supervising scientist report

120

MOUNT LYELL REMEDIATION

Sediment transport in the King River, Tasmania

Helen Locher

Mount Lyell Remediation Research and Demonstration Program

a Tasmanian and Commonwealth Government initiative

supervising scientist report **120**

MOUNT LYELL REMEDIATION

Sediment transport in the King River, Tasmania

Helen Locher

COOPERATIVE RESEARCH CENTRE FOR
CATCHMENT HYDROLOGY

Department *of* Environment
and Land Management

supervising scientist

A joint program between the Supervising Scientist and the Department of Environment and Land Management, Tasmania.

This report describes research that is part of the Mt Lyell Remediation Research and Demonstration Program, a joint program between the Supervising Scientist and the Department of Environment and Land Management, Tasmania.

Helen Locher–Co-operative Research Centre for Catchment Hydrology,
Monash University Melbourne

Supervising Scientist
Tourism House, Blackall Street, Barton ACT 2600 Australia

ISSN 1325-1554

ISBN 0 642 24320 4

Printed in Tasmania by Australian Government Printing Services.

COOPERATIVE RESEARCH CENTRE FOR

CATCHMENT HYDROLOGY

The CRC for Catchment Hydrology was formed in 1992 as a cooperative joint venture of research and water industry parties under the Commonwealth Government's Cooperative Research Centre's program, with a mission to improve the understanding of catchment hydrology and its application to land and water management. The centre brings together the combined resources, skills and expertise of research and industry groups to tackle major environmental concerns including salinity, flooding, degradation of rivers and streams, and pollution of stormwater in cities.

R & D strengths

The CRC's main research programs are:

- Salinity: salinity processes in high water-table areas, managing irrigation and dryland salinity
- Forest hydrology: water yield from disturbed forest catchment areas, forest erosion
- Waterway management: sediment and nutrient delivery to streams, stream channel stability and rehabilitation, riparian zones
- Urban hydrology: water quality improvement in urban waterways, management of gross pollutants and detention ponds
- Flood hydrology: improved flood warnings, more reliable design flood estimates, regionalisation

Commercial significance of work – technology transfer

Australia faces significant losses each year due to land and water degradation. Flood damage is estimated at some $300 million annually, while agricultural production losses due to salinity amount to about $200 million each year. The centre's core research programs have already produced results which are useful to the water industry, such as improved ways of estimating the impact of logging on water yield from forests, and detailed information on urban pollution sources. More reliable ways of estimating peak spillway floods are being used for dam spillway upgrading, with substantial savings expected.

Training and education

The education and training program is directed at increasing the number and ability of trained staff for the land and water industry. The program includes workshops for industry staff (water and irrigation authorities, land management agencies, consultants), postgraduate research and courses, seminars on centre research and related work, and staff interchange.

COOPERATIVE RESEARCH CENTRE FOR
CATCHMENT HYDROLOGY

Participants

Parties

- Bureau of Meteorology
- Department of Natural Resources and the Environment, Vic
- Melbourne Water
- Murray-Darling Basin Commission
- University of Melbourne
- CSIRO Land and Water
- Goulburn-Murray Water
- Monash University
- Southern Rural Water
- Wimmera-Mallee Water

Associates

- Department of Land and Water Conservation, NSW
- Hydro-Electric Corporation, Tas
- Department of Natural Resources, Qld
- State Forests of NSW

Contact information

Professor Russell Mein
Director
CRC for Catchment Hydrology
Department of Civil Engineering
Monash University
Clayton Vic 3168
Tel: +61 3 9905 4980
Fax: +61 3 9905 5033
Email:
russell.mein@eng.monash.edu.au

Professor Tom McMahon
Deputy Director
CRC for Catchment Hydrology
Dept Civil & Environmental Engineering
The University of Melbourne
Parkville Vic 3052
Tel: +61 3 9344 6641
Fax: +61 3 9344 6215
Email:
tam@engineering.unimelb.edu.au

Dr Rob Vertessy
Deputy Director
CRC for Catchment Hydrology
CSIRO Land and Water
GPO Box 1666
Canberra ACT 2601
Tel: +61 6 246 5790
Fax: +61 6 246 5845
Email:
rob.vertessy@cbr.clw.csiro.au

Foreword

The King River Sediment Study has been investigated as part of a PhD degree by the author, commencing in 1993. This working paper was prepared in early 1995 as an interim data document, to provide other MLRRDP researchers with information on the research already being undertaken on the King River. Most of the data presented in this document was collected while the Mount Lyell Copper Mine was still discharging tailings into the river system ('pre-mine closure'). Since original publication of this working paper by the Cooperative Research Centre for Catchment Hydrology, the author has completed the thesis, which includes data analyses for the pre-mine closure samples and a similar range of investigations for post-mine closure.

Data presented in this document was the best available data at the time of writing. Subsequent sample collection and analyses have allowed fine-tuning of information presented here. The reader is referred to the PhD thesis for complete presentation of all data and analyses conducted as part of this study (Locher H 1997. Sediment storage and transport in the King River, Tasmania. PhD Thesis, Department of Civil Engineering, Monash University, Melbourne).

Some of the final conclusions of the thesis are as follows:

- 97 million tonnes of tailings, 4.47 million tonnes of smelter slag, and 10 million tonnes of topsoil were discharged into the King River system from the Mount Lyell lease site during the 1900s
- 80.5% of the smelter slag and 3.78% of the tailings discharged from the mine remain stored within the river system (excluding the delta)
- 87.3 million tonnes of tailings are stored within the delta
- copper concentrations are not a reliable tracer of mine-derived sediments in the sediment banks, because of leaching
- bed load represented 1.8% of the total sediment load pre-mine closure, and 33% of the total sediment load post-mine closure
- total sediment load in the river post-mine closure is 9% of the pre-mine closure load
- suspended sediment loads have reduced several orders of magnitude post-mine closure; spikes in concentration with the start-up of the power station have reduced from several thousand mg/L to several hundred mg/L post-mine closure
- suspended sediment loads pre-mine closure were uniform throughout the King River; post-mine closure the loads show net erosion with distance downstream
- erosion pins on the sediment banks showed net aggradation pre-mine closure, and net degradation post-mine closure
- the river system showed bed degradation and bank erosion in response to mine closure; these will eventually stabilise due to armouring of the channel bed, re-adjustment of the sediment bank faces, and revegetation of the sediment banks

HELEN LOCHER

Executive summary

The King River system on the west coast of Tasmania has received a total of 97 million tonnes of fine-grained sediments ('tailings') from the Mount Lyell Copper Mine in Queenstown. These sediments were discharged over the period 1916 to 1994, in addition to 1.4 million tonnes of smelter slag and an estimated 10 million tonnes of topsoil. This report presents the results to date of the King River Sediment Study, a PhD study on the response of the river system to this artificially high sediment load.

Of the total tonnage of sediments discharged into the river system, an estimated 3.4 million tonnes are in sediment banks and a maximum of 10 million tonnes are in the river bed in the last 8 km of the King River, raising the river bed by as much as 9 m. About 100 million m^3 are stored in a delta at the mouth of the King River where it meets Macquarie Harbour. Reduced peak flows from a power scheme in the upper King River commencing in 1992 curtailed the further growth of the sediment banks, but caused an increased rate of deposition in the bed close to the river mouth. The processes of deposition and scour of fresh tailings on the sediment banks were very dynamic while the mine was discharging its tailings, due to the regular fluctuations in water level from the power station operations.

Suspended sediment concentrations while the mine discharged its tailings typically ranged from 10,000 mg/L in the Queen River (into which the tailings were discharged) to 500 mg/L in the lower King River under the power station's efficient operating load. Suspended sediment concentrations were very uniform across the channel cross-section, as was particle size (median grain size 7–8 µm). Concentrations rose as much as two orders of magnitude (100–10,000 mg/L) due to the initial flush of water with the power station coming on line, creating a wave of sediment clearly traceable as it propagated downstream. Since the mine has ceased to discharge tailings, suspended sediment concentrations are dramatically lower, in the range of 10–20 mg/L, and no longer uniform across the channel cross-section.

Ongoing work in this study involves comparison of pre- and post-mine closure suspended sediment and bed load transport rates, monitoring of changes in hydraulic geometry and sediment bank stability, and application of flow and sediment transport models to the King River.

Contents

Tables

Figures

Maps

Plates

Acknowledgments

This research is an integral component of the King River–Macquarie Harbour Environmental Study, a cooperative study coordinated by the Tasmanian Department of Environment and Land Management (DELM), and funded by the Tasmanian Hydro-Electric Commission (HEC) and Renison Goldfields Consolidated Ltd. The support of the study's program manager, Dr Lois Koehnken, is gratefully acknowledged. The HEC's Water Resources Section has provided considerable field and boat support, installed and maintained much of the equipment used in this study, and made their data freely available. Particular thanks go to Peter Harding of the Water Resources Section. The DELM Laboratory has provided office space and assistance with sample analysis, with special thanks to Helga Pirzi.

The scholarship for this PhD study is provided by the Cooperative Research Centre for Catchment Hydrology (CRCCH), within the Department of Civil Engineering at Monash University. The supervision of Associate Professor Bob Keller, the advice of Dr Ian Rutherfurd and Dr David Dunkerley (Department of Geography), and the support of Dr Cathy Wilson (CRCCH Project Leader, CSIRO Division of Water Resources) is gratefully acknowledged. The assistance of Romeny Lynch and Paul Gribben in sample analysis is most appreciated.

1 Introduction

1.1 Background

The King River catchment on the west coast of Tasmania, shown on map 1.1, carried for 78 years what was undisputably the highest continuous sediment load of any river in Australia (Olive & Rieger 1986).

The source of the sediment and the major activity in the King River catchment area for most of the 20th century has been the Mount Lyell copper mine at Queenstown. 1,500,000 tonnes of tailings per annum have been disposed of into the King River catchment since the mine introduced an ore preconcentration process involving grinding and chemical flotation in 1916. Tailings are the fine-grained waste sediments from which, in the milling process, the copper concentrate is separated. Significant concentrations of heavy metals are under certain chemical conditions adsorbed onto the sediments and thus transported into the river system, and ultimately into Macquarie Harbour. In addition to a total tailings discharge estimated at 95 million tonnes, an estimated 10 million tonnes of topsoil and 1.4 million tonnes of smelter slag have also been carried down the Queen River from the Queenstown area.

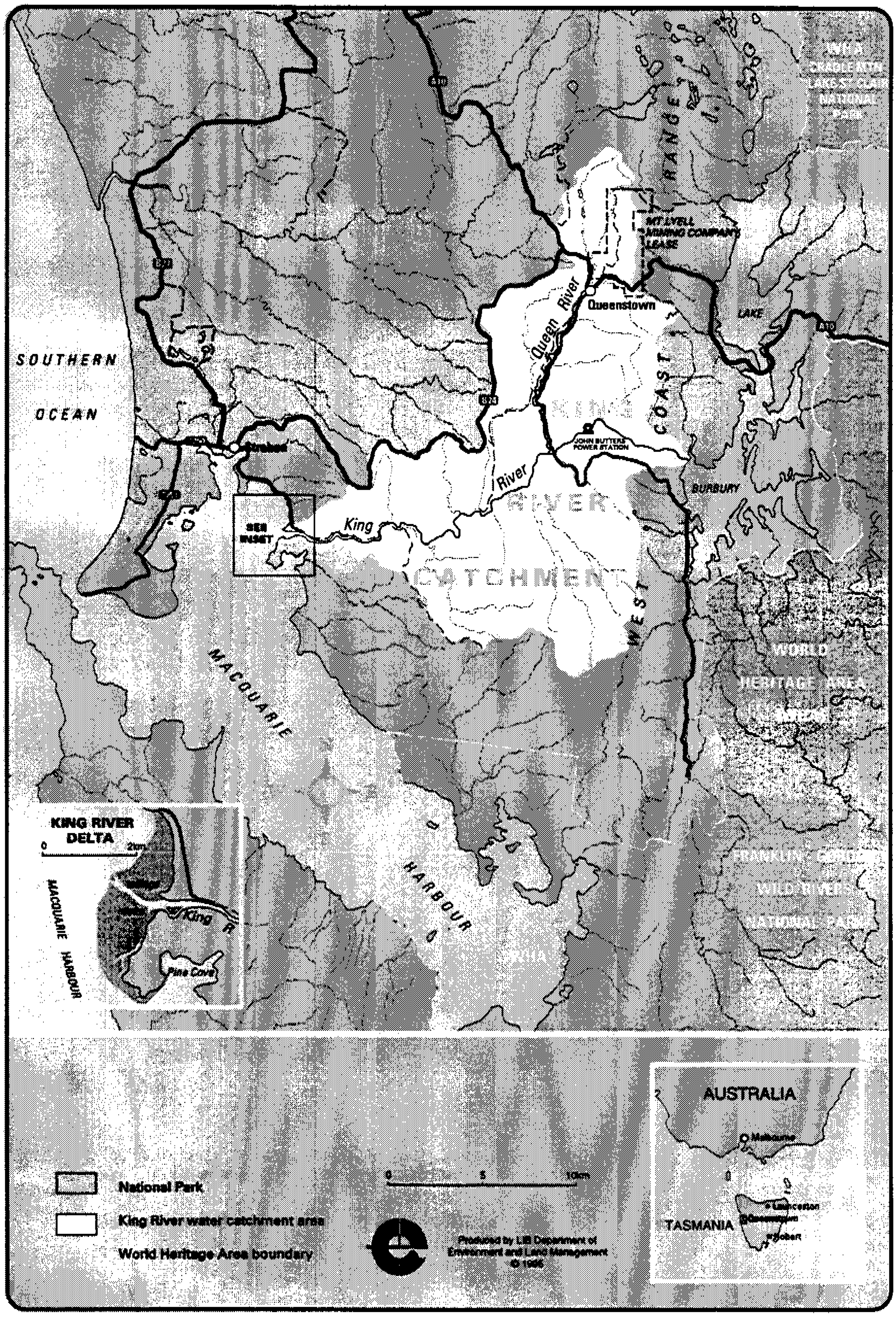
These mine tailings have created prominent sediment banks, channel infilling and point bars in the King River system, and a 250 hectare delta at the mouth of the King River where it meets Macquarie Harbour. Since 1992 flow in the King River has been controlled by a hydro-power scheme which has been shown to have a significant influence on the transport, deposition and remobilisation of tailings in the lower King River. The Mount Lyell copper mine closed in December 1994, and although another company has taken over the lease site, mine tailings will no longer be discharged directly into the river system. In this report, 'pre-mine closure' refers to the period while Mount Lyell was discharging its tailings, and 'post-mine closure' refers to the period since the discharge of tailings ceased on 10 December 1994.

1.2 Study context

The King River Sediment Study looks specifically at the response of the King River system to the artificially imposed sediment load from mining activities in Queenstown. It is being conducted as a PhD study within the Co-operative Research Centre for Catchment Hydrology at Monash University, and commenced in May 1993.

The King River Sediment Study is an integral part of a larger Tasmanian Department of Environment and Land Management study of the King River–Macquarie Harbour system. The King River–Macquarie Harbour Environment Study commenced in February 1993 and was set up as a cooperative effort involving the Hydro-Electric Commission, Renison Goldfields Consolidated Ltd (parent company of Mount Lyell Copper Mine), and several Tasmanian government departments.

