supervising scientist report **104**

MOUNT LYELL REMEDIATION

Review of historical literature and data on the sources and quality of effluent from the Mount Lyell lease site

Christopher V McQuade,
John F Johnston &
Shelley M Innes

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 Mount Lyell Remediation Research and Demonstration Program, a joint program between the Supervising Scientist and the Department of Environment and Land Management, Tasmania.

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ERRATUM

Page iv paragraph 3 - North Lyell Tunnel should read West Lyell Tunnel

Executive summary

This paper is the first in a series produced through the joint Federal/Tasmanian 'Mount Lyell Remediation Research and Demonstration Program'. The paper presents a summary of mining operations at Mount Lyell, characterises the environmental impacts and collates technical data from numerous sources which are to be used in other projects within the program. Data are derived from the previous mine operator, The Mount Lyell Mining and Railway Company Limited, the Hydro-Electric Commission, Department of Environment and Land Management Environmental Management Division and Copper Mines of Tasmania.

The Mount Lyell Mine is situated 2 km north of Queenstown, Western Tasmania, Australia. Queenstown is 270 km north-west of Hobart, the State capital and approximately 25 km inland from the west coast and the Southern Ocean. The Mount Lyell mining field is situated in a belt of rocks known as the 'Mount Read Volcanics' which extend approximately 60 km north and 25 km south of Queenstown. The Mount Read Volcanics comprise one of the richest mineral provinces of its type in the world.

The Mount Lyell mining leases 1M/95 and 2M/95 are situated in the headwaters of the Queen River which has its confluence with the King River approximately 15 km below the lease sites. The King River drains into the north-eastern end of Macquarie Harbour, a 276 km^2 harbour with a narrow mouth to the Southern Ocean.

Mining operations in the Mount Lyell region have produced over 1.3 million tonnes of copper, 750 tonnes of silver and 45 tonnes of gold since mining commenced in the early 1890s. This is equivalent to over four billion dollars worth of metal in 1995 terms. Environmental controls were non-existent for the majority of the period of mining and processing operations, and as a consequence there is a legacy of environmental degradation.

The nature of the mining methods (open-cut and underground), the number of mining operations and their infrastructure (over 40 at the turn of the century), mineral processing (pyritic smelting and conventional flotation and smelting), and riverine waste disposal of both liquid and solid wastes have resulted in severe environmental damage to not only the immediate mine area of approximately 13 km^2, but an adjacent area covering 50 km^2. Impacts to the physical landscape include the removal of 15 km^2 of vegetation and soil as a result of wood cutting and burning, substantial modification to the hydrology, and an increased erosion load in the Queen and King Rivers. Catchments downstream of the mine experienced degradation of natural river water quality, the creation of tailings levees along river banks, and a 2.5 km^2 tailings delta at the mouth of the King River where it discharges into Macquarie Harbour.

The high pyritic level of the waste rock dumps (>10%), the large exposed surface area from open-cut voids, extensive underground workings and associated caved areas, and the high rainfall of the region (2500–3000 mm) combine to produce extensive acidic leachate. The acid leachate, containing copper, zinc, aluminium, iron, manganese, and sulphate, is generated by the oxidation of exposed pyrite. Surface water flows leaving the lease are characterised by a pH of 2.5 to 3.5. It is expected that the mine area will continue to be a source of acidic leachate for many centuries unless remediation strategies are adopted to address the problem.

When mining operations by The Mount Lyell Mining and Railway Company Limited (MLMRCL) ceased on 15 December 1994, it was estimated, using median concentrations and flows, that copper loads alone in the effluent water leaving the mine site were in excess of 2000 kg/d. Maximum daily discharge rates may be up to ten times this level. Approximately

100 million tonnes of tailings have been disposed of to the Queen River. Beached tailings in the riverine system and the tailings delta in Maquarie Harbour continue to be a source of metal contamination to the aquatic system. For a single West Lyell waste rock dump monitored by Australian Nuclear Science and Technology Organisation (ANSTO) it is predicted acid generation may continue at reducing rates for greater than 600 years. Measurements have shown that approximately 130 tonnes of copper and 1300 tonnes of sulphate per year leach from this dump alone.

