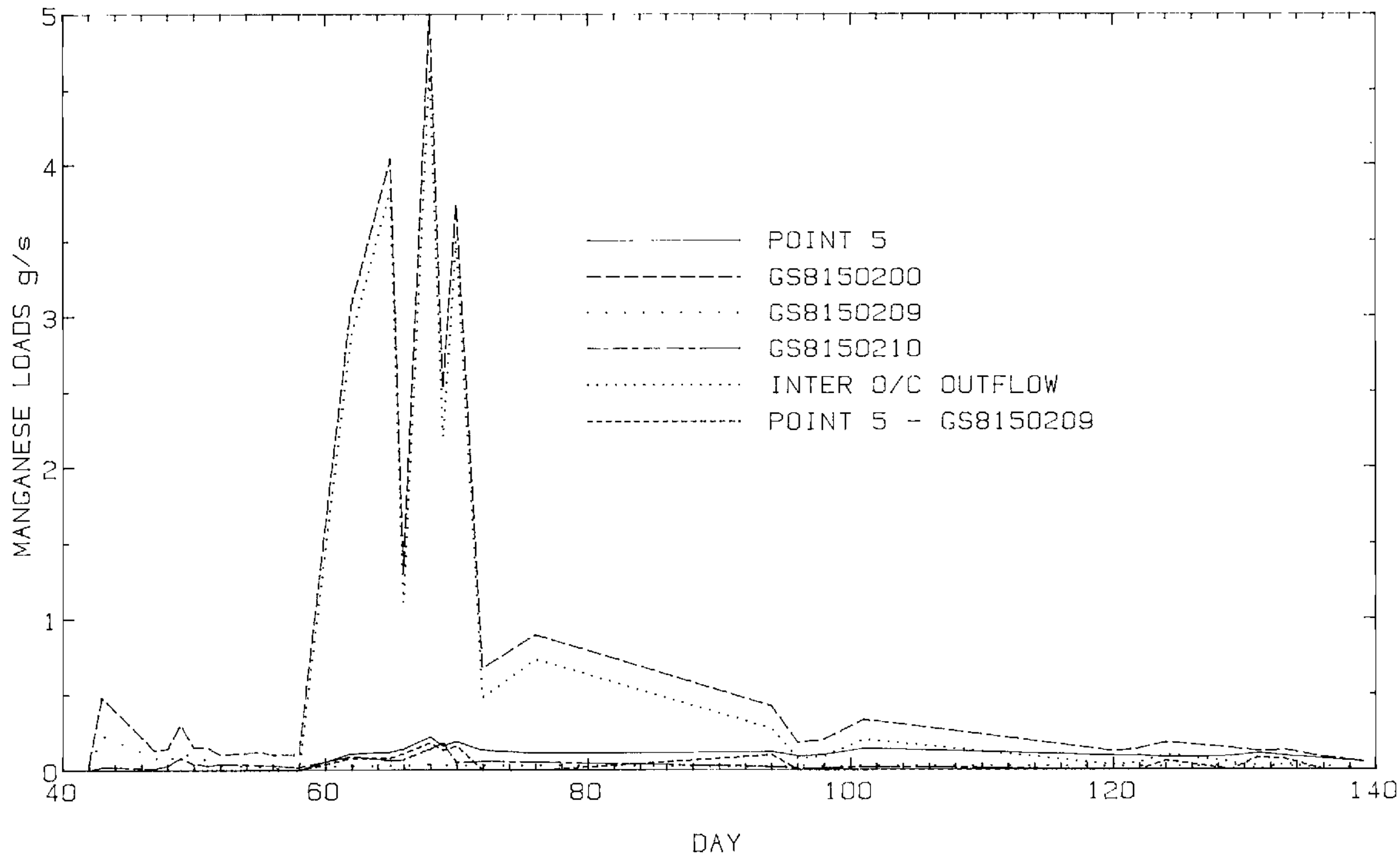

Figure 4.37 1986-87 mine site manganese loads

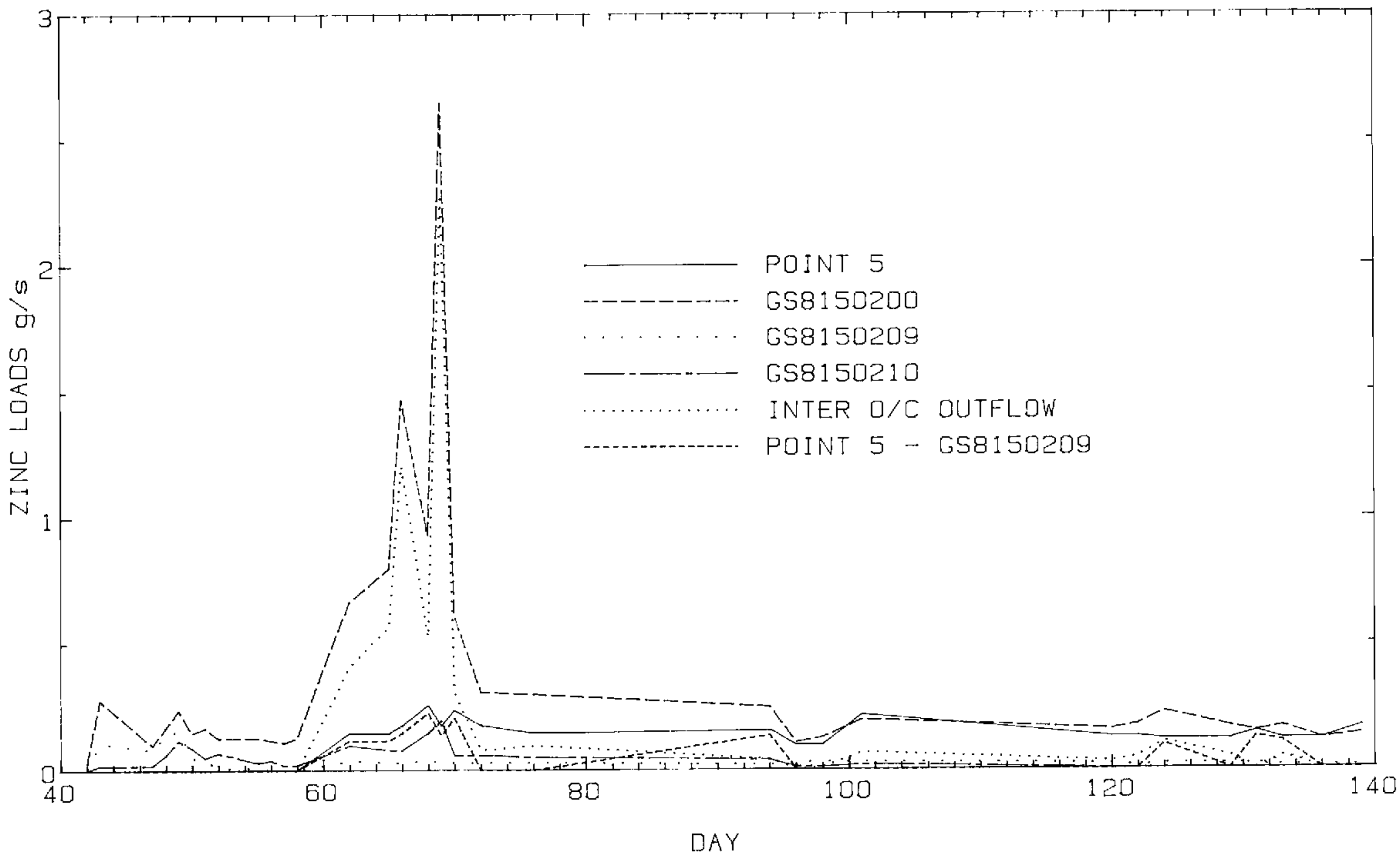

Figure 4.38 1986-87 mine site zinc loads

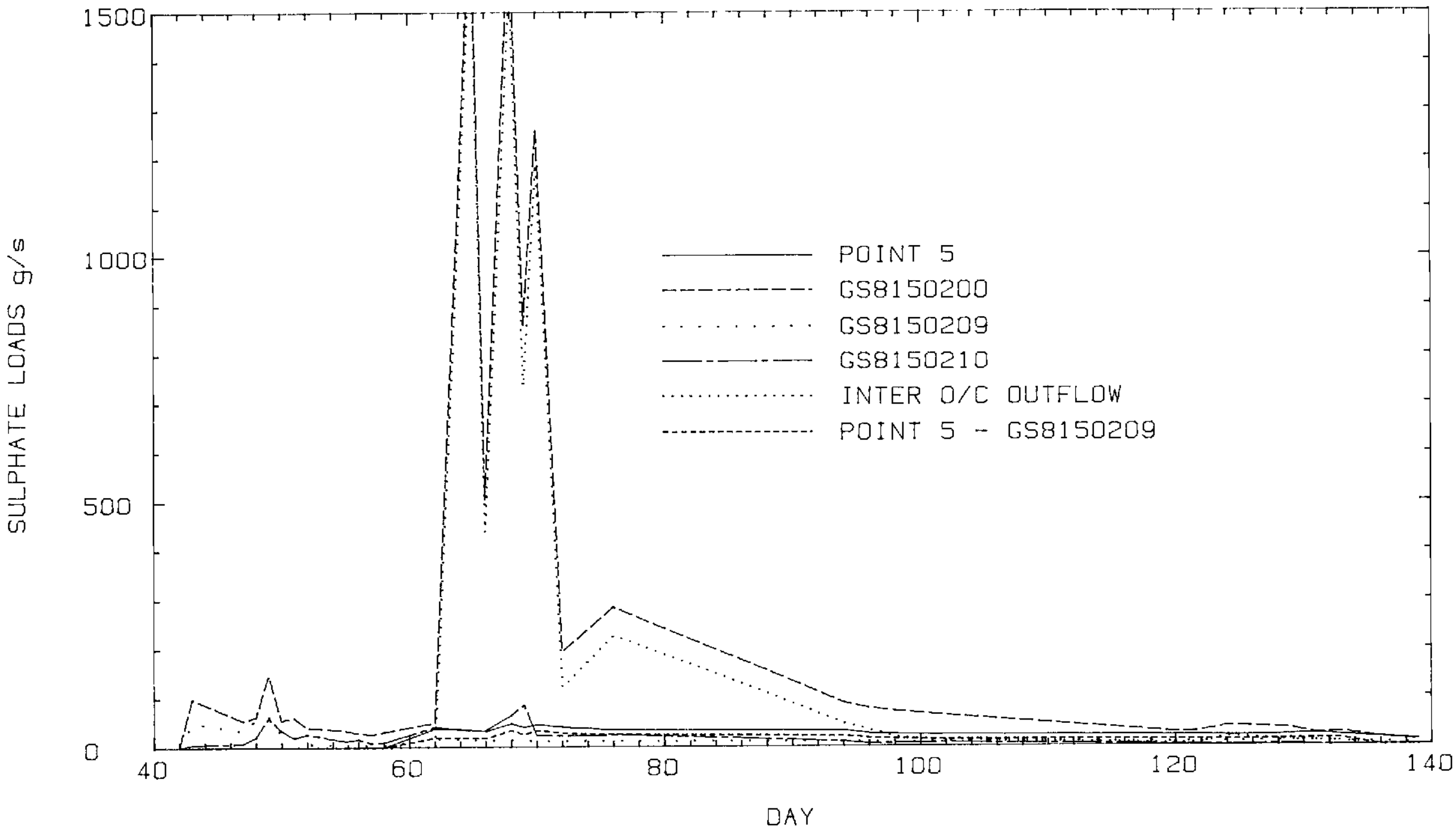

Figure 4.39 1986-87 mine site sulphate loads

APPENDIX B

SURFACE WATER HYDROLOGY
(Chapter 4)

TABLES

Table 4.2 1986-87 Day To Date Conversion Table

DAY	DATE	DAY	DATE	DAY	DATE
1	04/12/86	51	23/01/87	101	14/03/87
2	05/12/86	52	24/01/87	102	15/03/87
3	06/12/86	53	25/01/87	103	16/03/87
4	07/12/86	54	26/01/87	104	17/03/87
5	08/12/86	55	27/01/87	105	18/03/87
6	09/12/86	56	28/01/87	106	19/03/87
7	10/12/86	57	29/01/87	107	20/03/87
8	11/12/86	58	30/01/87	108	21/03/87
9	12/12/86	59	31/01/87	109	22/03/87
10	13/12/86	60	01/02/87	110	23/02/87
11	14/12/86	61	02/02/87	111	24/03/87
12	15/12/86	62	03/02/87	112	25/03/87
13	16/12/86	63	04/02/87	113	26/03/87
14	17/12/86	64	05/02/87	114	27/03/87
15	18/12/86	65	06/02/87	115	28/03/87
16	19/12/86	66	07/02/87	116	29/03/87
17	20/12/86	67	08/02/87	117	30/03/87
18	21/12/86	68	09/02/87	118	31/03/87
19	22/12/86	69	10/02/87	119	01/04/87
20	23/12/86	70	11/02/87	120	02/04/87
21	24/12/86	71	12/02/87	121	03/04/87
22	25/12/86	72	13/02/87	122	04/04/87
23	26/12/86	73	14/02/87	123	05/04/87
24	27/12/86	74	15/02/87	124	06/04/87
25	28/12/86	75	16/02/87	125	07/04/87
26	29/12/86	76	17/02/87	126	08/04/87
27	30/12/86	77	18/02/87	127	09/04/87
28	31/12/86	78	19/02/87	128	10/04/87
29	01/01/87	79	20/02/87	129	11/04/87
30	02/01/87	80	21/02/87	130	12/04/87
31	03/01/87	81	22/02/87	131	13/04/87
32	04/01/87	82	23/02/87	132	14/04/87
33	05/01/87	83	24/02/87	133	15/04/87
34	06/01/87	84	25/02/87	134	16/04/87
35	07/01/87	85	26/02/87	135	17/04/87
36	08/01/87	86	27/02/87	136	18/04/87
37	09/01/87	87	28/02/87	137	19/04/87
38	10/01/87	88	01/03/87	138	20/04/87
39	11/01/87	89	02/03/87	139	21/04/87
40	12/01/87	90	03/03/87	140	22/04/87
41	13/01/87	91	04/03/87	141	23/04/87
42	14/01/87	92	05/03/87	142	24/04/87
43	15/01/87	93	06/03/87	143	25/04/87
44	16/01/87	94	07/03/87	144	26/04/87
45	17/01/87	95	08/03/87	145	27/04/87
46	18/01/87	96	09/03/87	146	28/04/87
47	19/01/87	97	10/03/87	147	29/04/87
48	20/01/87	98	11/03/87	148	30/04/87
49	21/01/87	99	12/03/87	149	01/05/87
50	22/01/87	100	13/03/87	150	02/05/87

Table 4.3 1987-88 Day to Date Conversion Table

DAY	DATE	DAY	DATE	DAY	DATE
1	21-12-87	48	06-02-88	95	24-03-88
2	22-12-87	49	07-02-88	96	25-03-88
3	23-12-87	50	08-02-88	97	26-03-88
4	24-12-87	51	09-02-88	98	27-03-88
5	25-12-87	52	10-02-88	99	28-03-88
6	26-12-87	53	11-02-88	100	29-03-88
7	27-12-87	54	12-02-88	101	30-03-88
8	28-12-87	55	13-02-88	102	31-03-88
9	29-12-87	56	14-02-88	103	01-04-88
10	30-12-87	57	15-02-88	104	02-04-88
11	31-12-87	58	16-02-88	105	03-04-88
12	01-01-88	59	17-02-88	106	04-04-88
13	02-01-88	60	18-02-88	107	05-04-88
14	03-01-88	61	19-02-88	108	06-04-88
15	04-01-88	62	20-02-88	109	07-04-88
16	05-01-88	63	21-02-88	110	08-04-88
17	06-01-88	64	22-02-88	111	09-04-88
18	07-01-88	65	23-02-88	112	10-04-88
19	08-01-88	66	24-02-88	113	11-04-88
20	09-01-88	67	25-02-88	114	12-04-88
21	10-01-88	68	26-02-88	115	13-04-88
22	11-01-88	69	27-02-88	116	14-04-88
23	12-01-88	70	28-02-88	117	15-04-88
24	13-01-88	71	29-02-88	118	16-04-88
25	14-01-88	72	01-03-88	119	17-04-88
26	15-01-88	73	02-03-88	120	18-04-88
27	16-01-88	74	03-03-88	121	19-04-88
28	17-01-88	75	04-03-88	122	20-04-88
29	18-01-88	76	05-03-88	123	21-04-88
30	19-01-88	77	06-03-88	124	22-04-88
31	20-01-88	78	07-03-88	125	23-04-88
32	21-01-88	79	08-03-88	126	24-04-88
33	22-01-88	80	09-03-88	127	25-04-88
34	23-01-88	81	10-03-88	128	26-04-88
35	24-01-88	82	11-03-88	129	27-04-88
36	25-01-88	83	12-03-88	130	28-04-88
37	26-01-88	84	13-03-88	131	29-04-88
38	27-01-88	85	14-03-88	132	30-04-88
39	28-01-88	86	15-03-88	133	01-05-88
40	29-01-88	87	16-03-88	134	02-05-88
41	30-01-88	88	17-03-88	135	03-05-88
42	31-01-88	89	18-03-88	136	04-05-88
43	01-02-88	90	19-03-88	137	05-05-88
44	02-02-88	91	20-03-88	138	06-05-88
45	03-02-88	92	21-03-88	139	07-05-88
46	04-02-88	93	22-03-88	140	05-02-88
47	05-02-88	94	23-03-88	141	09-05-88

Table 4.4 1986-87 East Finniss River Water Quality at GS8150097

DATE	FLOW (1 X 10^6)	pH	COND (μS/cm)	Cu	Mn (mg/l)	Zn	SO_4	Ra226 (mBq/l)
04-12-86	21.3	6.4	88	.05	.37	.56	38	270
05-12-86	3.15	6.1	190	.30	1.0	.27	83	350
06-12-86	4.31							
07-12-86	1.66			NO SAMPLE TAKEN				
08-12-86	.443							
09-12-86	8.00	4.7	580	2.7	2.9	1.5	290	610
10-12-86	3.27	4.6	600	2.6	2.6	1.5	300	410
11-12-86	.873	4.5	700	3.4	3.7	3.6	350	420
12-12-86	.128	4.6	800	3.2	3.5	3.3	410	530
13-12-86	.018	4.6	820	3.4	3.7	3.5	510	560
14-12-86								
15-12-86								
16-12-86								
17-12-86								
18-12-86								
19-12-86								
20-12-86								
21-12-86								
22-12-86								
23-12-86								
24-12-86								
25-12-86								
26-12-86								
27-12-86			NO FLOW					
28-12-86								
29-12-86								
30-12-86								
31-12-86								
01-01-87								
02-01-87								
03-01-87								
04-01-87								
05-01-87								
06-01-87								
07-01-87								
08-01-87								
09-01-87								
10-01-87								
11-01-87								
12-01-87								
13-01-87								
14-01-87								
15-01-87	23.8			1.6	2.1	1.3		350
16-01-87	59.7			1.5	1.3	.69		250
17-01-87	99.4	5.3	1 120	1.3	1.5	.34	600	110
18-01-87	124	5.1	920	1.1	1.4	.33	460	140
19-01-87	50.4	5.2	1 020	1.1	1.6	.39	530	94
20-01-87	28.3	4.9	860	1.3	1.5	.75	420	80
21-01-87	44.2	5.0	800	1.5	1.4	.72	390	80
22-01-87	29.9	4.8	740	1.4	1.3	.57	360	110

DATE	FLOW (1 X 10^6)	pH	COND (μS/cm)	Cu	Mn (mg/l)	Zn	SO_4	Ra-226 (mBq/l)
23-01-87	18.6	4.7	980	1.8	1.8	.76	510	78
24-01-87	13.8	4.8	960	2.1	1.8	1.1	480	110
25-01-87	13.9	4.7	790	1.8	1.5	.98	380	100
26-01-87	13.2	4.7	860	2.1	1.7	1.4	440	82
27-01-87	11.3	4.7	770	1.8	1.5	1.1	370	80
28-01-87	99.4	4.9	710	1.4	1.4	1.0	310	89
29-01-87	95.9	4.8	590	1.4	1.2	.92	270	80
30-01-87	8.90	4.7	600	1.4	1.2	1.1	280	80
31-01-87	20.7	4.6	580	1.4	1.1	.98	270	100
01-02-87	170	4.9	670	.90	.90	.40	310	94
02-02-87	226	5.2	1 010	1.2	1.2	.28	510	69
03-02-87	253	5.1	1 090	1.3	1.3	.26	570	73
04-02-87	222	5.3	930	1.0	1.1	.26	470	52
05-02-87	207	5.2	880	.95	1.1	.26	420	53
06-02-87	366	5.3	920	.95	1.1	.22	460	65
07-02-87	194	5.6	810	.80	1.0	.24	400	45
08-02-87	200	5.0	570	.60	.80	.24	260	80
09-02-87	740	5.7	450	.25	.60	.10	200	120
10-02-87	353	5.4	630	.50	.80	.18	290	80
11-02-87	414	5.4	620	.40	.80	.16	290	51
12-02-87	204	5.8	580	.45	.75	.18	260	42
13-02-87	154	6.1	490	.45	.70	.22	220	42
14-02-87	178	5.9	460	.43	.65	.23	210	54
15-02-87	232	5.8	390	.37	.57	.19	180	58
16-02-87	261	6.0	450	.38	.62	.18	200	46
17-02-87	247	6.0	430	.42	.61	.20	190	39
18-02-87	264	6.2	430	.33	.59	.17	190	49
19-02-87	351	6.1	310	.24	.43	.15	130	53
20-02-87	359	6.2	380	.25	.52	.13	160	53
21-02-87	239	6.6	370	.25	.50	.14	160	44
22-02-87	524	6.5	330	.15	.40	.10	140	43
23-02-87	826	6.7	290	.10	.35	.08	120	66
24-02-87	491	6.5	390	.15	.50	.10	170	53
25-02-87	275	6.5	410	.25	.55	.14	180	45
26-02-87	214	6.4	390	.25	.55	.16	170	31
27-02-87	266	6.2	350	.25	.50	.16	150	47
28-02-87	284	6.3	350	.25	.50	.12	150	33
01-03-87	214	6.3	340	.30	.50	.14	140	35
02-03-87	173	6.4	330	.30	.45	.16	140	52
03-03-87	148	6.4	330	.30	.45	.18	140	42
04-03-87	135	6.3	320	.25	.45	.18	140	34
05-03-87	121	6.3	310	.30	.45	.20	130	39
06-03-87	111	6.1	320	.35	.45	.20	130	26
07-03-87	100	6.0	310	.32	.45	.23	130	34
08-03-87	89.9	6.1	310	.32	.44	.24	140	38
09-03-87	80.5	6.1	320	.31	.44	.26	140	38
10-03-87	73.3	6.3	330	.33	.44	.27	140	33
11-03-87	146	5.8	270	.40	.40	.24	120	79
12-03-87	232	5.9	270	.27	.43	.15	120	41
13-03-87	141	6.2	290	.26	.43	.17	120	36
14-03-87	102	6.1	290	.26	.43	.19	120	35

Table 4.4 Cont'd

DATE	FLOW (1 X 10^6)	pH	COND (μS/cm)	Cu	Mn (mg/l)	Zn	SO_4	Ra-226 (mBq/l)
15-03-87	81.7	6.1	310	.27	.44	.23	130	31
16-03-87	71.1	6.1	240	.16	.21	.23	97	32
17-03-87	65.0	6.1	310	.31	.44	.26	130	33
18-03-87	61.8	6.2	310	.28	.44	.21	130	54
19-03-87	56.6	6.2	330	.30	.45	.28	140	29
20-03-87	51.9	5.9	340	.35	.46	.31	150	29
21-03-87	302	6.0	280	.20	.56	.17	100	58
22-03-87	280	6.0	300	.20	.61	.13	110	48
22-03-87	130	6.0	310	.19	.64	.15	120	38
24-03-87	94.2	5.9	320	.21	.65	.20	120	38
25-03-87	84.0	5.8	330	.20	.64	.21	130	33
26-03-87	76.2	5.7	320	.19	.63	.20	130	40
27-03-87	69.4	5.3	350	.20	.63	.22	130	30
28-03-87	65.8	6.1	330	.19	.62	.23	130	30
29-03-87	59.3	6.1	330	.17	.62	.23	130	25
30-03-87	53.7	6.1	340	.17	.61	.23	130	30
31-03-87	47.9	6.0	340	.20	.65	.25	130	31
01-04-87	40.4	5.9	300	.23	.67	.28	140	31
02-04-87	35.5	5.7	380	.44	.73	.38	150	34
03-04-87	31.9	5.8	380	.38	.76	.35	160	33
04-04-87	28.6	6.0	410	.35	.79	.34	170	0
05-04-87	25.6	5.9	430	.36	.84	.37	180	43
06-04-87	22.7	5.9	450	.55	.75	.45	200	46
07-04-87	20.0	5.8	470	.69	1.0	.51	210	46
08-04-87	17.1	5.8	500	.87	1.1	.55	220	45
09-04-87	14.1	5.8	530	1.0	1.1	.61	240	44
10-04-87	16.0	5.9	540	1.3	1.2	.68	240	48
11-04-87	33.0	5.1	610	1.9	1.0	.84	280	55
12-04-87	28.6	5.1	450	.82	.64	.49	200	46
13-04-87	18.5	5.4	440	.45	.59	.46	200	39
14-04-87	13.1	5.4	520	.65	.56	.69	260	50
15-04-87	9.85	5.4	560	.82	.72	.66	290	50
16-04-87	7.46	5.3	610	1.1	.89	.77	310	64
17-04-87	5.62	5.2	670	1.4	1.0	.90	340	64
18-04-87	4.70	5.2	700	1.6	1.1	.98	370	65
19-04-87	3.65	5.2	730	1.7	1.1	1.1	400	92
20-04-87	2.86	5.1	750	1.9	1.2	1.2	410	89
21-04-87	2.23	5.0	790	2.0	1.3	1.2	430	110
22-04-87	1.68	4.8	810	2.0	1.4	1.3	440	110
23-04-87	1.26	4.8	830	2.1	1.4	1.3	450	140
24-04-87	.890	4.8	840	2.2	1.4	1.3	450	150
25-04-87	.683	4.8	850	2.2	1.5	1.3	440	160
26-04-87	.419	4.8	850	2.3	1.5	1.3	430	160
27-04-87	.240	4.9	830	2.2	1.5	1.3	425	200
28-04-87	.165	4.9	820	2.2	1.5	1.3	420	150
29-04-87	.111	4.9	810	2.2	1.5	1.3	420	190
30-04-87	.061	4.9	810	2.2	1.6	1.2	420	190
01-05-87	.034	4.9	820	2.2	1.5	1.2	400	210
02-05-87	.012	4.8	820	2.3	1.6	1.3	450	240

Table 4.5 1987-88 East Finniss River water quality at GS8150097

DATE	FLOW (l/s)	pH	COND (µs/cm)	Cu	Mn	Zn	SO_4	Ra-226 (mBq/l)
					(mg/l)			
21-12-87	257	4.9	400	1.4	1.5	1.9	170	250
22-12-87	273	4.9	400	0.91	0.82	1.1	180	120
23-12-87	807	4.8	410	0.84	0.75	0.94	180	130
24-12-87	408	6.0	360	0.68	0.56	0.78	160	98
25-12-87	434	4.5	630	1.7	1.2	1.6	300	190
26-12-87	276	5.0	290	0.61	0.55	0.56	120	91
27-12-87	108	5.1	430	0.87	0.76	0.93	200	120
28-12-87	56	4.6	820	2.2	1.6	2.2	420	150
29-12-87	37	4.5	900	2.4	1.9	2.4	470	170
30-12-87	28	4.4	960	2.5	2.1	2.7	500	210
31-12-87	24	4.5	970	2.6	2.1	2.8	510	240
01-01-88	17	4.4	970	2.5	2.1	2.9	510	220
02-01-88	12	4.6	970	2.5	2.1	2.7	510	240
03-01-88	20	4.5	930	2.5	2.2	2.8	480	210
04-01-88	33	4.5	890	2.4	2.1	2.6	470	230
05-01-88	18	4.4	950	2.5	2.2	2.8	500	210
06-01-88	11	4.6	940	2.5	2.2	2.7	490	240
07-01-88	6	4.4	900	2.4	2.1	2.6	470	270
08-01-88	3	4.5	930	2.4	2.2	2.7	480	290
09-01-88	25	4.4	980	2.6	2.3	2.8	520	280
10-01-88	23	4.4	1 000	2.9	2.5	3.3	580	240
11-01-88	55	4.4	1 100	3.2	2.7	3.8	640	210
12-01-88	38	4.3	1 400	3.9	3.3	5.6	800	240
13-01-88	15	4.3	1 600	4.4	3.8	6.6	930	200
14-01-88	6	4.2	1 600	4.4	4.0	6.9	950	210
15-01-88	2	4.2	1 600	4.3	4.0	6.9	940	210
16-01-88	908	4.5	630	1.5	1.5	0.86	300	120
17-01-88	564	4.7	730	1.1	1.7	0.35	350	47
18-01-88	241	4.7	720	1.2	1.7	0.42	350	58
19-01-88	153	4.6	690	1.2	1.6	0.54	330	70
20-01-88	412	4.7	600	1.3	1.3	0.66	280	88
21-01-88	523	4.7	580	0.84	1.3	0.39	260	78
22-01-88	328	4.9	610	0.68	1.4	0.40	280	76
23-01-88	214	5.0	590	0.67	1.3	0.42	280	67
24-01-88	186	5.2	580	0.69	1.3	0.46	270	75
25-01-88	169	5.0	550	0.86	1.2	0.58	260	74
26-01-88	205	5.4	500	0.69	0.96	0.54	230	85
27-01-88	376	4.4	490	1.1	1.1	0.58	210	87
28-01-88	319	4.7	580	0.78	1.3	0.43	270	73
29-01-88	211	4.8	570	0.92	1.2	0.46	270	67
30-01-88	153	5.2	540	0.64	1.1	0.52	250	51
31-01-88	265	5.1	540	0.72	1.2	0.47	250	54
01-02-88	405	5.0	540	0.74	1.2	0.44	260	61
02-02-88	307	4.9	570	0.99	1.3	0.45	270	47
03-02-88	190	5.1	560	0.85	1.3	0.44	270	67
04-02-88	139	5.1	540	0.68	1.2	0.46	250	63
05-02-88	133	5.1	530	0.66	1.1	0.47	250	75