As of 1995, the Commonwealth government's Office of the Supervising Scientist has become involved in rehabilitation issues in the river and harbour system. This working paper provides a baseline document available to other researchers which summarises the work which has been done on the King River sediments over the past two years. It outlines the scope of the research undertaken for the King River Sediment Study, the methods and locations of data collection, and the extent and summary descriptions of data presently available. It summarises what is known about the sediment storage and transport in the river system to date, and identifies the further work that is to be conducted as part of this PhD study.



Map 1.1 King River catchment below Lake Burbury

1.3 Study aim and objectives

The King River Sediment Study broadly aims to predict the impacts of catchment activities and regulated power station discharges on long-term river channel and delta stability. It has three major objectives:

1. To identify how the river system has responded to 78 years of an artificially imposed sediment load.
2. To monitor how the river system is responding to the sudden cessation of the artificially imposed sediment load.
3. To determine how a regulated flow regime can be exploited to minimise downstream environmental impacts arising from sediment storage and transport in the King River.

'River response' in this study incorporates changes in the hydraulic geometry of the river channel, changes in the extent, physical characteristics and stability of sediments in storage, and changes in the physical characteristics, concentrations and transport patterns of suspended and bed load sediments. Little to no background data existed for the King River prior to this study, so the achievement of objectives 1 and 2 has involved extensive field monitoring and data collection.

Objective 3 involves the development of a model for flow and sediment transport in the river system. This model will be used to predict the effects changes in flow patterns and catchment activities will have on sediment transport and channel stability.

Figure 1.1 outlines the approach being taken to achieve these study objectives. The results of this study and the geochemical work being conducted by the Department of Environment and Land Management will ultimately enable the development of an environmental management strategy for the King River–Macquarie Harbour system now that the Mount Lyell Copper Mine has closed.

1.4 Outline of this report

Section 2 summarises the available information on the history and quantities of wastes discharged from the Mount Lyell Copper Mine, and describes the characteristics of the sediment load.

Section 3 describes the receiving environment into which the mine tailings were discharged. This section briefly reviews the land uses, climate, geology, geomorphology, soils and vegetation of the King River catchment. Information on the hydrology and river channel hydraulics of the Queen and King Rivers is presented in more detail.

Section 4 looks in detail at the storages of mining-derived sediments in the river system. Subsections of this section present data from which estimates of storage quantities are derived, as well as data on sediment characteristics in each storage area.

Section 5 deals with stability of the sediment banks in the King River. Erosion processes are described, both while tailings were being discharged and since this practice has ceased. The results of monitoring of changes in bank form conducted for this study are also presented.

Section 6 focuses on the transport of sediments in suspension in the Queen and King Rivers, and section 7 focuses on bed load sediment transport. In both sections, the monitoring strategy employed for this study is presented, and the results reviewed from both when tailings were being discharged and since the tailings stopped. Particular emphasis is given to the variability of sediment characteristics and concentrations over space and time.

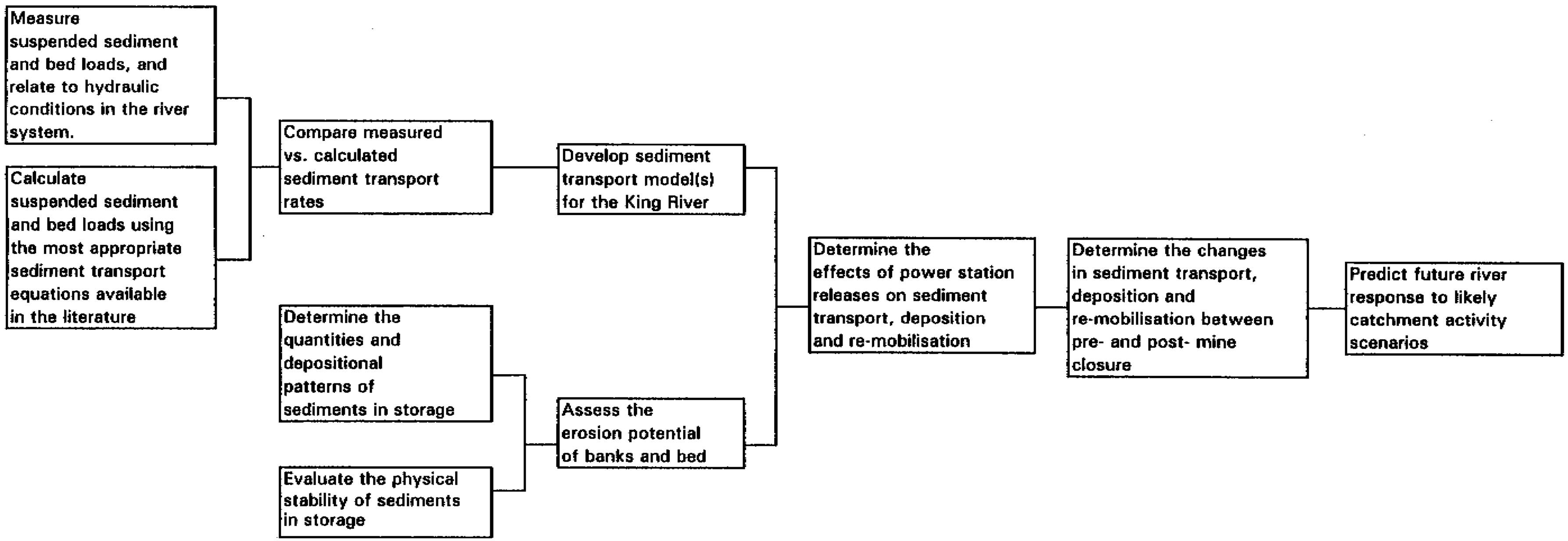


Figure 1.1 Approach to achieve study objectives

Section 8 introduces the modelling work being undertaken in this study. The first section discusses the sediment transport equations available in the literature and the approach being taken to evaluate those most appropriate. The second section describes the flow modelling required to supplement the other work being done for this study.

Section 9 provides a summary of progress to date, and outlines the further work to be done to complete this study.

2 The sediment load

2.1 History of sediment discharge

The longest established mining operation in Tasmania is the Mount Lyell Copper Mine at Queenstown, which was first worked for gold following its discovery in 1883, and from the 1890s until present has almost continuously been worked for copper. The original copper recovery was done by direct smelting using large quantities of pyrite, but this became unviable as pyrite grades began to decline. In 1922, the smelting was supplemented by an ore preconcentration process using grinding and flotation technologies. Tailings were the very fine grained waste sediments produced by the preconcentration process, and these were discharged directly into the Queen River (see plate 2.1). Figure 2.1 summarises the mine's records of tailings discharged into the Queen River.

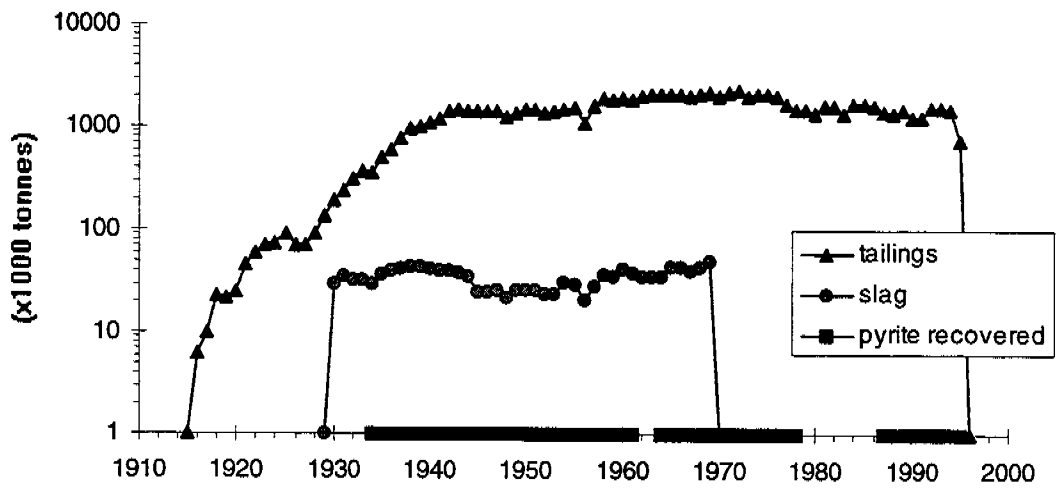


Figure 2.1 Mt Lyell discharge history

The mine's records for tailings discharge commence in 1915, and annual discharge rate climbed fairly steadily until about 1940. Between 1940 and 1995 the annual discharge rate has fluctuated between 1–2 million tonnes. The average discharge rate over the life of the mine has been 1.2 million tonnes per year, with a total of 97.4 million tonnes discharged.

Another by-product of mining were large quantities of siliceous black slag produced by the smelters. This material was retained on site (an estimated 6 million tonnes) until the commencement of pre-concentration, when the tailings were used to mobilise the smelter slag (Wood 1991). An estimated 1.4 million tonnes of slag produced between the period 1929-1970 have been discharged to the Queen River. Additionally, a rough calculation estimates that in the order of 10 million tonnes of topsoil from the lease site have been washed into the Queen and King Rivers over the life of the mine (Mount Lyell 1990).

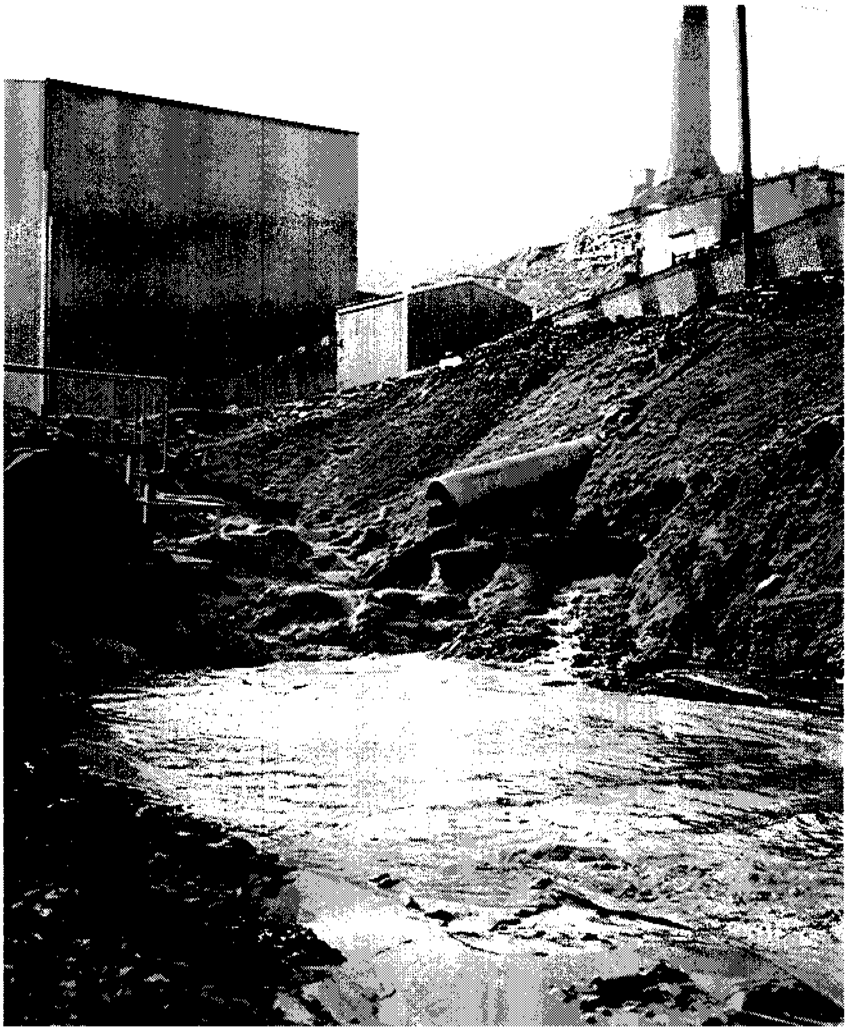


Plate 2.1 Tailings outfall at Mount Lyell

2.2 Tailings characteristics

2.2.1 Mineralogy

The Mount Lyell copper orebodies occur in metamorphosed volcanic sediments with small amounts of gold and silver. The tailings consist of alumino-silicates in various stages of weathering from a quartz sericite schist host rock, ground to a very uniform particle size in the milling operation. A typical chemical analysis of the material is shown in table 2.1 (Mount Lyell 1990). As shown, the quartz sericite schist parent material is comprised primarily of silica, alumina and iron with a small percentage of sulphur. Both the iron and sulphur are present predominantly as pyrite.

Table 2.1 Chemical analysis of Mount Lyell tailings

Analyte	Percentage
S_iO_2	58
Al_2O_3	10
Fe	11
S	6
CaO	0.6
Others	14.4

2.2.2 Particle size

Figure 2.2 shows a typical size analysis of tailing collected from the Mount Lyell outfall on 11 June 1993. This particle size distribution was obtained using a Malvern Laser Scatterer.

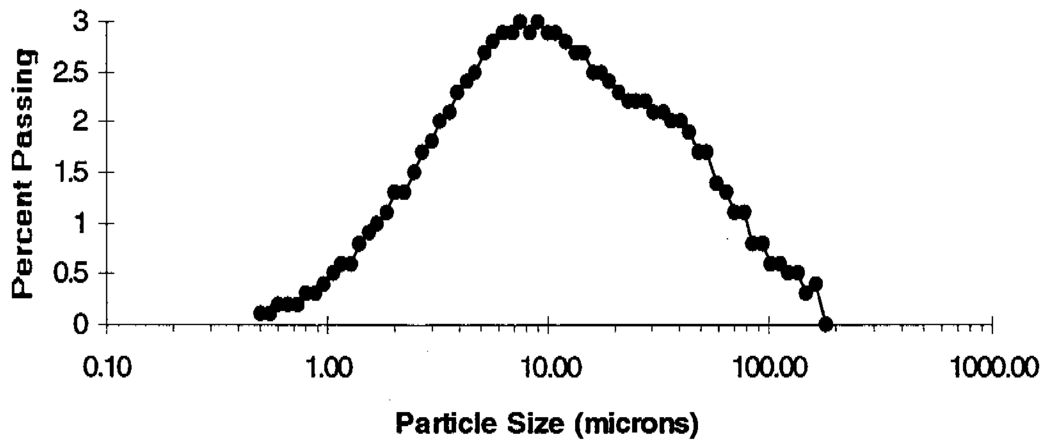


Figure 2.2 Mount Lyell tailings particle size distribution

The median grain size from the Malvern Laser Scatterer was found to be 11.02 microns, which is somewhat finer than the 26 microns determined by the Mount Lyell company using a hydrometer method (Mount Lyell 1990). The particle size distribution of three tailings samples collected at different periods during the month of June 1993 were found to be very consistent, as shown in table 2.2.

Table 2.2 Comparisons of tailing grain size

Date	Subsample	Median particle size (microns)				
		Test 1	Test 2	Test 3	Test 4	Average
25/6/93	1	10.66	10.65			10.66
	2	11.87	11.66			11.77
	3	12.07	11.52	11.39	11.38	11.59
11/06/93	1	12.66	11.51	11.38		11.85
	2	11.15	11.02			11.09
2/06/93	1	11.33	11.37			11.35
	2	11.6	11.04	10.5	10.58	10.93
					Minimum	**10.66**
					Maximum	**11.85**
					Median	**11.35**

The slag which was also discharged into the river has a reasonably consistent particle size distribution. As it came out of the smelters, the slag was poured into molten water and so granulated instantly into a fine, hard and very angular particulate material. A typical particle size distribution is shown in fig 2.3.