The monitoring dataset from Mount Lyell is highly variable. A good record of stream flow data exists for Hydro-Electric Commission (HEC) sites in the eastern hydrological catchment. Flow determinations for the lease site are estimates with the exception of a few monitored streams which have a short record of monitoring. Due to the high variability in water flow on the lease site, a long period of record is required to accurately define flow characteristics. The HEC has demonstrated a good relationship between catchment areas and median flows. Median flow values have generally been used to calculate mass loads by Environmental Geochemistry International (EGI), the HEC, and consultants Gutteridge Haskins and Davey (GH&D). Total flows calculated from median flow values may underestimate the actual flow by up to 500% where flow distributions are skewed as is the case on the Mount Lyell lease site. It has been shown that up to 80% of the total flow may occur in 20% of the discharge time as a result of catchment, rainfall, and runoff characteristics. This has important implications for the use of median flows to calculate mass pollutant loads. For environmental assessment, good quality information is required to develop time duration analysis of concentrations and loads, and the current dataset is inadequate for this application. As a result, reliance is placed on median flow values which are less than ideal.

Water quality data are highly variable with few trends being evident. An exception is MLMRCL station 6, North Lyell Tunnel, which demonstrates a gradual decrease in sulphate, iron, and copper mass loadings in the past five years. This is believed to represent a decrease in the rate of oxidation of sulphides as they are oxidised and leached.

Strong correlations exist between conductivity, sulphate and copper for waters derived from a single source. Conductivity may provide a useful indicator of copper loads in point source streams on the lease site. The correlation tends to break down when effluent sources are mixed.

Both the HEC and GH&D data suggest an inverse relationship between water quality parameters and flow suggesting concentrations may be diluted by rainfall.

For streams with low suspended solids and high acidity, total and dissolved metals are very similar. However, this was not the case for tailings contaminated waters where the abundance of adsorption sites on tailings particles resulted in a reduction in the dissolved metal content relative to total metal loads.

For surface catchments there is an obvious relationship between the catchment characteristics related to mining activities and pollutant loads. Catchments containing waste rock dumps and adits are highly contaminated. The major source is the Conveyor Tunnel in the Haulage Creek catchment which contributes up to 60% of total metal loads to the Queen River. The West Lyell waste rock dumps in this catchment are the second largest source of pollutants.

In order that environmental remediation strategies are effectively targeted for the maximum possible benefit, it is critically important that good quality monitoring data are collected. The provision of accurate environmental monitoring data will improve future site management decisions and enable cost-effective remediation strategies to be determined.

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- Mark Johnson of the HEC for providing historical information on monitoring of the region and hydrologic data used in this study;
- Copper Mines of Tasmania for their co-operation in providing monitoring data;
- Karen Johnston for her time and effort into the final preparation of this report.

1 Introduction

Over the past century, mining activities in the Mount Lyell region have resulted in considerable impact to the natural environment within and about the mining lease sites, the rivers and Macquarie Harbour. Impacts are related to the general landscape of the Queenstown area, the removal of vegetation and topsoil, changes to hydrology and water quality, and the deposition of tailings and slag in the rivers and harbour. In 1995, the Tasmanian and Federal Governments established a joint program to develop a strategy for remediating the environmental impact of past mining at Mount Lyell. The program was titled 'The Mount Lyell Remediation Research and Demonstration Program'. The authorities coordinating the program comprised the Tasmanian Department of Environment and Land Management's Division of Environmental Management, the Commonwealth Environment Protection Authority's Office of the Supervising Scientist (***oss***) and the Environmental Research Institute of the Supervising Scientist (***eriss***).

The Mount Lyell Remediation Research and Demonstration Program (MLRRDP) is a series of projects to investigate the extent and mechanisms of environmental impacts which have resulted from mining activities (Appendix A). Impacts ranged from acid drainage associated with mining, to the tailings deposits in the Queen and King Rivers, and Macquarie Harbour. The Program forms an important component of a larger and longer term Tasmanian Government program to understand and overcome these environmental impacts.