Table 4.5 Cont'd

DATE	FLOW (l/s)	pH	COND (µs/cm)	Cu	Mn (mg/l)	Zn	SO_4	Ra-226 (mBq/l)
06-02-88	149	5.0	590	1.1	1.2	0.73	290	79
07-02-88	126	4.7	620	1.4	1.4	0.81	310	99
08-02-88	133	4.9	620	1.0	1.3	0.76	300	68
09-02-88	1 270	4.9	430	0.86	0.84	0.44	200	100
10-02-88	2 750	5.0	680	1.1	1.4	0.26	330	68
11-02-88	1 140	4.0	670	1.2	1.4	0.31	310	59
12-02-88	1 180	5.1	540	0.86	1.1	0.29	260	58
13-02-88	3 010	5.6	550	0.68	1.1	0.21	260	62
14-02-88	1 520	5.2	580	0.89	1.2	0.24	280	52
15-02-88	1 060	5.7	520	0.60	0.84	0.45	240	45
16-02-88	1 030	5.7	510	0.64	1.1	0.27	230	36
17-02-88	880	5.8	470	0.47	0.96	0.25	220	23
18-02-88	770	5.8	450	0.39	0.85	0.25	200	36
19-02-88	690	6.0	420	0.27	0.75	0.24	190	27
20-02-88	1 650	5.8	340	0.24	0.70	0.20	140	79
21-02-88	2 340	5.7	440	0.47	0.87	0.18	200	73
22-02-88	3 650	5.6	450	0.49	0.90	0.18	200	56
23-02-88	1 790	5.8	460	0.41	0.96	0.19	200	42
24-02-88	1 250	6.1	410	0.29	0.72	0.21	180	46
25-02-88	1 040	6.0	390	0.24	0.68	0.21	170	29
26-02-88	921	6.2	380	0.18	0.66	0.20	160	31
27-02-88	843	5.9	360	0.12	0.56	0.19	150	25
28-02-88	772	6.5	350	0.14	0.65	0.20	150	35
29-02-88	702	6.0	340	0.14	0.63	0.22	150	37
01-03-88	630	6.2	340	0.09	0.60	0.19	140	29
02-03-88	570	6.3	330	0.09	0.59	0.21	140	29
03-03-88	500	6.7	330	0.07	0.56	0.22	140	33
04-03-88	444	6.4	330	0.08	0.50	0.24	140	33
05-03-88	425	6.5	330	0.11	0.51	0.28	140	27
06-03-88	449	6.3	360	0.25	0.61	0.36	150	26
07-03-88	391	6.7	350	0.15	0.55	0.26	150	23
08-03-88	332	6.6	350	0.08	0.52	0.25	150	26
09-03-88	273	6.3	370	0.10	0.57	0.33	160	33
10-03-88	692	6.0	380	0.78	0.70	0.45	160	57
11-03-88	543	6.0	350	0.29	0.70	0.24	150	57
12-03-88	301	6.2	360	0.18	0.66	0.26	160	37
13-03-88	212	6.2	380	0.18	0.68	0.34	170	45
14-03-88	161	6.5	410	0.17	0.73	0.42	180	47
15-03-88	224	6.3	400	0.26	0.67	0.43	180	56
16-03-88	167	5.8	530	1.5	0.84	0.74	250	82
17-03-88	122	5.6	500	1.1	0.79	0.60	230	62
18-03-88	88	5.8	480	0.68	0.71	0.55	220	60
19-03-88	78	5.8	520	0.78	0.79	0.64	240	70
20-03-88	192	5.5	560	1.1	0.93	0.80	270	86
21-03-88	189	4.7	660	2.3	1.4	1.03	330	76

DATE	FLOW (l/s)	pH	COND (µs/cm)	Cu	Mn	Zn	SO_4	Ra-226 (mBq/l)
					(mg/l)			
22-03-88	150	4.8	620	1.4	1.2	0.85	300	61
23-03-88	126	5.1	520	0.94	0.91	0.64	250	55
24-03-88	420	4.8	560	1.3	1.1	0.79	260	67
25-03-88	467	5.6	400	0.38	0.73	0.27	180	48
26-03-88	282	5.9	390	0.18	0.66	0.24	170	41
27-03-88	209	5.9	410	0.12	0.63	0.27	180	42
28-03-88	411	6.1	460	0.35	0.69	0.49	210	40
29-03-88	4 030	5.8	330	0.15	0.59	0.19	140	75
30-03-88	2 620	5.7	480	0.45	0.96	0.14	220	63
31-03-88	1 300	5.7	420	0.29	0.83	0.24	180	47
01-04-88	1 180	6.2	380	0.18	0.70	0.21	170	40
02-04-88	1 670	6.1	390	0.17	0.72	0.21	180	35
03-04-88	1 400	6.1	360	0.11	0.66	0.17	160	39
04-04-88	1 340	6.5	310	0.07	0.52	0.19	130	31
05-04-88	1 060	6.2	330	0.10	0.55	0.16	140	29
16-04-88	954	6.4	310	0.07	0.56	0.13	130	21
07-04-88	882	5.4	320	0.27	0.27	0.23	140	28
08-04-88	792	6.4	290	0.01	0.57	0.13	120	26
09-04-88	731	6.6	280	0.04	0.56	0.14	120	20
10-04-88	688	6.5	280	0.05	0.52	0.15	110	21
11-04-88	643	6.5	280	0.05	0.52	0.16	110	19
12-04-88	573	6.7	280	0.04	0.52	0.18	120	18
13-04-88	515	6.6	290	0.05	0.55	0.20	120	21
14-04-88	465	6.7	290	0.05	0.55	0.21	120	18
15-04-88	414	6.6	310	0.05	0.48	0.23	130	27
16-04-88	374	6.6	320	0.04	0.51	0.24	130	24
17-04-88	345	6.7	330	0.07	0.50	0.23	140	33
18-04-88	314	6.4	330	0.07	0.50	0.25	145	31
19-04-88	276	6.3	340	0.11	0.50	0.28	150	29
20-04-88	234	6.5	360	0.07	0.51	0.28	150	24
21-04-88	201	6.2	360	0.10	0.50	0.31	160	34
22-04-88	181	6.3	370	0.11	0.46	0.33	150	33
23-04-88	157	6.3	380	0.13	0.48	0.34	160	29
24-04-88	133	6.6	390	0.09	0.56	0.37	170	26
25-04-88	112	6.3	410	0.14	0.50	0.40	180	41
26-04-88	94	6.2	430	0.12	0.57	0.52	190	39
27-04-88	76	6.4	440	0.34	0.58	0.52	200	57
28-04-88	62	6.0	460	0.39	0.63	0.55	200	54
29-04-88	51	6.1	470	0.45	0.58	0.57	210	53
30-04-88	41	6.2	500	0.52	0.62	0.64	230	57
01-05-88	32	6.2	520	0.64	0.65	0.68	240	64
02-05-88	24	6.0	530	0.78	0.65	0.69	250	74
03-05-88	19	5.9	550	0.81	0.68	0.69	250	
04-05-88	14	6.1	550	0.73	0.70	0.68	260	
05-05-88	10	6.0	550	0.76	0.71	0.66	260	
06-05-88	7	6.0	560	0.74	0.69	0.68	260	
07-05-88	4	6.0	560	0.76	0.73	0.66	260	
08-05-88	2	6.1	550	0.71	0.75	0.61	260	
09-05-88	1	6.1	550	0.67	0.82	0.61	260	

Table 4.9 1986-87 East Finniss River pollutant loads at GS8150097

DATE	FLOW (l X 10^6)	Cu	Mn (kg)	Zn	SO_4 (t)	Ra-226 (MBq)
04-12-86	21.3	1.1	7.9	12	.81	5.8
05-12-86	3.15	.95	3.3	.85	.26	1.1
06-12-86	4.31					
07-12-86	1.66		NO SAMPLE TAKEN			
08-12-86	.443					
09-12-86	8.00	21	23	11	2.3	4.9
10-12-86	3.27	8.5	8.5	4.8	.96	1.3
11-12-86	.873	3.0	3.2	3.1	.30	.37
12-12-86	.128	.41	.44	.42	.05	.07
13-12-86	.018	.06	.07	.06	.01	.01
14-12-86						
15-12-86						
16-12-86						
17-12-86						
18-12-86						
19-12-86						
20-12-86						
21-12-86						
22-12-86						
23-12-86						
24-12-86						
25-12-86						
26-12-86						
27-12-86			NO FLOW			
28-12-86						
29-12-86						
30-12-86						
31-12-86						
01-01-87						
02-01-87						
03-01-87						
04-01-87						
05-01-87						
06-01-87						
07-01-87						
08-01-87						
09-01-87						
10-01-87						
11-01-87						
12-01-87						
13-01-87						
14-01-87						
15-01-87	23.8	38	50	31		8.3
16-01-87	59.7	90	78	41		15
17-01-87	99.4	130	150	34	60	11
18-01-87	124	140	170	41	57	17
19-01-87	50.4	55	81	20	27	4.7
20-01-87	28.3	36	42	21	12	2.3
21-01-87	44.2	66	62	32	17	3.5

DATE	FLOW (l X 10^6)	Cu	Mn (kg)	Zn	SO_4 (t)	Ra-226 (MBq)
22-01-87	29.9	42	39	17	11	3.3
23-01-87	18.6	33	33	14	8.7	1.5
24-01-87	13.8	29	25	15	6.6	1.5
25-01-87	13.9	25	21	14	5.3	1.4
26-01-87	13.2	28	22	18	5.8	1.1
27-01-87	11.3	20	17	12	4.2	.9
28-01-87	99.4	140	140	99	31	8.9
29-01-87	95.9	130	120	88	26	7.7
30-01-87	8.90	12	11	9.8	2.5	.71
31-01-87	20.7	29	22	20	5.6	2.1
01-02-87	170	150	150	68	53	16
02-02-87	226	270	270	63	120	16
03-02-87	253	330	330	66	140	18
04-02-87	222	220	250	58	100	12
05-02-87	207	200	230	54	87	11
06-02-87	366	350	400	81	170	24
07-02-87	194	160	190	47	78	8.7
08-02-87	200	120	160	48	52	16
09-02-87	740	180	440	74	150	89
10-02-87	353	180	280	64	100	28
11-02-87	414	170	330	66	120	21
12-02-87	204	92	150	37	53	8.6
13-02-87	154	69	110	34	34	6.5
14-02-87	178	77	120	41	37	9.6
15-02-87	232	86	130	44	41	13
16-02-87	261	99	160	47	51	12
17-02-87	247	100	150	49	48	9.6
18-02-87	264	87	160	45	50	13
19-02-87	351	84	150	53	46	19
20-02-87	359	90	190	47	57	19
21-02-87	239	60	120	33	38	11
22-02-87	524	79	210	52	73	23
23-02-87	826	83	290	66	99	55
24-02-87	491	74	250	49	83	26
25-02-87	275	69	150	39	50	12
26-02-87	214	54	120	34	36	6.6
27-02-87	266	67	130	43	40	13
28-02-87	284	71	140	34	43	9.4
01-03-87	214	64	110	30	30	7.5
02-03-87	173	52	78	28	24	9.0
03-03-87	148	44	67	27	21	6.2
04-03-87	135	34	61	24	19	4.6
05-03-87	121	36	54	24	16	4.7
06-03-87	111	39	50	22	14	2.9
07-03-87	100	32	45	23	13	3.4
08-03-87	89.9	29	40	22	12	3.2
09-03-87	80.5	25	35	21	11	3.1
10-03-87	73.3	24	32	20	10	2.4
11-03-87	146	58	58	35	17	11
12-03-87	232	63	100	35	27	9.5

Table 4.9 Cont'd

DATE	FLOW (1 X 10^6)	Cu	Mn (kg)	Zn	SO_4 (t)	Ra-226 (MBq)
13-03-87	141	37	61	24	17	5.1
14-03-87	102	27	44	19	13	3.6
15-03-87	81.7	22	36	19	11	2.5
16-03-87	71.1	11	15	16	6.9	2.3
17-03-87	65.0	20	29	16	8.7	2.2
18-03-87	61.8	17	27	13	8.2	3.3
19-03-87	56.6	17	25	16	7.8	1.6
20-03-87	51.9	18	24	16	7.6	1.5
21-03-87	302	60	170	51	31	18
22-03-87	280	56	170	36	31	13
23-03-87	130	25	83	20	15	4.9
24-03-87	94.2	20	61	19	12	3.6
25-03-87	84.0	17	54	18	11	2.8
26-03-87	76.2	14	48	15	9.6	3.1
27-03-87	69.4	14	44	15	8.7	2.1
28-03-87	65.8	13	41	15	8.3	2.0
29-03-87	59.3	10	37	14	7.5	1.5
30-03-87	53.7	9.1	33	12	6.9	1.6
31-03-87	47.9	9.7	31	12	6.4	1.5
01-04-87	40.4	9.3	27	11	5.5	1.3
02-04-87	35.5	16	26	13	5.5	1.2
03-04-87	31.9	12	24	11	5.1	1.1
04-04-87	28.6	10	23	9.7	4.9	1.0
05-04-87	25.6	9.2	22	9.5	4.6	1.1
06-04-87	22.7	12	17	10	4.4	1.0
07-04-87	20.0	14	21	10	4.1	.92
08-04-87	17.1	15	19	9.4	3.8	.79
09-04-87	14.1	15	16	8.6	3.3	.62
10-04-87	16.0	21	18	11	3.8	.77
11-04-87	33.0	63	33	27	9.2	1.8
12-04-87	28.6	23	18	14	5.7	1.3
13-04-87	18.5	8.3	11	8.5	3.6	.72
14-04-87	13.1	8.5	7.3	9.0	3.4	.66
15-04-87	9.85	8.1	7.1	6.5	2.8	.49
16-04-87	7.46	8.4	6.6	5.7	2.3	.48
17-04-87	5.62	8.0	5.6	5.1	1.9	.36
18-04-87	4.70	7.5	4.9	4.6	1.7	.31
19-04-87	3.65	6.4	4.1	3.9	1.4	.34
20-04-87	2.86	5.5	3.5	3.3	1.2	.25
21-04-87	2.23	4.6	2.9	2.7	.96	.25
22-04-87	1.68	3.4	2.3	2.1	.73	.18
23-04-87	1.26	2.7	1.8	1.7	.57	.18
24-04-87	.890	1.9	1.3	1.2	.40	.13
25-04-87	.683	1.5	1.0	.92	.30	.11
26-04-87	.419	.94	.64	.57	.18	.07
27-04-87	.240	.52	.36	.31	.10	.05
28-04-87	.165	.36	.25	.21	.07	.02
29-04-87	.111	.24	.17	.14	.05	.02
30-04-87	.061	.14	.09	.07	.03	.01
01-05-87	.034	.08	.05	.04	.01	.01
02-05-87	.012	.03	.02	.02	.01	.00

Table 4.10 1987-88 East Finniss River dissolved pollutant loads at GS8150097

DATE	FLOW (lx10^6/d)	Cu	Mn (kg/d)	Zn	SO_4 (t/d)	Ra-226 (MBq/d)
21-12-87	22.2	31	34	42	3.9	5.6
22-12-87	23.6	12	19	25	4.2	2.8
23-12-87	69.7	59	52	66	13	9.1
24-12-87	35.2	24	20	28	5.6	3.5
25-12-87	37.5	63	46	62	11	7.1
26-12-87	23.8	15	13	13	2.7	2.2
27-12-87	9.33	8.1	7.1	8.7	1.9	1.1
28-12-87	4.84	10	7.9	10	2.0	0.73
29-12-87	3.20	7.5	6.0	7.6	1.5	0.54
30-12-87	2.42	6.1	4.9	6.5	1.2	0.51
31-12-87	2.07	5.4	4.4	5.9	1.1	0.50
01-01-88	1.47	3.7	3.1	4.2	0.75	0.32
02-01-88	1.04	2.6	2.2	2.8	0.53	0.25
03-01-88	1.73	4.3	3.8	4.8	0.83	0.36
04-01-88	2.85	6.9	5.9	7.4	1.3	0.66
05-01-88	1.56	3.9	3.4	4.4	0.78	0.33
06-01-88	0.950	2.4	2.1	2.6	0.47	0.23
07-01-88	0.518	1.2	1.1	1.3	0.24	0.14
08-01-88	0.259	0.63	0.57	0.69	0.12	0.08
09-01-88	2.16	5.5	5.0	6.1	1.1	0.60
10-01-88	1.99	5.7	4.9	6.6	1.1	0.48
11-01-88	4.75	15	13	18	3	1.0
12-01-88	3.28	13	11	18	2.6	0.79
13-01-88	1.30	5.7	5.0	8.6	1.2	0.26
14-01-88	0.518	2.3	2.1	3.6	0.49	0.11
15-01-88	0.173	0.75	0.69	1.2	0.16	0.04
16-01-88	78.4	120	120	67	24	9.4
17-01-88	48.7	55	84	17	17	2.3
18-01-88	20.8	24	35	8.8	7.3	1.2
19-01-88	13.2	15	21	7.1	4.4	0.93
20-01-88	35.6	47	48	23	10	3.1
21-01-88	45.2	38	61	18	12	3.5
22-01-88	28.3	19	41	11	7.9	2.2
23-01-88	18	12	24	7.87	5.2	1.2
24-01-88	16.1	11	21	7.4	4.3	1.2
25-01-88	14.6	13	18	8.5	3.8	1.1
26-01-88	17.7	12	17	9.6	4.1	1.5
27-01-88	32.5	36	35	19	6.8	2.8
28-01-88	27.6	22	36	12	7.4	2.0
29-01-88	18.2	17	23	8.4	4.9	1.2
30-01-88	13.2	8.5	14	6.9	3.3	0.67
31-01-88	22.9	16	27	11	5.7	1.2
01-02-88	35.0	26	42	15	9.1	2.1
02-02-88	26.5	26	34	12	7.2	1.2
03-02-88	16.4	15	21	7.2	4.4	1.1
04-02-88	12.0	8.2	14	5.5	3.0	0.76
05-02-88	11.5	7.6	13	5.4	2.9	.86

Table 4.10 Cont'd

DATE	FLOW ($l \times 10^6$/d)	Cu	Mn (kg/d)	Zn	SO_4 (t/d)	Ra-226 (MBq/d)
06-02-88	12.9	14	16	9.4	3.7	1.0
07-02-88	10.9	16	15	8.8	3.4	1.1
08-02-88	11.5	12	15	8.7	3.4	0.78
09-02-88	109	94	92	48	22	11
10-02-88	238	250	330	62	78	16
11-02-88	98.5	110	130	31	31	5.8
12-02-88	102	88	110	30	27	5.9
13-02-88	260	180	290	55	68	16
14-02-88	131	120	160	32	37	6.8
15-02-88	91.6	55	77	41	22	4.1
16-02-88	89.0	57	97	24	20	3.2
17-02-88	76.0	36	73	19	17	1.8
18-02-88	66.5	26	57	17	13	2.4
19-02-88	59.6	16	45	14	11	1.6
20-02-88	143	34	100	29	20	11
21-02-88	202	95	180	36	40	15
22-02-88	315	150	280	57	63	18
23-02-88	155	63	150	29	31	6.5
24-02-88	108	31	78	23	19	5.0
25-02-88	89.9	22	61	19	15	2.6
26-02-88	79.6	14	53	16	13	2.5
27-02-88	72.8	8.7	41	14	11	1.8
28-02-88	66.7	9.3	43	13	10	2.3
29-02-88	60.7	8.5	38	13	9.1	2.2
01-03-88	54.4	4.9	33	10	7.6	1.6
02-03-88	49.2	4.4	29	10	6.9	1.4
03-03-88	43.2	3.0	24	9.5	6.1	1.4
04-03-88	38.4	3.1	19	9.2	5.4	1.3
05-03-88	36.7	4.0	19	10	5.1	0.99
06-03-88	38.8	9.7	24	14	5.8	1.0
07-03-88	33.8	5.1	19	8.8	5.1	0.78
08-03-88	28.7	2.3	15	7.2	4.3	0.75
09-03-88	23.6	2.4	13	7.8	3.8	0.78
10-03-88	59.8	47	42	27	9.6	3.4
11-03-88	46.9	14	33	11	7.0	2.7
12-03-88	26.0	4.7	17	6.8	4.2	0.96
13-03-88	18.3	3.3	12	6.2	3.1	0.82
14-03-88	13.9	2.4	10	5.8	2.5	0.65
15-03-88	19.4	5.0	13	8.3	3.5	1.1
16-03-88	14.4	22	12	11	3.6	1.2
17-03-88	10.5	11	8.3	6.3	2.4	0.65
18-03-88	7.60	5.2	5.4	4.2	1.7	0.46
19-03-88	6.74	5.3	5.3	4.3	1.6	0.47
20-03-88	16.6	18	15	13	4.5	1.4
21-03-88	16.3	38	23	17	5.4	1.2
22-03-88	13.0	19	15	11	3.9	0.79
23-03-88	10.9	10	9.9	7.0	2.7	0.60

DATE	FLOW ($l x 10^6/d$)	Cu	Mn (kg/d)	Zn	SO_4 (t/d)	Ra-226 (MBq/d)
24-03-88	36.3	48	39	29	9.4	2.4
25-03-88	40.3	15	29	11	7.3	1.9
26-03-88	24.4	4.4	16	5.9	4.1	1.0
27-03-88	18.1	2.2	1.1	4.9	3.2	0.76
28-03-88	35.5	12	24	17	7.5	1.4
29-03-88	348	52	210	66	49	26
30-03-88	226	100	220	32	50	14
31-03-88	112	33	93	27	20	4.4
01-04-88	102	18	71	21	17	4.1
02-04-88	144	25	100	30	26	5.1
03-04-88	121	13	80	21	19	4.7
04-04-88	116	8.1	60	22	15	3.6
05-04-88	91.6	9.2	50	15	13	2.7
06-04-88	82	5.8	46	11	11	1.7
07-04-88	76.2	21	21	18	11	2.1
08-04-88	68.4	0.68	39	8.9	8.2	1.8
09-04-88	63.2	2.5	35	8.8	7.6	1.3
10-04-88	59.4	3.0	31	8.9	6.5	1.2
11-04-88	55.6	2.8	29	8.9	6.1	1.1
12-04-88	49.5	2.0	26	8.9	5.9	0.89
13-04-88	44.5	2.2	24	8.9	5.3	0.93
14-04-88	40.2	2.0	22	8.4	4.8	0.72
15-04-88	35.8	1.8	17	8.2	4.6	0.97
16-04-88	32.3	1.3	16	7.8	4.2	0.78
17-04-88	29.8	2.1	15	6.9	4.2	0.98
18-04-88	27.1	1.9	14	6.8	3.9	0.84
19-04-88	23.8	2.6	12	6.7	3.6	0.69
20-04-88	20.2	1.4	10	5.7	3.0	0.49
21-04-88	17.4	1.7	8.7	5.4	2.8	0.59
22-04-88	15.6	1.7	7.2	5.2	2.4	0.52
23-04-88	13.6	1.8	6.5	4.6	2.2	0.39
24-04-88	11.5	1.0	6.4	4.2	2.0	0.30
25-04-88	9.68	1.4	4.8	3.9	1.7	0.40
26-04-88	8.12	0.97	4.6	4.2	1.5	0.32
27-04-88	6.57	2.2	3.8	3.4	1.3	0.37
28-04-88	5.36	2.1	3.4	3.0	1.1	0.29
29-04-88	4.41	2.0	2.6	2.5	0.93	0.23
30-04-88	3.54	1.8	2.2	2.3	0.81	0.20
01-05-88	2.76	1.8	1.8	1.9	0.66	0.18
02-05-88	2.07	1.6	1.4	1.4	0.52	0.15
03-05-88	1.64	1.3	1.1	1.1	0.41	
04-05-88	1.21	0.88	0.85	0.82	0.31	
05-05-88	0.864	0.66	0.61	0.57	0.22	
06-05-88	0.605	0.45	0.42	0.41	0.16	
07-05-88	0.346	0.26	0.25	0.23	0.09	
08-05-88	0.173	0.12	0.13	0.11	0.04	
09-05-88	0.043	0.03	0.04	0.03	0.01	

Table 4.16 1986-87 Finniss River water quality at GS8150204 - general parameters

DATE	pH	COND ($\mu S/cm$)	Ca	Mg (mg/l)	HCO_3	SO_4
17-01-87	5.2	340	13	29	13	150
19-01-87	6.8	380	33	21	40	130
20-01-87	6.7	390	31	23	44	130
21-01-87	6.7	290	20	18	36	86
22-01-87	6.5	53	24	4	19	25
23-01-87	6.2	75	38	5	11	18
24-01-87	6.4	130	7	8	14	45
26-01-87	6.6	160	7	13	20	62
27-01-87	6.7	99	4	8	30	25
28-01-87	6.8	98	4	7	33	22
29-01-87	6.8	110	5	8	32	38
30-01-87	6.7	110	4	8	26	32
31-01-87	6.7	130	5	10	28	38
02-02-87	6.3	130	3	6	11	44
03-02-87	6.5	220	19	11	12	83
05-02-87	6.5	200	16	9	19	65
07-02-87	6.8	240	20	12	17	87
10-02-87	6.4	110	7	5	17	30
18-02-87	6.5	99	7	5	16	28
24-02-87	6.3	120	8	6	11	40
28-02-87	6.6	90	5	5	21	21
03-03-87	6.9	110	6	7	26	28
07-03-87	6.9	130	6	9	33	33
10-03-87	6.8	140	7	10	36	36
14-03-87	6.9	150	10	39	34	37
17-03-87	6.9	170	8	12	39	44
21-03-87	6.8	120	6	9	40	26
24-03-87	6.9	170	9	12	33	51
28-03-87	7.0	190	9	14	40	54
31-03-87	6.2	220				57
04-04-87	6.4	240			68	68
07-04-87	6.6	260				65
11-04-87	6.2	310				100
14-04-87	6.5	260				65
21-04-87	7.6	300				57
24-04-87	8.1	280				46

Table 4.17 1986-87 Finniss River water quality at GS8150204 - heavy metals

DATE	Total			Filtrate (mg/l)		
	Cu	Mn	Zn	Cu	Mn	Zn
17-01-87	.95	.92	.53	.85	.80	.50
19-01-87				.94	.28	.47
20-01-87	.45	.45	.10	.25	.45	.10
21-01-87	.40	.35	.14	.20	.30	.10
22-01-87	.07	.77	.01	.03	.01	.01
23-01-87	.08	.10	.02	.08	.02	.02
24-01-87	.20	.16	.08	.09	.13	.06
26-01-87	.25	.25	.10	.15	.20	.08
27-01-87	.10	.10	.04	.05	.10	.04
28-01-87	.05	.10	.04	.05	.05	.02
29-01-87	.05	.10	.04	.05	.05	.02
30-01-87	.10	.15	.06	.05	.15	.04
31-01-87	.15	.20	.07	.12	.15	.05
02-02-87	.12	.14	.04	.06	.04	.03
03-02-87	.21	.25	.05	.17	.19	.04
05-02-87	.15	.21	.05	.09	.15	.04
07-02-87	.20	.28	.07	.10	.24	.05
10-02-87	.10	.10	.04	.05	.05	.02
18-02-87	.07	.14	.03	.05	.09	.02
24-02-87	.12	.15	.05	.07	.05	.04
28-02-87	.09	.06	.03	.04	.02	.02
03-03-87	.15	.09	.10	.08	.08	.07
07-03-87	.15	.29	.10	.08	.08	.09
10-03-87	.16	.16	.10	.08	.13	.07
14-03-87	.15	.18	.08	.09	.14	.06
17-03-87	.16	.20	.06	.10	.20	.05
21-03-87	.17	.14	.09	.10	.10	.04
24-03-87	.10	.23	.10	.07	.20	.08
28-03-87	.13	.24	.11	.05	.19	.10
31-03-87	.19	.26	.22	.07	.22	.16
04-04-87	.15	.26	.14	.10	.24	.13
07-04-87	.18	.28	.23	.06	.19	.12
11-04-87	.35	.40	.31	.10	.30	.23
14-04-87	.16	.24	.11	.05	.14	.10
21-04-87	.12	.22	.13	.06	.15	.09
24-04-87	.12	.20	.11	.05	.12	.07

Table 4.20 **1987-88 East Finniss River water quality at GS8150204 - general parameters**

DATE	FLOW (l/s)	pH	SC (µs/cm)	SO_4	Ca	Mg (mg/l)	HCO_3
30-01-88	770	6.6	240	99	13	17	43
31-01-88	800	6.7	230	61	12	16	46
01-02-88	940	6.5	360	130	18	26	31
02-02-88	750	6.6	370	140	21	26	31
03-02-88	510	6.6	180	110	21	23	34
04-02-88	410	6.7	310	105	18	22	39
06-02-88	340	6.9	300	100	16	22	41
07-02-88	310	6.7	300	94	16	22	41
08-02-88	270	6.8	370	135	17	28	34
09-02-88	2 260	6.5	390	135	16	32	32
16-02-88	6 730	6.2	130	38	9	8	16
17-02-88	4 390	6.4	150	49	10	10	17
18-02-88	3 630	6.4	160	50	10	10	19
19-02-88	3 140	6.4	170	50	9	11	21
20-02-88	7 020	6.4	150	38	7	9	28
21-02-88	12 600	6.3	150	41	10	9	20
22-02-88	19 600	6.2	150	48	9	9	14
23-02-88	22 700	6.0	81	23	5	5	10
24-02-88	15 400	6.0	61	18	3	4	8
25-02-88	5 750	6.1	110	33	6	7	12
26-02-88	4 470	6.3	130	39	6	9	15
27-02-88	4 440	6.4	130	36	6	9	19
28-02-88	4 000	6.4	130	36	6	9	22
29-02-88	3 320	6.4	140	38	0	0	0
29-03-88	16 000	6.5	110	29	4	7	17
30-03-88	25 000	6.0	120	28	7	6	16
31-03-88	6 930	6.2	104	29	5	6	13
01-04-88	21 700	5.9	124	36	6	7	16
02-04-88	14 400	5.9	94	18	4	5	21
03-04-88	14 400	5.9	82	19	4	4	12
04-04-88	12 200	6.1	77	18	5	5	17
05-04-88	9 770	6.0	85	21	5	5	15
06-04-88	7 420	6.1	81	19	3	5	17
24-12-87	7 780	5.9	65	10	2	4	12
25-12-87	3 390	6.1	66	13	2	5	13
26-12-87	4 950	5.9	76	10	2	5	19
27-12-87	1 690	6.1	71	12	3	5	16
28-12-87	850	6.2	96	23	4	7	19
29-12-87	540	6.0	130	31	4	10	20
30-12-87	400	6.2	130	36	5	11	22
31-12-87	350	6.3	130	31	6	10	24
01-01-88	290	6.2	140	33	6	11	25
02-01-88	230	6.1	120	32	6	10	27
03-01-88	250	6.2	120	29	5	9	29

DATE	FLOW (l/s)	pH	SC (µs/cm)	SO_4	Ca (mg/l)	Mg	HCO_3
04-01-88	390	6.3	140	39	6	12	28
05-01-88	360	6.7	140	29	N/A		
06-01-88	460	6.6	120	21	5	9	32
07-01-88	470	6.7	170	46	7	14	26
08-01-88	410	6.7	110	19	5	9	33
09-01-88	730	6.8	97	11	5	8	37
10-01-88	2 920	6.3	95	8	5	8	40
11-01-88	5 980	6.4	130	10	8	10	63
12-01-88	2 800	6.4	130	15	6	10	47
13-01-88	2 190	6.4	95	11	4	7	34
14-01-88	1 330	7.0	82	8	4	7	32
15-01-88	1 910	6.8	240	71	46	18	46
16-01-88	3 930	6.5	320	122	19	24	28
17-01-88	2 250	6.5	270	95	18	19	27
18-01-88	1 190	6.6	300	113	21	21	28
19-01-88	800	6.9	280	100	19	20	33
20-01-88	1 120	7.1	270	87	16	19	36
21-01-88	1 600	6.6	260	88	17	19	32
22-01-88	1 010	7.1	280	90	15	20	36
23-01-88	680	6.8	240	79	11	19	27
24-01-88	570	6.7	82	9	4	6	36
25-01-88	530	6.1	260	100	9	23	17
28-01-88	720	6.3	370	140	18	29	19
29-01-88	750	6.2	310	100	17	22	32

Table 4.21 1987-88 East Finnis River water quality at GS8150204 - heavy metals concentrations