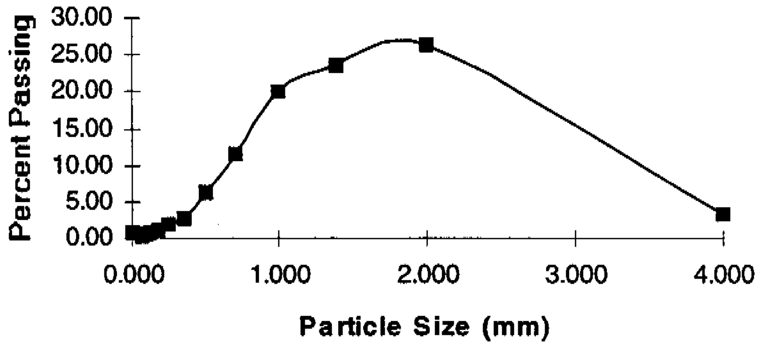


Figure 2.3 Mount Lyell slag particle size distribution

2.2.3 Other tailings characteristics

The specific gravity of a sample of dried tailings from the Mount Lyell outfall was analysed and found to be 2.9.

An examination of the tailings under a Scanning Electron Microscope showed them to be flat, platy and highly fractured, as shown in plate 2.2.

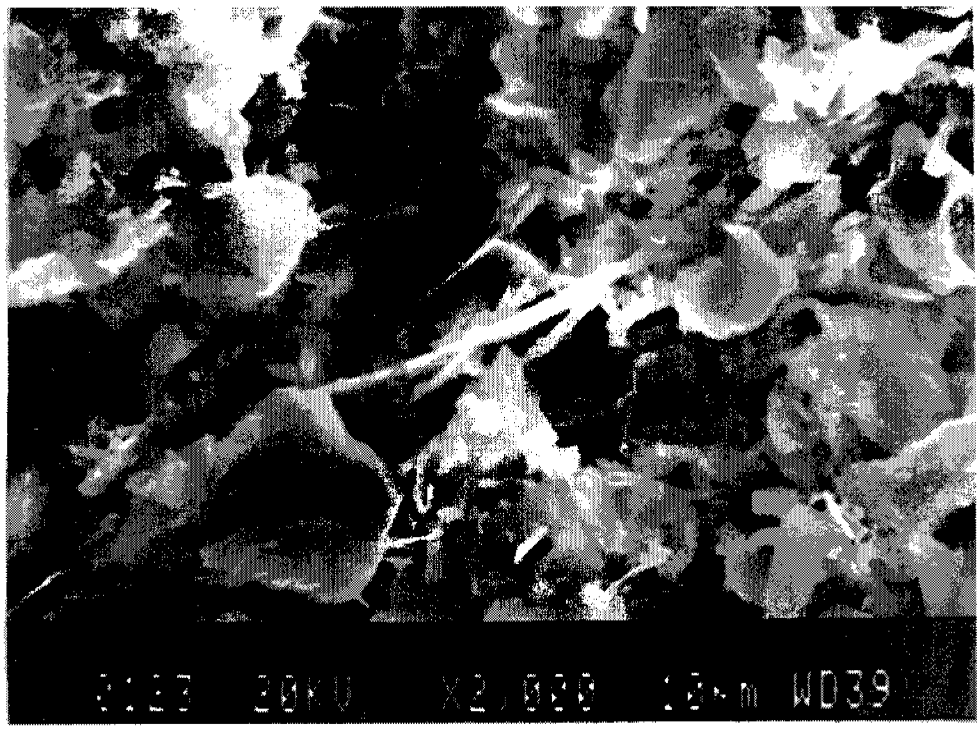


Plate 2.2 Tailings under the scanning electron microscope

2.3 Changes in tailings characteristics with time

The change of most relevance to this particular study is that of the particle size of tailings over time. As milling processes improved, the particle size distribution of the tailings has become increasingly finer. Based on known changes and improvements to the milling processes, Mount Lyell's mill superintendent John Geoghehan provided an estimate of particle size changes over time from which fig 2.4 was derived. Note that these sizes are consistent with the results of the mill's hydrometer analyses which give a slightly coarser particle size distribution than the Malvern Laser Scatter analyses used for this study.

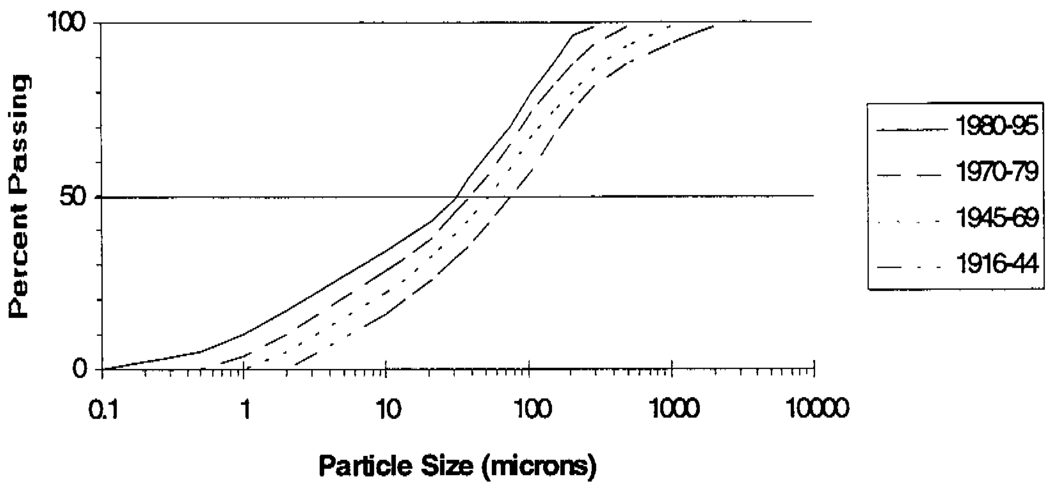


Figure 2.4 Mount Lyell tailings size changes

Other changes to the tailings characteristics over time relate to which orebody on the mining lease was being mined. The copper orebodies being mined on the Mount Lyell lease are of three main types:

1 Disseminated, with small grains of pyrite (iron sulphide) and chalcopyrite (copper iron sulphide) in schist;

2 Massive sulphide bodies with small veins of chalcopyrite and tennantite (copper arsenic sulphide) in nearly solid pyrite; and

3 High grade bornite (copper iron sulphide), chalcopyrite, chert (silica) orebodies.

The first type of orebody is by far the most common type of occurrence (Mount Lyell 1984), and is the one from which the typical chemical analysis in table 2.1 is based.

Changes to the chemical analysis shown in table 2.1 would also have occurred due to periods of pyrite removal from the tailings. This has varied over time depending on market demand and technological advances in recovery procedures and rates. Periods when pyrite was recovered were identified in fig 2.1. In recent years pyrite was removed at about 50% efficiency. The analysis shown in table 2.1 was conducted on a sample of tailings at a time when pyrite was *not* removed. During periods of pyrite removal the iron and sulphur levels would have been significantly lower, with sulphur approximately 3% and iron approximately 8% (Mount Lyell 1990). The level of pyrite has significance for the chemical reactiveness of the tailings stored in the river system, delta and harbour.

2.4 Summary

This section has summarised information about the mine wastes discharged into the river system. A total of 97 million tonnes of tailings, 1.4 million tonnes of smelter slag, and 10 million tonnes of topsoil are estimated to have gone into the King River system over the 100 year life of the Mount Lyell Copper Mine, until its closure in December 1994. The tailings are from a quartz sericite schist host rock, predominantly consisting of silica, alumina and iron. They are flat, platy and highly fractured, and have a specific gravity of 2.9. The mining company has periodically recovered pyrite from the tailings. Tailings have become progressively finer over the years, from a median grain size of about 75 μm down to 11 um. Slag has a median grain size of 0.160 mm.

These physical characteristics of the mine wastes all influence the way they are transported through the river system, and if and how they are stored. The next section looks at the characteristics of the receiving environment into which the mine wastes were discharged.

3 The receiving environment

3.1 History and land use

Mining was the major influence on the historical development of Tasmania's west coast, and most of the major towns have grown around the highly mineralised belt known as the Mount Read Volcanics. The major township in the King River catchment is Queenstown, shown on map 1.1, which in 1901 was the fourth largest town in Tasmania with a population of 5000. At present the population of Queenstown is approximately 3000, and the large copper deposit which has been its livelihood for the past century is still a viable mining operation. Considerable prospecting has also historically been conducted in the King River catchment, and two gold mines once operated at Lynchford (on the Queen River) and on Newall Creek (King River below the power station).

Strahan is located near the mouth of the King River and for many years was the major port for the mines and mining communities. Since 1896 ore was transported by railway from Queenstown along the Queen and King Rivers originally to the small port of Teepookana, 5 km above the King River mouth, and later to the port of Strahan.

Other major activities in the King River catchment are forestry and power generation. Timber harvesting for Huon pine dates back to the convict days on Macquarie Harbour, and the Tasmanian Forestry Commission still salvages Huon pines from the Teepookana Plateau above the old port town of Teepookana. Hydro-electric power generation commenced in April 1992 from the damming of the upper King River and creation of Lake Burbury. Construction relating to the King River Power Development, including road construction, dam building, and tunnel drilling, was undertaken during the decade prior to commissioning of the power station.

The King River flows out to Macquarie Harbour, which is approximately 276 km^2 in area and almost entirely land-locked. The main uses of Macquarie Harbour include aquaculture, tourist cruise boats, and recreational fishing. Fish farms are predominantly located in the northern end of the harbour. The harbour is also the receiving environment for municipal wastes from Queenstown and Strahan, and for the wastewater discharged from the Mount Lyell Copper Mine in Queenstown.

A large percentage of the catchment area of Macquarie Harbour is managed by the Tasmanian Parks and Wildlife Service and is known as the Southwest Conservation Area. A portion of this conservation area has been designated World Heritage Area. Most of the Southwest Conservation Area is inaccessible by conventional vehicles, although there is an extensive network of tracks associated with mineral exploration which are now used by bushwalkers.

3.2 Climate

The climate of Tasmania's west coast is dominated by the 'Roaring Forties', steady westerly winds which collect moisture over the Indian Ocean. The mountains of the West Coast Range cause a rapid uplift of the moist airstream resulting in a high annual rainfall averaging almost 2400 mm at Mount Lyell. Population centres on the west coast commonly experience rain on 200–240 days per year.

Rainfall is recorded at several locations in and around Queenstown and in Strahan. A summary of data available from the Bureau of Meteorology is given in table 3.1.

Table 3.1 Meteorological data available

Township	Station location	Period of record	Type of data
Strahan	Airport	1976–present	Automatic weather station
			Synoptic aeronautical
	Strahan Lodge	1991–present	Synoptic
	Various locations	1882–1991	Rainfall
		(discontinuous)	Periods of synoptic data
Queenstown	Mount Lyell	1906–present	Rainfall
	7XS radio station	1964–1994	Synoptic
		1995–onward	Station closed, perhaps continue just rainfall
	Lake Margaret power station	1945–present	Rainfall
	Lake Margaret dam	1912–present	Rainfall
	Aerodrome	1968–1988	?
	Gormanston	1895–present	Rainfall

Winter in Queenstown is characterised by cold, westerly airstreams which can result in heavy rains and an average temperature range of 2.3–12.7°C. Spring weather is more variable with a decreased severity and frequency of cold fronts. Summer is characterised by less rain and an average temperature range of 8–22.4°C. Prolonged periods of hot weather can occur in autumn when high pressure weather systems become stationary in the Tasman Sea (Dames & Moore 1989).

3.3 Geology and geomorphology

The geologic history of the King River catchment is summarised in table 3.2. Information in this section has been summarised from Banks et al (1977), Corbett et al (1977), Dames & Moore (1989) and Lake et al (1977).

The Mt Lyell mineralisation occurs within a geological sequence known as the Mount Read Volcanics, host to several major volcanogenic massive sulphide deposits of Cambrian age. The Mt Lyell deposits generally occur as lenticular zones of disseminated copper sulphides, predominantly chalcopyrite ($CuFeS_2$) with minor concentrations of silver and gold.

The most important geomorphological features in the King River catchment and much of Tasmania's west coast are a consequence of the underlying geology and periods of glaciation. Long mountain ridges run parallel to the coast and are separated by broad valleys. The drainage system has a distinct trellis pattern, with many rivers flowing between the parallel ridges with occasional gorge sections as they cut across the ridges. Quarzite and conglomerate units form the mountain ranges, and the King River and its tributary valleys are underlain by more erodible limestones, sandstones and siltstones. Three separate phases of glaciation occurred on Tasmania's west coast, resulting in the deposition of large quantities of glacial till or meltwater deposits on valley floors. Effects of valley glaciation can be seen in both the Comstock and Linda Valleys and other parts of the upper King River catchment.

Table 3.2 Geologic history of the King River catchment

Geological time scale	Approx time period (x million years)	Geological activity
Late Cambrian to Early Ordovician	530–500	Siliceous detritus known as Owen Conglomerate deposited mainly on eastern edge of important depositional basin known as the Dundas Trough
Early Ordovician	500–480	Period of rapid uplift; Great Lyell Fault a dominant feature
Middle to Upper Ordovician	480–435	Shallow sea over western Tasmania; carbonate mud and shelly detritus deposited to form Gordon Limestone
Lower Silurian to Early Devonian	435–380	Major folding and faulting (Tabberabberan Orogeny). Produced structures tending N-S including the West Coast Range, a broad N-S trending anticlinal structure in the Owen Conglomerate. Also produced WNW and NNW faults and folds.
Tertiary	65–7	Block faulting produced 10-km wide Macquarie Harbour Graben, a trough containing at least 220m of non-marine sands, clays and lignites, much of it lying below present sea level.
Pleistocene	2–.01	Three separate phases of glaciation. The Forth Glacial in the late Pleistocene (c.14,000 BP) may have influenced the King River.

The King River itself flows in a south-westerly direction and cuts through the West Coast Range which runs parallel to the coast. Just below the confluence of the Queen and King Rivers, the King River has eroded a deep gorge through the resistant quartzite of the West Coast Range, with steep to precipitous side slopes averaging 45°. Below this gorge section, the topography is more subdued although still rugged. Here the King River dissects an old erosion surface (the Henty surface) of weaker and more erodible sandstone, siltstone and limestone, and is fed by a number of minor creeks forming a trellis pattern. Valley sides have mean slopes of 30–45°, with steeper slopes where spines of rock outcrop occur. According to an HEC (1989) report, there is no evidence that the King River valley is structurally controlled.

3.4 Soils and vegetation

Most of the region is covered by different types of yellow podzolic soils, which occur in areas with a predominance of siliceous rocks. These are soils with soil profile in which the organic surface horizon is underlain by a leached greyish A horizon and a yellowish, often mottled B horizon.

Vegetation in the Macquarie Harbour catchment includes large regions of forests and button-grass plains, and is described in detail by Kirkpatrick (1977). Vegetation in the King River catchment is predominantly dense temperate rainforest, with species such as Blackwood (*Acacia melanoxylon*), Myrtle (*Nothogagus cunninghamii*) and King Billy Pine (*Athrotaxis selaginoides*) dominating the upland regions, and Huon Pine (*Lagastrobus franklinii*) prevalent along the watercourses.