The MLRRDP includes three related projects dealing with the management of the quantity and quality of effluent from the lease site, the primary source of pollutants into the river and Macquarie Harbour system. These are:

1 a review and presentation of historical literature and data for the characterisation of sources of effluent from the lease site;

2 identification of the potential options for managing effluent water from the lease site and recommendations for construction and operation of demonstration/evaluation trials; and

3 construction and evaluation of test cases.

Project 1, the subject of this report, presents a consolidation of available information. Project 2 builds on this information and identifies options to reduce the emission of acid drainage from the lease site. Project 3 involves the construction and evaluation of some of the options identified in Project 2.

This report provides an introduction to the site with a brief history of the mining and processing operations undertaken over the past century. The environmental impacts resulting from these operations are presented with an overview of available information on the current quantity and quality of effluent water from the lease site.

2 Site location and description

2.1 Location

The area disturbed by mining at Mount Lyell covers approximately 13 km^2. The site is within two kilometres of the township of Queenstown, which is located some 270 km north-west of Hobart and about 25 km from the west coast of Tasmania and the Southern Ocean (figure 2.1). The port of Strahan, located on Maquarie Harbour, was the main supply and export centre for regional mining following its establishment in 1880. Macquarie Harbour has a

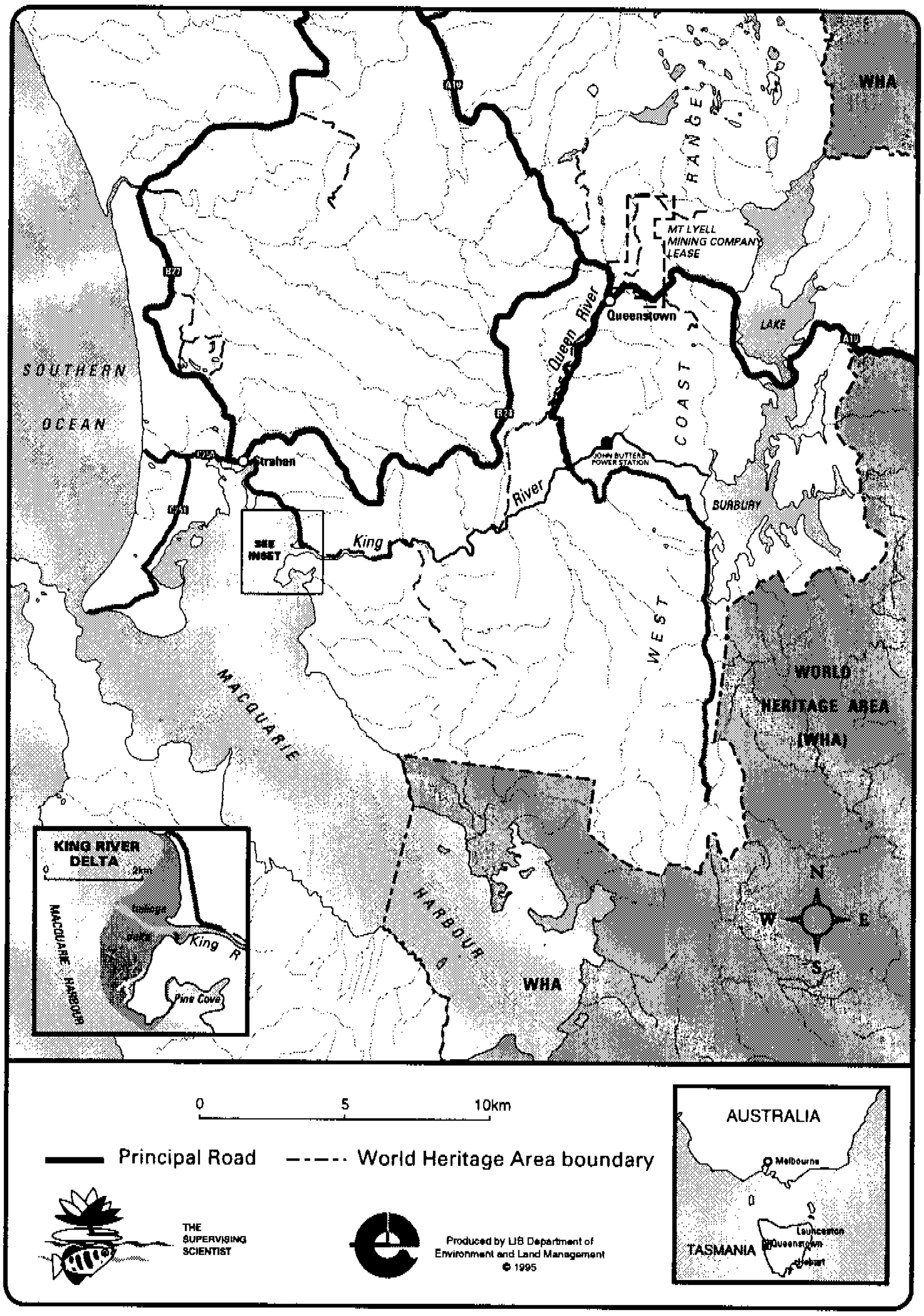

Figure 2.1 Regional map

water surface area of around 275 km^2 and is almost totally landlocked, with a narrow ocean mouth of a few hundred metres known as Hell's Gates (Locher 1995).

Queenstown was developed specifically to serve the Mount Lyell mining field at the turn of the century. The population of Queenstown was approximately 3360 in 1991 but exceeded 5000 in the early 1970s (Australian Bureau of Statistics 1991). The decrease in population reflected the downturn in the mining industry and the lower metal prices during the late eighties. Historically the town has provided housing for the work force and support services for The Mount Lyell

Mining and Railway Company operations, but more recently provides similar services for a number of other mining operations within the district, principally the Henty Gold Project. The town also serves as a regional centre for education, health, and other Government services.

2.2 Topography and drainage