DATE	FLOW (l/s)	pH	SC (µs/cm)	Cu sol	Cu tot	Mn sol (mg/l)	Mn tot	Zn sol	Zn tot	SO_4
24-12-87	7 780	5.9	65	.07	.11	.01	.04	.01	.06	10
25-12-87	3 390	6.1	66	.13	.12	.01	.06	.03	.09	13
26-12-87	4 950	5.9	76	.12	.40	.01	.17	.03	.12	10
27-12-87	1 690	6.1	71	.07	.14	.01	.09	.03	.08	12
28-12-87	850	6.2	96	.09	.18	.01	.13	.05	.10	23
29-12-87	540	6.0	130	.10	.24	.01	.20	.07	.13	31
30-12-87	400	6.2	130	.07	.17	.01	.14	.05	.11	36
31-12-87	350	6.3	130	.07	.17	.01	.13	.04	.11	31
01-01-88	290	6.2	140	.08	.17	.01	.16	.05	.11	33
02-01-88	230	6.1	120	.08	.13	.04	.15	.06	.12	32
03-01-88	250	6.2	120	.07	.12	.01	.14	.03	.10	29
04-01-88	390	6.3	120	.07	.10	.02	.15	.03	.10	39
05-01-88	360	6.7	140	.08	.13	.02	.10	.04	.10	29
06-01-88	460	6.6	120	.07	.11	.01	.09	.03	.09	21
07-01-88	470	6.7	170	.07	.19	.01	.21	.05	.16	46
08-01-88	410	6.7	110	.05	.08	.02	.11	.02	.08	19
09-01-88	730	6.8	97	.05	.08	.01	.07	.01	.07	11
10-01-88	2 920	6.3	95	.05	.06	.02	.26	.04	.08	8
11-01-88	5 980	6.4	129	.06	.10	.02	.31	.03	.10	10
12-01-88	2 800	6.4	129	.06	.08	.02	.05	.04	.11	15
13-01-88	2 190	6.4	95	.07	.07	.03	.05	.04	.09	11
14-01-88	1 330	7.0	82	.05	.05	.03	.09	.03	.09	8
15-01-88	1 910	6.8	240	.10	.32	.03	.38	.05	.44	71
16-01-88	3 930	6.5	320	.07	.20	.01	.25	.10	.23	120
17-01-88	2 250	6.5	270	.05	.40	.01	.41	.05	.22	95
18-01-88	1 190	6.6	300	.11	.27	.05	.33	.08	.19	110
19-01-88	800	6.9	280	.08	.19	.01	.29	.07	.17	100
20-01-88	1 120	7.1	270	.07	.21	.01	.30	.06	.18	87
21-01-88	1 600	6.6	260	.05	.17	.01	.23	.11	.19	88
22-01-88	1 010	7.1	280	.08	.18	.01	.22	.10	.21	90
23-01-88	680	6.8	240	.06	.19	.01	.21	.11	.21	79
24-01-88	570	6.7	82	.02	.03	.01	.08	.03	.07	9
25-01-88	530	6.1	260	.17	1.14	.07	.45	.19	.45	100
28-01-88	720	6.3	370	.22	.41	.53	.64	.31	.35	140
29-01-88	750	6.2	310	.09	.22	.15	.39	.15	.22	100
30-01-88	770	6.6	240	.06	.15	.01	.20	.08	.14	99
02-02-88	750	6.6	370	.21	.35	.51	.61	.21	.27	140
03-02-88	510	6.6	180	.15	.21	.40	.49	.17	.21	110

DATE	FLOW (l/s)	pH	SC (µs/cm)	Cu sol	Cu tot	Mn sol (mg/l)	Mn tot	Zn sol	Zn tot	SO_4
09-02-88	2 260	6.5	390	.14	.31	.31	.43	.25	.32	140
16-02-88	6 730	6.2	130	.08	.24	.03	.16	.02	.08	38
19-02-88	4 390	6.4	150	.10	.31	.11	.26	.05	.10	49
18-02-88	3 630	6.4	160	.08	.40	.16	.24	.04	.11	50
19-02-88	3 140	6.4	170	.14	.25	.01	.39	.03	.18	50
20-02-88	7 020	6.4	150	.03	.25	.01	.29	.04	.11	38
21-02-88	12 600	6.3	150	.08	.97	.05	.36	.01	.14	41
22-02-88	19 600	6.2	150	.06	.35	.03	.32	.02	.09	48
23-02-88	22 700	6.0	81	.01	.07	.04	.24	.02	.60	23
24-02-88	15 400	6.0	61	.04	.11	.01	.14	.02	.05	18
25-02-88	5 750	6.1	110	.04	.07	.01	.14	.03	.07	33
26-02-88	4 470	6.3	130	.01	.19	.02	.35	.04	.10	39
27-02-88	4 440	6.4	130	.06	.17	.01	.33	.04	.10	36
28-02-88	4 000	6.4	130	.01	.15	.01	.25	.05	.90	36
29-02-88	3 320	6.4	140	.07	.15	.01	.28	.05	.90	38
29-03-88	16 000	6.5	110	.04	.40	.01	.47	.01	.20	29
30-03-88	25 000	6.0	120	.08	.50	.01	.30	.04	.10	28
31-03-88	6 930	6.2	100	.05	.10	.01	.42	.04	.22	29
01-04-88	21 700	5.9	120	.04	.21	.01	.19	.03	.08	36
02-04-88	14 400	5.9	94	.03	.17	.01	.13	.03	.03	18
03-04-88	14 400	5.9	82	.05	.13	.01	.26	.03	.08	19
04-04-88	12 200	6.1	77	.06	.23	.01	.13	.03	.10	18
05-04-88	9 770	6.0	85	.06	.16	.01	.13	.03	.05	21
06-04-88	7 420	6.1	81	.05	.12	.01	.11	.03	.05	19

Table 4.22 **1987-88 East Finniss River water quality at GS8150204 - dissolved pollutant loads**

DATE	FLOW ($l x 10^6/d$)	pH	SC (μs/cm)	Cu	Mn	Zn (kg/d)	SO_4
24-12-87	670	5.9	65	47	6.7	6.7	6 700
25-12-87	290	6.1	66	38	2.9	8.8	3 800
26-12-87	430	5.9	76	51	4.3	13	4 300
27-12-87	150	6.1	71	10	1.5	4.4	1 800
28-12-87	73.4	6.2	96	6.6	.73	3.7	1 700
29-12-87	46.7	6.0	130	4.7	.47	3.3	1 400
30-12-87	34.6	6.2	130	2.4	.35	1.7	1 200
31-12-87	30.2	6.3	130	2.1	.30	1.2	940
01-01-88	25.1	6.2	140	2.0	.25	1.2	830
02-01-88	19.9	6.1	120	1.6	.79	1.2	640
03-01-88	21.6	6.2	120	1.5	.22	.65	630
04-01-88	33.7	6.3	140	2.4	0.67	1.0	1 300
05-01-88	31.1	6.7	140	2.5	.62	1.2	900
06-01-88	40.7	6.6	120	2.8	.40	1.2	840
07-01-88	41.6	6.7	170	2.8	.41	2.0	1 900
08-01-88	35.4	6.7	110	1.8	.71	.71	670
09-01-88	63.1	6.8	97	3.2	.63	.63	690
10-01-88	253	6.3	95	13	5.0	10	2 000
11-01-88	516	6.4	130	31	10	16	5 200
12-01-88	242	6.4	130	15	4.8	9.7	3 600
13-01-88	189	6.4	95	13	5.7	7.6	2 100
14-01-88	115	7.0	82	5.8	3.4	3.4	910
15-01-88	165	6.8	240	16	5.0	8.2	12 000
16-01-88	340	6.5	320	24	3.4	34	41 000
17-01-88	194	6.5	270	9.7	1.9	9.7	18 000
18-01-88	103	6.6	300	11	5.1	8.2	12 000
19-01-88	69.1	6.9	280	5.5	.69	4.8	6 900
20-01-88	96.8	7.1	270	6.8	.97	5.8	8 400
21-01-88	138	6.6	260	6.9	1.4	15	12 000
22-01-88	87.3	7.1	280	7.0	.87	8.7	7 900
23-01-88	58.8	6.8	240	3.5	.59	6.5	4 600
24-01-88	49.2	6.7	82	.98	.49	1.5	440
25-01-88	45.8	6.1	260	7.8	3.2	8.7	4 600
28-01-88	62.2	6.3	370	14	33	19	9 000
29-01-88	64.8	6.2	310	5.8	9.7	9.7	6 500

DATE	FLOW (lx10⁶/d)	pH	SC (µs/cm)	Cu	Mn	Zn (kg/d)	SO_4
30-01-88	66.5	6.6	240	4.0	.67	5.3	6 600
31-01-88	69.1	6.7	230	6.2	1.4	6.2	4 200
01-02-88	81.2	6.5	360	12	35	19	11 000
02-02-88	64.8	6.6	370	14	33	14	9 100
03-02-88	44.1	6.6	180	6.6	18	7.5	4 800
04-02-88	35.4	6.7	310	3.2	6.0	5.0	3 700
06-02-88	29.4	6.9	300	1.8	2.1	2.1	2 900
07-02-88	26.8	6.7	300	1.9	1.3	3.5	2 500
08-02-88	23.3	6.8	370	3.5	9.6	6.3	3 100
09-02-88	195	6.5	390	27	61	49	26 000
16-02-88	581	6.2	130	47	17	12	22 000
19-02-88	379	6.4	150	38	42	19	1 900
18-02-88	314	6.4	160	25	50	13	16 000
19-02-88	271	6.4	170	38	2.7	8.1	14 000
20-02-88	607	6.4	150	18	6.1	24	23 000
21-02-88	1 090	6.3	150	87	54	11	45 000
22-02-88	1 690	6.2	150	100	51	34	81 000
23-02-88	1 960	6.0	81	120	78	39	45 000
24-02-88	1 330	6.0	61	53	13	27	24 000
25-02-88	497	6.1	110	20	5.0	15	16 000
26-02-88	386	6.3	130	3.9	7.7	15	15 000
27-02-88	384	6.4	130	23	3.8	15	14 000
28-02-88	346	6.4	130	3.5	3.5	17	12 000
29-02-88	287	6.4	140	20	2.9	14	11 000
29-03-88	1 380	6.5	110	55	14	14	40 000
30-03-88	2 160	6.0	120	170	22	86	60 000
31-03-88	599	6.2	104	29	6.0	24	17 000
01-04-88	1 870	5.9	124	75	19	56	67 000
02-04-88	1 240	5.9	94	37	12	37	22 000
03-04-88	1 240	5.9	82	62	12	37	24 000
04-04-88	1 050	6.1	77	63	11	32	19 000
05-04-88	844	6.0	85	51	8.4	25	18 000
06-04-88	641	6.1	81	32	6.4	19	12 000

Table 4.46(a) GS8150200 - Dissolved pollutant loads

DATE	FLOW ($1X10^6/d$)	Cu	Mn (kg/d)	Zn	SO_4 (t/d)
02-01-88	.518	2.8	1.9	4.2	.58
05-01-88	.350	2.1	1.7	3.5	.44
08-01-88	1.38	9.0	7.8	20	2.0
09-01-88	.518	2.2	1.8	3.7	.47
12-01-88	1.21	5.0	4.0	8.2	1.2
19-01-88	8.81	8.3	7.7	16	2.3
21-01-88	9.42	8.5	7.0	7.7	2.4
29-01-88	7.34	5.6	5.3	6.7	1.7
02-02-88	8.47	5.6	5.7	7.0	1.8
05-02-88	8.64	9.4	9.2	11	3.0
09-02-88	38.9	56	40	35	13
16-02-88	138	230	180	35	58
12-02-88	44.9	65	50	26	17
16-02-88	35.2	39	42	17	11
19-02-88	20.6	20	22	14	5.6
23-02-88	60.5	59	64	23	16
26-02-88	29.2	24	26	15	6.7
01-03-88	17.8	14	15	12	3.9
04-03-88	11.6	10	9.4	11	2.5
08-03-88	10.4	7.2	8.3	10	2.3
11-03-88	16.1	13	16	11	3.5
15-03-88	11.2	17	14	18	4.3
18-03-88	7.3	6.8	8.5	10	2.0
22-03-88	8.81	8.1	10	11	2.7
25-03-88	15.0	11	14	11	3.6
29-03-88	195	35	110	31	29
31-03-88	46.7	41	44	19	11
05-04-88	36.5	24	28	15	7.3
08-04-88	22.6	14	15	11	4.4
12-04-88	14.6	9.6	11	10	3.3
15-04-88	11.6	7.4	7.5	10	2.2
19-04-88	10.1	5.4	7.6	10	1.9
22-04-88	9.07	5.0	6.4	9.4	1.8
26-04-88	6.91	5.4	6.2	9	1.5
29-04-88	4.41	5.0	6.1	8.9	1.5
03-05-88	.864	2.5	3.2	4.7	.69
09-05-88	.086	.93	1.3	2.0	.23
13-05-88	.086	.91	1.2	1.7	.20

Table 4.46(b) GS8150209 - Dissolved pollutant loads

DATE	FLOW (lX10^6/d)	Cu	Mn (kg/d)	Zn	SO_4 (t/d)
05-01-88	.173	2.1	1.9	4.5	.40
08-01-88	.518	5.7	5.9	16	1.4
12-01-88	.613	3.4	2.9	6.9	.80
19-01-88	6.91	2.7	2.7	9.1	1.3
22-01-88	6.91	4.3	5.1	11	1.4
29-01-88	7.78	3.3	4.2	11	1.4
02-02-88	8.64	3.3	3.4	5.8	1.5
05-02-88	7.78	7.8	7.4	9.7	2.8
09-02-88	13.0	19	14	15	4.4
10-02-88	11.2	7.3	6.6	8.3	2.4
12-02-88	10.4	7.7	6.7	8.8	2.5
16-02-88	9.50	4.5	5.2	7.4	1.8
19-02-88	9.50	4.9	6.1	8.2	1.8
23-02-88	8.64	6.9	6.7	8.7	2.8
26-02-88	8.64	5.7	5.8	7.7	1.6
01-03-88	9.50	6.5	6.8	9.1	1.8
04-03-88	8.21	5.4	5.8	8.0	1.6
08-03-88	7.78	4.8	5.6	7.9	1.6
11-03-88	7.34	4.6	5.4	7.3	1.5
15-03-88	9.50	16	14	17	4.5
18-03-88	9.50	7.6	10	13	2.6
22-03-88	7.78	7.2	8.7	10	2.1
25-03-88	8.64	2.9	5.4	7.6	1.8
29-03-88	86.4	2.6	5.2	6.9	4.0
31-03-88	13.0	6.9	6.7	10	2.5
05-04-88	9.50	4.9	5.5	7.6	1.6
08-04-88	9.07	4.3	4.9	7.3	1.5
12-04-88	8.47	4.7	5.0	7.5	1.4
15-04-88	7.78	3.6	4.7	7.1	1.3
19-04-88	7.78	3.7	4.9	7.5	1.3
22-04-88	7.78	4.23	5.3	8.1	1.5
26-04-88	6.05	4.5	5.2	7.9	1.3
29-04-88	3.89	4.4	5.1	8.0	1.4
03-05-88	.864	2.6	3.2	5.4	.73
09-05-88	.086	1.1	1.5	2.8	.30

Table 4.46(c) GS8150210 - Dissolved pollutant loads

DATE	FLOW (lX10⁶/d)	Cu	Mn (kg/d)	Zn	SO_4 (t/d)
05-01-88	.259	.88	.09	.81	.21
08-01-88	.864	3.1	1.2	2.95	.73
12-01-88	.613	1.6	.66	1.54	.40
19-01-88	1.73	4.5	1.7	3.99	.98
22-01-88	1.56	3.5	1.4	3.02	.81
29-01-88	.432	.73	.29	.66	.17
02-02-88	.605	.70	.28	.64	.19
05-02-88	.864	.60	.26	.66	1.9
09-02-88	6.91	4.8	2.3	5.18	1.38
10-02-88	8.64	22	8.5	19.61	4.41
12-02-88	4.75	9.6	3.7	8.22	2.00
16-02-88	4.32	7.5	2.9	6.35	1.56
19-02-88	3.46	5.2	2.0	4.39	1.11
23-02-88	6.91	9.3	3.8	4.29	2.00
26-02-88	4.32	5.5	2.7	2.72	1.25
01-03-88	2.59	2.5	1.1	1.22	.57
04-03-88	2.16	1.6	.69	.86	.43
08-03-88	1.73	.98	.40	.60	.31
11-03-88	1.30	.75	.34	.48	.26
15-03-88	1.73	.81	.40	.54	.29
22-03-88	.432	.24	.11	.16	.10
25-03-88	.864	1.1	.44	.53	.25
29-03-88	17.3	2.9	8.0	1.90	5.18
31-03-88	5.18	11	4.3	5.08	2.07
05-04-88	2.77	4.5	1.8	1.94	.77
08-04-88	2.59	3.5	1.4	1.56	.55
12-04-88	1.73	1.5	.64	.73	.35
15-04-88	1.56	1.1	.45	.61	.25
19-04-88	.864	.43	.12	.18	.10
22-04-88	.605	.34	.05	.08	.01
26-04-88	.518	.03	.01	.01	.00
29-04-88	.173	.01	<.01	<.01	<.01

Table 4.46(d) GS8150211 - Dissolved pollutant loads

DATE	FLOW (lX10^6/d)	Cu	Mn (kg/d)	Zn	SO_4 (t/d)
19-01-88	6.74	1.2	.94	1.4	.38
22-01-88	9.33	2.2	1.8	2.8	.65
29-01-88	6.83	1.5	1.0	.96	.51
02-02-88	8.21	1.6	1.4	2.4	.58
05-02-88	7.09	2.3	1.4	1.6	.81
09-02-88	9.59	2.1	2.5	3.6	1.4
10-02-88	9.59	3.5	2.4	4.3	.98
12-02-88	9.25	3.3	1.4	1.3	.79
16-02-88	9.42	3.6	1.8	2.9	.70
19-02-88	8.99	2.1	1.8	3.5	.75
23-02-88	9.33	2.2	1.3	1.6	.76
26-02-88	9.25	1.9	1.0	1.1	.67
01-03-88	9.33	2.0	1.2	1.4	.77
04-03-88	8.55	1.8	1.7	2.1	.68
08-03-88	7.00	1.5	1.4	1.1	.57
11-03-88	7.78	1.9	1.5	1.3	.62
15-03-88	6.83	2.3	2.3	1.9	.91
18-03-88	5.18	1.6	1.7	1.1	.49
22-03-88	32	15	22	10	5.2
25-03-88	7.69	1.6	1.4	1.5	.55
29-03-88	170	18	1.67	5.0	3.3
31-03-88	9.50	2.0	1.1	.86	.63
05-04-88	9.50	1.8	1.1	1.1	.57
08-04-88	9.25	1.3	.83	1.0	.49
12-04-88	8.29	1.1	.91	.83	.39
15-04-88	7.78	1.2	1.0	1.0	.40
19-04-88	7.86	1.0	.86	.79	.35
22-04-88	7.95	.95	.87	.72	.34
26-04-88	5.18	.67	.78	.57	.32
29-04-88	3.11	.50	.59	.37	.22
03-05-88	.778	.44	.47	.34	.16

Table 4.46(e) GS8150212 - Dissolved pollutant loads

DATE	FLOW ($lX10^6$/d)	Cu	Mn (kg/d)	Zn	SO_4 (t/d)
19-01-88	.086	.15	.06	.02	.04
22-01-88	.173	.30	.29	.04	.08
29-01-88	.086	.14	.14	.02	.04
02-02-88	.259	.47	.44	.06	.12
09-02-88	19	38	30	4.6	9.1
10-02-88	112	200	170	28	48
12-02-88	29.4	49	45	7.6	12
16-02-88	21.6	28	31	5.2	7.8
19-02-88	7.78	8.7	11	1.6	2.4
23-02-88	44.1	48	52	8.8	12.8
26-02-88	16.4	11	18	2.5	3.6
01-03-88	4.32	3.0	4.6	.60	.91
04-03-88	1.21	.96	1.3	.18	.25
08-03-88	.864	.73	1.0	.13	.20
11-03-88	1.73	1.5	2.0	.28	.40
25-03-88	3.46	3.3	4.4	.59	.86
29-03-88	125	110	150	20	31
31-03-88	28.5	26	31	5.4	6.8
05-04-88	24.2	11	22	3.1	4.4
08-04-88	12.1	4.5	11	1.5	2.0
12-04-88	4.32	2.1	4.0	.60	.76
15-04-88	.864	.57	.90	.13	.18

Table 4.46(f) GS8150213 - Dissolved pollutant loads

DATE	FLOW ($lX10^6/d$)	Cu	Mn (kg/d)	Zn	SO_4 (t/d)
19-01-88	2.07	.46	.95	.68	.25
22-01-88	11.51	1.4	3.7	1.8	.79
29-01-88	3.80	1.3	2.7	1.6	.61
02-02-88	11.1	1.5	4.6	1.8	.78
05-02-88	4.32	.91	1.9	.48	.43
09-02-88	95.9	44	59	58	16
10-02-88	89.9	22	17	13	7.1
12-02-88	72.2	8.7	19	17	5.2
16-02-88	65.3	9.1	14	9.8	3.8
19-02-88	38.0	4.2	5.3	6.8	1.7
23-02-88	75.2	14	11	11	5.3
26-02-88	48.7	8.3	6.3	7.3	3.1
01-03-88	39.9	4.0	3.2	2.4	1.8
04-03-88	24.1	2.7	1.5	1.5	1.0
08-03-88	13.9	1.7	3.2	1.3	.89
11-03-88	18.3	2.0	4.0	.92	.84
15-03-88	9.76	1.2	1.8	.39	.52
25-03-88	2.59	.36	.41	.10	.13
29-03-88	259	21	2.6	2.6	2.1
31-03-88	79.7	10	12	4.0	3.8
05-04-88	66.1	8.6	2.6	2.0	2.5
08-04-88	53.1	4.8	4.2	1.6	1.8
12-04-88	26.9	2.2	1.3	.81	.86
15-04-88	17.0	1.4	.85	.51	.56
19-04-88	11.4	.91	.91	.34	.47
22-04-88	4.667	.42	.61	.23	.25
26-04-88	1.30	.22	.86	.31	.19

Table 4.46(g) GS8150214 - Dissolved pollutant loads

DATE	FLOW $(1X10^6/d)$	Cu	Mn (kg/d)	Zn	SO_4 (t/d)
16-01-88	.864	.72	1.4	.17	.29
19-01-88	3.45	2.8	6.0	.55	1.1
22-01-88	10.4	7.9	16	1.7	3.0
29-01-88	6.05	5.0	9.4	1.0	1.8
02-02-88	12.1	9.2	18	2.1	3.4
05-02-88	3.02	4.4	5.9	.73	.91
09-02-88	21.6	18	32	3.7	5.8
10-02-88	60.5	43	81	9.1	16
12-02-88	38.9	24	49	5.8	9.3
16-02-88	38.9	16	33	5.8	7.4
19-02-88	32.8	14	24	3.9	5.3
23-02-88	51.8	18	43	5.7	8.3
26-02-88	36.3	13	21	3.6	4.4
01-03-88	27.6	8.0	12	2.5	2.6
04-03-88	19.1	5.4	7.3	1.5	1.7
08-03-88	13.8	4.0	5.7	1.2	1.3
11-03-88	20.7	6.4	8.7	3.7	1.9
15-03-88	4.32	1.0	2.8	.73	.48
18-03-88	.518	.13	.20	.08	.06
22-03-88	.432	.12	.25	.06	.05
25-03-88	25.9	6.2	14	3.4	3.1
29-03-88	69.1	21	48	9.0	9.0
31-03-88	47.5	12	37	5.7	6.7
05-04-88	38.0	12	20	3.4	3.7
08-04-88	32.8	8.2	13	2.6	2.5
12-04-88	27.6	6.4	11	1.9	1.9
15-04-88	17.3	4.7	9.2	1.6	1.7
19-04-88	9.93	2.7	5.8	.99	.99
22-04-88	4.75	1.5	3.0	.52	.48
26-04-88	.432	.10	.38	.06	.06

Table 4.47(a) GS8150200 - Dissolved pollutant concentrations

DATE	FLOW (l/s)	pH	SC (µs/cm)	Cu	Mn (mg/l)	Zn	SO_4
02-01-88	6	3.1	1 800	5.4	3.6	8.1	1 100
05-01-88	4	3.9	2 000	6.0	4.8	10	1 300
08-01-88	16	3.6	2 300	6.5	5.7	14	1 500
09-01-88	6	3.9	1 500	4.3	3.5	7.1	950
12-01-88	14	3.9	1 600	4.2	3.3	6.8	900
19-01-88	102	4.9	550	.94	.87	1.8	260
21-01-88	109	4.8	540	.90	.74	.82	250
29-01-88	85	5.0	500	.76	.72	.91	230
02-02-88	98	5.0	450	.66	.67	.83	210
05-02-88	100	4.6	700	1.1	1.1	1.3	350
09-02-88	450	4.6	690	1.4	1.0	.89	340
16-02-88	1 600	4.6	840	1.7	1.3	.25	420
12-02-88	520	4.8	740	1.5	1.1	.57	370
16-02-88	407	4.7	640	1.1	1.2	.49	320
19-02-88	238	4.8	560	.99	1.1	.68	270
23-02-88	700	4.9	570	.98	1.1	.38	270
26-02-88	338	4.9	490	.84	.90	.51	230
01-03-88	206	4.8	470	.79	.86	.68	220
04-03-88	134	4.7	450	.87	.81	.95	220
08-03-88	120	4.8	460	.69	.80	1.0	220
11-03-88	186	4.8	480	.78	.97	.7	220
15-03-88	130	4.5	740	1.5	1.3	1.6	380
18-03-88	85	4.5	560	.92	1.2	1.4	270
22-03-88	102	4.5	610	.92	1.2	1.3	310
25-03-88	174	5.1	500	.75	.95	.75	240
29-03-88	2 260	5.9	330	.18	.57	.16	150
31-03-88	540	5.1	520	.88	.95	.41	240
05-04-88	422	5.3	430	.65	.76	.41	200
08-04-88	261	5.2	410	.62	.68	.50	190
12-04-88	169	5.0	400	.66	.72	.71	190
15-04-88	134	4.9	400	.64	.65	.89	190
19-04-88	117	4.9	410	.53	.75	1.0	190
22-04-88	105	5.0	410	.55	.71	1.0	200
26-04-88	80	4.5	460	.78	.90	1.3	220
29-04-88	51	4.1	680	1.1	1.4	2.0	340
03-05-88	10	3.5	1 400	2.8	3.7	5.5	800
09-05-88	1	3.1	3 700	11	15	23	2 700
13-05-88	1	3.2	3 400	11	13	20	2 300

Table 4.47(b) GS815209 - Dissolved pollutant concentrations

DATE	FLOW (l/s)	pH	SC (µs/cm)	Cu	Mn	Zn	SO_4
					(mg/l)		
05-01-88	2	3.2	3 300	12	11	26	2 300
08-01-88	6	3.1	3 700	11	11	32	2 600
12-01-88	7	3.6	2 100	5.6	4.7	11	1 300
19-01-88	80	5.7	420	.39	.39	1.3	190
22-01-88	80	5.2	430	.62	.73	1.6	200
29-01-88	90	5.5	410	.43	.54	1.4	180
02-02-88	100	5.6	380	.38	.39	.67	170
05-02-88	90	4.7	710	1.0	.95	1.3	360
09-02-88	150	4.9	680	1.5	1.1	1.2	340
10-02-88	130	5.3	450	.65	.59	.74	210
12-02-88	120	5.1	520	.74	.65	.85	240
16-02-88	110	6.0	420	.47	.55	.78	190
19-02-88	110	5.0	410	.52	.64	.86	190
23-02-88	100	4.9	490	.80	.78	1.0	320
26-02-88	100	4.9	420	.66	.67	.89	190
01-03-88	110	4.7	430	.68	.72	.96	190
04-03-88	95	4.7	430	.66	.70	.98	200
08-03-88	90	4.8	440	.62	.72	1.0	210
11-03-88	85	4.8	450	.62	.74	1.0	210
15-03-88	110	4.4	890	1.7	1.5	1.8	470
18-03-88	110	4.6	550	.80	1.1	1.4	270
22-03-88	90	4.5	600	.92	1.1	1.3	270
25-03-88	100	5.7	450	.34	.62	.88	210
29-03-88	1 000	5.9	130	.03	.06	.08	46
31-03-88	150	5.4	400	.53	.52	.80	190
05-04-88	110	5.3	380	.51	.58	.80	170
08-04-88	105	5.5	370	.47	.54	.80	170
12-04-88	98	5.2	380	.55	.59	.88	170
15-04-88	90	5.1	380	.46	.61	.91	170
19-04-88	90	5.1	380	.48	.63	.97	170
22-04-88	90	5.0	410	.55	.68	1.0	190
26-04-88	70	4.7	460	.74	.86	1.3	220
29-04-88	45	4.2	690	1.1	1.3	2.1	350
03-05-88	10	3.5	1 500	3.0	3.7	6.2	850
09-05-88	1	2.9	4 700	13.3	17	32	3 500

Table 4.47(c) GS8150210 - Dissolved pollutant concentrations

DATE	FLOW (l/s)	pH	SC (μs/cm)	Cu	Mn (mg/l)	Zn	SO_4
05-01-88	3	4.4	1 300	3.4	.34	3.12	800
08-01-88	10	4.5	1 500	3.6	1.4	3.42	840
12-01-88	7	4.5	1 100	2.5	1.1	2.52	650
19-01-88	20	4.5	1 100	2.6	1.0	2.31	570
22-01-88	18	4.6	950	2.2	.88	1.94	520
29-01-88	5	4.7	780	1.7	.67	1.53	400
02-02-88	7	4.7	620	1.2	.46	1.06	310
05-02-88	10	5.1	470	.69	.30	.76	220
09-02-88	80	4.8	440	.69	.33	.75	200
10-02-88	100	4.5	930	2.6	.98	2.27	510
12-02-88	55	4.6	790	2.0	.78	1.73	420
16-02-88	50	4.6	710	1.7	.68	1.47	360
19-02-88	40	4.7	630	1.5	.58	1.27	320
23-02-88	80	4.7	570	1.4	.55	.62	290
26-02-88	50	4.5	580	1.3	.63	.63	290
01-03-88	30	4.8	460	.95	.42	.47	220
04-03-88	25	5.2	430	.73	.32	.40	200
08-03-88	20	5.6	400	.57	.23	.35	180
11-03-88	15	5.5	420	.58	.26	.37	200
15-03-88	20	5.5	380	.47	.23	.31	170
22-03-88	5	5.6	470	.55	.25	.38	230
25-03-88	10	4.8	590	1.2	.51	.61	290
29-03-88	200	6.3	290	.17	.46	.11	300
31-03-88	60	4.6	770	2.2	.82	.98	400
05-04-88	32	4.6	640	1.6	.66	.70	280
08-04-88	30	4.7	560	1.3	.53	.60	210
12-04-88	20	4.9	470	.87	.37	.42	200
15-04-88	18	5.1	440	.69	.29	.39	160
19-04-88	10	6.1	360	.50	.14	.21	120
22-04-88	7	6.2	190	.56	.08	.14	9
26-04-88	6	6.2	62	.05	.01	.01	1
29-04-88	2	6.4	70	.05	.01	.01	1

Table 4.47(d) GS8150211 - Dissolved pollutant concentrations

DATE	FLOW (l/s)	pH	SC (µs/cm)	Cu	Mn (mg/l)	Zn	SO_4
12-01-88	9	3.5	1 900	3.9	3.5	5.23	1 200
19-01-88	78	6.3	170	.17	.14	.21	56
22-01-88	108	6.3	190	.23	.19	.30	70
29-01-88	79	6.4	200	.22	.15	.14	74
02-02-88	95	6.3	200	.20	.17	.29	71
05-02-88	82	6.2	280	.32	.20	.23	110
09-02-88	111	6.0	340	.22	.26	.38	150
10-02-88	111	6.1	260	.36	.25	.45	100
12-02-88	107	6.4	220	.36	.15	.14	85
16-02-88	109	6.2	200	.38	.19	.31	74
19-02-88	104	6.2	220	.23	.20	.39	84
23-02-88	108	6.5	210	.23	.14	.17	81
26-02-88	107	6.5	190	.20	.11	.12	73
01-03-88	108	6.5	210	.21	.13	.15	83
04-03-88	99	6.4	220	.21	.20	.24	80
08-03-88	81	6.9	220	.22	.20	.16	82
11-03-88	90	6.8	220	.24	.19	.17	80
15-03-88	79	6.3	320	.33	.33	.28	130
18-03-88	60	6.1	240	.30	.32	.21	95
22-03-88	366	4.7	380	.47	.71	.33	160
25-03-88	89	6.5	220	.21	.18	.19	72
29-03-88	1 919	6.3	91	.11	.01	.03	20
31-03-88	110	6.5	180	.21	.12	.09	66
05-04-88	110	6.6	170	.19	.11	.11	60
08-04-88	107	6.6	150	.14	.09	.11	53
12-04-88	96	6.4	150	.13	.11	.10	47
15-04-88	90	6.5	160	.15	.13	.13	52
19-04-88	91	6.6	150	.13	.11	.10	44
22-04-88	92	6.5	150	.12	.11	.09	43
26-04-88	60	6.4	180	.13	.15	.11	61
29-04-88	36	6.1	200	.16	.19	.12	72
03-05-88	9	4.8	470	.56	.60	.44	210