The early pyritic smelting operations at the Mount Lyell copper mine had a substantial and long-lasting affect on the vegetation in the Queenstown area. The smelting produced up to 200,000 tonnes per annum of sulphur dioxide (SO_2) emissions, which killed the young vegetation growing back after regional timber cutting and frequent bushfires. The high annual rainfall washed the unprotected topsoil off the hills around Queenstown. Although less damaging smelting methods were introduced in 1904, smelting did not entirely cease until 1969. An estimated 1500 ha of land around Queenstown was almost completely devoid of vegetation, and a further 2500 ha substantially denuded (Wood 1991).

The bare hills around Queenstown result in rapid runoff of rainfall which translates into rapid increases in the discharge of the local rivers following precipitation events. Also associated with this region is acid rock drainage, resulting from a series of chemical reactions due to the exposure of sulphidic rocks to oxygen and water. The products of acid rock drainage include increased acidity of surface waters and frequently result in the mobilisation of metals and other elements into the aquatic environment.

3.5 Hydrology

3.5.1 Catchment areas and receiving body

The King River catchment has an area of 809 km^2, and at the Sailor Jack Creek monitoring site has a mean annual yield of 1.76×10^9 m^3. Figure 3.1 is a flood frequency analysis curve for the King River, based on records from the King at Crotty gauging station. This curve shows that the 1:5 year flood is between 500 and 600 m^3/sec, and the 1:100 year flood is between 800 and 1200 m^3/sec. This data is from the Crotty station (now under Lake Burbury) over the period March 1924 to July 1991.

The receiving body for the King River is Macquarie Harbour near Strahan. The harbour has been found to be a stratified estuary with fresh water at the surface and well-oxygenated ocean water at depth (Creswell et al 1989). The intermediate water mass within the harbour has more brackish salinities and lower oxygen than the underlying or overlying water. The other major tributary to Macquarie Harbour is the Gordon River catchment. It is the third largest in the State and the largest in western Tasmania, being approximately 5217 km^2, with a mean annual yield of 7.4×10^9 m^3 (from the monitoring record at Butlers Island).

The largest sub-catchment to the King is the Queen River, with a catchment of 79.3 km^2 and a mean annual yield of 165×10^6 m^3. A flood frequency analysis for the Queen River is shown in fig 3.2, based on records from the Queen River below Lynchford Camp. The records cover a period of only 6 years, hence the very wide confidence intervals. This figure shows that the 1:5 year flood is between 90 and 125 m^3/sec, and the 1:100 year flood is between 100 and 330 m^3/sec.

There are a number of small sub-catchments contributing to the flow in the Queen and King Rivers, as shown in fig 3.3. Median flows have been estimated using a catchment area-flow relationship developed by the HEC for small streams in the King River catchment (HEC 1988). Table 3.3 shows that total flows from the sub-catchments average less that 0.4 cumecs. While a median flow rate is not a particularly useful figure, it does provide an indication that the subcatchments are not a significant contribution to the total flow.

3.5.2 King River power scheme

The King River hydro-electric power scheme came on line in February 1992. Flow in the King River is now controlled by the King River Power Station, which releases water at an optimum power-generating rate of between 70 and 80 m^3/sec (depending on lake level) generally during daylight hours, and often releases no water at night. The mean annual run-off at the Sailor Jack Creek monitoring site, over the period of 1924 to 1984, is 56.9 m^3/sec. This site was not operative for several years during which the power station came on line, so post-power station flow records are based on monitoring from the nearby King below Queen River site. The mean annual run-off from the King below Queen site, based only on the 1993–94 record, is 55.8 m^3/sec. As shown in fig 3.4, average flows have not significantly altered, but maximum recorded flows have dropped from 830 to 240 m^3/sec, and the shape of the cumulative frequency distribution curve has significantly altered.

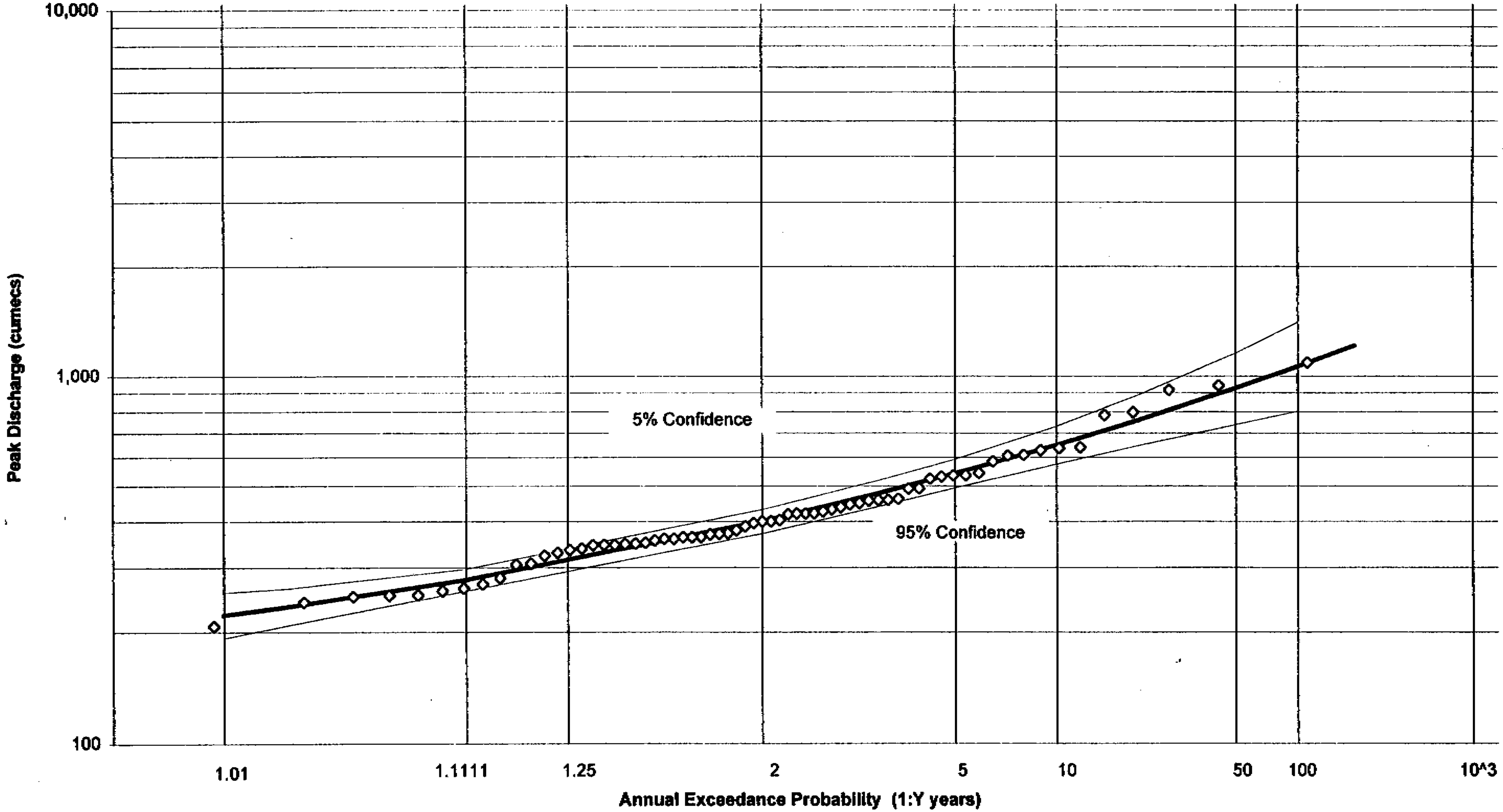


Figure 3.1 Flood frequency analysis for the King River

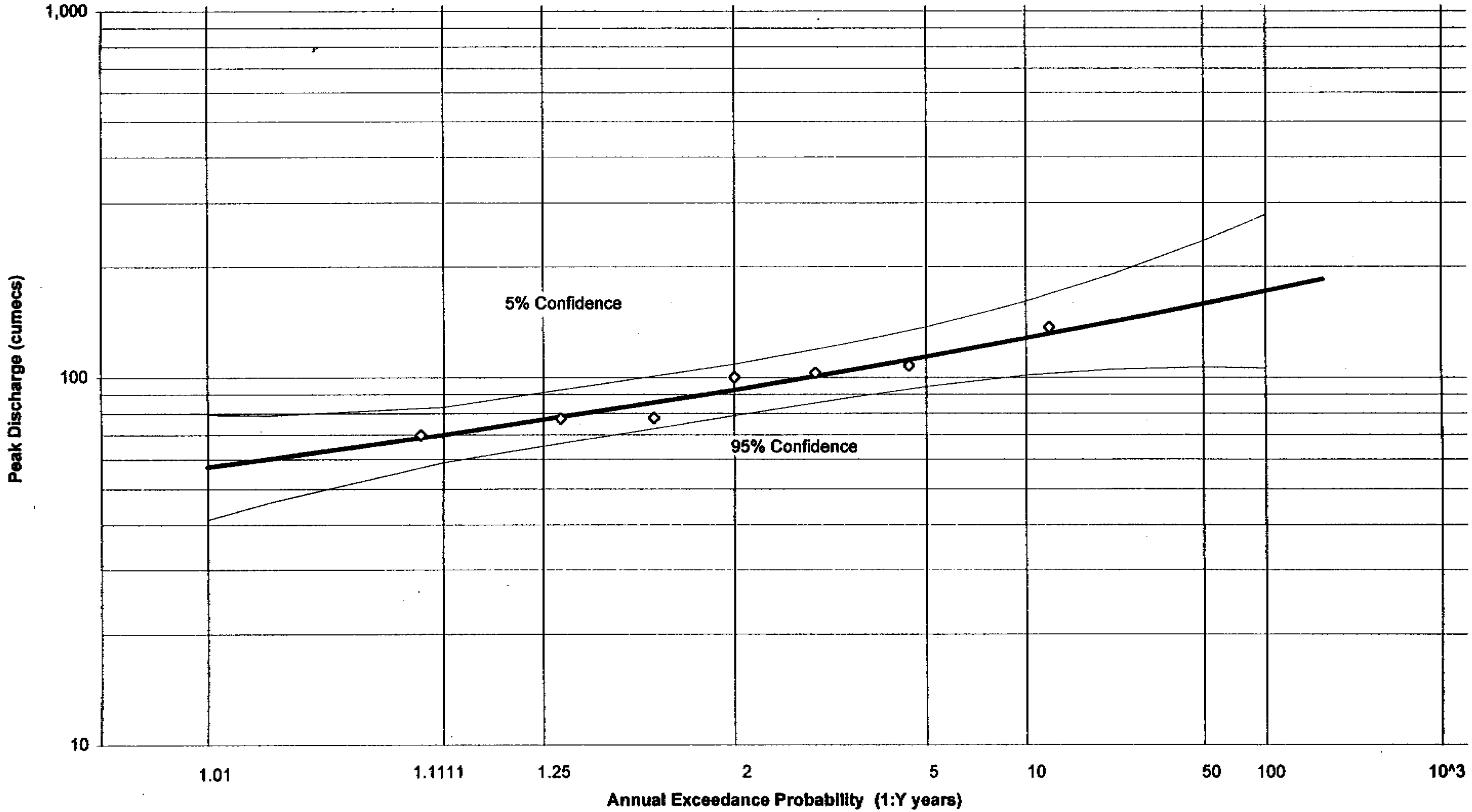


Figure 3.2 Flood frequency analysis for the Queen River

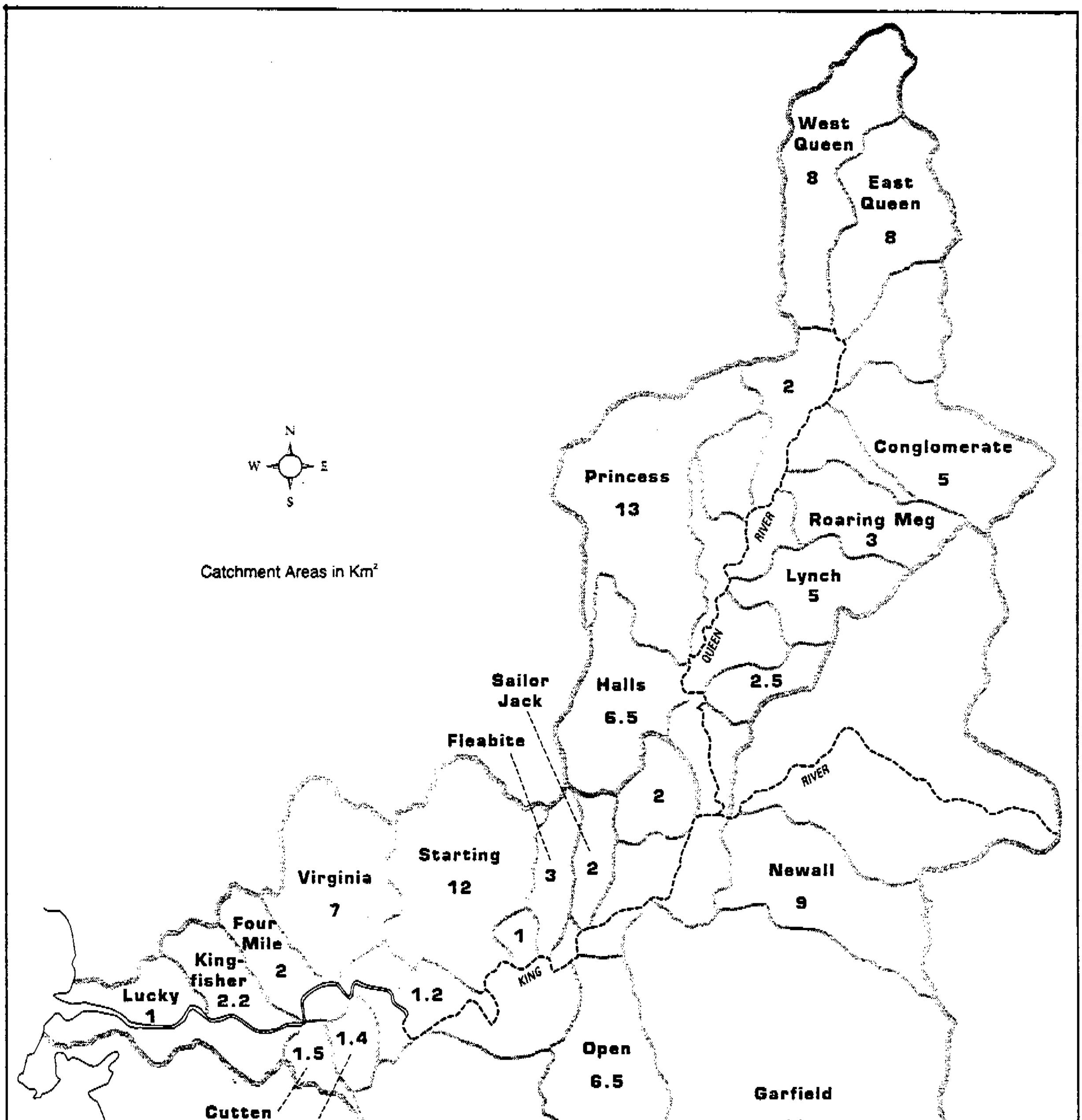


Figure 3.3 King and Queen River sub-catchments

Table 3.3 King and Queen River sub-catchments

Catchment name	Bank	Area (km²)	Median flow (L/sec)	Catchment name	Bank	Area (km²)	Median flow (L/sec)
	Queen River				**King River**		
West Queen	right	8	193.41	Newall	left	9	220.08
East Queen	left	5.5	128.14	un-named	right	2	41.85
Conglomerate	left	5	115.37	Garfield	left	48	1362.18
Roaring Meg	left	3	65.63	Sailor Jack	right	2	41.85
un-named	right	2	41.85	Open	left	6.5	153.98
Lynch	left	5	115.37	Fleabite	right	3	65.63
Princess	right	13	329.10	Starting	right	12	301.53
un-named	left	2.5	53.62	un-named	right	1.2	23.67
Halls	right	6.5	153.98	Swift	left	25	671.22
				Lower Landing	left	1.4	28.12
	Total	**50.50 sq km**	**1.20 m³/sec**	Virginia	right	7	167.04
				Four-Mile	right	2	41.85
				Cutten	left	1.5	30.38
				Kingfisher	right	2.2	46.53
				Lucky	right	1	19.30
F = (19.3 + 5.4 * log A) * A							
F = Flow in L/sec; A = Area in km²					**Total**	**123.8 sq km**	**3.22 m³/sec**

3.5.3 Hydrological monitoring

Flow and tide gauging stations on the Queen and King Rivers and in Macquarie Harbour have been established and maintained by the Tasmanian Hydro-Electric Commission. Those sites from which data has been used for this study are shown on map 3.1. Table 3.4 summarises the type of data and the time periods available from these stations. In addition, the HEC's System Control keeps records of time periods and power generating levels of the John Butters Power Station; a rating curve is available to convert power generation to flow discharge.