Queenstown is situated in the physiographic region of Tasmania known as the Western Ranges which comprise a series of quartzite and conglomerate units forming dissected mountain ranges (Corbett 1976). Many of the mountains in this region exhibit glacial features including cirque lakes, moraines and glacial erratics. From about 300 m at the foot of the West Coast Range, the Western Coastal Platform slopes westward to end near the coast. The platform is deeply incised by the major west flowing river systems including the King, Queen, Henty and Pieman Rivers.

The mining operations are located within the west coast mountain range with Mount Lyell (920 m), on the Cape Horn Spur, being situated about two kilometres north of the mining field. Philosophers Ridge runs between the spurs of Mount Lyell and Mount Owen (1146 m) forming the eastern border of the West Lyell open-cut (figure 2.2). Gradients of the region are typically one in two to one in four.

Geological control of the topography and drainage is evident, with the resistant Owen Conglomerate generally controlling the drainage pattern. The major rivers are confined to either the underlying or softer overlying formations, particularly the Gordon Limestone. Philosophers Ridge forms the main hydrological divide within the Mount Lyell mining lease area, with water to the east flowing via Lyell-Comstock Creek through the Sedgwick Valley and Linda Creek through the Chamouni Valley to Lake Burbury. On the western side, Conglomerate and Haulage (Glovers) Creeks and the East and West Queen Rivers drain surface runoff into the Queen River which has its confluence with the King River approximately 15km downstream of the mine site. The drainage catchments are illustrated in figure 2.3.

The catchment of the King River is 809 km^2 with an annual discharge of 60.2 m^3/s (South West Tasmania Resources Survey 1980) and its major sub-catchment, the Queen River, is 79.3 km^2 with an annual runoff of 5.2 m^3/s. The elevation at the point where tailings are discharged into Haulage Creek is 200 m (Australian Height Datum, AHD) and falls at an average gradient of 1:90 through the Queen River to the King River. Below this confluence the gradient is a gentler 1:350 to Macquarie Harbour.

Mining operations have significantly changed the runoff characteristics of the area through the removal of vegetation, the excavation of large open pits, the development of underground workings, placement of mining and processing infrastructure and the development of waste-rock and process waste dumps. The waste rock dumps cover an area of around 90 ha. The six open pits in the area, with a combined surface area of 57 ha (table 2.1), collect and store rainfall, and discharge rainfall/runoff to mine workings or groundwater via adits and fracture systems in the base of the pits. The catchment area of the West Lyell open-cut is increasing in size as the pit walls collapse as a result of underground mining. The surface expression of an extensive fracture system along the south-western and eastern sides, were observed during field visits associated with this project, implies that the actual catchment area is greater than the pit perimeter.