Table 4.47(e) GS8150212 - Dissolved pollutant concentrations

DATE	FLOW (l/s)	pH	SC (µs/cm)	Cu	Mn	Zn	SO_4
					(mg/l)		
19-01-88	1	4.5	920	1.7	.73	.25	470
22-01-88	2	4.5	910	1.8	1.7	.24	460
29-01-88	1	4.7	920	1.7	1.6	.26	470
02-02-88	3	4.6	930	1.8	1.7	.24	470
09-02-88	220	4.5	930	2.0	1.6	.24	490
10-02-88	1 300	4.6	860	1.8	1.5	.25	430
12-02-88	340	4.6	830	1.7	1.5	.26	420
16-02-88	250	4.7	730	1.3	1.4	.24	360
19-02-88	90	4.9	660	1.1	1.5	.20	310
23-02-88	510	5.1	600	1.1	1.2	.20	290
26-02-88	190	5.7	500	.68	1.1	.15	220
01-03-88	50	5.6	460	.69	1.1	.14	210
04-03-88	14	5.6	460	.79	1.1	.15	210
08-03-88	10	5.4	490	.84	1.2	.15	230
11-03-88	20	5.3	490	.86	1.2	.16	230
25-03-88	40	5.0	530	.95	1.3	.17	250
29-03-88	1 450	5.0	530	.88	1.2	.16	250
31-03-88	330	5.4	510	.92	1.1	.19	240
05-04-88	280	6.0	400	.44	.92	.13	180
08-04-88	140	6.1	380	.37	.89	.12	170
12-04-88	50	5.9	400	.48	.93	.14	180
15-04-88	2	5.7	450	.66	1.0	.15	210

Table 4.47(f) GS8150213 - Dissolved pollutant concentrations

DATE	FLOW (l/s)	pH	SC (µs/cm)	Cu	Mn (mg/l)	Zn	SO_4
19-01-88	24	5.3	280	.22	.46	.33	120
22-01-88	133	5.8	180	.12	.32	.16	69
29-01-88	44	4.5	360	.35	.70	.42	160
02-02-88	129	5.1	180	.13	.41	.16	70
05-02-88	50	4.5	250	.21	.44	.11	100
09-02-88	1 110	4.6	390	.46	.62	.60	170
10-02-88	1 040	6.5	210	.24	.19	.15	79
12-02-88	836	6.0	190	.12	.26	.23	72
16-02-88	756	6.3	160	.14	.22	.15	58
19-02-88	440	6.3	140	.11	.14	.18	45
23-02-88	870	6.6	190	.19	.14	.14	71
26-02-88	564	6.6	170	.17	.13	.15	63
01-03-88	462	6.8	130	.10	.08	.06	44
04-03-88	279	6.4	120	.11	.06	.06	42
08-03-88	161	6.6	170	.12	.23	.09	64
11-03-88	212	6.4	130	.11	.22	.05	46
15-03-88	113	6.2	150	.12	.18	.04	53
25-03-88	30	6.6	150	.14	.16	.04	50
29-03-88	3 000	6.2	48	.08	.01	.01	8
31-03-88	922	6.5	140	.13	.15	.05	48
05-04-88	765	6.3	120	.13	.04	.03	37
08-04-88	614	6.6	110	.09	.08	.03	33
12-04-88	311	6.6	110	.08	.05	.03	32
15-04-88	197	6.7	110	.08	.05	.03	33
19-04-88	132	6.3	120	.08	.08	.03	41
22-04-88	54	6.2	150	.09	.13	.05	54
26-04-88	15	4.5	350	.17	.66	.24	150

Table 4.47(g) GS8150214 - Dissolved pollutant concentrations

DATE	FLOW (l/s)	pH	SC (µs/cm)	Cu	Mn (mg/l)	Zn	SO_4
16-01-88	10	4.5	710	.83	1.6	.20	340
19-01-88	40	4.4	670	.81	1.7	.16	320
22-01-88	120	4.5	610	.76	1.5	.16	290
29-01-88	70	4.5	610	.83	1.6	.17	290
02-02-88	140	4.6	590	.76	1.5	.17	280
05-02-88	35	4.2	650	1.5	2.0	.24	300
09-02-88	250	4.5	580	.83	1.5	.17	270
10-02-88	700	4.8	560	.71	1.3	.15	260
12-02-88	450	4.9	520	.62	1.3	.15	240
16-02-88	450	5.3	410	.40	.85	.15	185
19-02-88	380	6.1	350	.42	.72	.12	160
23-02-88	600	5.9	370	.35	.83	.11	160
26-02-88	420	6.3	290	.37	.59	.10	120
01-03-88	320	6.4	230	.29	.42	.09	94
04-03-88	221	6.4	220	.28	.38	.08	87
08-03-88	160	6.6	230	.29	.41	.09	91
11-03-88	240	6.3	240	.31	.42	.18	93
15-03-88	50	6.0	280	.24	.64	.17	110
18-03-88	6	5.9	290	.26	.38	.16	120
22-03-88	5	5.9	300	.27	.59	.14	120
25-03-88	300	6.0	280	.24	.55	.13	120
29-03-88	800	5.9	330	.30	.69	.13	130
31-03-88	550	5.9	350	.26	.78	.12	140
05-04-88	440	6.2	260	.31	.53	.09	98
08-04-88	380	6.4	210	.25	.40	.08	76
12-04-88	320	6.5	210	.23	.40	.07	70
15-04-88	200	6.4	260	.27	.53	.09	96
19-04-88	115	6.3	270	.27	.58	.10	100
22-04-88	55	6.3	280	.32	.63	.11	100
26-04-88	5	5.7	310	.23	.88	.13	130

Table 4.48(a) GS8150200 - Water quality

	MAX. CONC.	FLOW	DATE	MIN. CONC.	FLOW	DATE	MEAN CONC.
Copper	10.9	1.0	9/5/88	.18	4 500	29/3/88	.91
Manganese	14.7	1.0	9/5/88	.57	4 500	29/3/88	.94
Zinc	23.0	1.0	9/5/88	.16	4 500	29/3/88	.56
Sulphate	2 700	1.0	9/5/88	150	4 500	29/3/88	265

Number of samples:		38
Days of flow:		140
Units:	Concentration	mg/l
	Flow	l/s

Table 4.48(b) GS815209 - Water quality

	MAX. CONC.	FLOW	DATE	MIN. CONC.	FLOW	DATE	MEAN CONC.
Copper	3.9	9.0	12/1/88	<.01	1 900	29/3/88	.21
Manganese	3.5	9.0	12/1/88	<.01	1 900	29/3/88	.15
Zinc	5.3	9.0	12/1/88	.03	1 900	29/3/88	.15
Sulphate	1 200	9.0	12/1/88	20	1 900	29/3/88	265

Number of samples:		32
Days of flow:		115
Units:	Concentration:	mg/l
	Flow	l/s

Table 4.48(c) GS8150210 - Water quality

	MAX. CONC.	FLOW	DATE	MIN. CONC.	FLOW	DATE	MEAN CONC.
Copper	3.6	1.0	8/1/88	.05	2	29/4/88	1.26
Manganese	1.4	1.0	8/1/88	<.01	2	29/3/88	.57
Zinc	3.4	1.0	8/1/88	<.01	2	29/3/88	.90
Sulphate	840	1.0	8/1/88	<10	2	29/3/88	320

Number of samples: 32
Days of flow: 110
Units: Concentration mg/l
Flow l/s

Table 4.48(d) GS8150211 - Water quality

	MAX. CONC.	FLOW	DATE	MIN CONC.	FLOW	DATE	MEAN CONC.
Copper	12.1	4.0	5/1/88	.03	2 000	29/3/88	.56
Manganese	11.4	4.0	8/1/88	.06	2 000	29/3/88	.60
Zinc	32.0	4.0	8/1/88	.08	2 000	29/3.88	.90
Sulphate	2 600	4.0	8/1/88	46	2 000	29/3/88	190

Number of samples: 35
Days of flow: 126
Units: Concentration mg/l
Flow l/s

Table 4.48(e) GS8150212 - Water quality

	MAX. CONC.	FLOW	DATE	MIN. CONC.	FLOW	DATE	MEAN CONC.
Copper	1.8	1.0	19/1/88	.37	124	8/4/88	1.19
Manganese	1.7	3.0	22/1/88	.89	124	8/4/88	1.29
Zinc	.26	15.0	29/1/88	.12	124	8/4/88	.20
Sulphate	490	12.0	9/2/88	165	124	8/4/88	320

Number of Samples: 35
Days of Flow: 126
Units: Concentration mg/l
Flow l/s

Table 4.48(f) GS8160213 - Water quality

	MAX. CONC.	FLOW	DATE	MIN. CONC.	FLOW	DATE	MEAN CONC.
Copper	.46	1 110	9/2/88	<.01	610	8/4/88	.15
Manganese	.70	44.0	29/1/88	<.01	5 500	29/3/88	.16
Zinc	.60	1 100	9/2/88	<.01	610	8/4/88	.05
Sulphate	175	180	22/3/88	8	5 500	29/3/88	55

Number of Samples: 27
Days of Flow: 94
Units: Concentration mg/l
Flow l/s

Table 4.48(g) GS8150214 - Water quality

	MAX. CONC.	FLOW	DATE	MIN. CONC.	FLOW	DATE	MEAN CONC.
Copper	1.8	1.0	19/1/88	.37	124	8/4/88	1.19
Manganese	1.7	3.0	22/1/88	.89	124	8/4/88	1.29
Zinc	.26	15.0	29/1/88	.12	124	8/4/88	.20
Sulphate	490	12.0	9/2/88	165	124	8/4/88	320

Number of samples:		35
Days of flow		126
Units:	Concentration	mg/l
	Flow	l/s

APPENDIX C

WATER QUALITY OF THE OPEN CUTS
(Chapter 6)