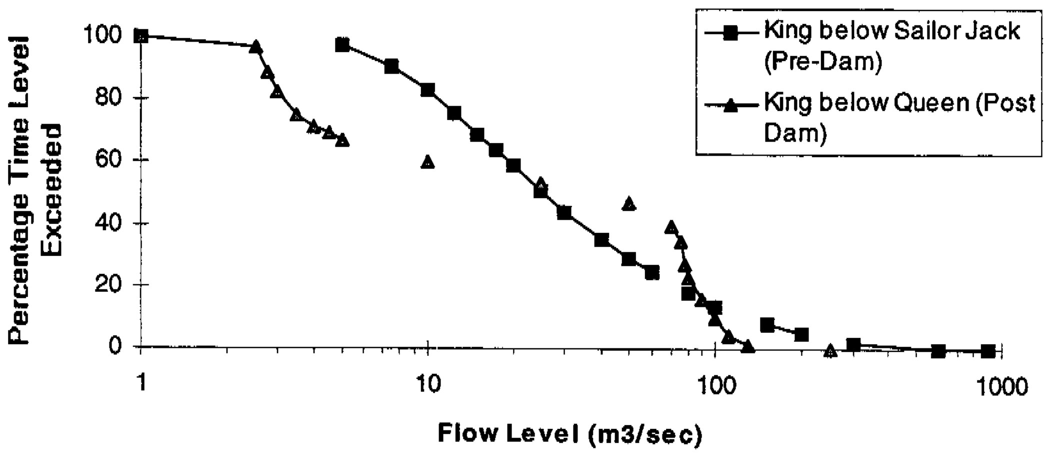
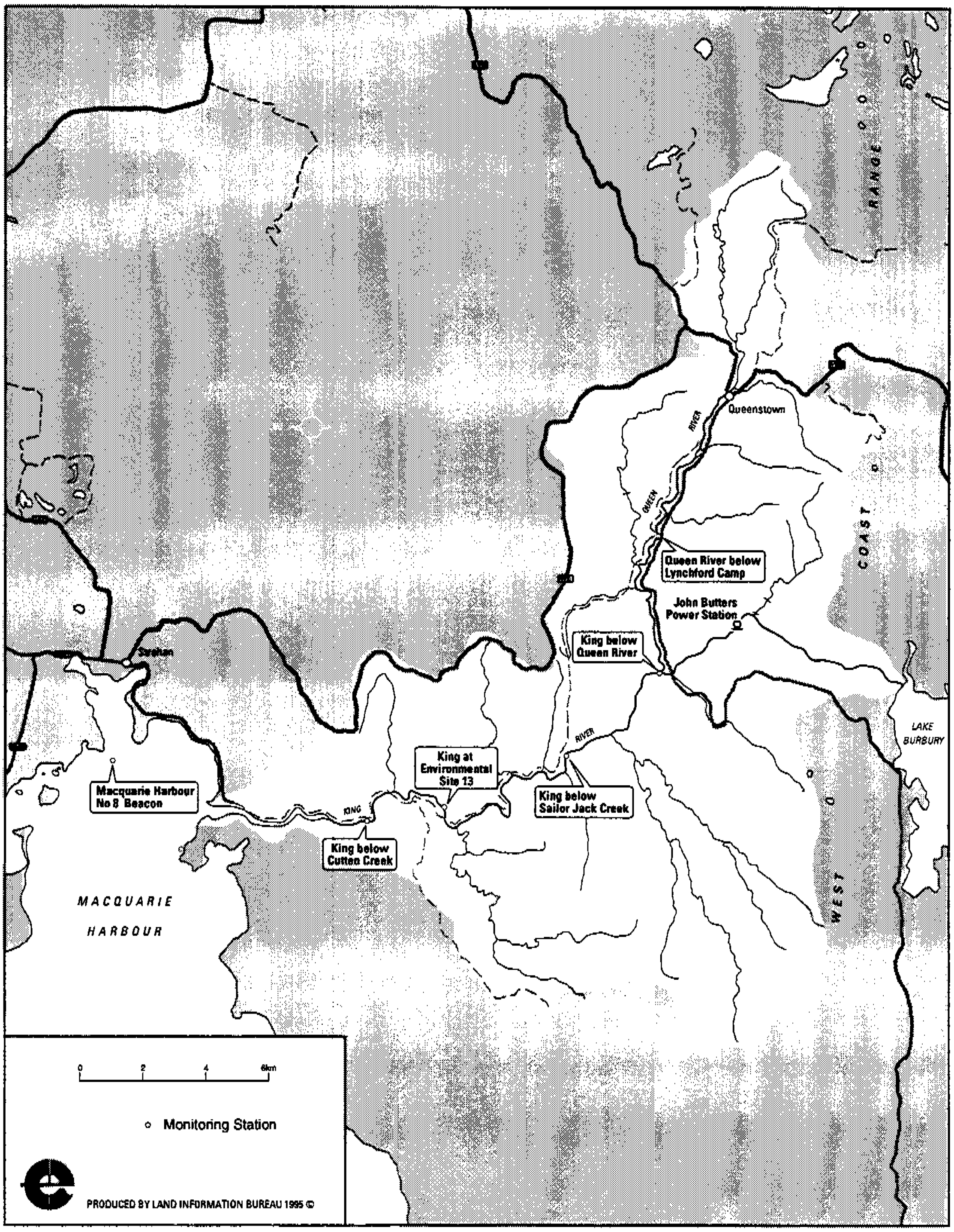


Figure 3.4 King River flows: Pre-dam vs post-dam



Map 3.1 Locations of hydrological monitoring stations

Table 3.4 King River hydrological monitoring

Station	Type	Period of record	Missing data
Queen b/l Lynchford	gauging	16/8/86–present	16/8/86–30/1/87 peak flows only; 31/1–8/3/87 missing; 10/4–11/7/87 discontinuous
King b/l Queen	gauging	3/10/91–present	none missing
King b/l Sailor Jack	gauging	23/1/85–present	31/1–1/2/85, 26/2–1/3/85, 13–25/3/85,15/6–13/8/87, 31/8–8/10/87,19/2–29/3/88, 21/4–6/5/88, 4/2–10/3/89, 12–17/4/89, 1–6/12/89, 18/6–3/7/90, 17/9–3/10/91, 8/12/91–11/6/93, 26/5–26/7/94
Environmental Station 13	level	29/6/94–present	10/2–24/3/95
King b/l Cutten Creek	level	15/10/86–present	8/1–15/12/87,19/1–10/3/89, 16/4–1/6/92
Macquarie Harbour No 8 Beacon	level	20/7/93–present	none missing

Table 3.5 provides annual summaries of hydrological data for the six monitoring stations used for this study. An 'x' denotes missing data, and where followed by a number it indicates the maximum or minimum recorded value (not accounting for the missing period) for that particular year.

Table 3.5 Annual flow/level summaries from King River hydrological stations

Station and parameter		1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Queen below Lynchford											
Flow (m^3/s)	Max.		x	x123.9	69.7	77.8	136.8	102.9	77.4	107.6	100.1
	Min.		x	x0.94	0.82	0.67	0.71	1.01	0.83	1.08	0.80
	Ave.		x	x	4.95	3.99	5.39	5.11	5.04	5.29	6.98
King below Queen											
Flow (m^3/s)	Max.							x	218.0	212.9	316.0
	Min.							x	2.23	2.30	2.09
	Ave.							x	44.4	49.9	61.7
King below Sailor Jack											
Flow (m^3/s)	Max.	171.6	699.7	x793.5	x744.1	x571.1	x841.2	x513.7	x	260.5	x193.1
	Min.	5.89	3.85	x7.51	x4.26	x5.63	x4.23	x5.81	x	1.20	x0.63
	Ave.	32.6	62.4	x	x	x	x	x	x	x	x
Environmental site no 13											
Level (m)	Max.										4.40
	Min.										-0.39
	Ave.										1.30
King below Cutten Ck											
Level (m)	Max.		x	x	4.83	x4.08	4.87	4.34	x5.53	3.35	3.13
	Min.		x	x	-0.27	x-0.20	-0.20	-0.28	x-0.31	-0.26	-0.26
	Ave.		x	x	0.65	x	0.69	0.42	x	0.79	0.95
Macquarie Harbour No 8 Beacon											
Level (m)	Max.									0.75	1.43
	Min.									-0.14	-0.18
	Ave.									0.22	0.24

3.6 River channel hydraulics

3.6.1 General characteristics

The channel hydraulics of the Queen-King River system are critically significant to the transport patterns of the mining-derived sediments. For the purposes of this study, numbered stations have been identified as shown on map 3.2. Not shown on this map are Station 1 which equates to the Mount Lyell tailings outfall, Station 2 which is at the hydrological monitoring station Queen River below Lynchford Camp, and Station 3 which is at hydrological monitoring station King River below Queen River (see map 3.1).

The King River channel is generally 1–2 m deep, and varies from 50–100 m wide. At scour points (eg rock promontories), the channel is up to 10 or more metres deep. Figure 3.5 shows typical channel cross-section shapes at progressively downstream stations. Of interest are the terraced banks on the Queen River, the distinctly U-shaped channel of the King between Stations 3 and 15, and the double channel configuration between Station 15 and the river mouth, with the more elevated bar in the center. Also noteworthy is the fact that the river bottom at Station 13 is below sea level.

Map 3.3 depicts the river bottom surface characteristics which influence the channel roughness in the lower reaches of the King River. These are the reaches which appear to be most affected by the mine wastes. The King River above Station 9 has a rock base with occasional coarse gravel/cobble bars, and both the Queen River and the King River above the Queen River confluence are coarse gravel bed rivers. Between Stations 11 and 15 the bottom consists of a series of coarse gravel bars alternating with deeper pools, and sections of a hardpan which is believed to be mining-derived. Downstream of Station 15 the bottom consists of tailings and fine gravels.

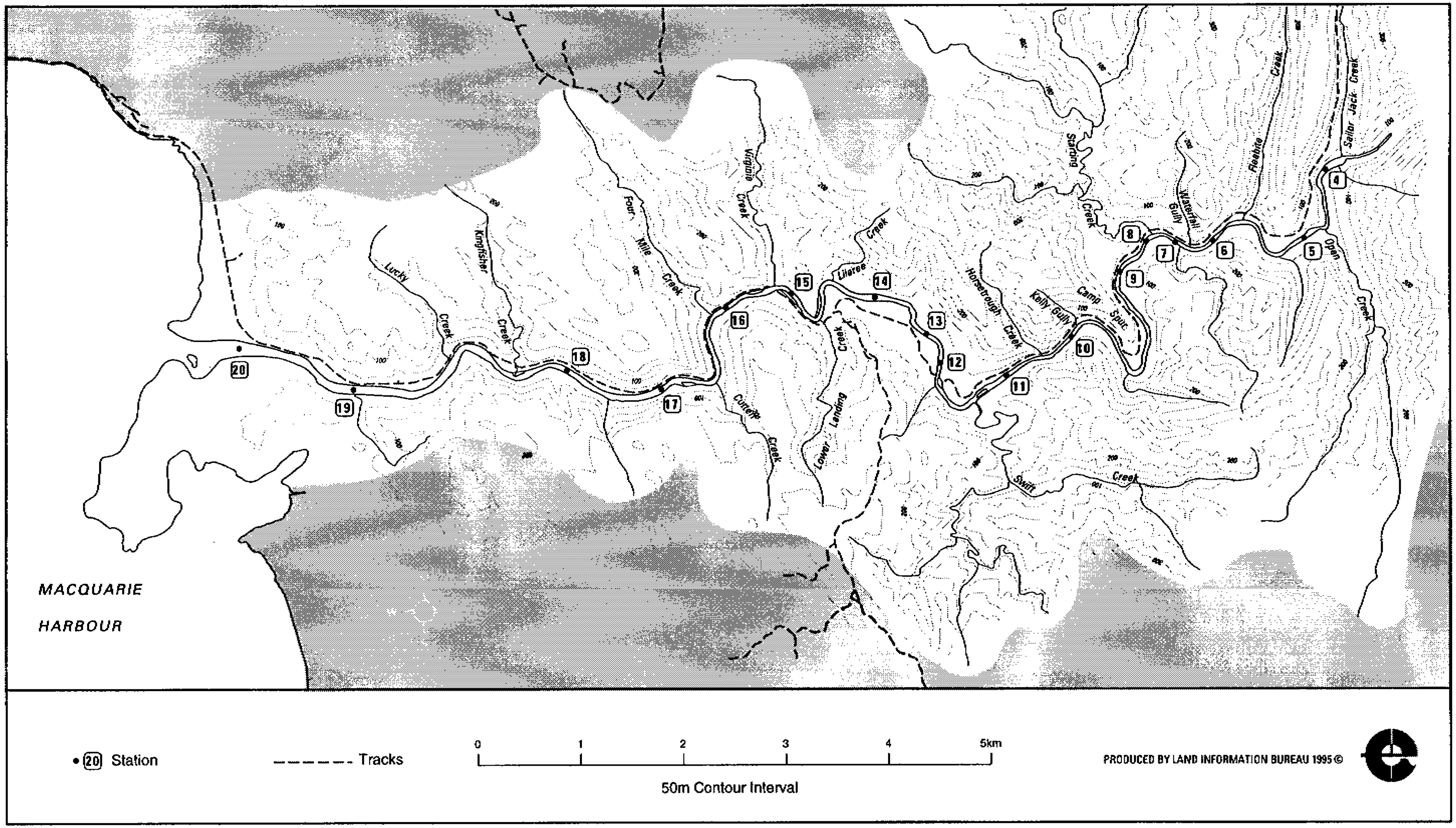
3.6.2 Water surface elevation profile

The water surface elevation profile is one of the most important of the hydraulic parameters with regard to sediment transport, and for this study the major changes are summarised in table 3.6.