MLMRCL (1994a) noted that the connecting pathways for water between the Comstock open-cut and the underground workings are not well known. Rainwater collected in the southern portion of the West Lyell open-cut drains into the mine workings of Prince Lyell from where it is pumped to the surface and discharged into Haulage Creek. No records of

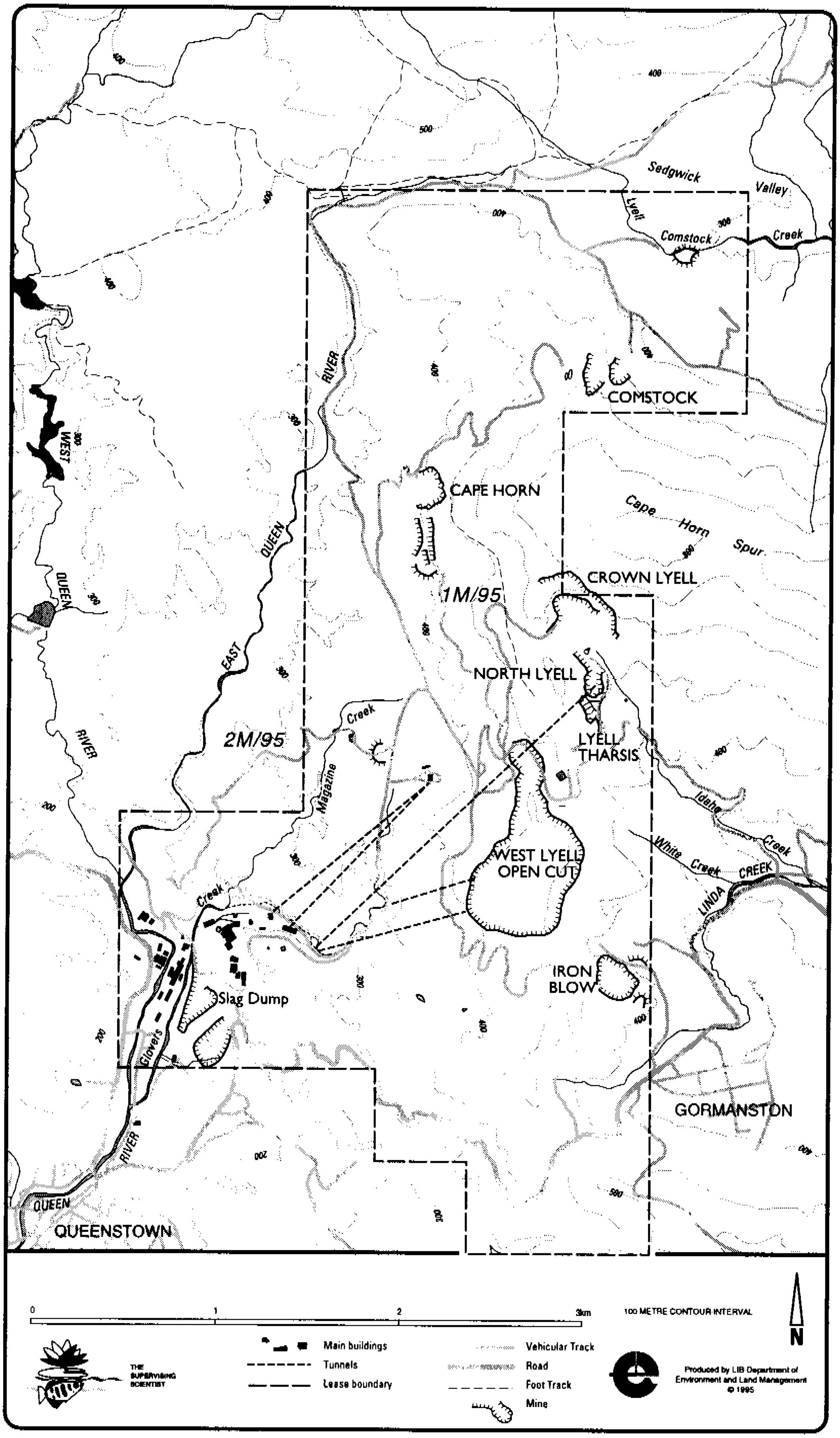

Figure 2.2 Lease site

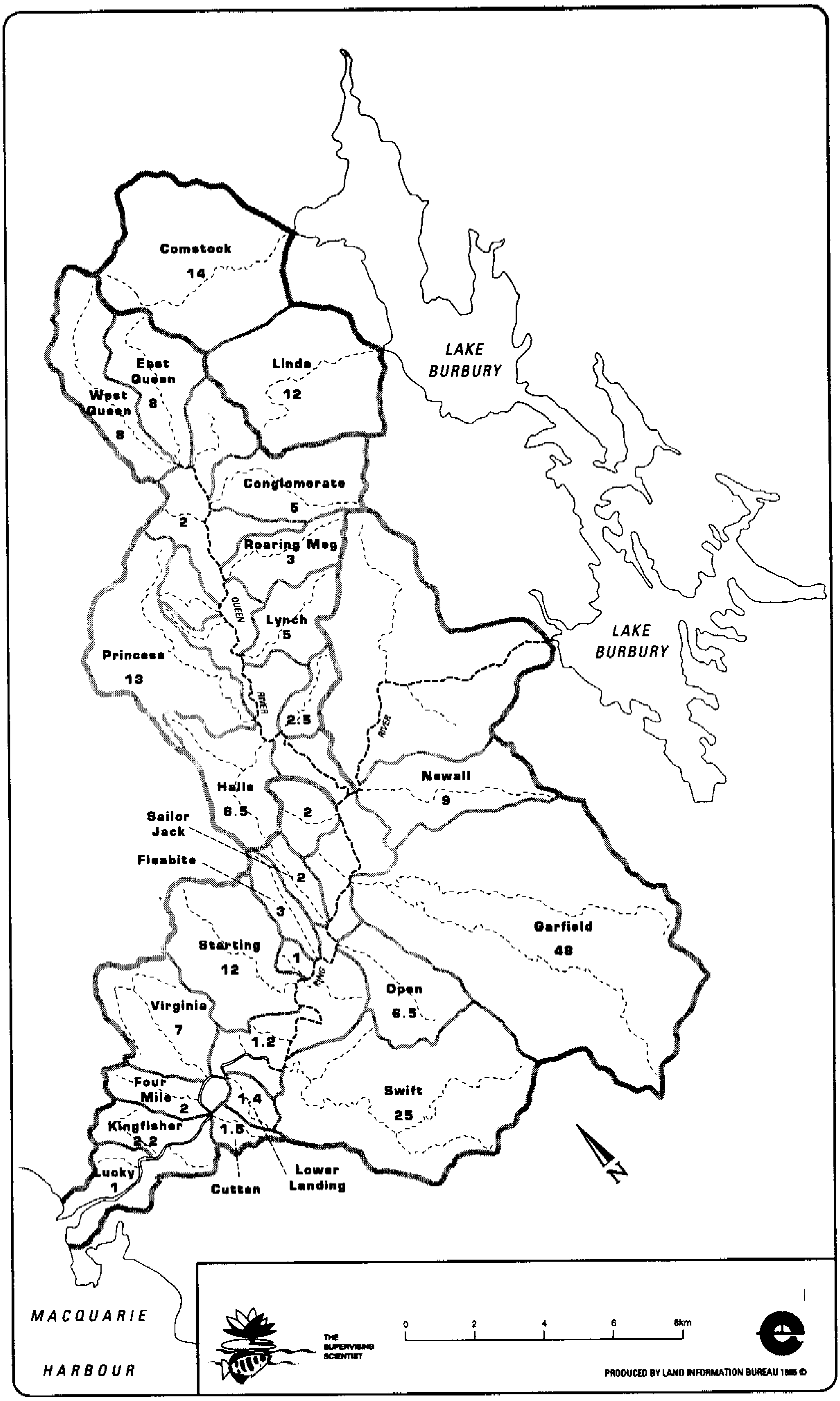

Figure 2.3 Regional surface water drainage network of the Mount Lyell mine and vicinity (modified after Locher 1995)

metered discharge volumes were kept, although some pump hours were documented. An adit in the northern end of the West Lyell open-cut drains this portion of the catchment into the North Tunnel. It is understood that there has been no study of the effects of mining on the local surface and groundwater hydrology.