FIGURES

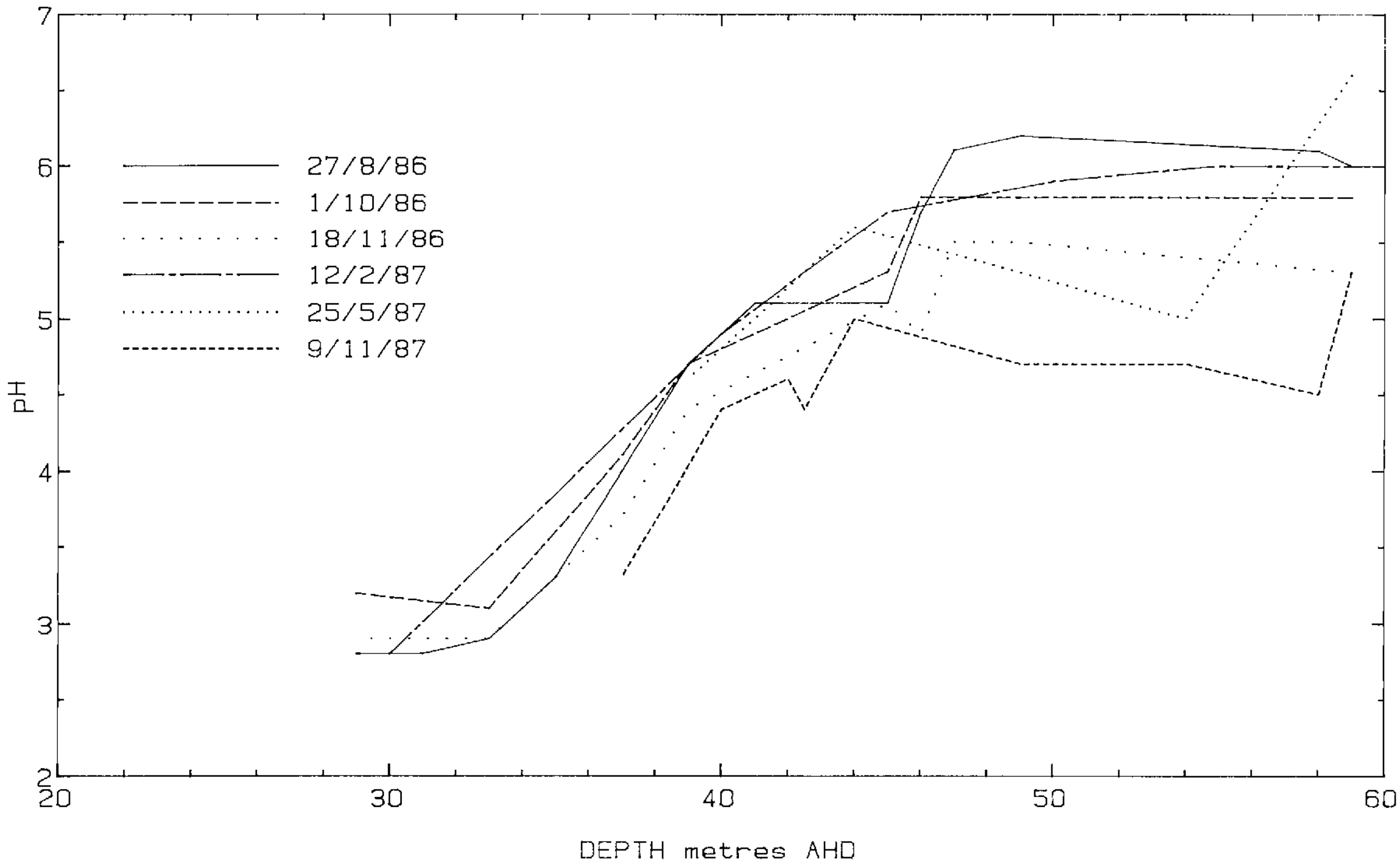

Figure 6.2 1986-87 White's Open Cut pH profiles

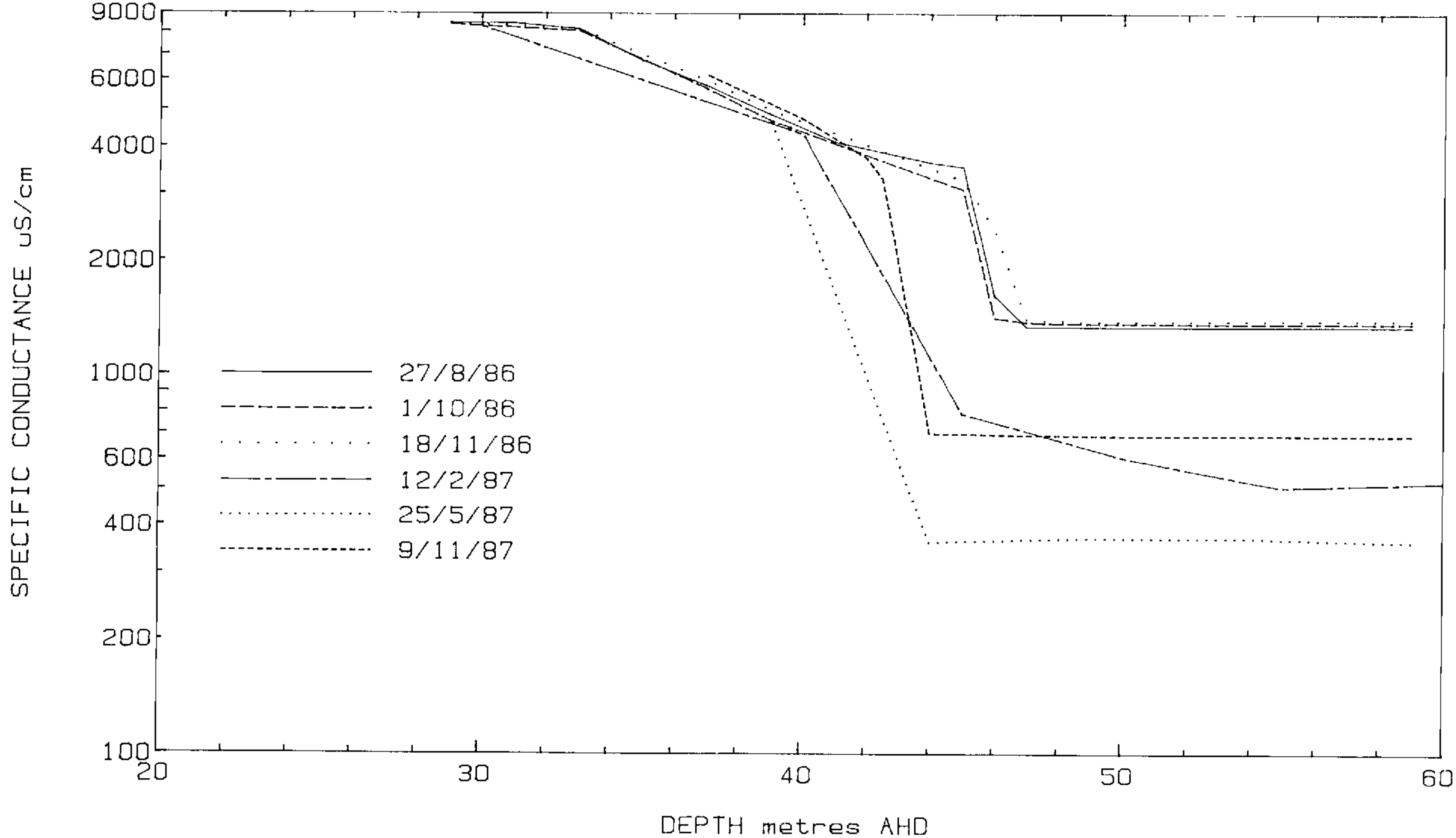

Figure 6.3 1986-87 White's Open Cut specific conductance profiles

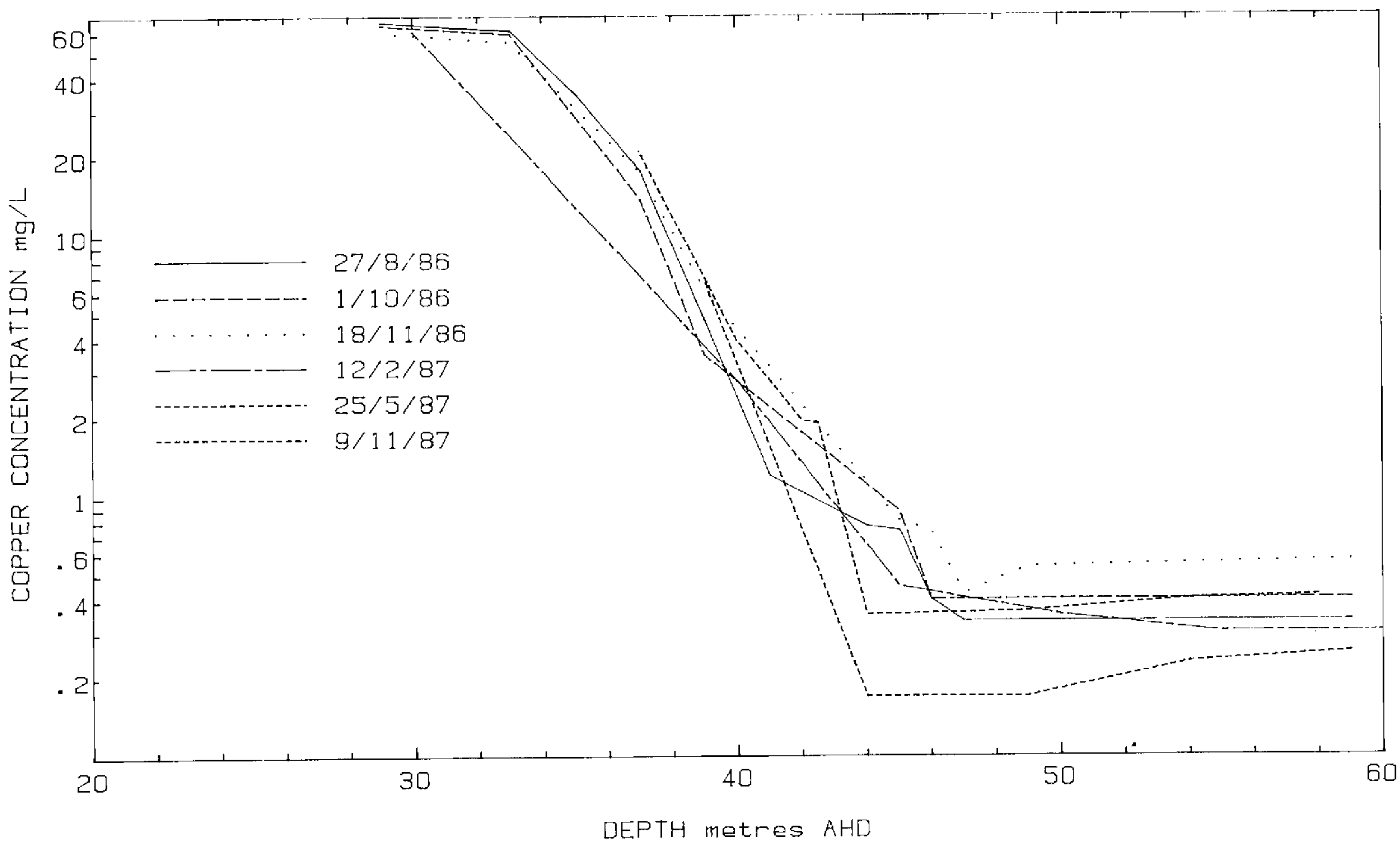

Figure 6.4 1986-87 White's Open Cut copper profiles

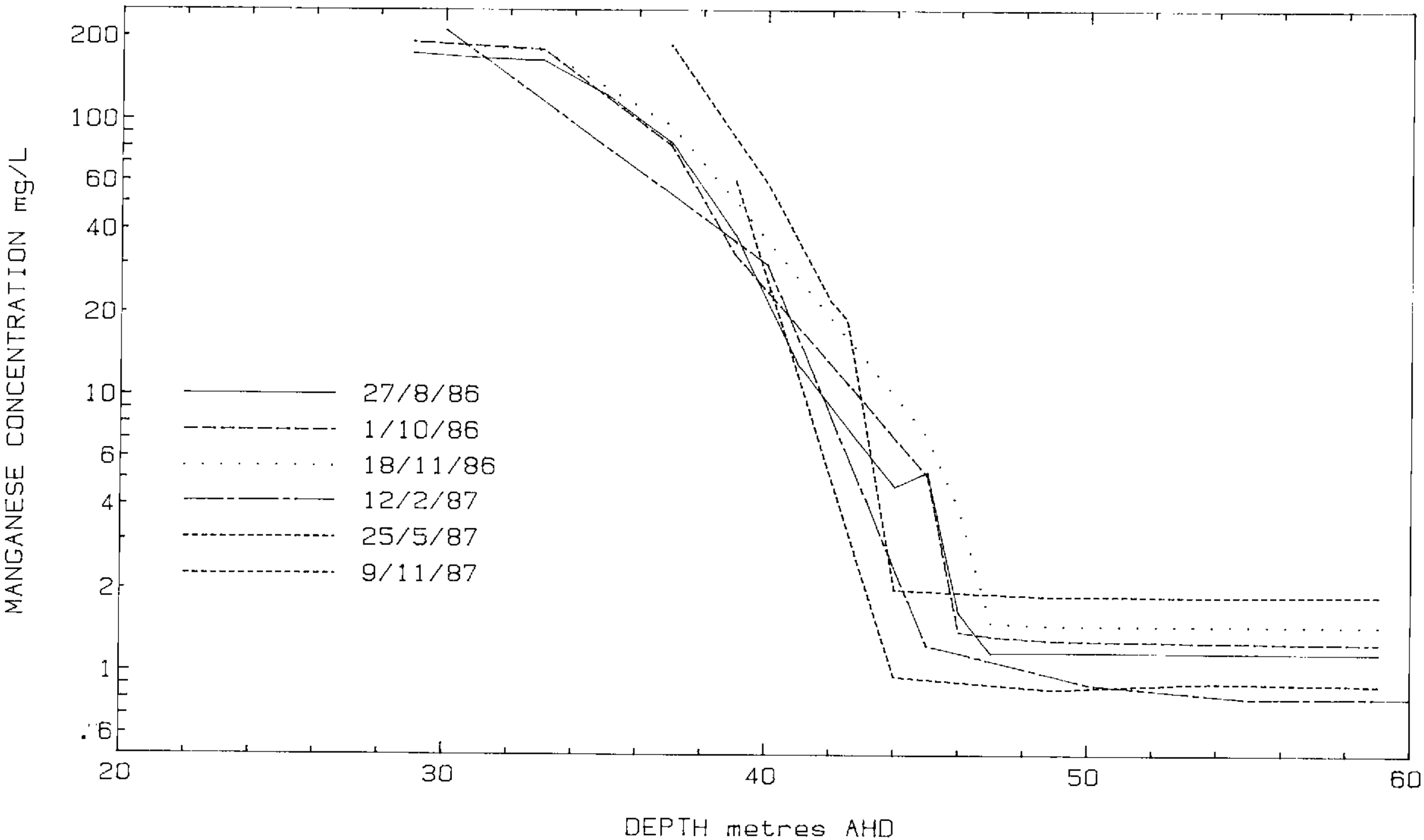

Figure 6.5 1986-87 White's Open Cut manganese profiles

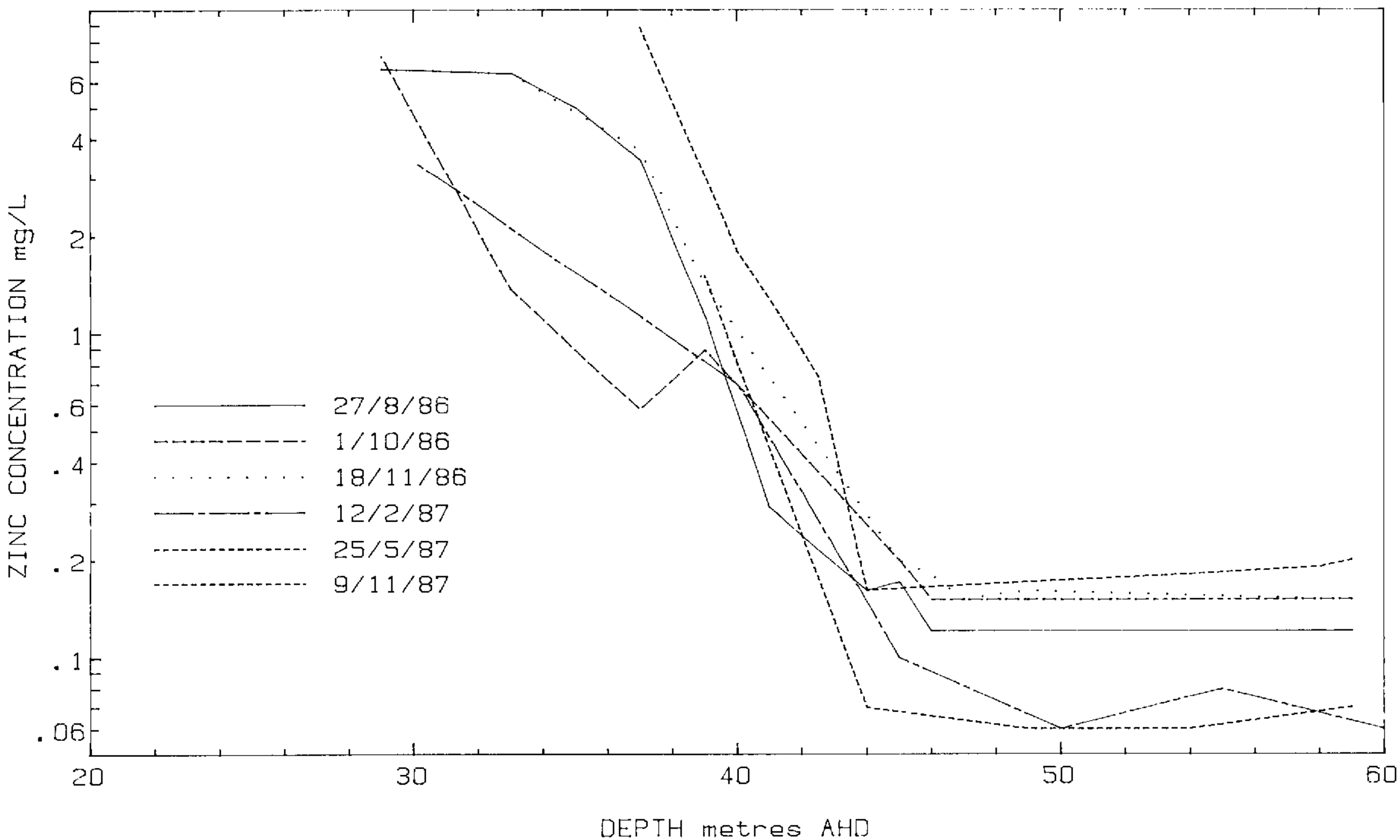

Figure 6.6 1986-87 White's Open Cut zinc profiles

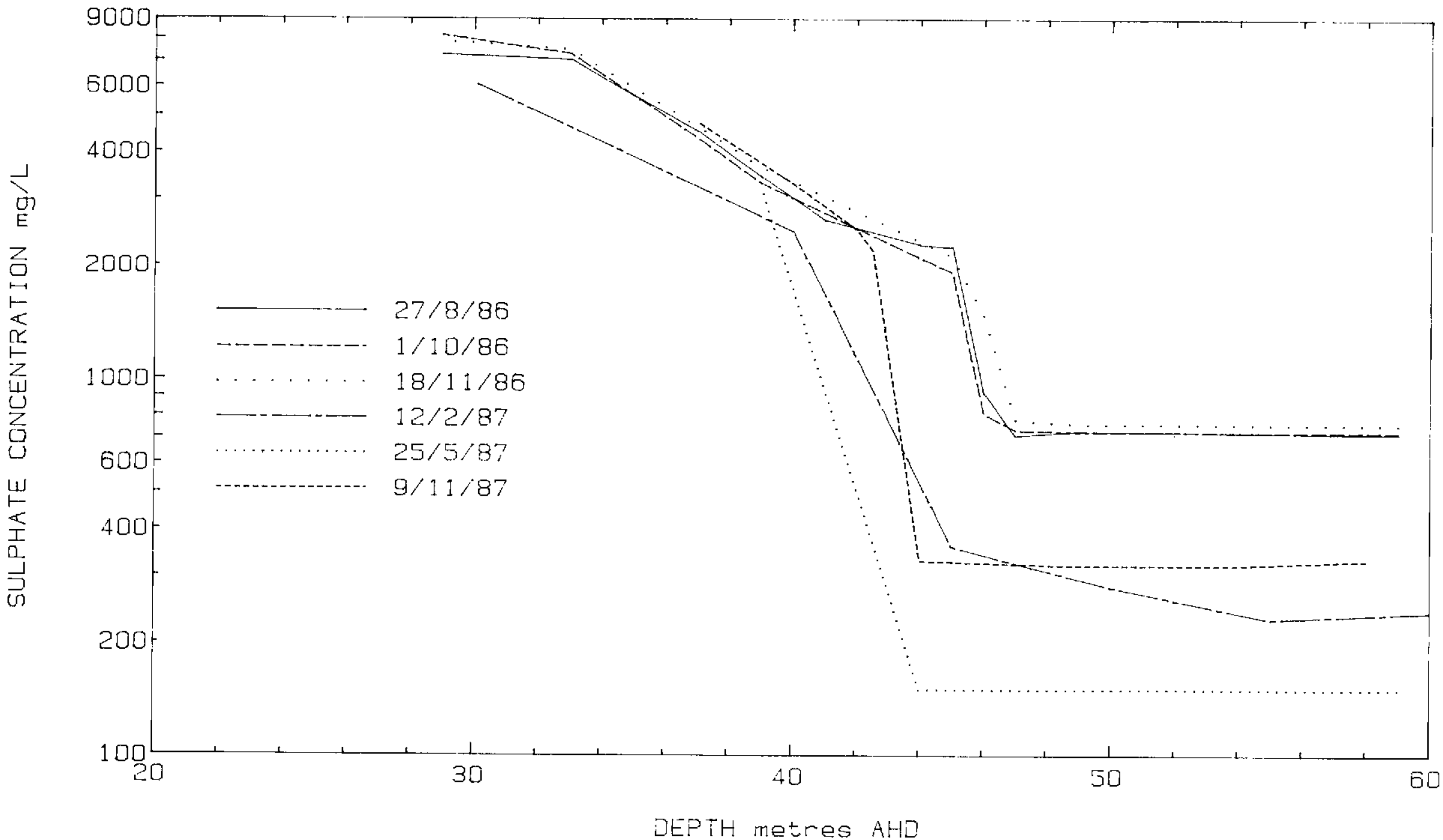

Figure 6.7 1986-87 White's Open Cut sulphate profiles

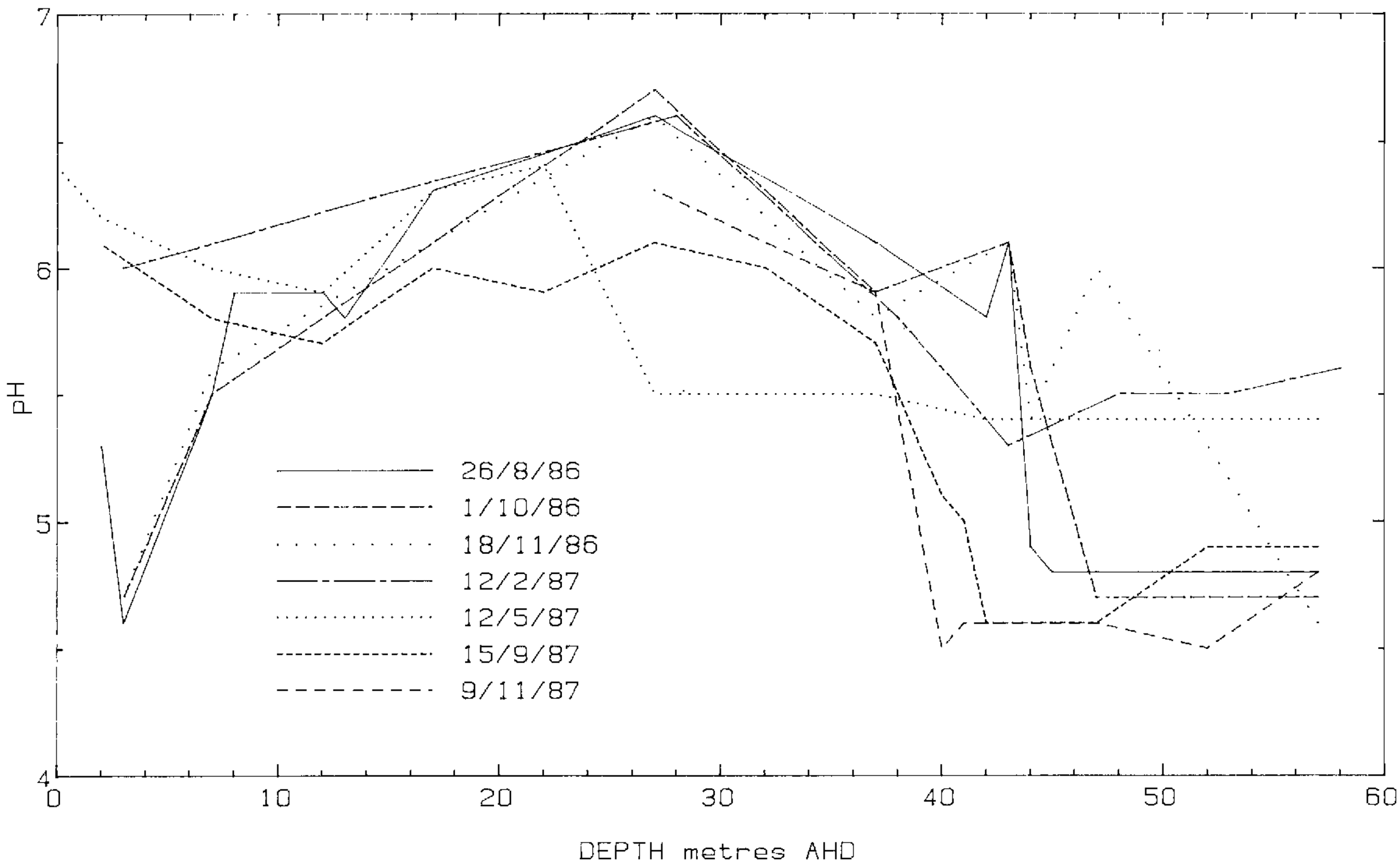

Figure 6.8 1986-87 Intermediate Open Cut pH profiles

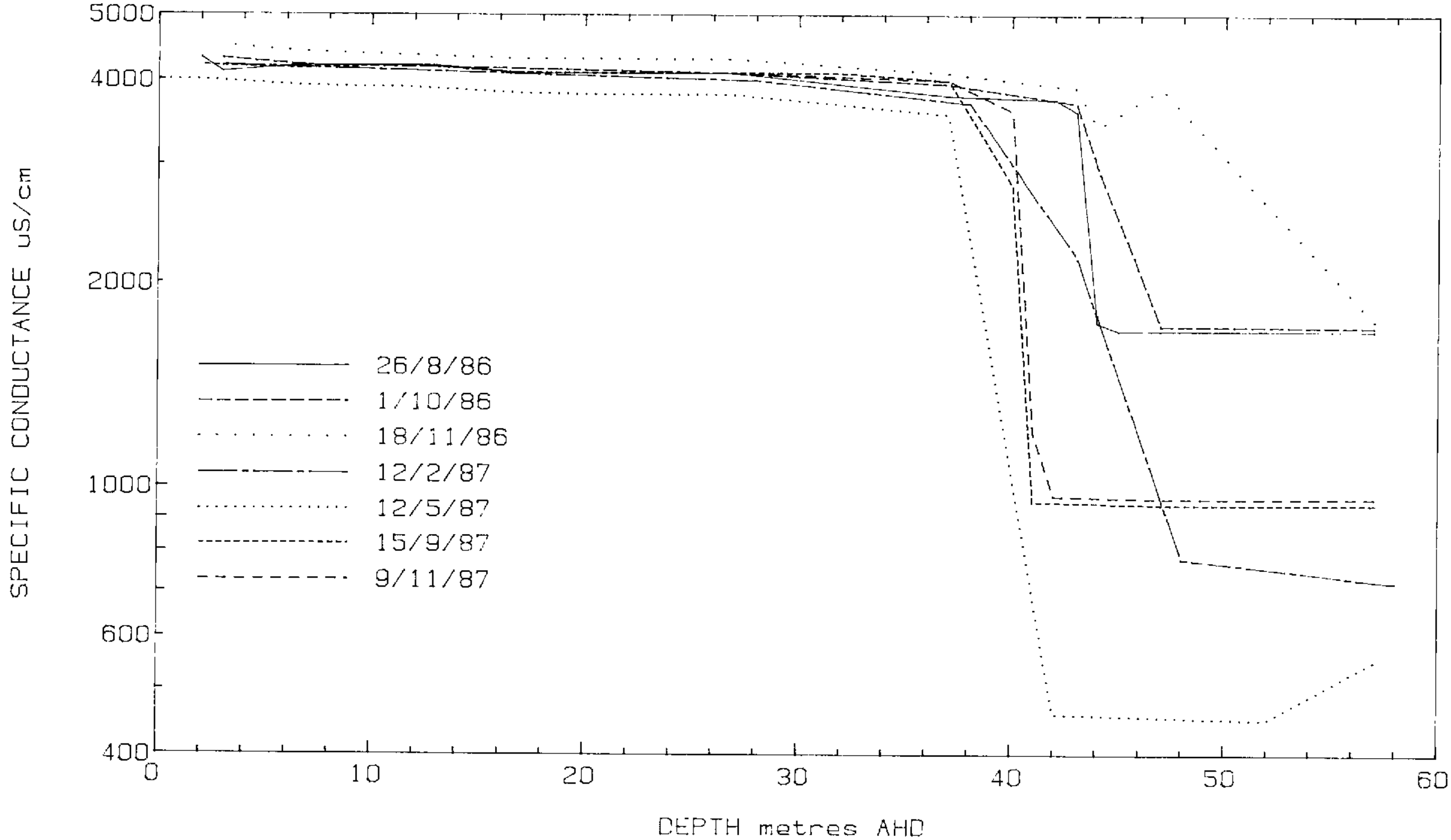

Figure 6.9 1986-87 Intermediate Open Cut specific conductance profiles

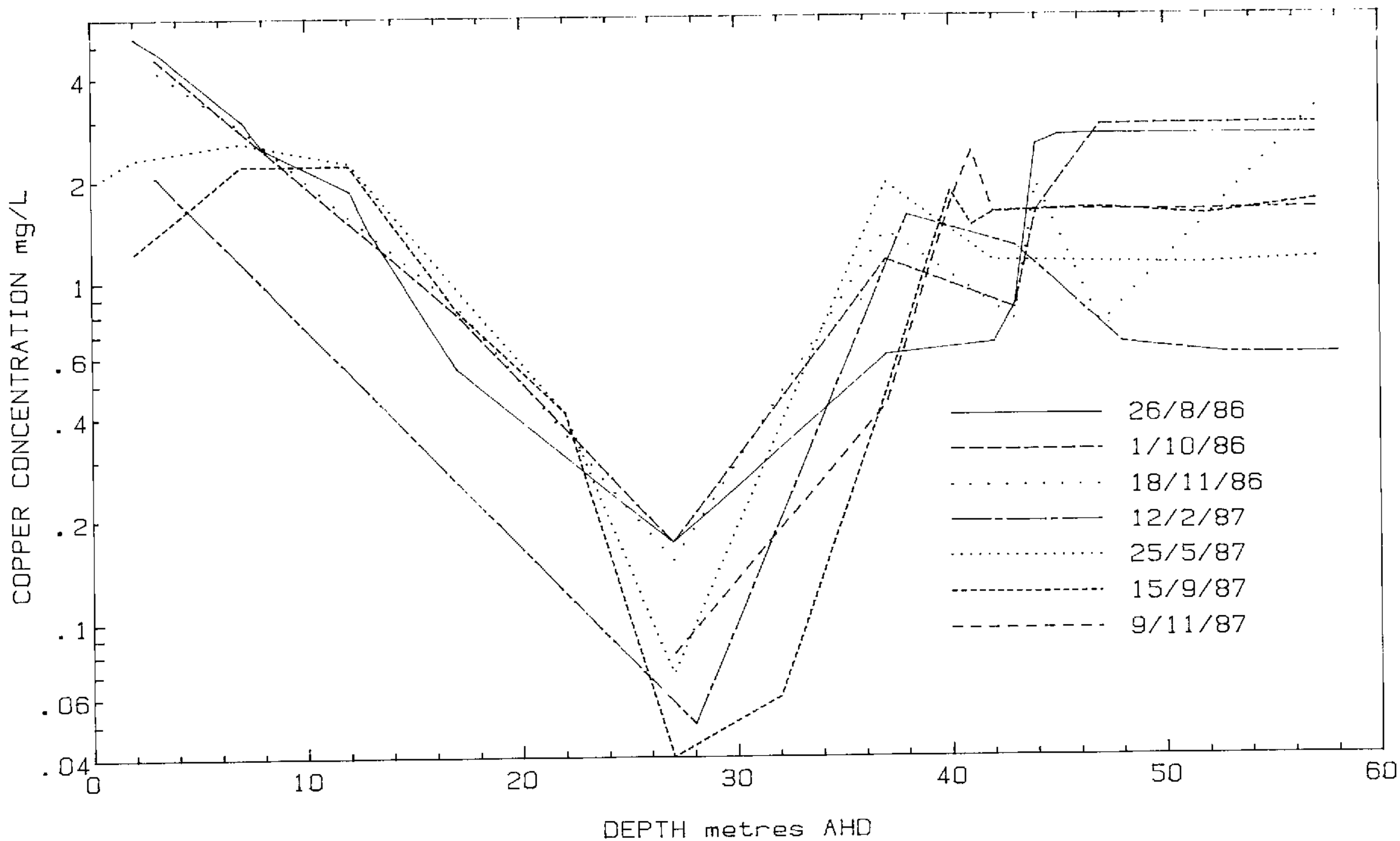

Figure 6.10 1986-87 Intermediate Open Cut copper profiles

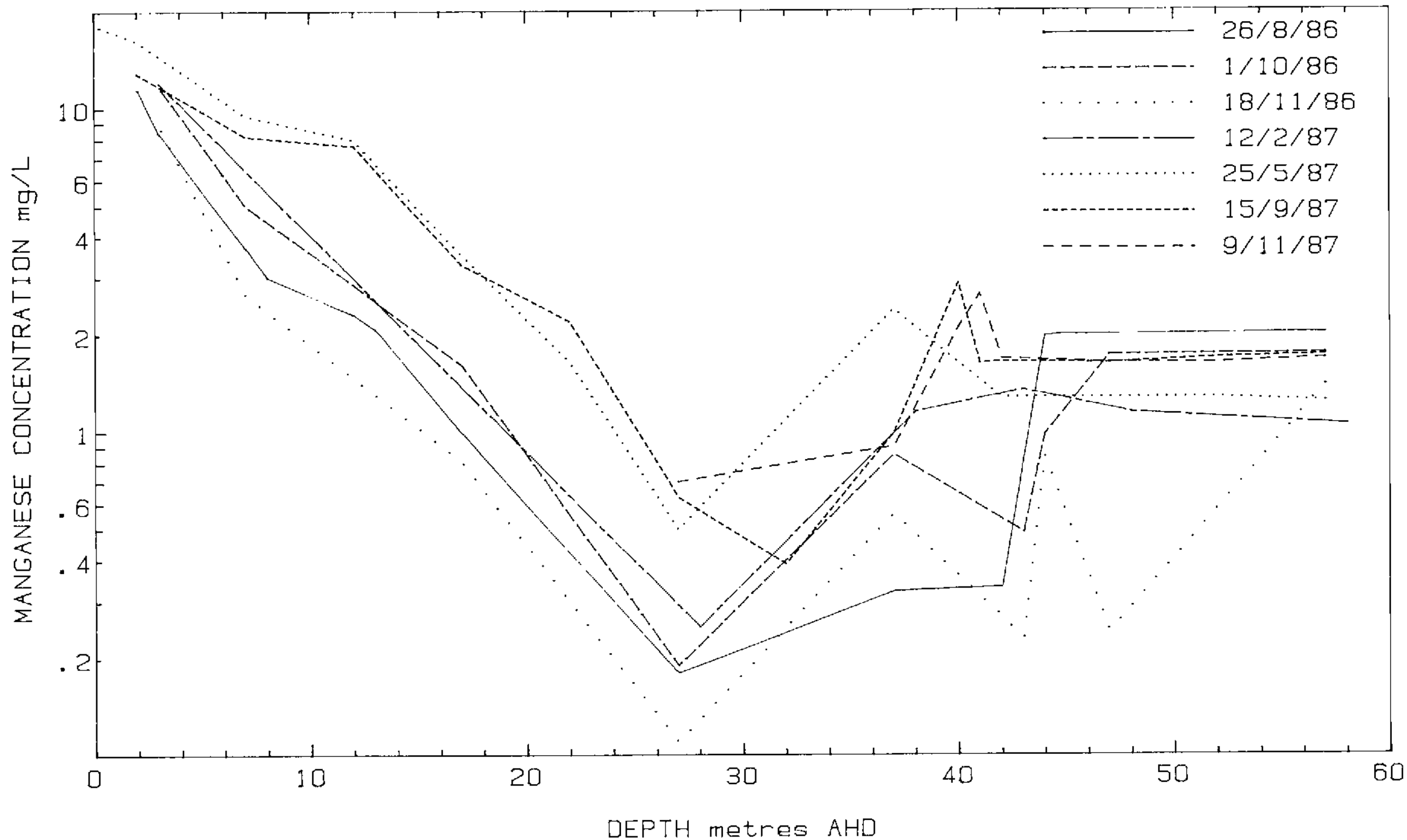

Figure 6.11 1986-87 Intermediate Open Cut manganese profiles

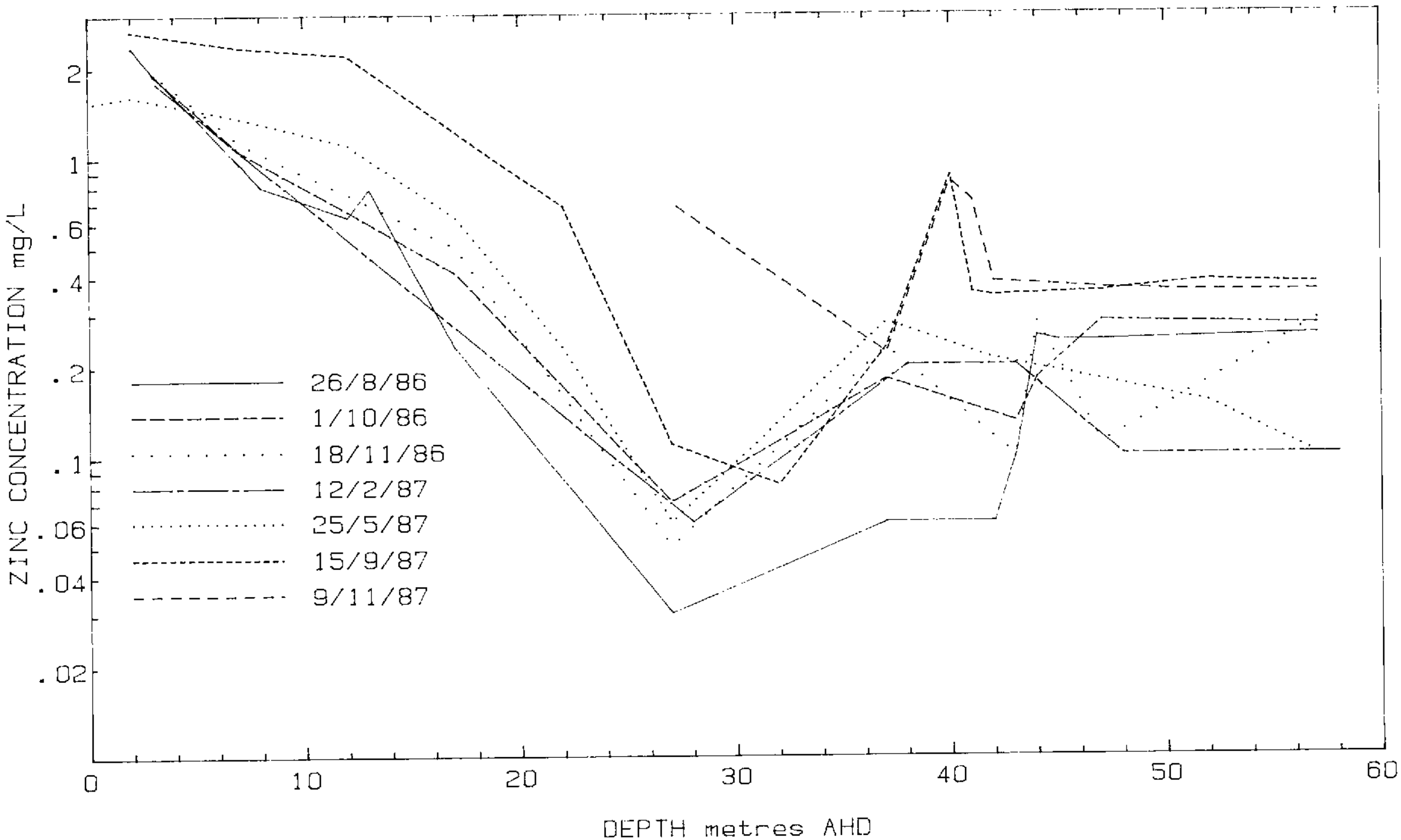

Figure 6.12 1986-87 Intermediate Open Cut zinc profiles

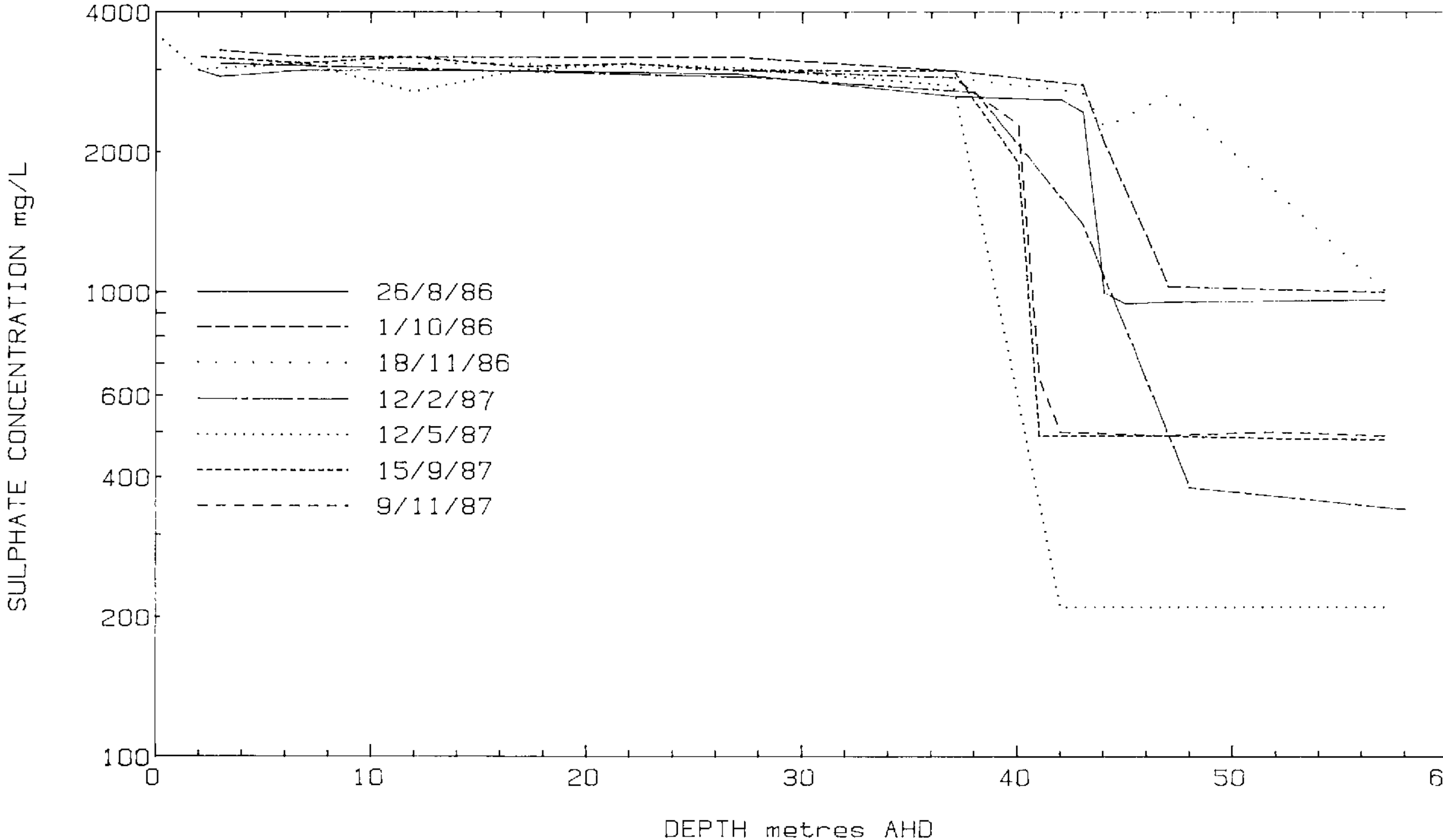

Figure 6.13 1986-87 Intermediate Open Cut sulphate profiles

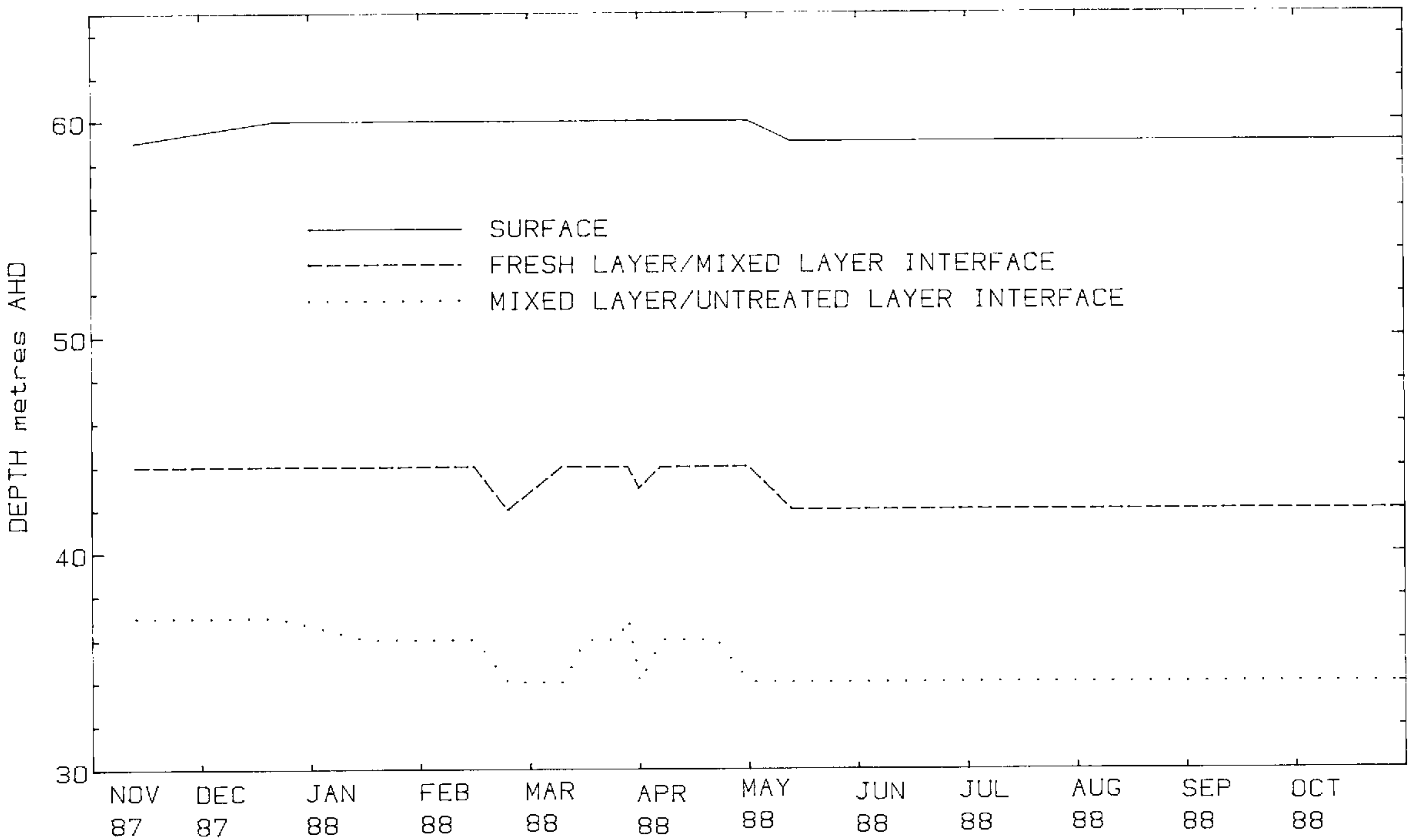

Figure 6.14 White's Open Cut 1987-88 profiles

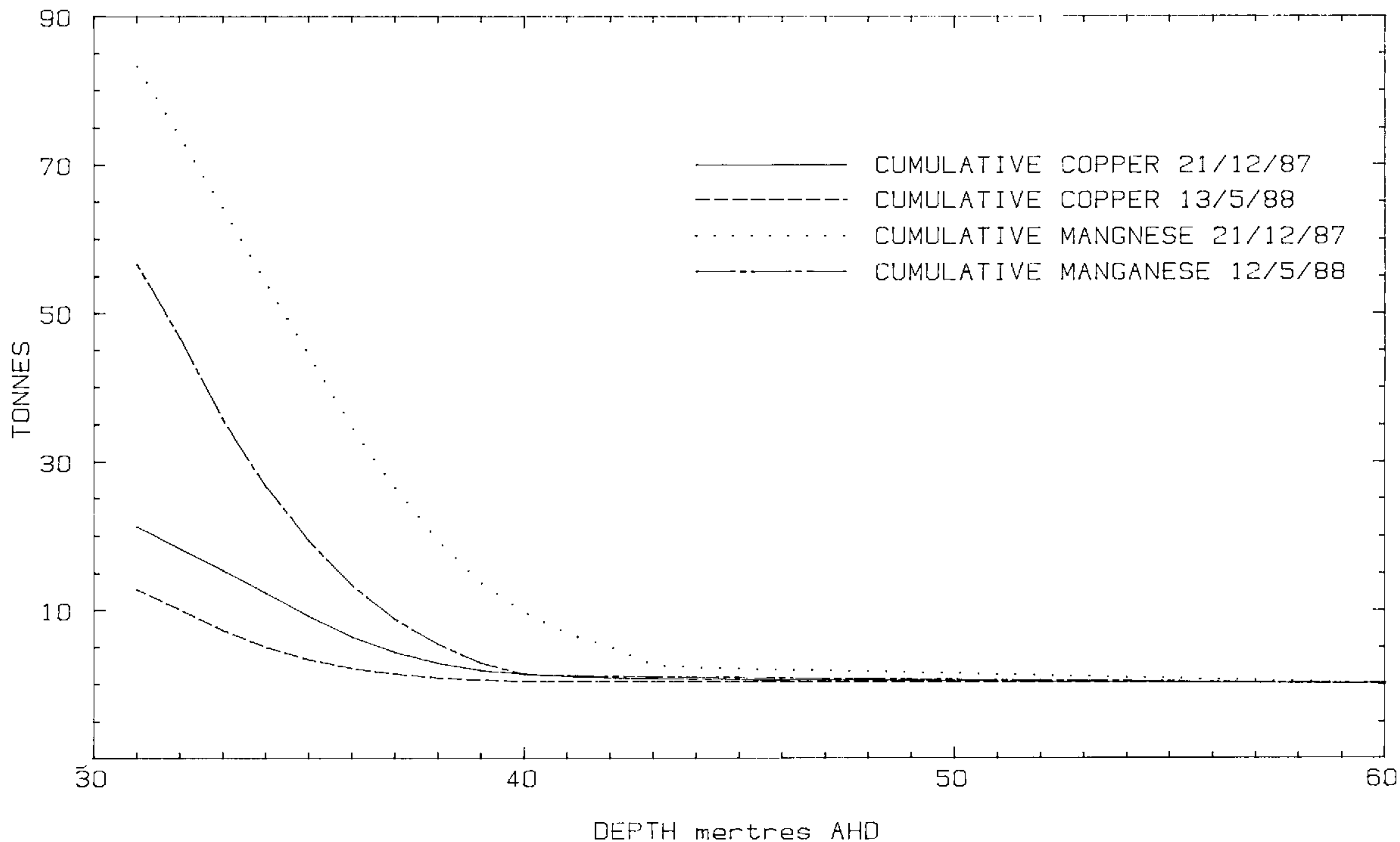

Figure 6.15 White's Open Cut 1987-88, cumulative copper & manganese

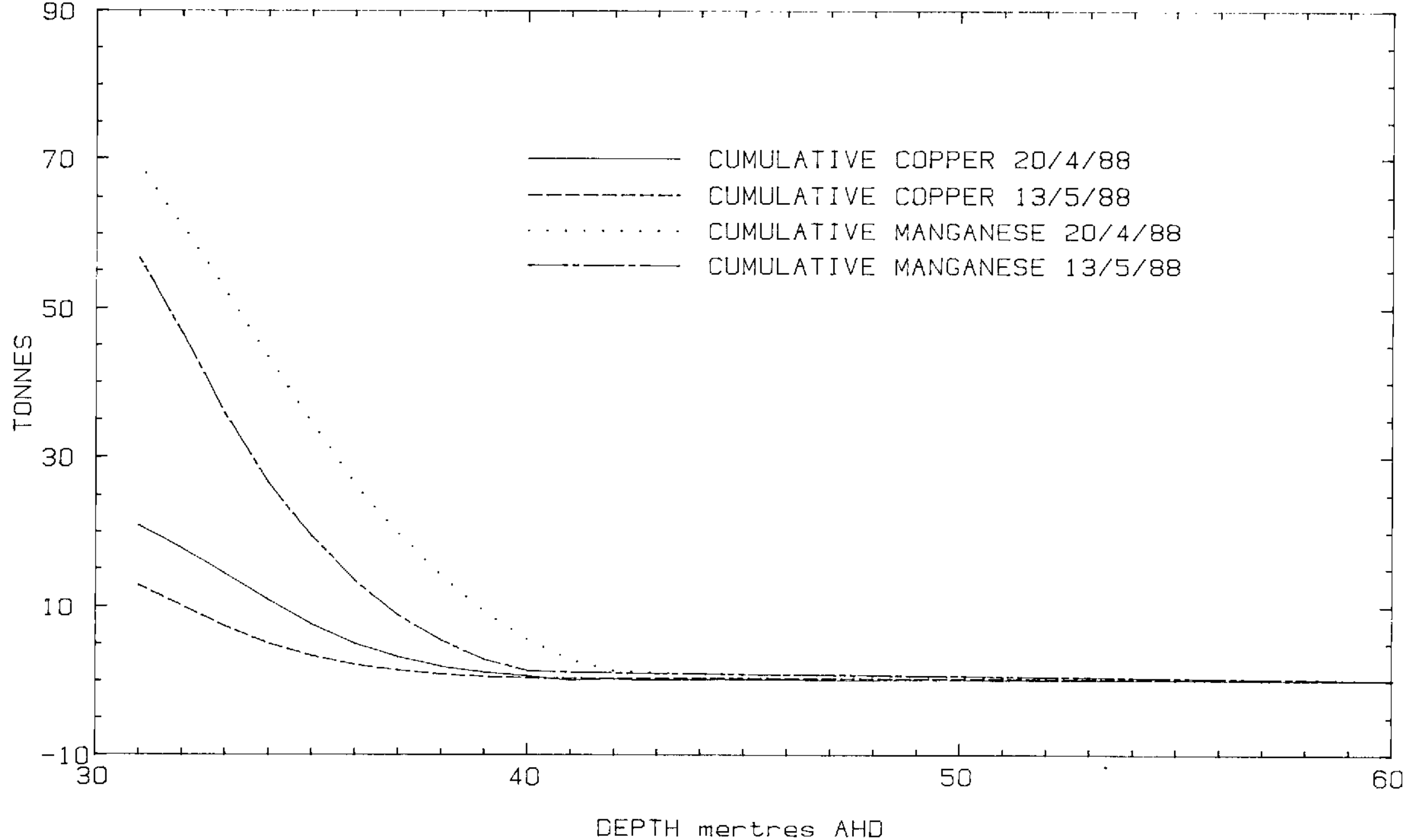

Figure 6.16 White's Open Cut 1987-88, comparison of heavy metals 20/4/88 & 13/5/88