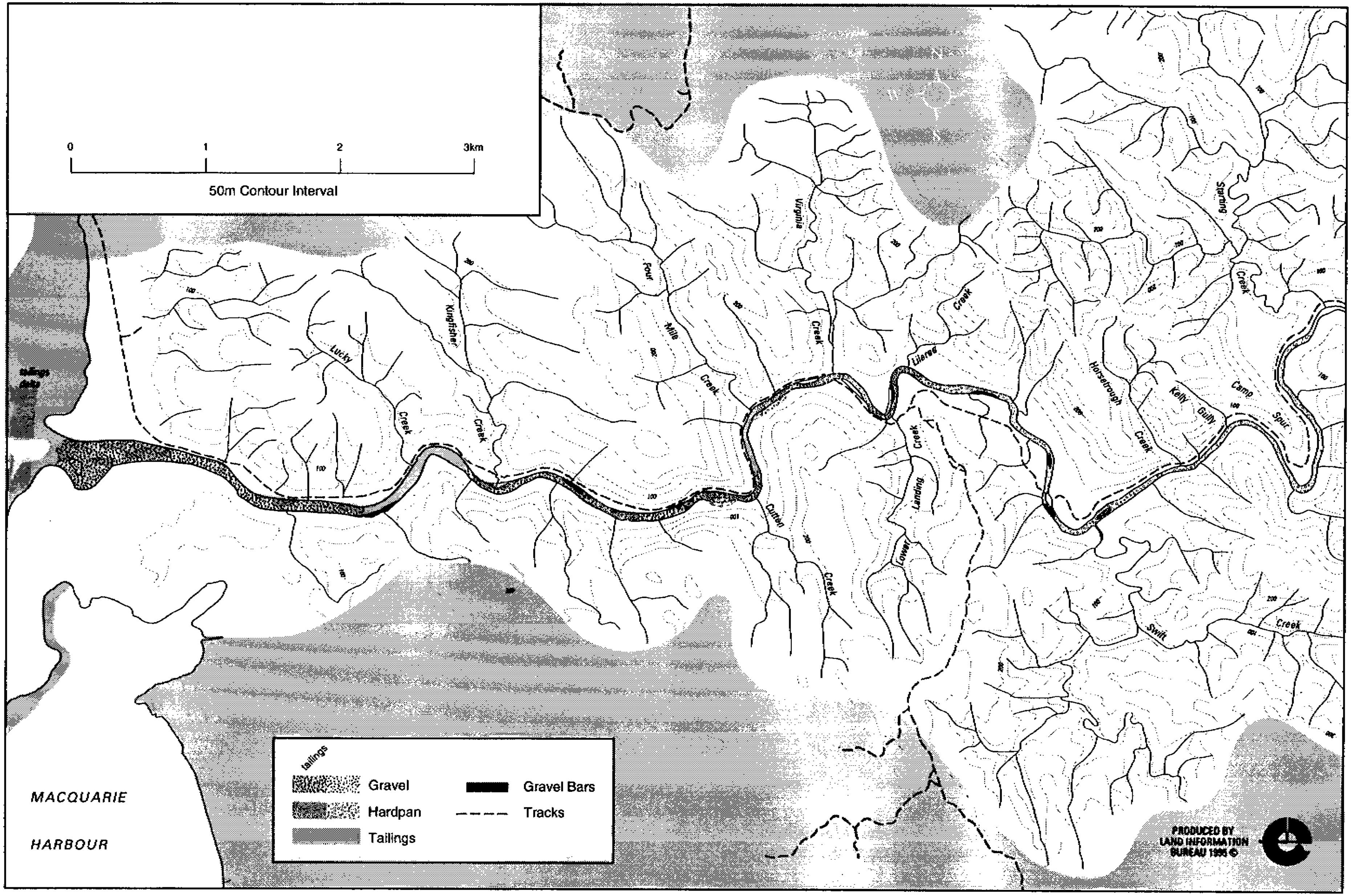
Table 3.6 King River catchment gradient changes

Reach	Boundaries	Elevation (m AHD)	Distance (km)	Gradient	
Queen below mine site	Mount Lyell tailings outfall	200	13.2	1:82	0.0122
	Confluence with King	40			
King River Gorge	Confluence with Queen	40	5.1	1:170	0.0059
	Sailor Jack Creek	10			
Lower King	Sailor Jack Creek	10	18.2	1:1916	0.00052
	Macquarie Harbour	0.5			

As can be seen, the Queen River between the mine site and the confluence has a steep gradient of 0.012. In the King River gorge between the confluence of the King and Queen Rivers and Sailor Jack Creek, the gradient is still considered steep at 0.006. At Sailor Jack Creek the river flattens considerably, with a gradient of 0.0005 out to the river mouth. Figure 3.6 shows a more detailed survey of the water surface elevation profile for the King River between Station 4 (at 16 km) and Station 20 (at 0 km).



Map 3.2 Station locations



Map 3.3 Bottom surface characteristics

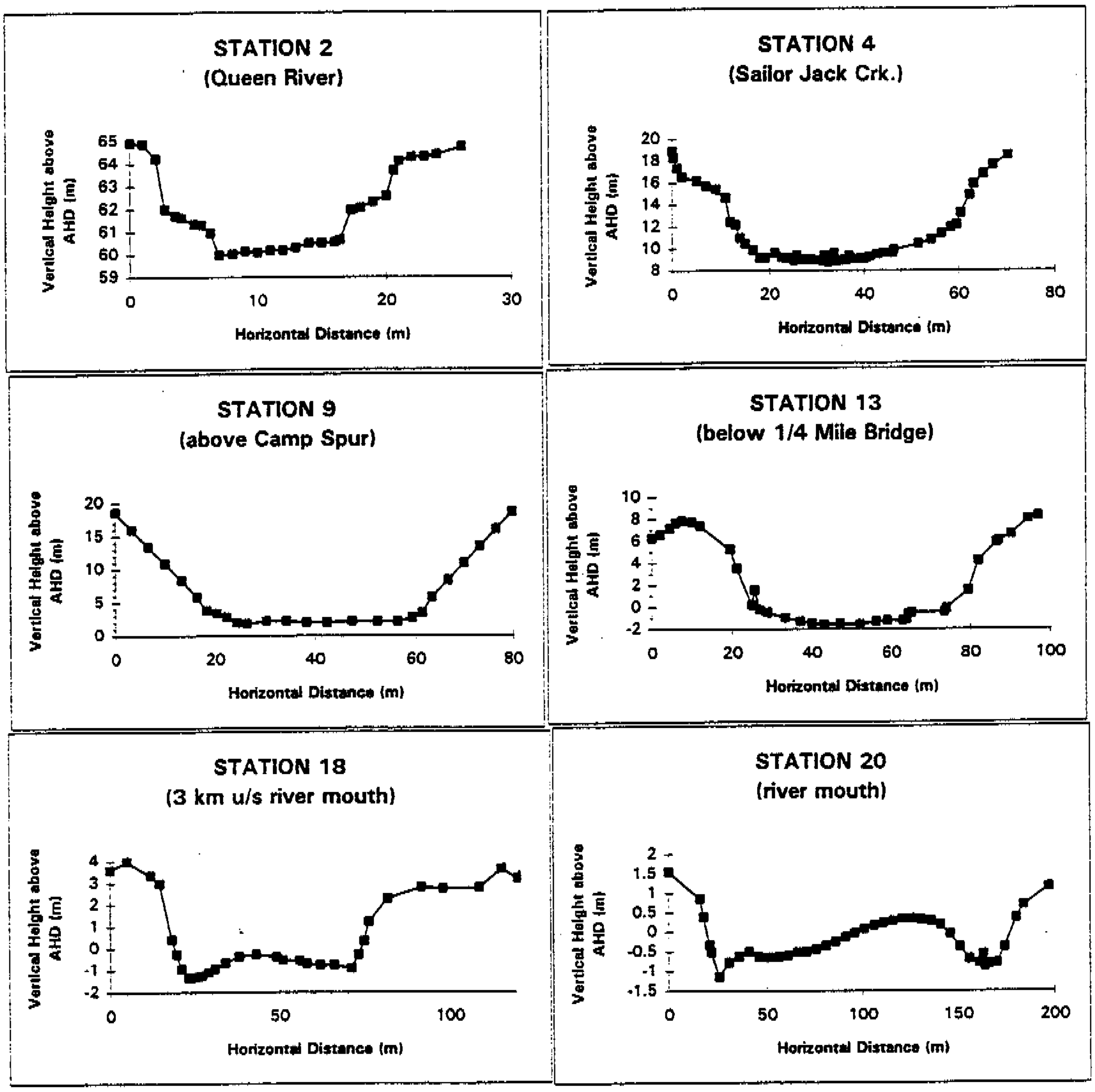


Figure 3.5 Channel cross sections

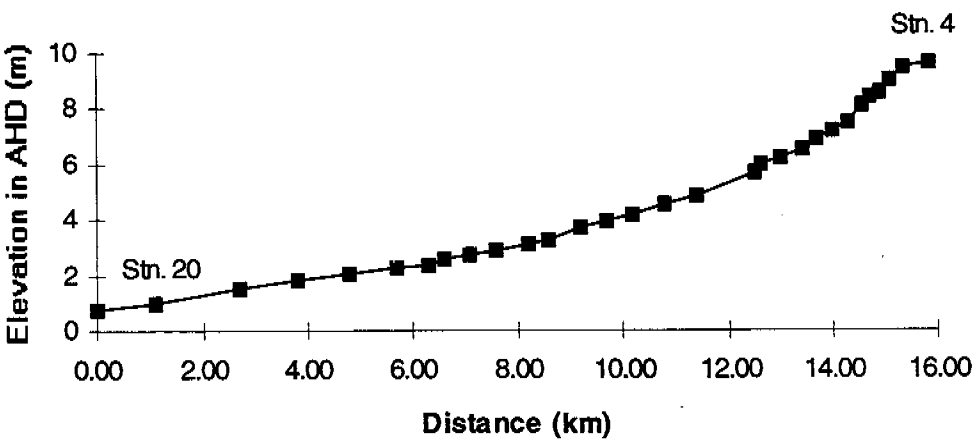


Figure 3.6 King River water surface elevation

The water surface elevation profile is greatly influenced by the power station activities. Figure 3.7 shows typical water level changes due to power station operations, and table 3.7 shows typical time lags for changes in water level to propagate downstream. The water level rise due to the power station turning on propagates much more slowly than the fall in water level due to the power station turning off, presumably due to the much greater energy required. However, once the water level change begins to occur at a station, the flow level becomes steady much more quickly for a water level rise than for a water level fall.

Table 3.7 Propagation times for water level changes in King River

Location	Dist. downstream	Power station turns OFF		Power station turns ON
Power Station	0.00 km	0000 hours		0000 hours
Station 13	13.10 km	0045 to 0430 hours	(steady drop)	0215 to 0315 hours
		0430 to 0730 hours	(shallow drop)	(steady rise)
Cutten Creek	17.15 km	0130 to 0530 hours	(steady drop)	0300 to 0450 hours
		0530 to 0930 hours	(shallow drop)	(steady rise)

The other significant influence on the water surface elevation profile in the King River is the tidal influence from Macquarie Harbour. Figure 3.8 illustrates the changes in water level over a period of several days. Station 3 (the King below Queen River hydrological monitoring station) clearly shows the changes in flow with the power station off for 24 hours on 12 July 1994, and on for 24 hours on 13 July 1994. At low flow (power station OFF), the influence of the Macquarie Harbour tidal changes can be seen at the Cutten Creek monitoring station, but not as far upstream as Station 13. At high flow (power station ON), the tidal variations in Macquarie Harbour do not influence water levels at any of the King River monitoring stations. The same trend shown in fig 3.8 for the Cutten Creek monitoring station is seen at all points between Teepookana railway bridge and the river mouth.

The tidal zone was shown in this monitoring exercise to extend up to Teepookana Bridge and possibly somewhat higher, but does not extend as far upstream as Station 13. Furthermore, the tidal influence was limited to backwater affects; under the flow and harbour conditions during this tidal monitoring exercise, there was no evidence of a saline wedge intruding up the King River at any flow level. Whether or not there is intrusion of a saline wedge if the power station is off for several consecutive days is unknown.

3.6.3 Gauging summaries

Appendix 1 includes summaries of all HEC gaugings for the Queen River below Lynchford Camp, the King below Queen River, and the King River at Sailor Jack. Mean current velocities in the Queen River have varied between 0.175 and 2.378 m/s over a flow range of 0.515 to 73.19 m^3/sec. Mean current velocities in the King River below Sailor Jack Creek have ranged from 0.222 and 3.653 m/s over a flow range of 3.082 to 475.8 m^3/sec.

Additional gaugings have been conducted as part of this study at Stations 2, 4, 13 and 18 in conjunction with collection of suspended and bed load sediment samples. These results are presented in sections 6 and 7.