Table 2.1 Catchment areas of the open-cuts

Open-cut	Catchment area (ha)	Open-cut	Catchment area (ha)
West Lyell[1]	37	Crown Lyell	7
Iron Blow	5	Lyell Tharsis	2
Cape Horn	2	Comstock	4

1 The catchment area is continuing to increase with the failure of the pit walls

In the Comstock Valley, the hydrology has been altered by drainage works designed to minimise pollutant loads to Lake Burbury, a site for recreational fishing. A proportion of runoff from mine disturbed areas has been redirected into the East Queen River, but, without planned maintenance it is uncertain how long these strategies will remain effective. These diversion works include:

- from July 1991, acid discharge from the Comstock open-cut and Comstock 5 level adit was diverted from the Lyell–Comstock Creek to the East Queen River just below the mine water intake pump station;
- also in July 1991, a rock-filled embankment was constructed at the Crown Lyell open-cut to divert runoff from the Linda catchment to Haulage Creek via the North Lyell underground workings;
- the Tharsis adit was initially sealed on 23 October 1992, in order to redirect drainage out of the Linda catchment back through the old mine workings to Haulage Creek via the North Lyell Tunnel. In late November 1992, the plug was found to have failed and was re-grouted in May 1993. During a site visit in May 1995, water was being allowed to freely drain from the adit through a pipe and valve system installed through the base of the concrete plug;
- following the completion of mining at the Iron Blow, the open-cut was flooded, and water now drains this pit into the headwaters of Linda Creek via an adit.

The depletion of high grade ore suitable for pyritic smelting and the depletion of firewood supplies close to Queenstown as a result of large scale clearing, required an additional energy source for the smelters and mining operations. To the north of Queenstown in 1914, The Mount Lyell Mining and Railway Company Limited constructed Margaret Dam on the Yolande River, forming Lake Margaret (the Lake Margaret power development was later sold to the HEC in 1985). In 1991, the HEC completed a second major hydro-electric scheme with the construction of the Crotty Dam on the King River and the Darwin Dam at Andrews Divide, forming Lake Burbury. The HEC controls the water release from these dams to provide electricity into the Tasmanian power grid.

Three minor dams located on the West Queen River retain water which is directed to the processing area for the mill water supply. The water is pumped to the mill-head tanks and overflow from the processing area enters Haulage Creek. The West Queen dams are filled with water from Lake Margaret in times of low water supply. Mine water is pumped from the East Queen River to head tanks above the Prince Lyell Shaft, eventually discharging via the Conveyor Tunnel to Haulage Creek.

2.3 Climate

The climate of the west coast region is classified as temperate maritime. Queenstown is 25 km from the Southern Ocean, thus heat absorption and storage by the sea produces much milder winters and cooler summers than in continental climates of the same latitudes, although this effect diminishes with altitude and distance from the coast.

Situated between latitudes 40°S and 45°S, Tasmania is under the influence of a broad band of westerly winds known as the 'Roaring Forties'. These prevailing winds produce a marked west to east variation in cloudiness and rainfall across the State. Characteristically high rainfall occurs in the mountainous western half of the State where elevated regions induce orographic rainfall from the passage of frontal systems embedded in the dominant westerly airstream (figure 2.4). Queenstown receives rainfall on approximately 240 days of the year and the region receives the least amount of sunshine in Australia.