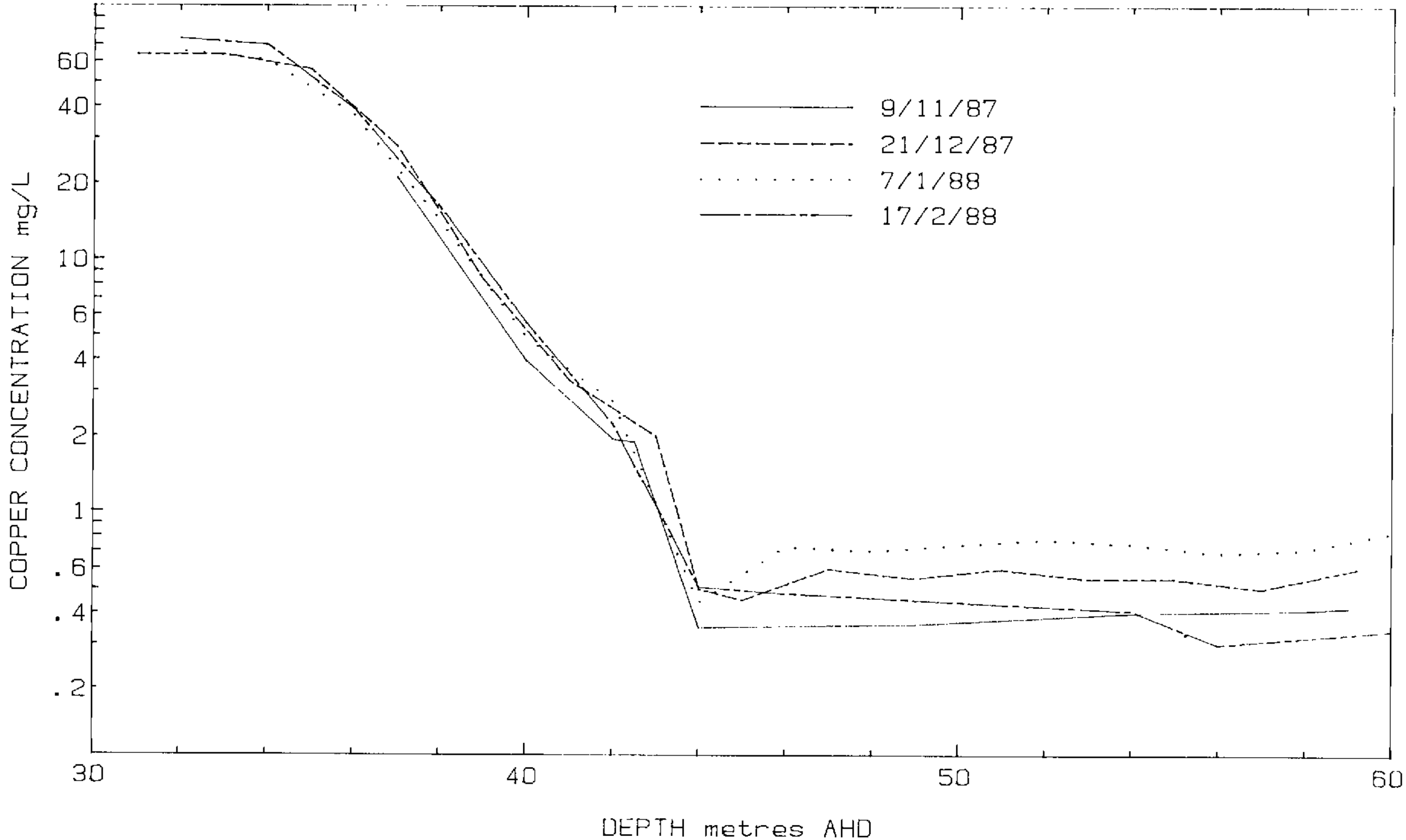

Figure 6.17 White's Open Cut 1987-88, copper concentration start of wet season

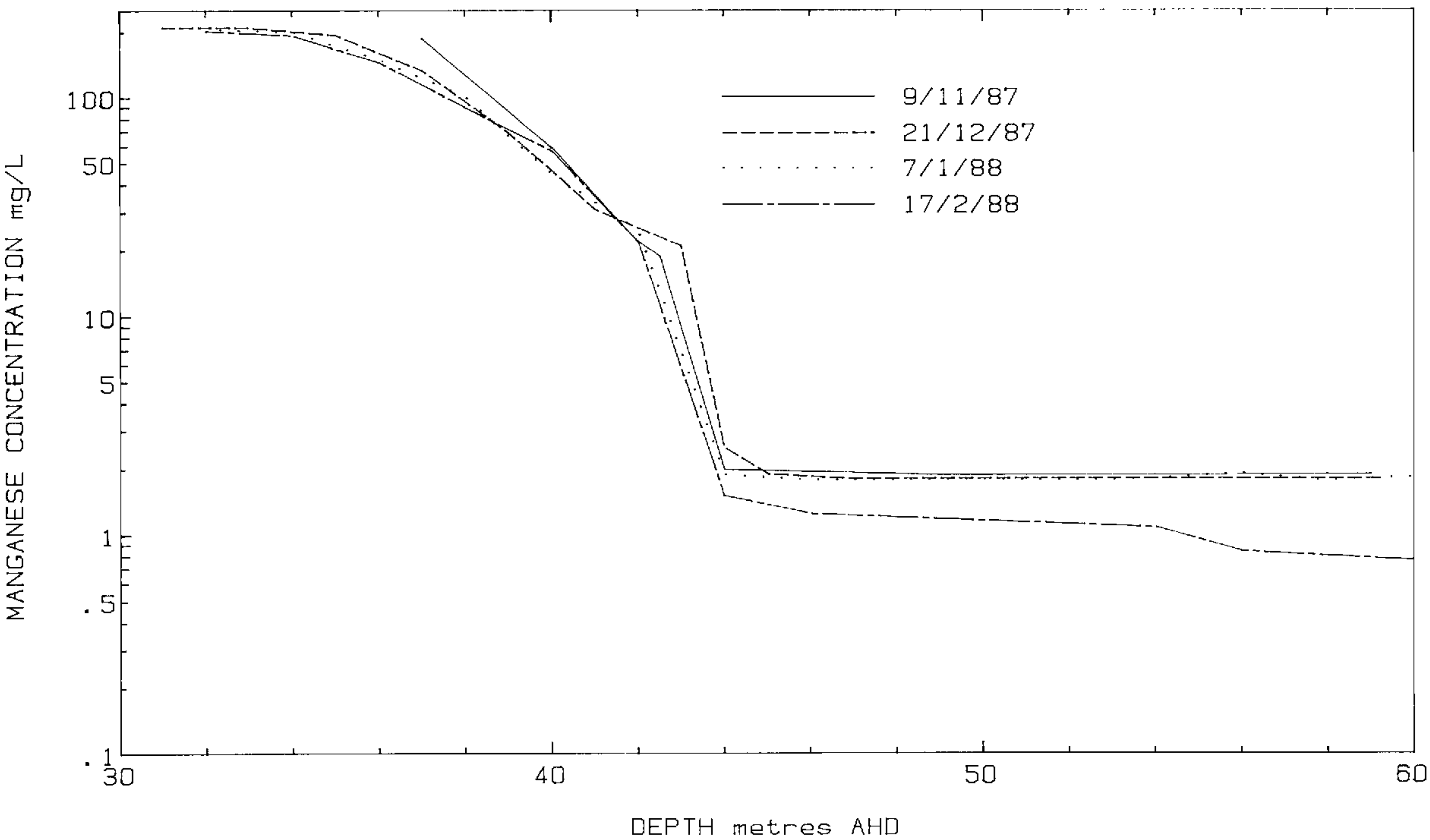

Figure 6.18 White's Open Cut 1987-88, manganese concentration start of wet season

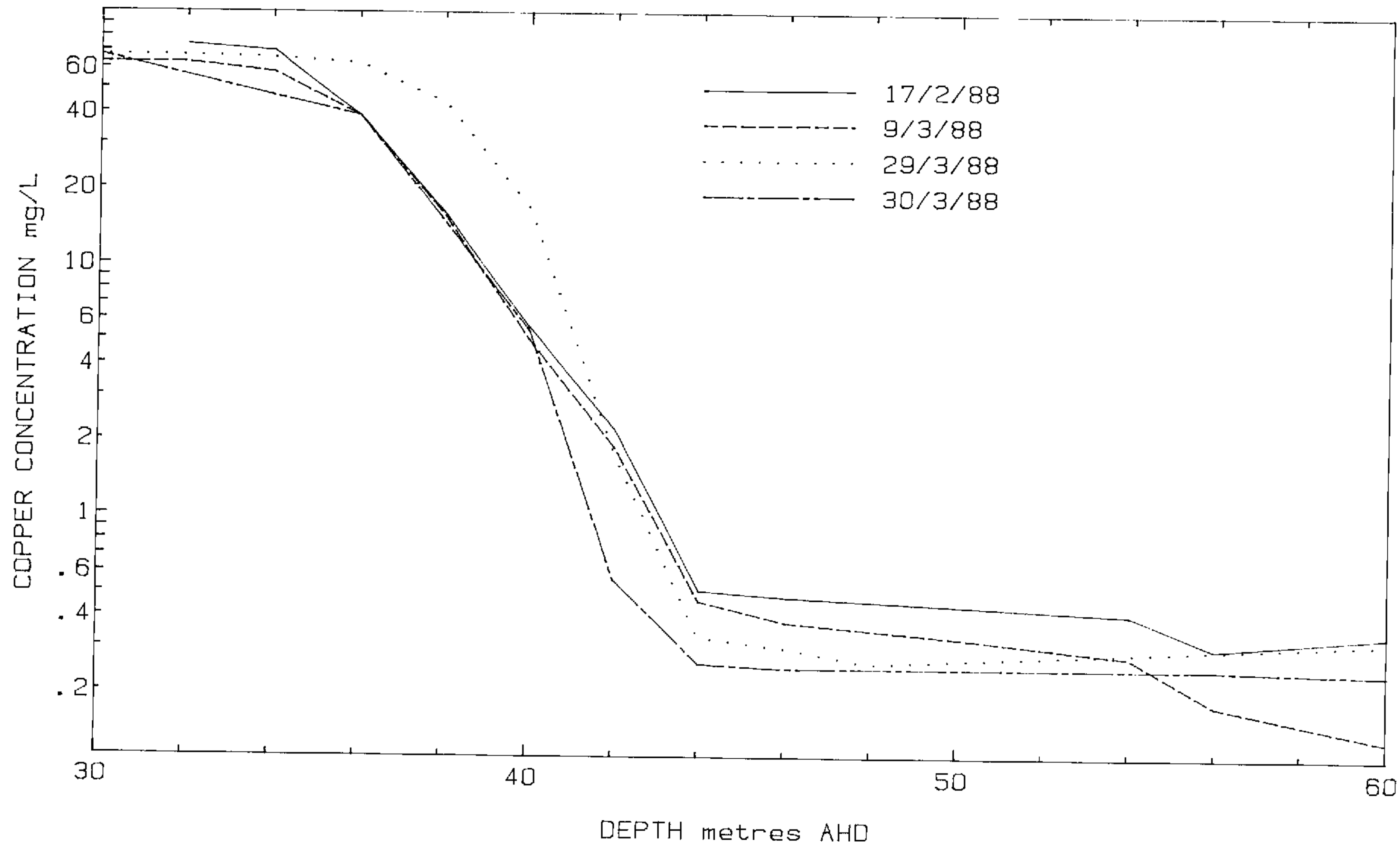

Figure 6.19 White's Open Cut 1987-88, copper concentration middle of wet season

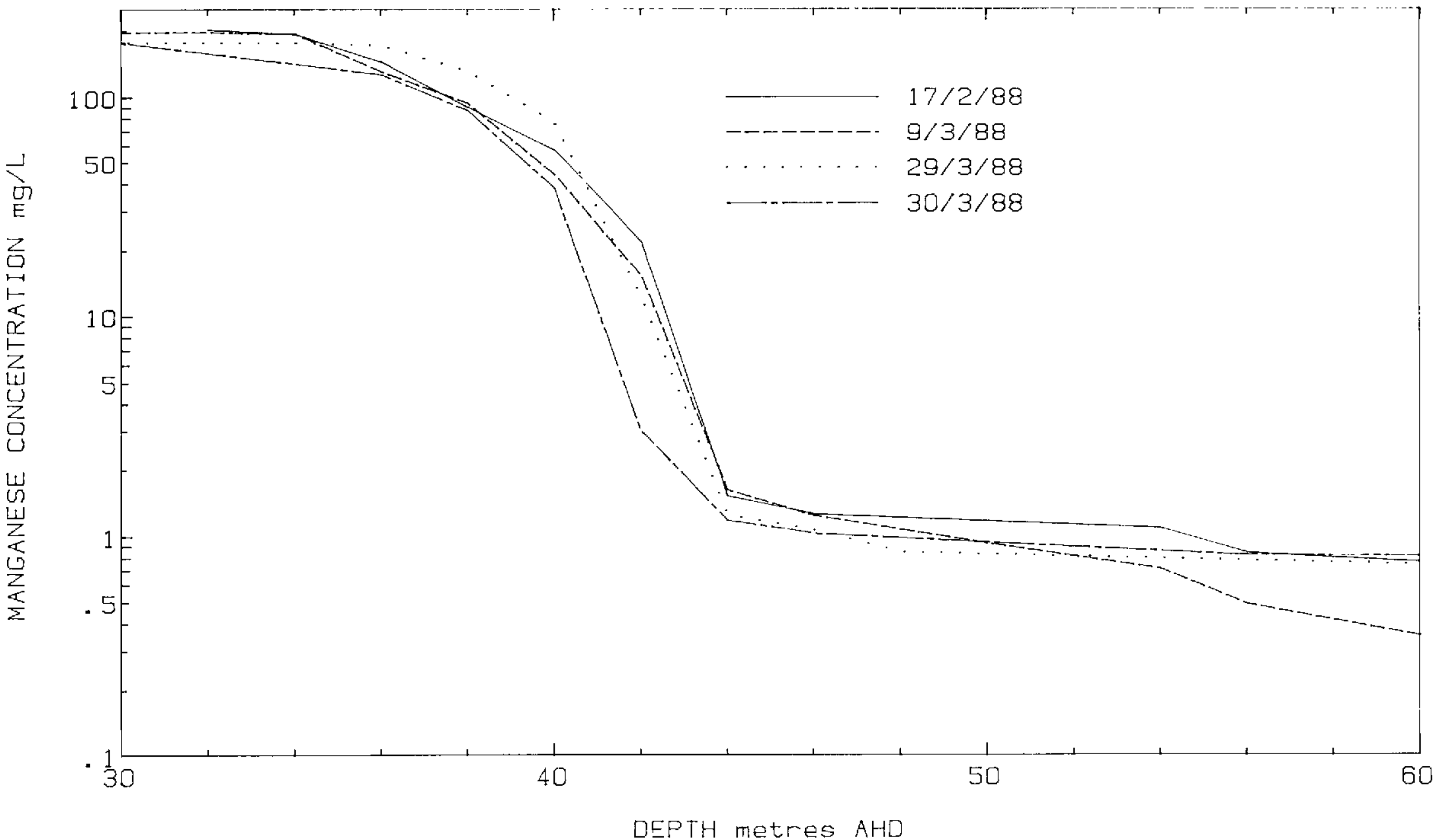

Figure 6.20 White's Open Cut 1987-88, manganese concentration middle of wet season