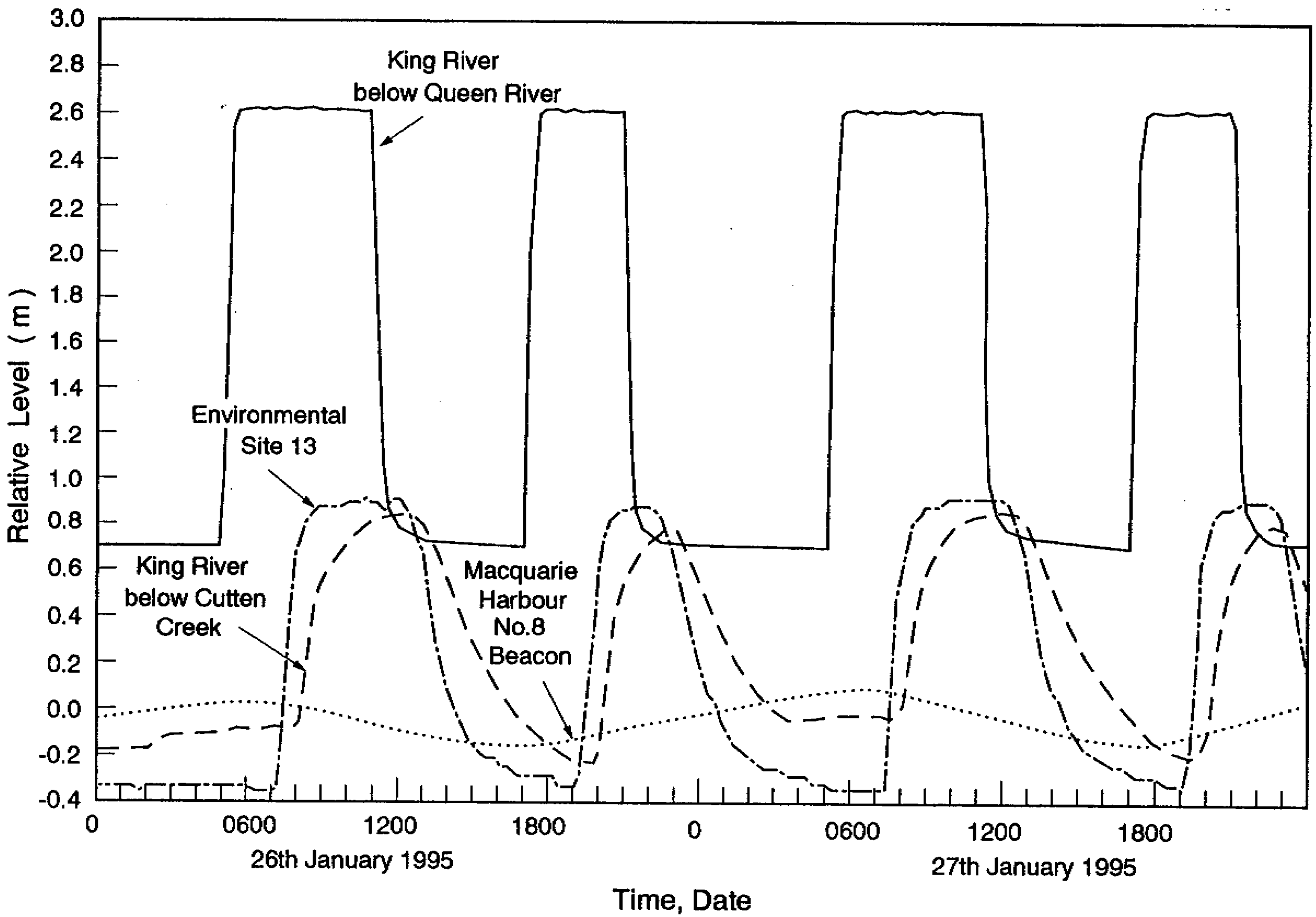


Figure 3.7 Water level changes due to power station operations

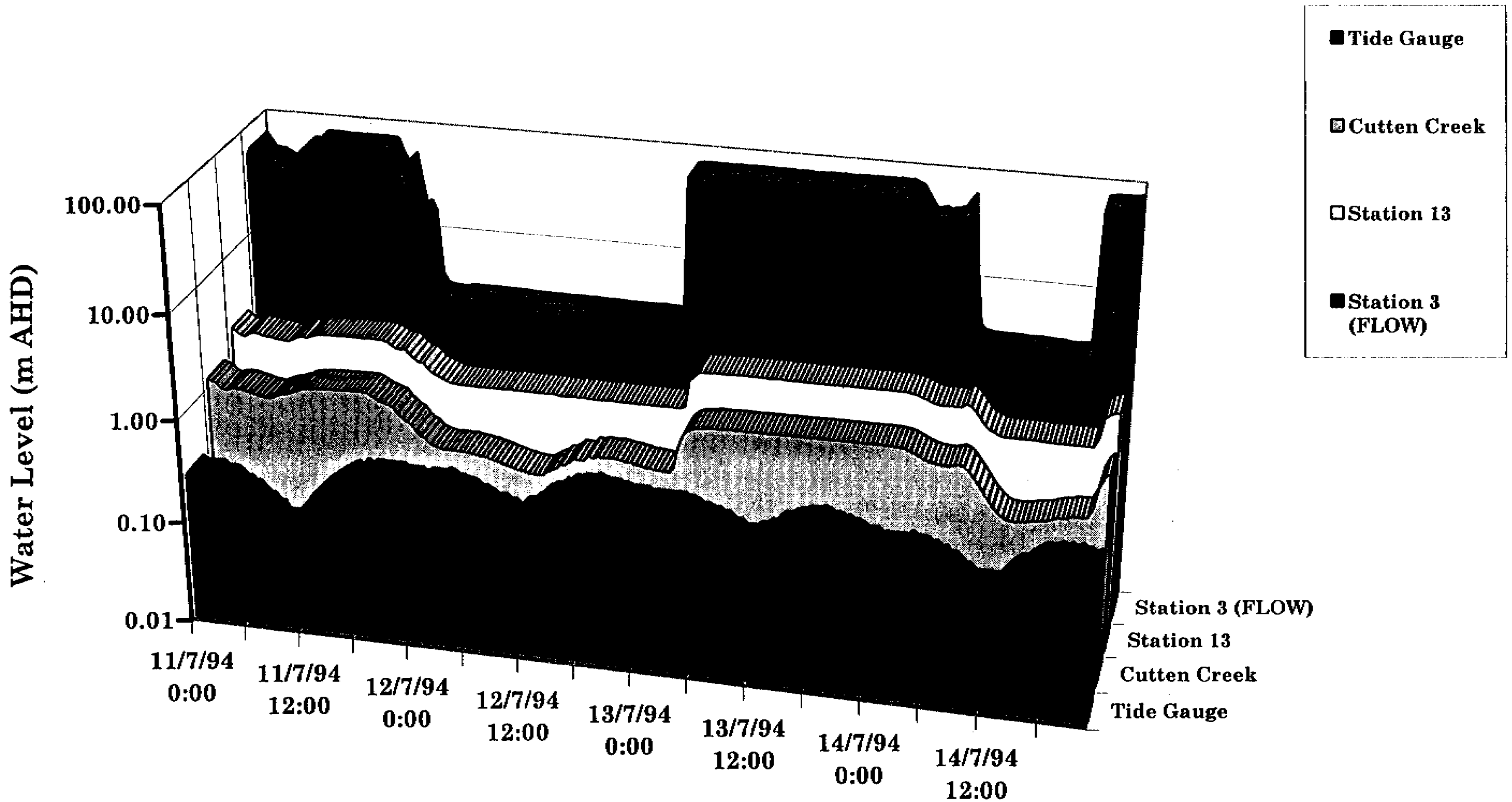


Figure 3.8 King River tidal exercise

3.7 Summary

This section has described the receiving environment for the tailings. The catchment area has a history of mining and forestry activities, and is largely undisturbed except for the mining operations in Queenstown and changes to the river system due to the mining practices. A power station established on the King River in 1992 has significantly altered the flow patterns and reduced the peak annual flow from 830 to 240 m^3/sec. Channel gradients are very steep on the Queen River (into which tailings were discharged) and on the King River just below the confluence with the Queen, and then noticeably flatten the last 18 km to the river mouth. The tidal zone from the receiving body of Macquarie Harbour extends about 5 km up the King River mouth to just above an old railway bridge known as Teepookana Bridge, but the tidal influence is only evident when the power station is not discharging.

The characteristics of the receiving environment influence how the mine wastes are transported and stored in the river system. The next section examines where and how mine-derived sediments have been stored in the river system, and focuses particularly on the quantities and characteristics of the sediments in storage.

4 Sediment storages

4.1 Queen River

The Queen River is essentially a conduit for mine wastes from Queenstown to the King River. Its gradient is sufficiently steep that there is little to no long term storage of tailings. There are extensive coarse gravel and cobble bars and banks in the Queen River, but no tailings banks. When the mine was discharging tailings, the Queen River was a rich grey colour likened to 'liquid cement' (plate 4.1); this was said to clear very quickly whenever the mill was shut down for maintenance. Now that tailings are no longer being discharged, the river has an unnatural red staining due to the high iron concentrations in the run-off from the lease site (plate 4.2).

In Queenstown, every two to three years the local council 'cleans out' the bottom of the Queen River with an excavator. The need for this is totally unrelated to the tailings, but is in response to the regular transport of cobbles down from Conglomerate Creek which over time can 'dam' the Queen River and pose flooding problems for neighbouring areas. The Council cleaned out the bottom of the Queen River in December 1994.

The only known tailings storage in the Queen River is just above the confluence with the King River (plate 4.3). Here sediment banks have built up, presumably from when there was a high flow in the King River effectively 'damming' the tailings being carried down the Queen. The older age of the deposits is evident by the reddish-brown colouration of oxidised tailings and their relatively coarse sand size. While the mine was still discharging, fresh tailings deposits at the base of the older deposits were grey, unoxidised, and classified as a fine silt.

While tailings were being discharged, the confluence of the King and Queen Rivers was a dramatic sight (as shown in plate 4.3) due to the coming together of the characteristically black organic-rich natural waters of the King with the chalky white tailings-laden waters of the Queen. There was a sharp dividing line for perhaps 100 m in which swirls of tailings-laden water sank and re-emerged amidst the black waters, until the confluence narrows and the mixture proceeded as a mottled dilute grey-brown solution. The dynamics of this mixing zone changed significantly depending upon the relative flows in the King and Queen Rivers. When the power station was off, the flow was insufficient to move the tailings coming down the King River, and so they would temporarily settle out at the confluence (see plate 4.4) until the power station came on line again and re-mobilised them on down the King River.