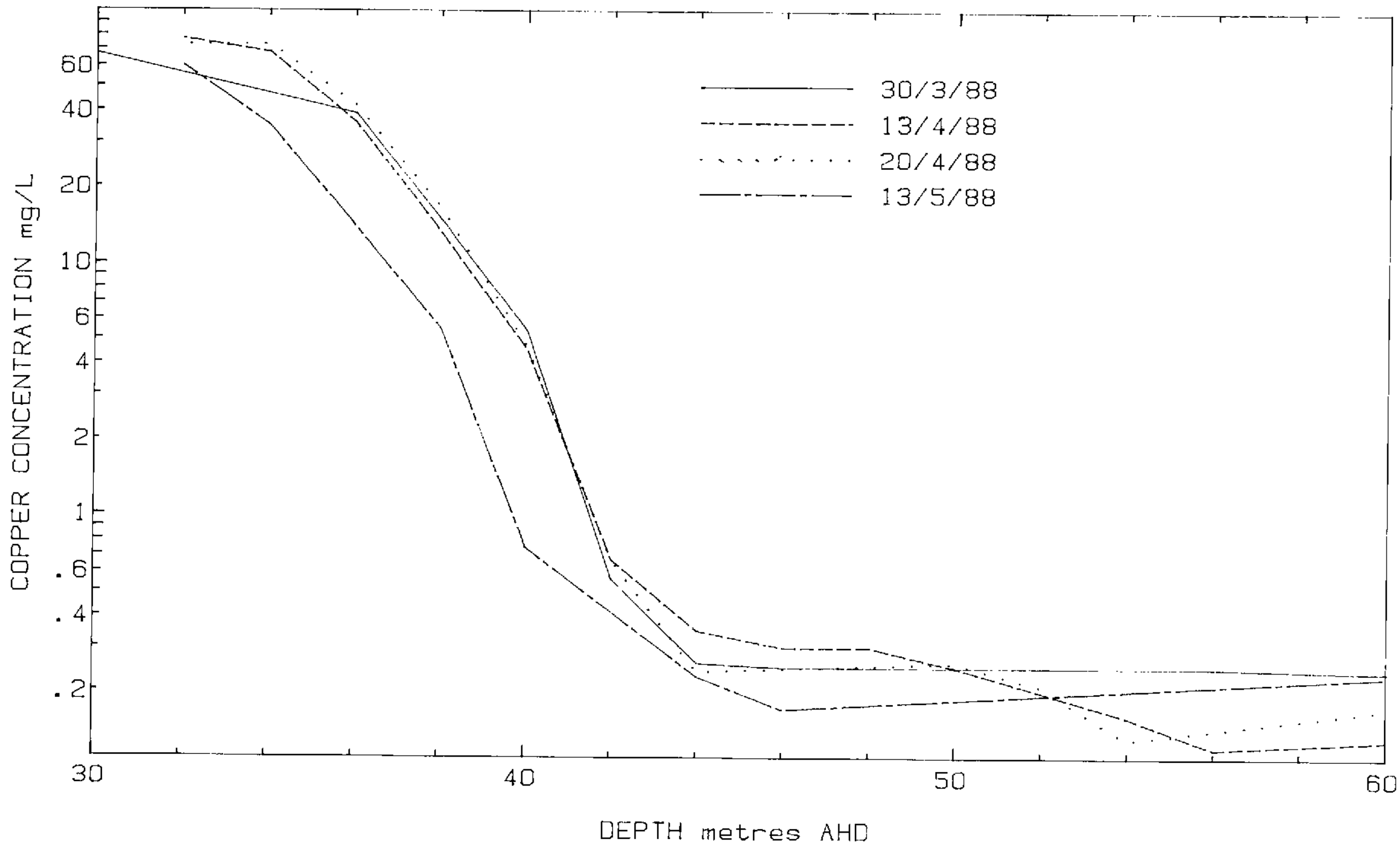

Figure 6.21 White's Open Cut 1987-88, copper concentration end of wet season

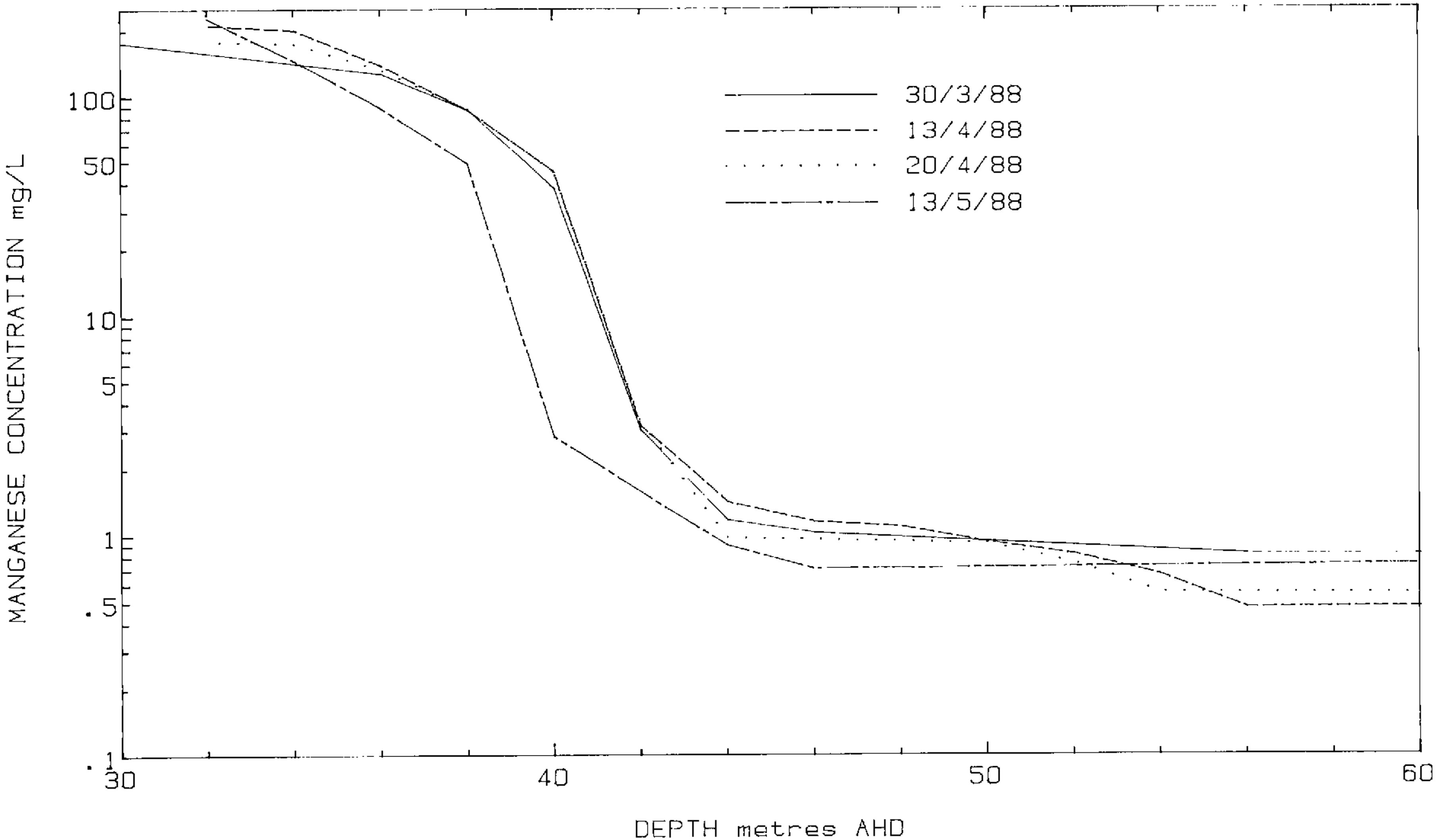

Figure 6.22 White's Open Cut 1987-88, manganese concentration end of wet season

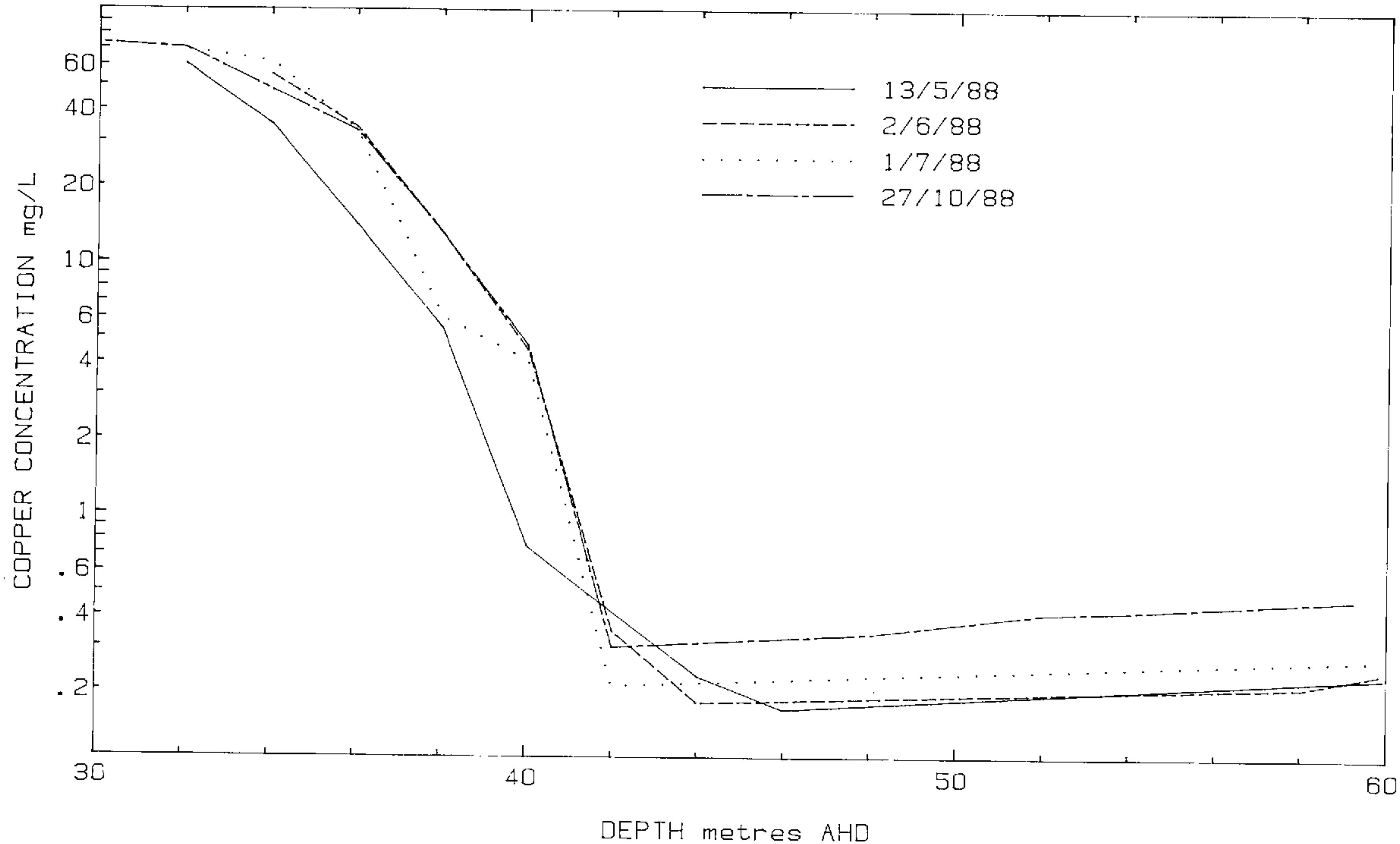

Figure 6.23 White's Open Cut 1987-88, copper concentration dry season

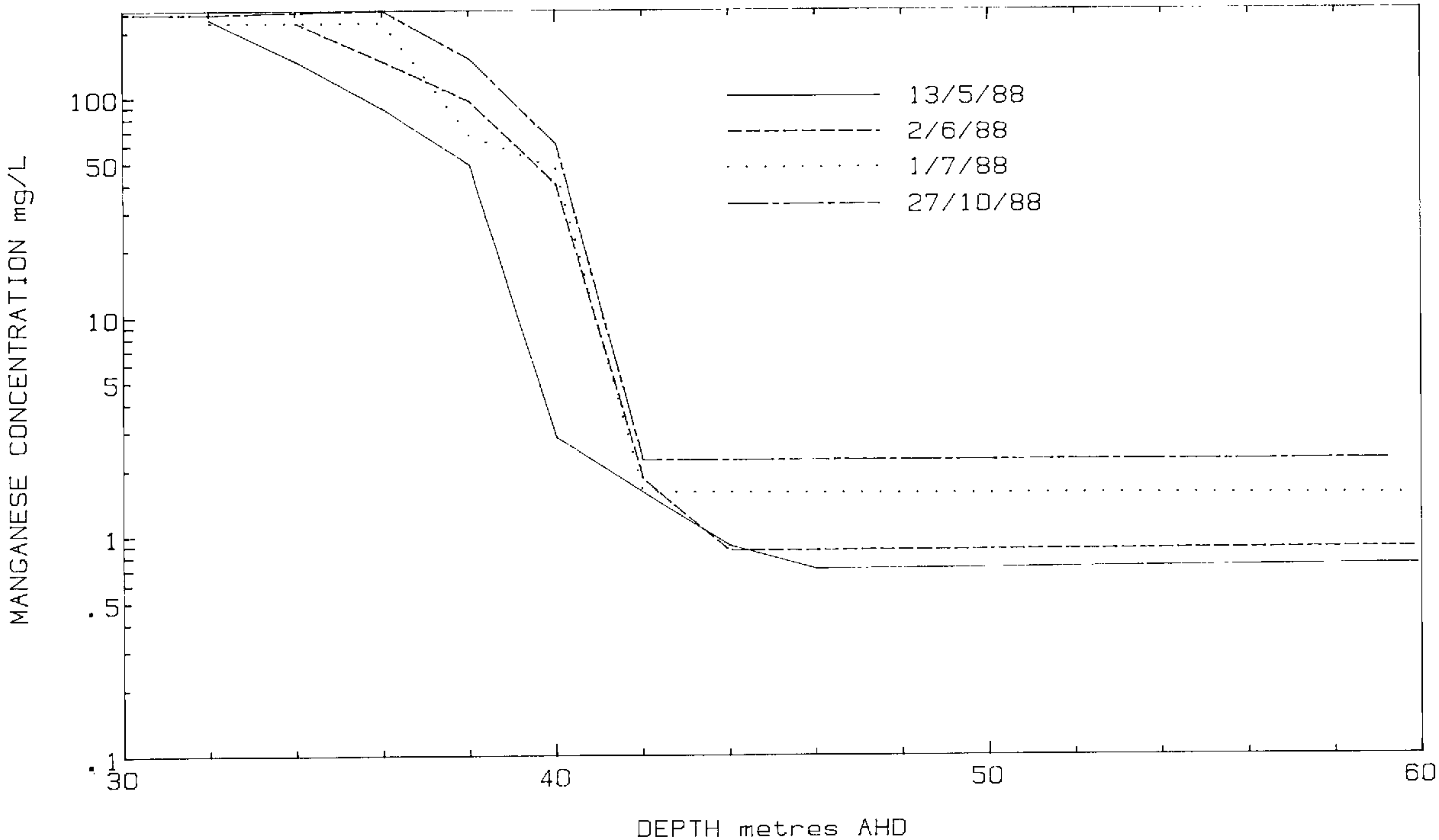

Figure 6.24 White's Open Cut 1987-88, manganese concentration dry season

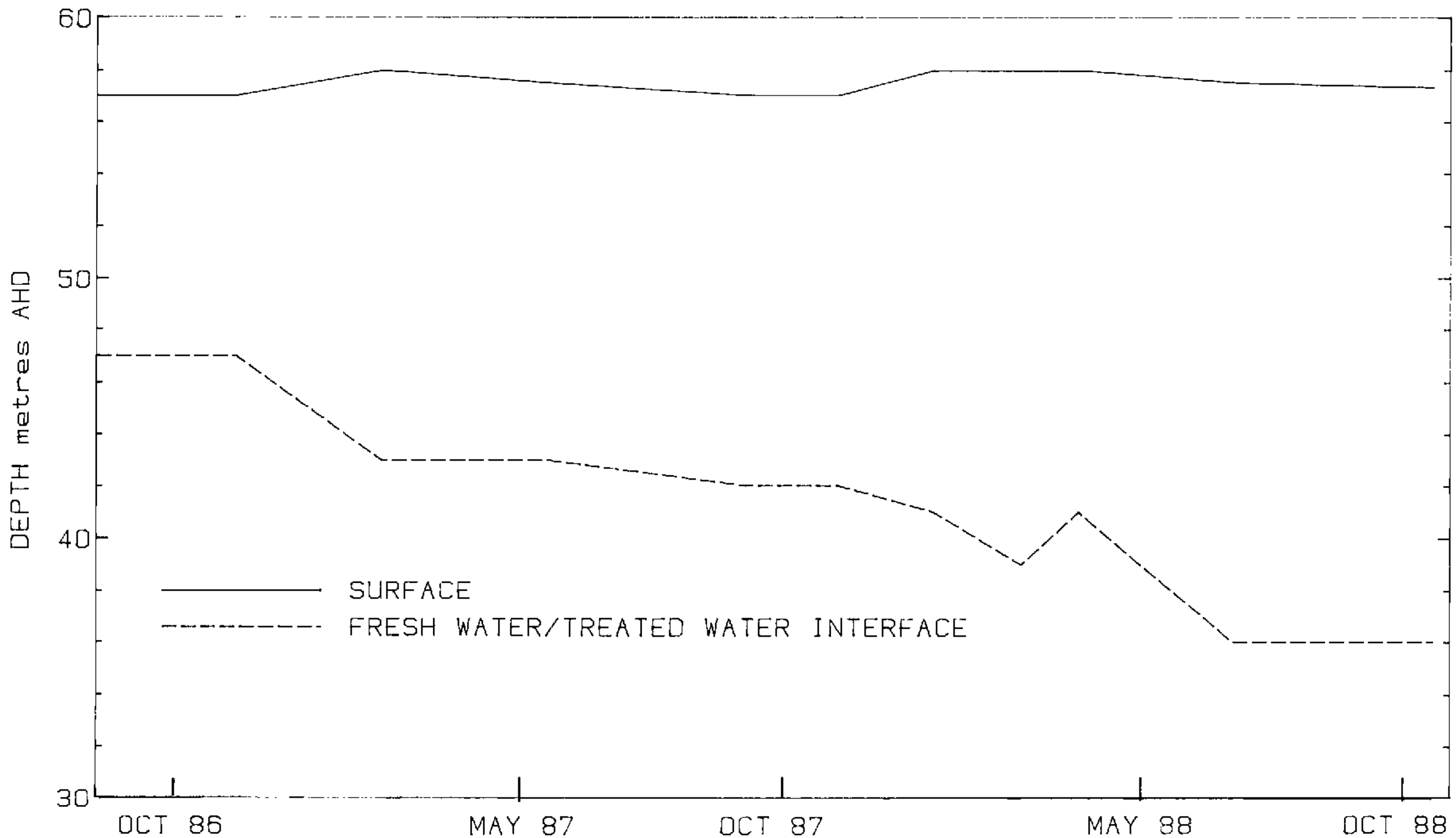

Figure 6.25 Intermediate Open Cut 1987-88, profiles

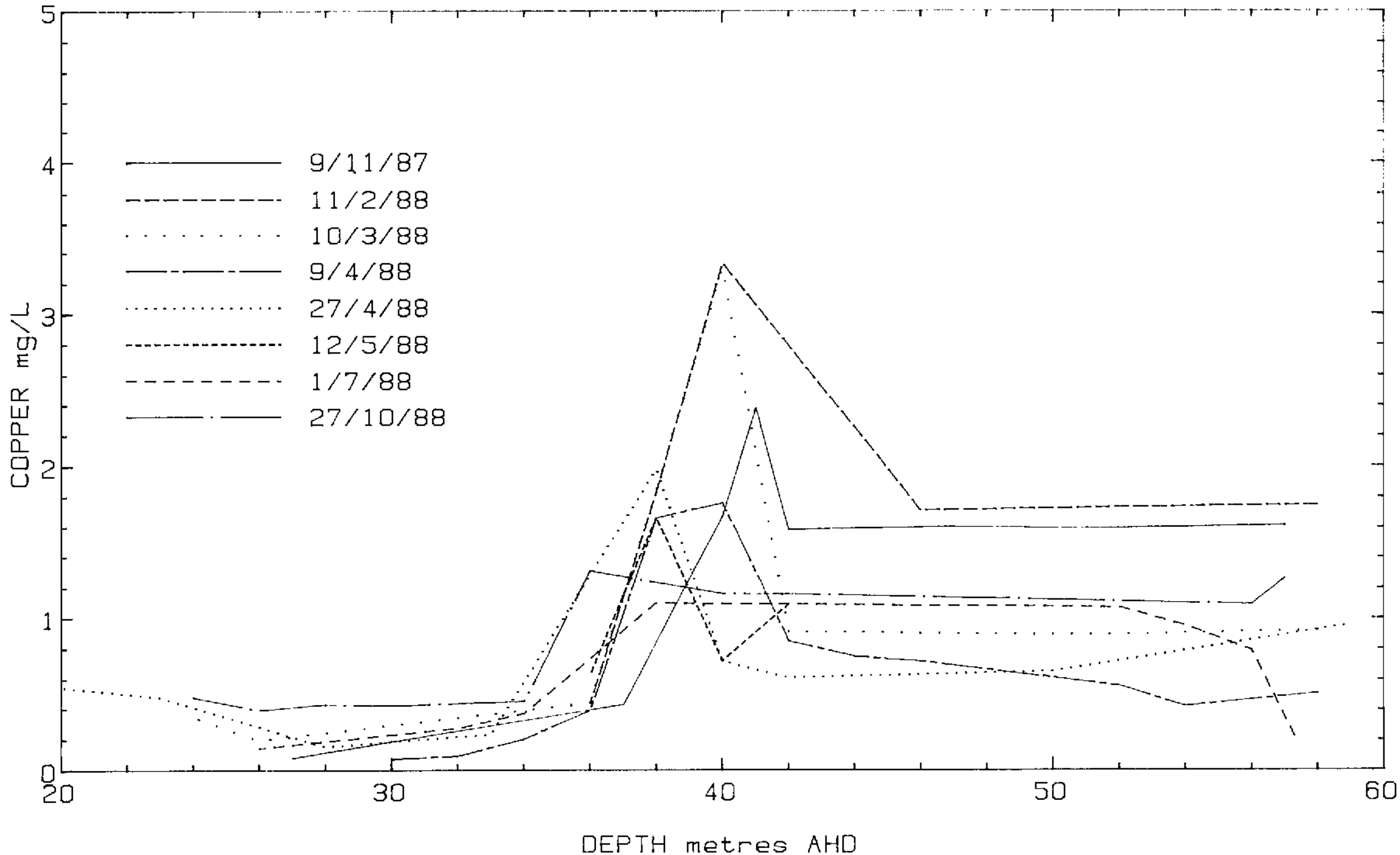

Figure 6.26 Intermediate Open Cut 1987-88, copper concentration

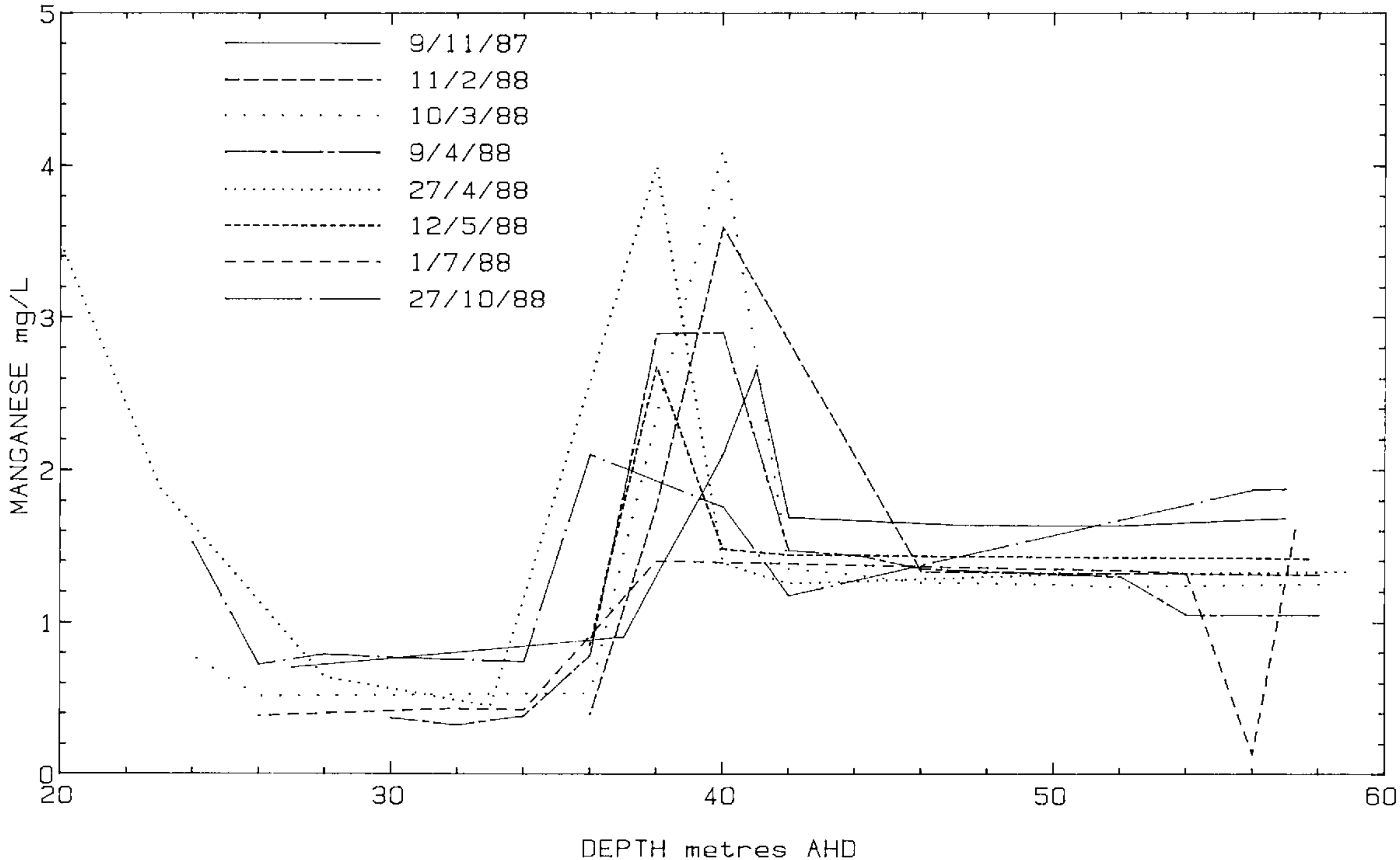

Figure 6.27 Intermediate Open Cut 1987-88, manganese concentration

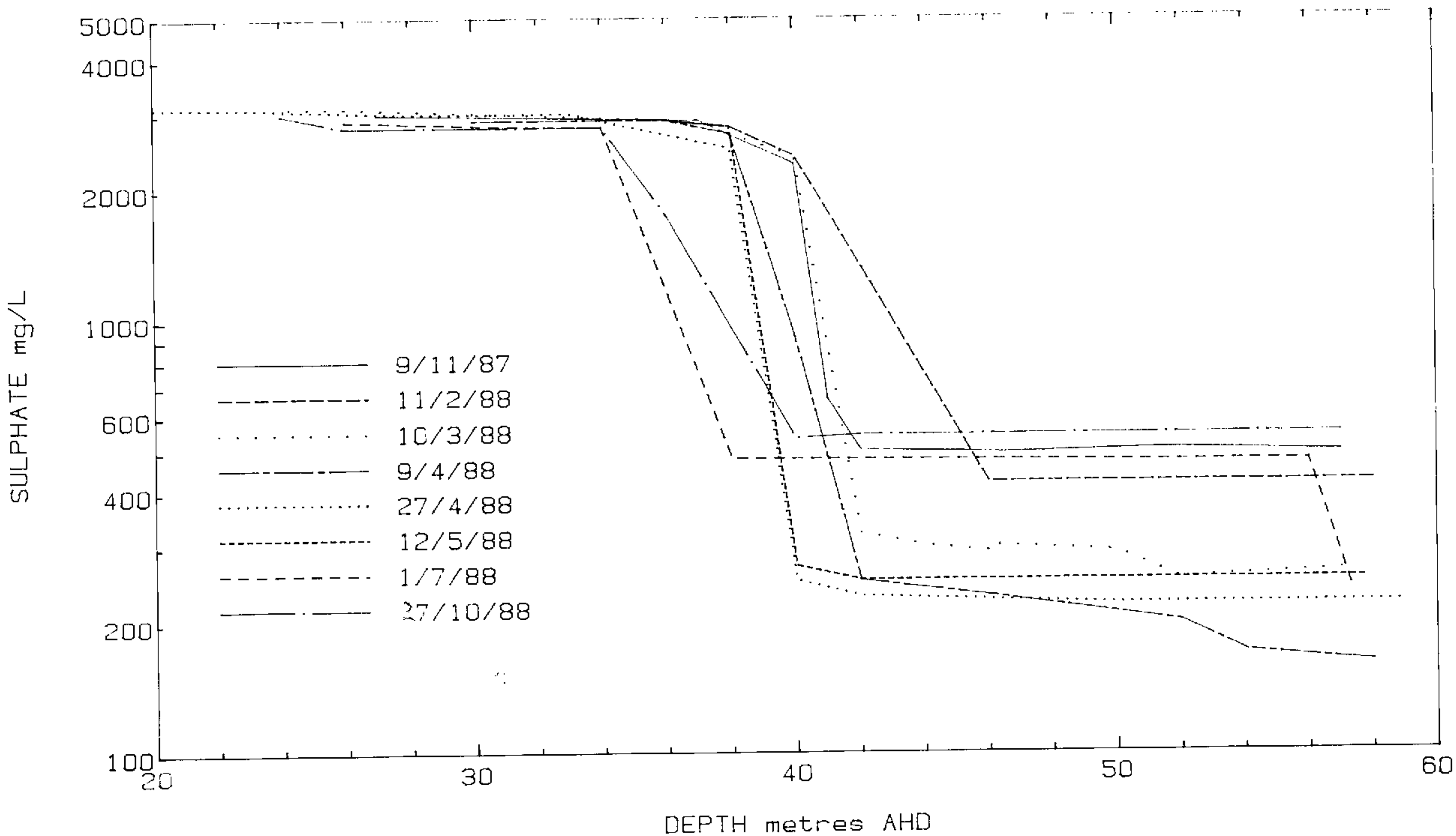

Figure 6.28 Intermediate Open Cut 1987-88, sulphate concentration

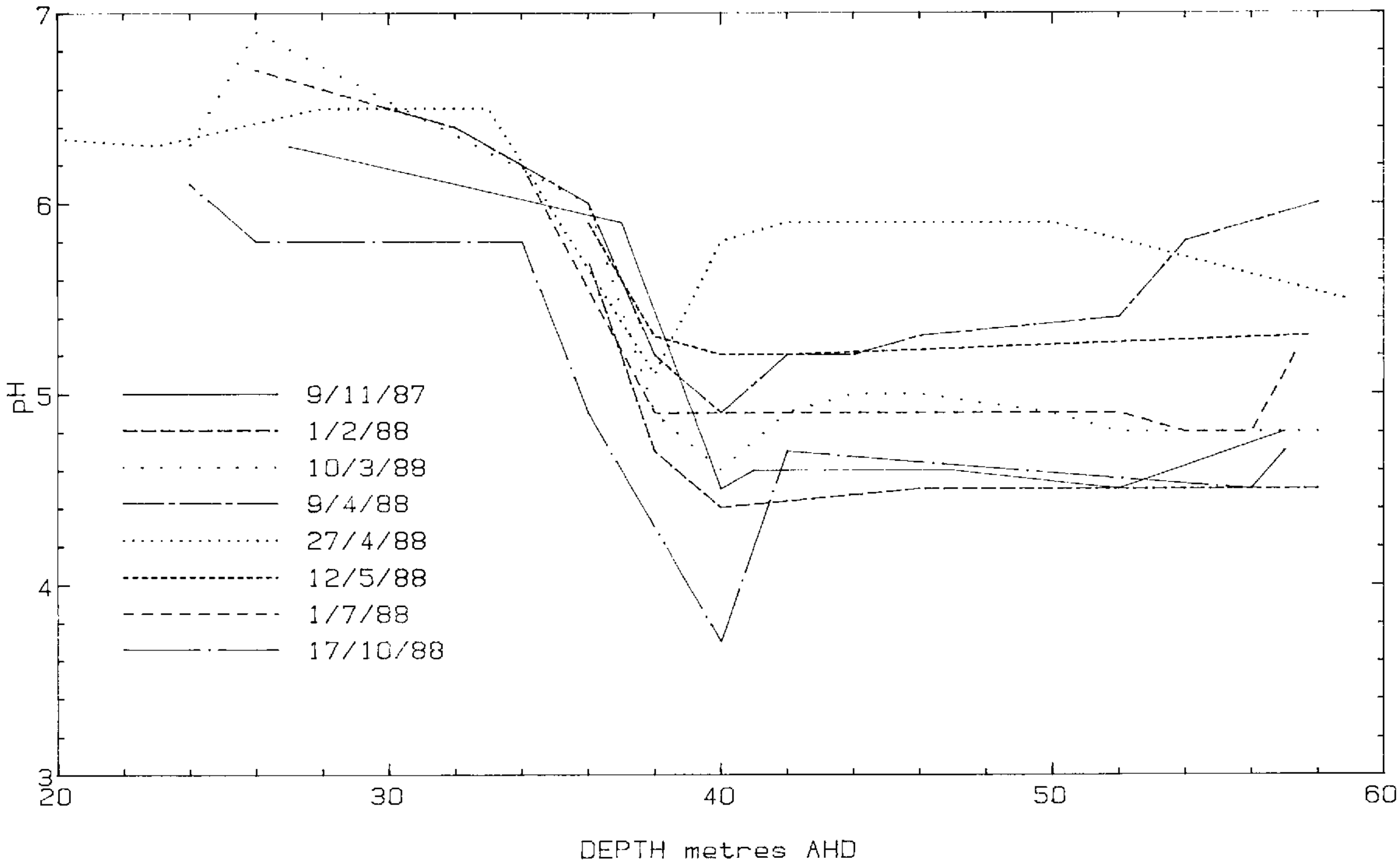

Figure 6.29 Intermediate Open Cut 1987-88, pH

APPENDIX D

WATER QUALITY OF THE OPEN CUTS
(Chapter 6)

TABLES

Table 6.1 White's Open Cut water quality August 1986-November 1987

Date	AHD (m)	pH	SC (μS/cm)	Cu	Mn (mg/l)	Zn	SO_4
27-08-86	59.0	6.0	1340	.33	1.2	.12	720
27-08-86	49.0	6.2	1340	.33	1.2	.12	730
27-08-86	47.0	6.1	1340	.33	1.2	.12	710
27-08-06	46.0	5.7	1620	.40	1.6	.12	920
27-08-86	45.0	5.1	3560	.74	5.3	.17	2250
27-08-86	44.0	5.1	3650	.77	4.7	.16	2290
27-08-86	41.0	5.1	4130	1.2	13	.29	2650
27-08-86	39.0	4.7	4870	4.7	39	1.2	3450
27-08-86	37.0	4.0	5800	18	83	3.5	4550
27-08-86	35.0	3.3	6760	35	122	5.0	5640
27-08-86	33.0	2.9	8190	62	163	6.4	7050
27-08-86	31.0	2.8	8480	64	167	6.5	7170
27-08-86	29.0	2.8	8480	67	174	6.6	7260
01-10-86	59.0	5.8	1360	.40	1.3	.15	720
01-10-86	49.0	5.8	1360	.40	1.3	.15	730
01-10-86	47.0	5.8	1380	.40	1.4	.15	730
01-10-86	46.0	5.8	1420	.40	1.4	.15	810
01-10-86	45.0	5.3	3100	.88	5.2	.20	1920
01-10-86	39.0	4.7	4690	3.5	33	.89	3310
01-10-86	37.0	4.1	5700	14	81	.58	4360
01-10-86	33.0	3.1	8100	60	180	1.4	7300
01-10-86	29.0	3.2	8410	65	190	7.2	8140
18-11-86	59.0	5.3	1390	.56	1.5	.15	753
18-11-86	49.0	5.5	1380	.53	1.5	.16	760
18-11-86	47.0	5.5	1400	.42	1.5	.15	780
18-11-86	46.0	4.9	2420	.74	3.9	.18	1470
18-11-86	45.0	5.1	3290	.81	7.2	.20	2130
18-11-86	39.0	4.4	5000	6.2	51	1.4	3650
18-11-86	37.0	3.7	6000	18	96	3.7	4680
18-11-86	33.0	2.9	8200	56	178	6.4	7500
18-11-86	29.0	2.9	8500	60	191	6.6	7870
12-02-87	60.0	6.0	520	.30	.80	.06	240
12-02-87	55.0	6.0	510	.30	.80	.08	230
12-02-87	50.0	5.9	610	.35	.90	.06	280
12-02-87	45.0	5.7	790	.45	1.3	.10	360
12-02-87	40.0	4.9	4320	2.8	30	.70	2470
12-02-87	30.0	2.8	8300	61	210	3.4	6100

Date	AHD (m)	pH	SC (µS/cm)	Cu	Mn	Zn (mg/l)	SO_4
25-05-87	59.0	6.6	360	.25	.89	.07	150
25-05-87	54.0	5.0	370	.23	.91	.06	150
25-05-87	49.0	5.3	370	.17	.86	.06	150
25-05-87	44.0	5.6	360	.17	.96	.07	150
25-05-87	39.0	4.6	4700	6.7	61	1.5	3200
09-11-87	59.0	5.3	690	.42	1.9	.20	330
09-11-87	58.0	4.5	690	.41	1.9	.19	330
09-11-87	54.0	4.7	690	.40	1.9	.18	320
09-11-87	49.0	4.7	690	.36	1.9	.17	320
09-11-87	44.0	5.0	700	.35	2.0	.16	330
09-11-87	42.5	4.4	3300	1.9	19	.74	2200
09-11-87	42.0	4.6	3740	2.0	22	.89	2500
09-11-87	40.0	4.4	4740	4.0	59	1.8	3300
09-11-87	37.0	3.3	6200	21	186	8.9	4800

Table 6.2 Intermediate Open Cut water quality August 1986-November 1987

Date	AHD (m)	pH	SC (μS/cm)	Cu	Mn (mg/l)	Zn	SO_4
27-08-86	57.0	4.8	1700	2.7	2.0	.25	960
27-08-86	47.0	4.8	1700	2.7	2.0	.24	950
27-08-86	45.0	4.8	1700	2.6	2.0	.24	940
27-08-86	44.0	4.9	1750	2.5	2.0	.25	1000
27-08-86	43.0	6.1	3600	.84	.82	.10	2450
27-08-86	42.0	5.8	3750	.65	.33	.06	2600
27-08-86	37.0	6.1	3800	.60	.32	.06	2650
27-08-86	27.0	6.6	4100	.17	.18	.03	2950
27-08-86	17.0	6.3	4100	.55	.99	.23	3000
27-08-86	13.0	5.8	4200	1.4	2.1	.78	3000
27-08-86	12.0	5.9	4200	1.9	2.3	.63	3000
27-08-86	8.0	5.9	4200	2.5	3.0	.80	3000
27-08-86	7.0	5.5	4200	3.0	3.7	.96	3000
27-08-86	3.0	4.6	4100	4.8	8.4	1.9	2900
27-08-86	2.0	5.3	4300	5.4	11	2.4	3000
01-10-86	57.0	4.7	1720	2.9	1.7	.27	1000
01-10-86	47.0	4.7	1730	2.8	1.7	.28	1030
10-10-86	44.0	5.6	2980	1.6	.98	.18	2100
01-10-86	43.0	6.1	3700	.82	.49	.13	2800
01-10-86	37.0	5.9	3950	1.1	.85	.18	3000
01-10-86	27.0	6.7	4100	.17	.19	.07	3200
01-10-86	17.0	6.1	4160	.80	1.0	.41	3200
01-10-86	7.0	5.5	4200	2.8	5.0	1.1	3200
01-10-86	3.0	4.7	4300	4.6	12	1.9	3300
18-11-86	57.0	4.6	1760	3.2	1.4	.28	1010
18-11-86	47.0	6.0	3900	.73	.24	.11	2670
18-11-86	44.0	5.4	3400	1.9	.84	.28	2260
18-11-86	43.0	6.1	3900	.76	.23	.10	2700
18-11-86	37.0	5.8	4100	1.4	.56	.23	2900
18-11-86	27.0	6.6	4300	.15	.11	.05	3000
18-11-86	17.0	6.1	4300	.85	.81	.50	3100
18-11-86	7.0	5.6	4400	2.9	2.7	1.1	3100
18-11-86	3.0	4.7	4500	4.2	8.9	2.0	3100
12-02-87	58.0	5.6	720	.60	1.1	.10	340
12-02-87	53.0	5.5	750	.60	1.1	.10	360
12-02-87	48.0	5.5	780	.65	1.2	.10	380
12-02-87	43.0	5.3	2200	1.3	1.4	.20	1400
12-02-87	38.0	5.8	3700	1.6	1.2	.20	2700
12-02-87	28.0	6.6	4000	.05	.25	.06	2900
12-02-87	3.0	6.0	4200	2.1	12	1.8	3100

Date	AHD (m)	pH	SC (μS/cm)	Cu	Mn	Zn (mg/l)	SO_4
25-05-87	57.0	5.4	550	1.1	1.2	.10	210
25-05-87	52.0	5.4	450	1.1	1.3	.15	210
25-05-87	42.0	5.4	460	1.1	1.3	.21	210
25-05-87	37.0	5.5	3560	1.9	2.4	.28	2790
25-05-87	27.0	5.5	3810	.07	.50	.06	3040
25-05-87	22.0	6.4	3810	.41	1.7	.23	3100
25-05-87	17.0	6.3	3830	.95	3.5	.63	3000
25-05-87	12.0	5.9	3900	2.2	8.0	1.1	2700
25-05-87	7.0	6.0	3920	2.5	9.5	1.4	3100
25-05-87	2.0	6.2	4000	2.3	16	1.6	3000
25-05-87	.0	6.4	4000	1.9	18	1.5	3600
09-11-87	57.0	4.9	940	1.7	1.7	.37	480
09-11-87	52.0	4.9	940	1.5	1.7	.38	484
09-11-87	47.0	4.6	940	1.6	1.6	.35	490
09-11-87	42.0	4.6	950	1.6	1.7	.34	490
09-11-87	41.0	5.0	950	1.4	1.6	.35	490
09-11-87	40.0	5.1	2800	1.8	2.9	.86	1900
09-11-87	37.0	5.7	4000	.47	.99	.23	3000
09-11-87	32.0	6.0	4100	.06	.39	.08	3000
09-11-87	27.0	6.1	4100	.04	.63	.11	3000
09-11-87	22.0	5.9	4100	.41	2.2	.68	3100
09-11-87	17.0	6.0	4100	.82	3.3	1.2	3050
09-11-87	12.0	5.7	4200	2.2	7.7	2.2	3200
09-11-87	7.0	5.8	4150	2.2	8.2	2.4	3100
09-11-87	2.0	6.1	4200	1.2	13	2.7	3200

Table 6.3 White's Open Cut profiling data 1987-88

Date	AHD (m)	pH	SC (μS/cm)	Cu	Mn (mg/l)	Zn	SO_4
09-11-87	59.0	5.3	690	.42	1.88	.20	330
09-11-87	58.0	4.5	690	.41	1.88	.19	330
09-11-87	54.0	4.7	690	.40	1.87	.18	320
09-11-87	49.0	4.7	690	.36	1.88	.17	320
09-11-87	44.0	5.0	700	.35	1.99	.16	330
09-11-87	42.5	4.4	3300	1.90	18.90	.74	2200
09-11-87	42.0	4.6	3740	1.95	22.00	.89	2500
09-11-87	40.0	4.4	4740	3.95	59.00	1.80	3300
09-11-87	37.0	3.3	6200	21.01	186.00	8.85	4800
21-12-87	59.2	4.5	690	.60	1.80	.08	320
21-12-87	57.0	4.4	710	.50	1.80	.08	320
21-12-87	55.0	4.6	710	.55	1.80	.08	320
21-12-87	53.0	4.6	700	.55	1.80	.08	320
21-12-87	51.0	4.7	700	.60	1.80	.06	320
21-12-87	49.0	4.7	700	.55	1.80	.06	320
21-12-87	47.0	4.7	700	.60	1.80	.06	320
21-12-87	45.0	4.8	720	.45	1.90	.06	330
21-12-87	44.0	4.7	900	.50	2.50	.06	420
21-12-87	43.0	4.2	3800	2.00	21.00	.50	2400
21-12-87	41.0	4.2	4400	3.30	31.00	.76	2860
21-12-87	39.0	4.1	5100	8.30	69.00	1.75	3500
21-12-87	37.0	3.2	6500	28.00	133.00	4.90	4800
21-12-87	35.0	2.9	8000	56.00	194.00	6.30	6600
21-12-87	33.0	2.8	8400	64.00	210.00	6.90	7100
21-12-87	31.0	2.8	8500	64.00	210.00	6.80	7200
07-01-88	59.9	4.2	700	.82	1.83	.07	330
07-01-88	58.0	4.5	700	.71	1.77	.06	330
07-01-88	56.0	4.6	700	.69	1.91	.06	330
07-01-88	54.0	4.6	700	.75	1.80	.06	330
07-01-88	52.0	4.6	700	.78	1.77	.06	330
07-01-88	50.0	4.6	700	.74	1.80	.06	330
07-01-88	48.0	4.7	700	.70	1.78	.06	330
07-01-88	46.0	4.7	700	.73	1.78	.06	700
07-01-88	44.0	4.8	740	.44	1.89	.04	740
07-01-88	42.0	4.5	4100	2.73	25.00	.57	2800
07-01-88	40.0	4.3	4800	4.90	45.00	1.19	3300
07-01-88	38.0	3.4	5800	14.10	101.00	3.25	4400
07-01-88	36.0	3.1	6900	37.00	150.00	5.30	5600
07-01-88	34.0	3.0	8100	61.00	201.00	6.60	7200
07-01-88	32.0	3.0	8300	66.00	207.00	7.03	7500

Date	AHD (m)	pH	SC (µS/cm)	Cu	Mn	Zn	SO_4
					(mg/l)		
13-01-88	59.9	4.7	700	.79	1.75	.15	330
13-01-88	58.0	4.6	700	.67	1.72	.14	330
13-01-88	56.0	4.6	700	.75	1.77	.14	330
13-01-88	54.0	4.6	700	.79	1.72	.13	330
13-01-88	52.0	4.6	700	.78	1.74	.14	330
13-01-88	50.0	4.6	700	.78	1.73	.14	330
13-01-88	48.0	4.6	700	.83	1.75	.13	330
13-01-88	46.0	4.7	700	.77	1.72	.13	330
13-01-88	44.0	4.7	750	.52	1.87	.12	360
13-01-87	42.0	4.5	3800	2.07	22.00	.49	2530
13-01-88	40.0	4.3	4700	5.00	45.00	1.19	3400
13-01-88	38.0	3.4	5700	14.40	92.00	5.01	4300
13-01-88	36.0	3.2	6900	36.00	150.00	6.50	5600
13-01-88	34.0	3.1	7800	60.00	200.00	7.12	7150
13-01-88	32.0	3.1	8300	63.00	210.00	7.14	8200
21-01-88	60.0	4.6	600	.72	1.30	.13	280
21-01-88	50.0	4.5	670	.72	1.40	.13	320
21-01-88	44.0	4.6	720	.54	1.50	.10	350
21-01-88	42.0	4.5	3600	1.90	16.00	2.30	2400
21-01-88	40.0	4.4	4600	4.40	41.00	1.10	3300
21-01-88	38.0	3.4	5800	17.00	97.00	3.50	4500
21-01-88	36.0	3.2	6600	31.00	130.00	4.90	5300
28-01-88	60.0	4.8	600	.74	1.20	.13	280
28-01-88	50.0	4.7	680	.76	1.40	.12	320
28-01-88	44.0	4.7	720	.66	1.50	.11	350
28-01-88	42.0	4.5	3700	2.60	17.00	.44	2500
28-01-88	40.0	4.2	4850	5.90	50.00	1.30	3500
28-01-88	38.0	3.5	5600	13.00	84.00	1.10	4200
28-01-88	36.0	3.2	6700	34.00	135.00	5.50	5400
03-02-88	60.0	4.8	600	.75	1.20	.26	270
03-02-88	50.0	4.8	690	.69	1.43	.26	320
03-02-88	44.0	4.8	750	.57	1.60	.21	360
03-02-88	42.0	4.6	3800	2.02	18.00	.92	2500
03-02-88	40.0	4.3	4800	4.79	50.00	2.21	3400
03-02-88	38.0	3.5	5700	13.80	93.00	5.95	4500
03-02-88	36.0	3.2	6900	37.00	133.00	11.05	5700
03-02-88	34.0	2.9	8200	71.00	182.00	15.00	7300

Table 6.3 Cont'd

Date	AHD (m)	pH	SC (μS/cm)	Cu	Mn (mg/l)	Zn	SO_4
10-02-88	60.6	4.7	570	.69	1.12	.26	260
10-02-88	50.0	4.8	610	.65	1.27	.25	280
10-02-88	44.0	4.8	630	.63	1.37	.24	290
10-02-88	42.0	4.5	3700	1.99	17.00	.87	2400
10-02-88	40.0	4.4	4700	4.77	48.00	2.14	3300
10-02-88	38.0	3.5	5700	13.00	80.00	5.80	4200
10-02-88	36.0	3.2	6900	37.00	131.00	11.60	5600
10-02-88	34.0	2.9	8100	69.00	158.00	15.70	7200
17-02-88	60.0	5.9	380	.34	.76	.10	170
17-02-88	56.0	5.7	400	.30	.84	.09	180
17-02-88	54.0	5.4	490	.41	1.09	.10	220
17-02-88	46.0	5.3	530	.48	1.26	.11	250
17-02-88	44.0	5.3	590	.51	1.52	.11	280
17-02-88	42.0	4.8	3900	2.22	22.00	.51	2600
17-02-88	40.0	4.5	4820	5.60	57.00	1.19	3500
17-02-88	38.0	3.4	5800	16.00	90.00	3.10	4400
17-02-88	36.0	3.1	7000	39.00	145.00	5.80	5600
17-02-88	34.0	2.9	8200	70.00	193.00	7.30	7200
17-02-88	32.0	2.8	8500	74.00	203.00	7.50	7400
24-02-88	60.2	6.0	340	.24	.72	.12	140
24-02-88	54.0	5.9	390	.24	.89	.12	170
24-02-88	52.0	5.9	420	.28	.98	.13	180
24-02-88	48.0	5.8	460	.32	1.15	.14	200
24-02-88	46.0	5.9	480	.32	1.25	.13	210
24-02-88	44.0	5.6	560	.40	1.55	.14	250
24-02-88	42.0	5.5	860	.58	2.81	.18	420
24-02-88	40.0	4.8	4500	3.74	34.00	.90	3100
24-02-88	38.0	3.7	5400	9.72	72.00	2.20	3900
24-02-88	36.0	3.2	6500	28.00	125.00	4.70	5100
24-02-88	34.0	2.9	7900	65.00	182.00	7.00	6700
24-02-88	32.0	2.8	8500	76.00	198.00	7.50	7600
24-02-88	30.0	2.8	8600	79.00	206.00	7.50	7700
02-03-88	40.0	4.8	2800	1.70	14.50	.36	1800
02-03-88	38.0	4.6	4600	4.30	40.00	1.00	3300
03-02-88	36.0	3.6	5400	11.00	69.00	2.40	4000
02-03-88	34.0	3.1	6800	41.00	137.00	5.50	5600
02-03-88	32.0	2.9	8200	65.00	183.00	7.90	7300
02-03-88	30.0	2.8	8500	69.00	197.00	8.10	7800

Date	AHD (m)	pH	SC (µS/cm)	Cu	Mn (mg/l)	Zn	SO_4
09-03-88	60.0	6.1	240	.13	.35	.07	95
09-03-88	56.0	5.9	270	.18	.49	.07	110
09-03-88	54.0	6.0	330	.28	.71	.07	140
09-03-88	50.0	5.7	420	.33	.93	.08	190
09-03-88	46.0	4.8	490	.38	1.24	.08	220
09-03-88	44.0	5.2	590	.46	1.62	.10	270
09-03-88	42.0	4.8	3120	1.88	15.40	.39	2000
09-03-88	40.0	4.6	4800	5.00	44.00	1.18	3300
09-03-88	38.0	3.4	5800	15.65	94.00	3.35	4300
09-03-88	36.0	3.2	6810	39.00	131.00	5.80	5400
09-03-88	34.0	2.9	8100	58.00	194.00	8.10	7200
09-03-88	32.0	2.8	8500	63.00	197.00	8.00	7700
09-03-88	30.0	2.8	8500	63.00	197.00	8.30	7800
16-03-88	60.0	6.1	260	.22	.50	.10	110
16-03-88	56.0	5.9	260	.17	.51	.09	110
16-03-88	54.0	5.7	330	.27	.74	.10	145
16-03-88	52.0	5.6	410	.31	1.97	.11	180
16-03-88	50.0	5.6	430	.32	1.06	.11	190
16-03-88	48.0	5.6	470	.35	1.20	.11	220
16-03-88	46.0	5.4	490	.36	1.33	.14	230
16-03-88	44.0	5.5	640	.40	1.95	.13	300
16-03-88	42.0	4.8	3600	2.19	20.00	.50	2400
16-03-88	40.0	4.5	4900	5.88	51.00	1.36	3700
16-03-88	38.0	3.4	5800	15.90	95.00	3.30	4400
16-03-88	36.0	3.2	6800	39.00	151.00	5.45	5600
16-03-88	34.0	3.0	8000	71.00	196.00	7.70	7200
23-03-88	60.0	6.1	286	.29	.58	.14	119
23-03-88	54.0	5.7	302	.24	.64	.13	128
23-03-88	52.0	5.7	412	.31	.96	.13	181
23-03-88	50.0	5.7	436	.33	1.03	.13	193
23-03-88	48.0	5.6	471	.34	1.16	.14	222
23-03-88	46.0	5.8	508	.41	1.35	.14	231
23-03-88	44.0	5.8	630	.43	1.79	.11	296
23-03-88	42.0	4.7	3250	2.04	15.85	.41	2048
23-03-88	40.0	4.6	4790	4.92	43.00	1.12	3349
23-03-88	38.0	3.5	5710	12.10	82.00	2.70	4177
23-03-88	36.0	3.1	6930	34.00	143.00	5.30	5586
23-03-88	34.0	2.9	8200	57.00	196.00	6.80	7511
23-03-88	32.0	2.9	8470	62.00	208.00	7.10	7695
23-03-88	30.0	3.0	8500	62.00	209.00	7.10	7774

Table 6.3 Cont'd

Date	AHD (m)	pH	SC (μS/cm)	Cu	Mn (mg/l)	Zn	SO_4
29-03-88	60.1	5.7	361	.32	.74	.13	155
29-03-88	48.0	5.8	384	.26	.85	.12	168
29-03-88	46.0	5.8	449	.30	1.07	.13	206
29-03-88	44.0	5.7	499	.33	1.25	.14	232
29-03-88	42.0	4.8	2860	1.77	12.35	.42	1846
29-03-88	40.0	3.4	5770	16.65	77.00	3.25	4389
29-03-88	38.0	3.1	6970	44.00	132.00	5.55	5720
29-03-88	36.0	2.9	8210	63.00	172.00	7.60	7746
29-03-88	34.0	2.9	8380	66.00	177.00	7.70	7922
29-03-88	32.0	2.8	8480	67.00	177.00	7.70	7900
29-03-88	30.0	2.8	8500	67.00	177.00	8.00	7800
30-03-88	60.1	6.0	371	.24	.81	.13	160
30-03-88	56.0	5.6	380	.25	.82	.13	164
30-03-88	46.0	5.9	510	.25	1.03	.13	192
30-03-88	44.0	5.8	476	.26	1.18	.14	216
30-03-88	42.0	5.4	1000	.56	3.00	.15	517
30-03-88	40.0	4.6	4760	5.42	38.00	1.19	3450
30-03-88	38.0	3.5	5700	14.80	87.00	3.10	4290
30-03-88	36.0	3.2	6800	39.00	127.00	5.30	5570
30-03-88	30.0	2.8	8500	67.00	177.00	7.70	7850
06-04-88	60.2	6.3	260	.07	.46	.09	96
06-04-88	56.0	6.1	290	.11	.58	.09	115
06-04-88	48.0	6.1	420	.13	.99	.13	180
06-04-88	46.0	5.8	440	.23	1.07	.14	190
06-04-88	44.0	5.9	490	.29	1.28	.14	220
06-04-88	42.0	5.0	1960	1.21	7.42	.26	1140
06-04-88	40.0	4.6	4810	5.45	47.00	1.18	3510
06-04-88	38.0	3.4	5750	14.00	83.00	3.05	4450
06-04-88	36.0	3.1	6920	37.00	144.00	5.70	5540
06-04-88	34.0	2.9	8130	56.00	192.00	7.40	7120
06-04-88	32.0	2.8	8450	61.00	206.00	7.70	7700
06-04-88	30.0	2.8	8560	61.00	203.00	7.80	7700

Date	AHD (m)	pH	SC (µS/cm)	Cu	Mn	Zn (mg/l)	SO_4
13-04-88	60.1	6.3	235	.13	.47	.08	91
13-04-88	56.0	6.4	233	.12	.47	.07	91
13-04-88	54.0	6.1	300	.16	.66	.09	123
13-04-88	52.0	6.0	340	.20	.82	.10	144
13-04-88	50.0	6.0	370	.25	.93	.11	160
13-04-88	48.0	5.8	420	.30	1.10	.11	190
13-04-88	46.0	5.8	430	.30	1.16	.11	190
13-04-88	44.0	5.7	400	.35	1.43	.12	225
13-04-88	42.0	5.4	930	.67	3.15	.17	480
13-04-88	40.0	4.7	4650	4.57	45.00	1.06	3360
13-04-88	38.0	3.5	5600	13.25	87.00	2.90	4250
13-04-88	36.0	3.2	6740	36.00	139.00	5.90	5400
13-04-88	34.0	2.9	8050	68.00	202.00	8.40	7050
13-04-88	32.0	2.9	8370	77.00	213.00	9.00	7700
20-04-88	60.0	6.3	270	.13	.53	.10	110
20-04-88	54.0	6.3	280	.11	.53	.05	115
20-04-88	52.0	6.1	360	.17	.79	.07	360
20-04-88	46.0	6.1	390	.11	.92	.08	170
20-04-88	44.0	6.0	410	.13	1.01	.09	190
20-04-88	42.0	5.6	1280	.66	4.30	.17	710
20-04-88	40.0	4.7	4780	4.58	48.00	1.16	3500
20-04-88	38.0	3.5	5700	13.50	87.00	3.05	4300
20-04-88	36.0	3.2	6800	36.00	129.00	5.70	5500
20-04-88	34.0	2.9	7860	67.00	177.00	8.20	7120
20-04-88	32.0	2.9	8400	73.00	188.00	8.80	7750
29-04-88	59.7	6.4	270	.17	.54	.08	110
29-04-88	54.0	6.4	280	.13	.55	.07	280
29-04-88	52.0	6.2	340	.21	.75	.09	140
29-04-88	50.0	6.0	380	.26	.92	.10	170
29-04-88	44.0	6.0	400	.24	.98	.10	175
29-04-88	42.0	5.6	1000	.67	3.27	.15	520
29-04-88	40.0	4.7	4700	4.72	45.00	1.11	1560
29-04-88	38.0	3.4	5800	16.50	88.00	3.30	2070
29-04-88	36.0	3.1	7000	42.00	133.00	5.80	5500
29-04-88	34.0	3.0	8050	73.00	175.00	8.40	7000
29-04-88	32.0	3.0	8200	73.00	179.00	8.80	7300

Table 6.3 Cont'd

Date	AHD (m)	pH	SC (μS/cm)	Cu	Mn (mg/l)	Zn	SO_4
13-05-88	59.9	6.5	340	.23	.73	.11	140
13-05-88	46.0	6.4	340	.17	.70	.10	140
13-05-88	44.0	6.4	410	.23	.90	.11	180
13-05-88	40.0	5.8	990	.75	2.81	.19	480
13-05-88	38.0	4.6	4700	5.50	49.00	1.34	3400
13-05-88	36.0	3.5	5600	14.00	89.00	3.50	4200
13-05-88	34.0	3.1	6800	35.00	146.00	5.80	5500
13-05-88	32.0	2.8	8400	60.00	228.00	7.70	7600
01-07-88	59.5	6.3	550	.27	1.54	.08	240
01-07-88	42.0	6.3	560	.21	1.59	.07	240
01-07-88	40.0	4.7	4500	4.10	47.00	1.08	3100
01-07-88	38.0	4.0	4900	6.10	67.00	1.50	3500
01-07-88	36.0	3.2	6600	33.00	221.00	5.10	5100
01-07-88	34.0	2.9	8000	62.00	201.00	7.40	6900
01-07-88	32.0	2.8	8400	69.00	220.00	7.80	7400
27-10-88	59.2	5.8	635	.47	2.21	.15	290
27-10-88	54.0	5.1	630	.42	2.20	.15	290
27-10-88	52.0	5.1	630	.41	2.20	.15	290
27-10-88	48.0	5.9	630	.34	2.20	.15	280
27-10-88	42.0	5.8	640	.30	2.20	.15	290
27-10-88	40.0	4.7	4500	4.70	61.00	1.20	3200
27-10-88	38.0	3.4	5600	12.90	150.00	3.15	4200
27-10-88	36.0	3.2	6700	33.00	250.00	6.00	5200
27-10-88	32.0	2.9	8300	70.00	240.00	8.40	7800
27-10-88	24.0	2.8	8400	84.00	250.00	8.47	7900

Table 6.4 Intermediate Open Cut profiling data 1987-88

Date	AHD (m)	pH	SC (µS/cm)	Cu	Mn (mg/l)	Zn	SO_4
09-11-87	57.0	4.8	960	1.61	1.68	.35	490
09-11-87	52.0	4.5	960	1.59	1.63	.35	500
09-11-87	47.0	4.6	960	1.60	1.64	.36	490
09-11-87	42.0	4.6	970	1.58	1.69	.38	500
09-11-87	41.0	4.6	1200	2.38	2.66	.71	650
09-11-87	40.0	4.5	3600	1.67	2.10	.82	2300
09-11-87	37.0	5.9	4000	.43	.90	.22	2900
09-11-87	27.0	6.3	4100	.08	.70	.70	3000
07-01-88	57.3	4.5	970	2.01	1.70	.25	500
07-01-88	56.0	4.4	970	2.03	1.70	.18	500
07-01-88	54.0	4.4	960	2.04	1.67	.17	500
07-01-88	52.0	4.5	960	2.08	1.68	.17	500
07-01-88	50.0	4.5	960	2.07	1.67	.17	500
07-01-88	48.0	4.5	960	2.02	1.66	.18	500
07-01-88	46.0	4.5	960	2.20	1.67	.17	500
07-01-88	44.0	4.5	960	1.96	1.63	.17	500
07-01-88	42.0	4.5	980	2.01	1.71	.17	510
07-01-88	40.0	4.4	3540	2.91	3.49	.75	2500
07-01-88	38.0	4.6	3730	2.11	2.70	.54	2700
07-01-88	36.0	5.6	4000	.47	.60	.14	3000
07-01-88	34.0	5.9	4100	.23	.36	.10	2900
21-01-88	58.0	4.5	920	1.77	1.59	.20	470
21-01-88	44.0	4.5	970	1.91	.58	.20	500
21-01-88	42.0	4.5	1000	1.96	1.73	.23	530
21-01-88	40.0	4.4	3500	2.90	3.64	.78	2400
21-01-88	38.0	4.7	3900	1.79	2.28	.48	2750
21-01-88	36.0	6.1	4000	.40	.48	.13	2900
28-01-88	57.8	4.5	940	1.89	1.46	.25	480
28-01-88	44.0	4.5	970	1.92	1.45	.21	500
28-01-88	42.0	4.5	1000	1.98	1.59	.24	520
28-01-88	40.0	4.4	3500	3.11	3.27	.88	2400
28-01-88	38.0	4.7	3900	1.83	1.92	.50	2700
28-01-88	36.0	5.9	4000	.43	.41	.10	2900

Table 6.4 Cont'd

Date	AHD (m)	pH	SC (μS/cm)	Cu	Mn (mg/l)	Zn	SO_4
04-02-88	58.0	4.6	950	1.97	1.11	.21	490
04-02-88	44.0	4.5	970	1.96	1.06	.22	500
04-02-88	42.0	4.5	1000	2.09	1.60	.26	540
04-02-88	40.0	4.5	3500	2.77	2.98	.71	2500
04-02-88	38.0	4.7	3800	2.01	1.87	.49	2800
04-02-88	36.0	5.5	4000	.70	.44	.05	2900
11-02-88	58.0	4.5	840	1.75	1.31	.17	420
11-02-88	46.0	4.5	850	1.71	1.33	.18	420
11-02-88	40.0	4.4	3400	3.33	3.59	.83	2400
11-02-88	38.0	4.7	3900	1.83	1.76	.42	2800
11-02-88	36.0	5.7	4100	.44	.39	.09	2900
18-02-88	57.9	5.0	680	1.19	1.27	.20	330
18-02-88	54.0	4.6	690	1.09	1.26	.16	330
18-02-88	52.0	4.6	740	1.20	1.32	.17	360
18-02-88	50.0	4.6	770	1.28	1.36	.18	380
18-02-88	42.0	4.6	790	1.34	1.38	.19	390
18-02-88	40.0	4.5	3500	2.90	3.14	.83	2400
18-02-88	38.0	4.8	3900	1.67	1.88	.47	2700
18-02-88	36.0	5.7	4000	.45	.47	.11	2900
18-02-88	34.0	6.0	4100	.23	.27	.09	2900
25-02-88	58.0	5.3	510	.68	1.10	.12	240
25-02-88	50.0	5.0	590	.72	1.23	.14	280
25-02-88	42.0	5.0	610	.84	1.27	.15	290
25-02-88	40.0	5.0	680	.99	1.37	.17	330
25-02-88	38.0	4.9	3600	2.01	2.42	.49	2500
25-02-88	36.0	5.9	4000	.44	.62	.13	2900
25-02-88	34.0	5.9	4000	.33	.45	.13	2900
25-02-88	32.0	6.4	4100	.13	.29	.08	2900
03-03-88	40.0	4.6	3600	2.77	3.24	.76	2500
03-03-88	38.0	3.5	4100	1.56	1.87	.43	2800
03-03-88	36.0	6.0	4100	.40	.45	.15	2900
03-03-88	34.0	6.2	4100	.20	.33	.09	2900
03-03-88	32.0	6.4	4100	.11	.25	.06	2900
03-03-88	30.0	6.4	4100	.08	.26	.05	3000
03-03-88	28.0	6.4	4100	.10	.34	.07	3000

Date	AHD (m)	pH	SC (µS/cm)	Cu	Mn (mg/l)	Zn	SO_4
10-03-88	52.0	4.8	510	.89	1.23	.18	250
10-03-88	50.0	4.9	590	.89	1.25	.19	290
10-03-88	46.0	5.0	590	.90	1.26	.18	300
10-03-88	46.0	5.0	590	.90	1.26	.18	290
10-03-88	44.0	5.0	610	.91	1.31	.17	300
10-03-88	44.0	5.0	610	.91	1.31	.17	300
10-03-88	42.0	4.9	650	.91	1.35	.17	320
10-03-88	40.0	4.6	3400	3.30	4.11	1.01	2400
10-03-88	38.0	4.9	3800	1.84	2.35	.55	2700
10-03-88	36.0	6.0	4100	.44	.53	.15	2900
10-03-88	26.0	6.9	4100	.19	.51	.16	3100
10-03-88	24.0	6.3	4100	.35	.78	.23	3100
17-03-88	58.0	5.1	520	1.02	1.29	.12	240
17-03-88	56.0	4.6	520	.82	1.25	.11	240
17-03-88	50.0	4.9	530	.93	1.26	.12	240
17-03-88	48.0	4.9	590	.91	1.29	.13	280
17-03-88	44.0	5.0	600	.90	1.31	.13	280
17-03-88	42.0	4.9	670	1.01	1.46	.16	320
17-03-88	40.0	4.7	3500	2.71	3.86	.76	2500
17-03-88	38.0	5.4	2805	1.00	1.42	.25	2800
17-03-88	36.0	6.0	4000	.41	.57	.08	2900
17-03-88	26.0	6.5	4100	.13	.52	.06	2900
24-03-88	58.0	5.7	540	.90	1.17	.17	250
24-03-88	46.0	5.9	550	.65	1.07	.15	260
24-03-88	44.0	5.6	610	.80	1.21	.17	290
24-03-88	42.0	5.9	670	.76	1.30	.19	320
24-03-88	40.0	5.2	3600	2.46	3.55	.81	2500
24-03-88	38.0	5.4	3900	1.48	1.80	.45	2800
24-03-88	36.0	6.0	4100	.48	.48	.17	2900
31-03-88	58.0	5.5	540	.67	1.00	.15	240
31-03-88	48.0	5.1	540	.74	1.15	.15	260
31-03-88	42.0	5.4	560	.73	1.13	.17	260
31-03-88	40.0	5.0	1100	1.16	1.71	.31	590
31-03-88	38.0	5.3	3900	1.47	1.69	.43	2800
31-03-88	36.0	5.9	4100	.39	.42	.17	2900
31-03-88	24.0	6.2	4200	.00	.00	.23	3000

Table 6.4 Cont'd

Date	AHD (m)	pH	SC (µS/cm)	Cu	Mn (mg/l)	Zn	SO_4
07-04-88	58.0	6.0	380	.51	1.05	.15	160
07-04-88	54.0	5.8	380	.42	1.05	.15	170
07-04-88	52.0	5.4	450	.56	1.30	.18	200
07-04-88	46.0	5.3	500	.72	1.35	.19	230
07-04-88	44.0	5.2	520	.75	1.44	.20	240
07-04-88	42.0	5.2	550	.85	1.47	.21	250
07-04-88	40.0	4.9	1600	1.76	2.90	.52	910
07-04-88	38.0	5.2	3900	1.66	2.89	.53	2700
07-04-88	36.0	6.0	4100	.39	.78	.17	2900
07-04-88	34.0	6.2	4100	.20	.38	.12	2900
07-04-88	32.0	6.4	4100	.09	.32	.09	2900
07-04-88	30.0	6.5	4120	.07	.37	.08	2900
14-04-88	58.0	5.7	470	.64	1.24	.18	220
14-04-88	42.0	5.6	460	.61	1.22	.17	220
14-04-88	40.0	5.1	820	1.06	1.91	.26	420
14-04-88	38.0	5.1	3800	1.87	3.06	.58	2800
14-04-88	36.0	6.1	4000	.37	1.60	.17	3000
21-04-88	58.0	5.7	490	.71	1.41	.21	230
21-04-88	42.0	5.4	480	.68	1.44	.19	240
21-04-88	40.0	4.9	3300	2.88	4.76	.94	2400
21-04-88	38.0	5.3	4000	1.06	2.15	.38	3000
21-04-88	36.0	5.9	4100	.49	.87	.20	3000
21-04-88	34.0	6.3	4100	.25	.48	.12	3100
21-04-88	32.0	6.7	4100	.15	.37	.09	3100
21-04-88	30.0	6.4	4100	.13	.38	.08	3100
21-04-88	28.0	6.5	4100	.14	.56	.01	3100
21-04-88	26.0	6.4	4100	.23	1.17	.23	3000
21-04-88	24.0	6.4	4100	.36	1.52	.28	3000
21-04-88	22.0	6.2	4200	.49	2.11	.44	3000
21-04-88	20.0	6.1	4200	.76	3.13	.65	3000
21-04-88	16.0	6.0	4200	1.28	14.00	.96	3100
21-04-88	14.0	6.1	4200	1.63	7.75	1.25	3100
21-04-88	8.0	6.4	4400	.68	10.90	1.23	3200
21-04-88	6.0	6.5	4400	.15	11.60	1.02	3200
21-04-88	4.0	6.8	4500	.12	10.80	.95	3300
21-04-88	3.0	8.1	4300	.05	.07	.03	3000

Date	AHD (m)	pH	SC (μS/cm)	Cu	Mn (mg/l)	Zn	SO_4
27-04-88	58.8	5.5	480	.95	1.33	.18	220
27-04-88	50.0	5.9	480	.65	1.31	.15	220
27-04-88	42.0	5.9	480	.61	1.25	.17	230
27-04-88	40.0	5.8	520	.72	1.39	.19	250
27-04-88	38.0	5.1	3600	1.98	4.00	.75	2500
27-04-88	33.0	6.5	4100	.23	.45	.11	3000
27-04-88	28.0	6.5	4100	.15	.64	.11	3000
27-04-88	23.0	6.3	4100	.48	1.89	.37	3100
27-04-88	8.0	6.5	4400	.83	9.95	1.05	3200
27-04-88	6.0	6.8	400	.11	10.70	.88	3300
27-04-88	4.0	6.8	4500	.11	10.80	.79	3300
27-04-88	3.0	7.6	4400	.01	11.00	.54	3300
12-05-88	57.7	5.3	530	.78	1.41	.21	250
12-05-88	42.0	5.2	540	1.09	1.44	.20	250
12-05-88	40.0	5.2	570	.72	1.48	.21	270
12-05-88	38.0	5.3	3900	1.66	2.68	.47	2800
12-05-88	36.0	5.9	4000	.63	.85	.21	2900
02-06-88	57.6	5.4	630	1.12	1.53	.23	300
02-06-88	56.0	4.8	630	.94	1.54	.20	300
02-06-88	40.0	5.0	640	.91	1.52	.20	310
02-06-88	38.0	5.4	3900	1.16	2.09	.32	2800
02-06-88	36.0	5.9	4100	.38	.84	.15	3000
02-06-88	32.0	6.3	4100	.11	.33	.05	3000
01-07-88	57.3	5.2	560	1.22	1.61	.06	240
01-07-88	56.0	4.8	920	.79	1.33	.19	470
01-07-88	54.0	4.8	920	.95	1.32	.20	470
01-07-88	52.0	4.9	910	1.07	1.34	.19	470
01-07-88	38.0	4.9	920	1.10	1.40	.20	480
01-07-88	34.0	6.2	3900	.37	.42	.09	2800
01-07-88	32.0	6.4	3900	.27	.43	.09	2800
01-07-88	26.0	6.7	4000	.14	.38	.06	2900
27-10-88	57.0	4.7	1040	1.26	1.88	.29	540
27-10-88	56.0	4.5	1100	1.09	1.87	.29	540
27-10-88	42.0	4.7	1050	1.16	1.17	.26	540
27-10-88	40.0	3.7	1130	1.16	1.76	.25	530
27-10-88	36.0	4.9	2570	1.31	2.10	.45	1740
27-10-88	34.0	5.8	3900	.45	.74	.19	2800
27-10-88	30.0	5.8	3900	.42	.77	.19	2800
27-10-88	28.0	5.8	3900	.43	.79	.18	2800
27-10-88	26.0	5.8	3900	.39	.72	.18	2800
27-10-88	24.0	6.1	3900	.48	1.52	.34	3000

APPENDIX E

Extract from

SOIL CONSERVATION AND LAND UTILIZATION ACT

Division 4 - Control of Public Restricted Use Areas

20B. DECLARATION BY COMMISSION

(1) The Council may recommend to the Commission that an area of land be declared a Restricted Use Area.

(2) If the Commission is satisfied, on the recommendation of the Council, that of land is subject to soil erosion through use or continued use of it by the public, the Commission may, by notice in the Gazette, declare that area to be a Restricted Use Area.

(3) A person may request the Council to recommend that the Commission make a declaration in accordance with sub-section (2) in relation to -

(a) open land of which that person is a landholder;

(b) public land adjacent to land of which that person is the landholder; or

(c) land vested in or under the control of a proper authority and adjacent to land of which that person is a landholder.

(4) A proper authority may request the Council to recommend that the Minister make a declaration in accordance with sub-section (2) in relation to -

(a) land vested in, or under the management or control of, that proper authority; or

(b) public land adjacent to land vested in, or under the management or control of, that proper authority.

(5) The Council shall not make a recommendation under sub-section (1) in respect of land vested in, or under the control of, proper authority except at the request of that proper authority.

(6) A declaration under sub-section (2) shall -

(a) define the land to which it relates by reference to a map or plan; and

(b) indicate where the map or plan may be inspected.

(7) The map or plan shall be kept and displayed -

(a) at the place indicated in the declaration; and

(b) at all police stations in the vicinity of the area to which the declaration relates,

and shall at all reasonable times be available for inspection without fee by members of the public.

(8) The Commission may exempt from the effect of a declaration made under sub-section (2) such roads in the area of land to which the declaration relates

as the Commission shall define in the declaration, and may in that declaration stipulate -

(a) the persons or classes of persons who may use those roads; or

(b) the types of vehicles that may be used on those roads.

20C. OFFENCE RELATING TO USE OF RESTRICTED USE AREA

(1) Except with and in accordance with the written permission of the proper authority, a person within a Restricted Use Area shall not -

(a) unless he is on an exempted road, have in his possession or use a motor vehicle;

(b) remove or damage any vegetation;

(c) take or remove any sand, gravel, rock, clay or earth;

(d) interfere with any erosion prevention works; or

(e) cause water or other fluid to be drained or to flow over the area.

Penalty: 500 dollars

(2) Where a stipulation has been made under section 20B(8)(a) or (b), in respect of an exempted road -

(a) a person -

(i) other than a person stipulated; or

(ii) other than one of a class of persons stipulated, in relation to that road shall not use that exempted road; and

(b) a person shall not have in his possession or use a vehicle other than a stipulated type of vehicle on that exempted road.

Penalty: 500 dollars

(3) Where permission is granted under sub-section (1) by the proper authority, that authority -

(a) may limit the use to a use of part of the Restricted Use Area by a motor vehicle, or a class of motor vehicle; or

(b) may impose such other conditions as to the use of the Restricted Use Area as it sees fit.

20D. POWERS OF OFFICERS

(1) A Member of the Police Force or an Officer may require a person who, he reasonable believes, has committed an offence against section 20C to give his full name and address to that member of the Police Force or Officer.

(2) A person -

(a) shall not refuse to give his name and address;
and

(b) shall not give a false name or address,

to a member of the Police Force or to an Officer.

(3) A person shall not obstruct, hinder or molest a member of the Police Force or an Officer in the exercise of his powers under this Ordinance.

Penalty: 200 dollars