Plate 4.1 Queen River pre-mine closure

Plate 4.2 Queen River post-mine closure

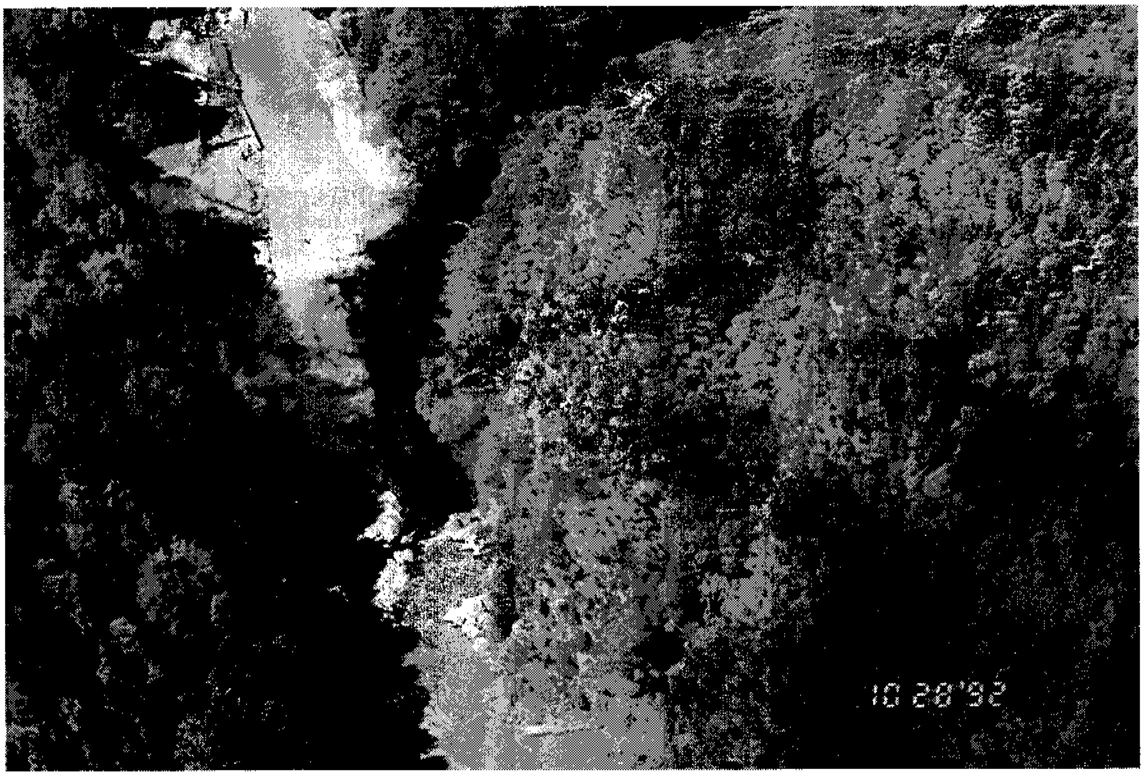


Plate 4.3 Confluence of the Queen and King Rivers

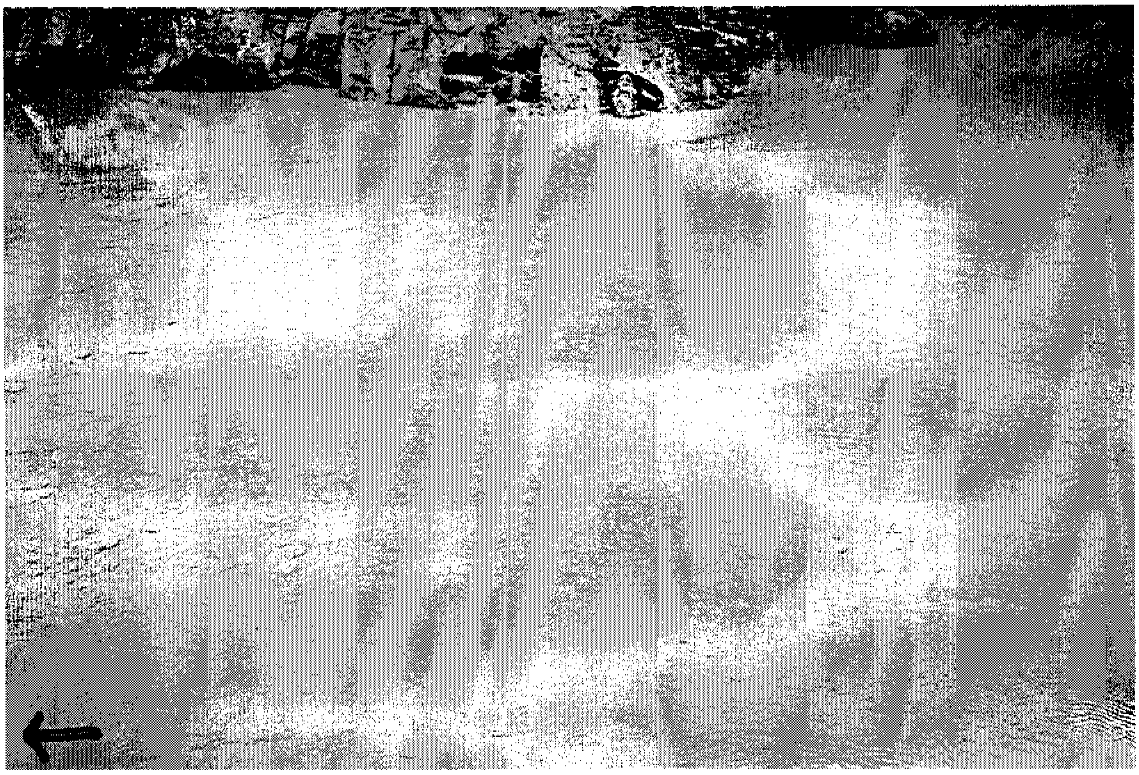


Plate 4.4 Tailings at the confluence with the power station off

4.2 King River banks

4.2.1 Locations

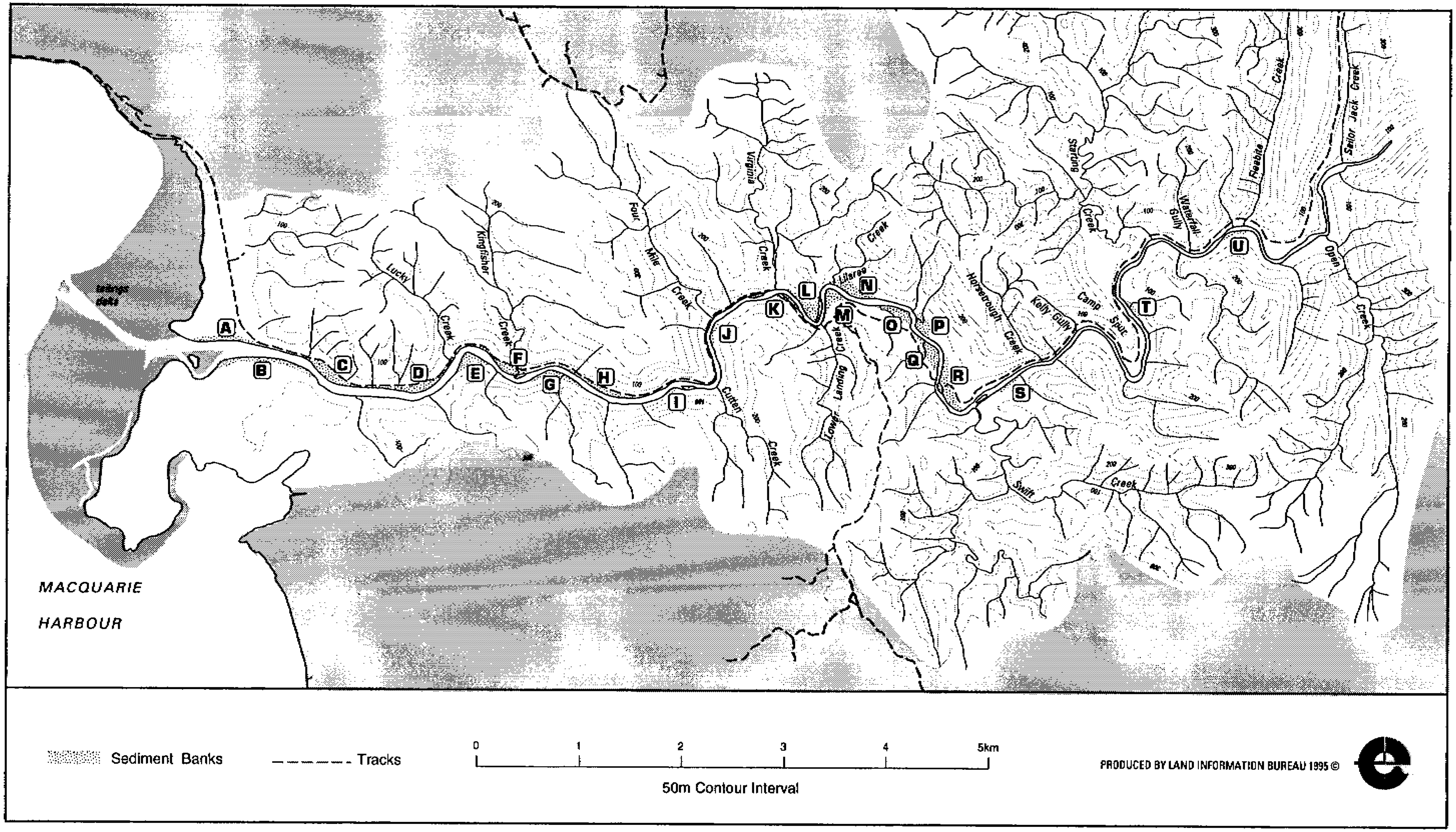
The most visible storages of sediment in the King River are in the sediment banks, remarkable for their artificial orange/red colour (from the oxidised pyrites) and dead tree stumps due to either metal toxicity or the acid generating nature of the tailings in storage. Map 4.1 shows the locations and labelling of the tailings banks in the King River. From the contours, the river appears to be a confined alluvial channel, and the mining sediments have deposited wherever the local topography has permitted sediment storage.

An initial visual survey of surface area of sediment banks was conducted at an early stage of this study, with the results shown in table 4.1. Volumes have been estimated by making assumptions about the depth of mining sediments in the banks. More detailed information collected from a trench and a comprehensive augering survey indicate that this initial estimate is reasonably accurate. Total sediment volume in the river banks is estimated to be 2.15 million m^3, or 3.44 million tonnes.

Table 4.1 Initial estimates of King River sediment bank storage

Reach above stn no	Av. bank height (m)	Av. tailings depth (m)	Av. bank width (m)	Total bank length (m)	Sed. bank volume (m^3)
4					
5					
6	5	1.25	25	450	14063
7	5	1.25	12	500	7500
8	6	1.50	12	600	10800
9	5	1.25	10	250	3125
10	5	1.25	15	2820	52875
11	5	1.25	18	1100	24750
12	6	4.50	90	1070	433350
13	5	3.75	140	850	446250
14	5	3.75	100	850	318750
15	4.5	3.38	100	1300	438750
16	3.75	2.81	25	680	47813
17	3.25	2.44	40	1500	146250
18	2	1.00	15	100	1500
19	1.8	0.90	55	2850	141075
20	0.8	0.40	75	2200	66000
river mouth	0.5	0.25	100	1000	25000
Total =				**17120 km**	**2152850 m^3**
					x 1.60
					= 3.44 million tonnes

The tonnage assumes a specific weight of deposit of 1.60. This figure is based on an average of two samples, one from Bank F and one from Bank M, for which an undisturbed sample of a known volume was collected, dried and weighed. 3.44 million tonnes is a surprisingly small figure given that total mine discharge is estimated to be 97 million tonnes (excluding slag and topsoil contributions).



Map 4.1 Locations and labelling of sediment banks

Between Stations 12 and 15 are the most sizeable deposits of sediments, between two railway bridges known as Quarter Mile Bridge (upstream end of this stretch) and Teepookana Bridge (downstream). The sediment banks are on both sides of the river on the inside bends, rising in height to 5–6 m above low water level and extending back from the river bank up to 100m (plate 4.5). The height of these deposits is consistent with the height to which the King River historically rose during peak flows. Flow records from the Sailor Jack Creek gauging station show peak flows in the order of 840 m^3/sec since recording began in 1985, corresponding to a river level rise of just over 5m.

Below Teepookana Railway Bridge, near Station 15, the river gradually widens and frequent long, broad, relatively flat (1–2 m above low water level) beaches are prominent inside the river bends (plate 4.6). These beaches would get entirely inundated at high flows, unlike the higher banks above Teepookana Bridge.

4.2.2 Trench

A trench was cut into one of the large sediment banks on Bank M during February 1994. This trench was dug on an opportunity basis when the local Forestry Commission had an excavator working nearby, so it was not properly shored up and only a few samples were able to be taken. The trench was approximately 40m long by 5m deep, and gave some indication as to how the banks have developed (plates 4.7 and 4.8). It appears from the stratigraphy that the original banks were in a levee configuration, and the present day banks have grown away from the river during successive periods of high flow when the tailings are able to be deposited behind the crest of the bank. Levee banks are found in the lower Gordon River as shown in plate 4.9. This interpretation is consistent with the present day shape of the large sediment banks with a crest similar to a dune crest on the 'back' side away from the river. Wind processes also appear to have a significant role in the shape of the banks.

Due to safety concerns the trench was not left open for long, and was unable to be comprehensively sampled. Seven samples were collected at a height of about 1m above the mean water level and at approximately 5m intervals back from the waters edge. These were sent to ANSTO for analysis of Caesium-137. Caesium-137 is a radioactive isotope produced from nuclear explosions, which adsorbs onto fine sediments and has proven to be an effective tracer. In Australia it has been present between 1954 and 1979, with the peak year being 1964. The half life of this isotope is 30 years, so the detectable levels in the earlier years are diminishing (Longmore 1982; Campbell et al 1982).

Caesium was found to be present in five of the trench samples, proving that the sediments at the depths sampled were exposed to the atmosphere since 1954. The Caesium values do not contradict the hypothesis of bank growth by overtopping of levee banks, as lower values were found where the levee was likely to have been. Figure 4.1 is a rough diagram showing the trench profile, the general stratigraphy, the Caesium-137 results in mBq-cm^2, and in parentheses the median particle size in mm.

In these samples, there is no correlation between Caesium-137 levels and particle size, but there are many other factors which may influence the Caesium levels. The amount of time the sediments were exposed to the atmosphere and the year(s) of exposure would also influence the concentrations of Caesium which are present. Considerable information could be gained from Caesium analyses in these banks with a rigorous sample collection and analysis program.

Plate 4.5 Large sediment banks above Teepookana Bridge

Plate 4.6 Large sediment banks below Teepookana Bridge

Plate 4.7 Trench

Plate 4.8 Trench stratigraphy

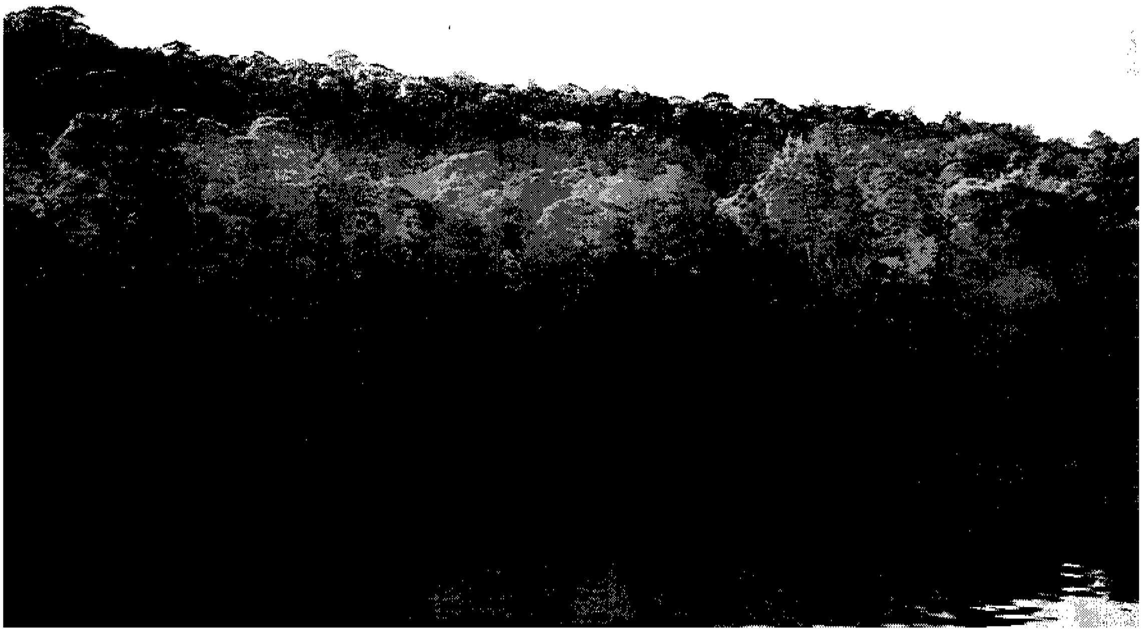


Plate 4.9 Levee banks in Gordon River

4.2.3 Augering survey

A more comprehensive augering survey of the sediment banks was conducted during the week of 11–15 July 1994. The purpose of this survey was to help define the extent of storage of mine-derived sediment, to get some idea of depositional patterns, and to identify the nature of the material in the banks so as to assess its erosion potential and what type of material the river may have to transport if the banks do erode significantly.

Augering was done on six banks, three of the large sediment banks above Teepookana Bridge, and three of the flat sediment banks between Teepookana Bridge and the river mouth. The locations and labelling of auger holes are shown on map 4.2.

During the same week a botanical survey was conducted of the vegetation on the selected sediment banks (Barker 1994). The vegetation survey clearly identified the mature stands of vegetation and where there was likely to be original sediment banks close to the bank surface.

Figures 4.2 and 4.3 show the results of the augering survey for two of the sediment banks, Bank L which is a point bar above Teepookana Bridge, and Bank H which is inside a gentle bend below Teepookana Bridge.

As shown in the plan view of Bank L in fig 4.2, auger hole LL1 was very near the nose of the point bar behind some mature trees, LL2 was in a mature stand of vegetation identified in Barker (1994) as community 1, and LL3 was on the downstream side of the point bar amongst some seedlings. Shown for each auger hole are the depths of stratigraphic changes in metres AHD, field texture, field colour, and copper levels. Copper was analysed in selected auger samples to see if it would be a reliable and less expensive indicator of mine-derived versus natural sediments in the banks.

The copper results shown in fig 4.2 verify that copper is an excellent indicator of mine-derived sediments and enable a line to be drawn with a fair degree of confidence between the tailings and the natural bank.

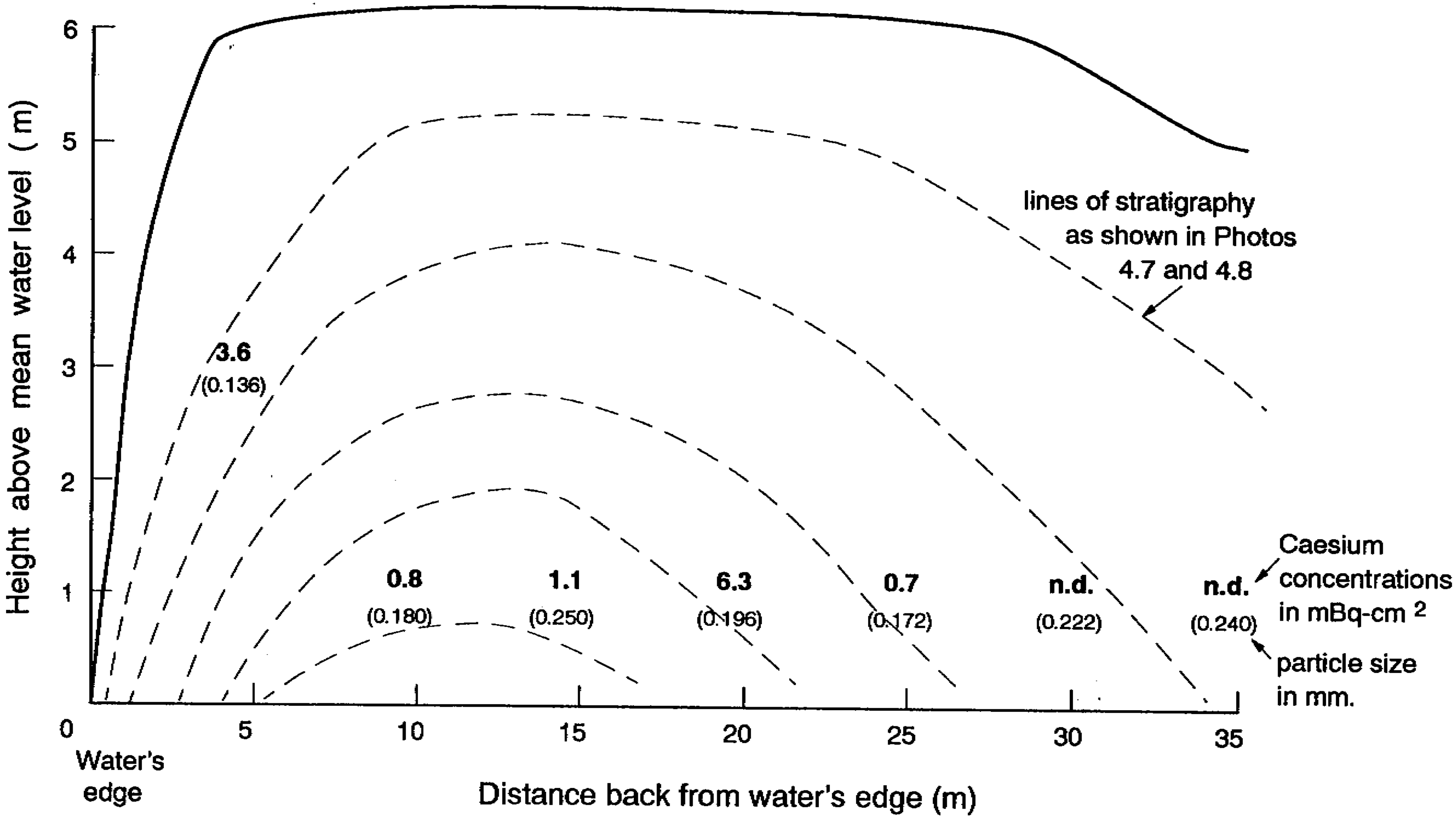


Figure 4.1 Schematic stratigraphy of trench through sediment bank M