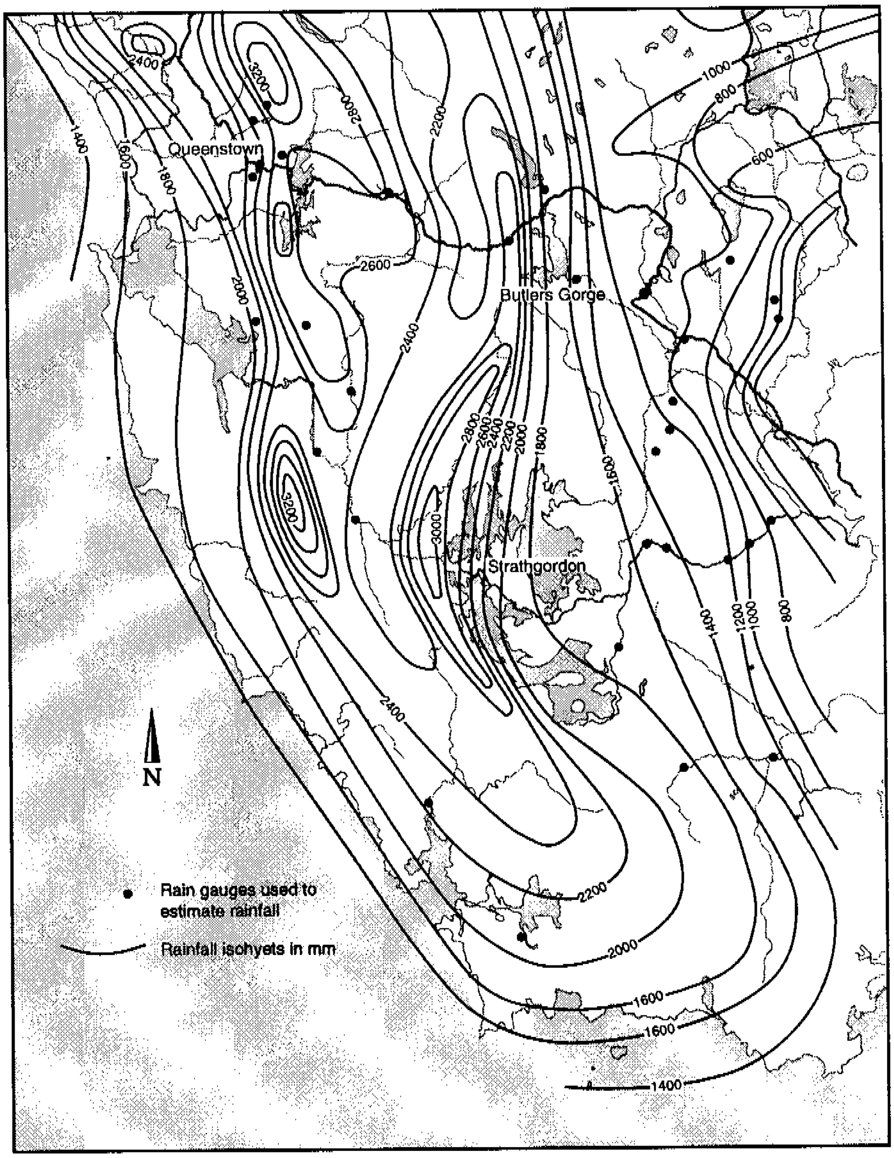

Figure 2.4 Regional annual rainfall

Throughout the west coast region, rainfall generally exceeds the effective rainfall (that required to initiate and maintain plant growth above the wilting point) in all months except January. Annual average rainfall for Queenstown is 2400 mm and 2520 mm for Mount Lyell (calculated from 30 years of data to 1993 recorded at station 097034 located in the township of Queenstown, and 87 years of data to 1993 recorded at station 097008 located on the mine site of Mount Lyell, respectively). The general rainfall statistics are provided in table 2.2. Because Mount Lyell is slightly higher than Queenstown, it receives slightly higher rainfall in the summer months.

Table 2.2 Rainfall statistics for stations 097008 (Mount Lyell) and 097034 (Queenstown)

Month	Mean rainfall (mm)		Median rainfall (mm)		Number of rain days	
Station	Mount Lyell	Queenstown	Mount Lyell	Queenstown	Mount Lyell	Queenstown
January	151	148	146	136	16	17
February	122	101	111	83	13	13
March	163	144	160	143	17	17
April	224	209	215	202	19	21
May	244	242	227	227	21	22
June	234	219	228	197	19	21
July	260	269	265	267	22	24
August	264	264	264	261	23	24
September	247	246	247	261	21	23
October	228	210	222	182	21	22
November	200	181	202	193	19	19
December	184	172	175	166	18	19
Total	2517	2394	2473	2412	229	242

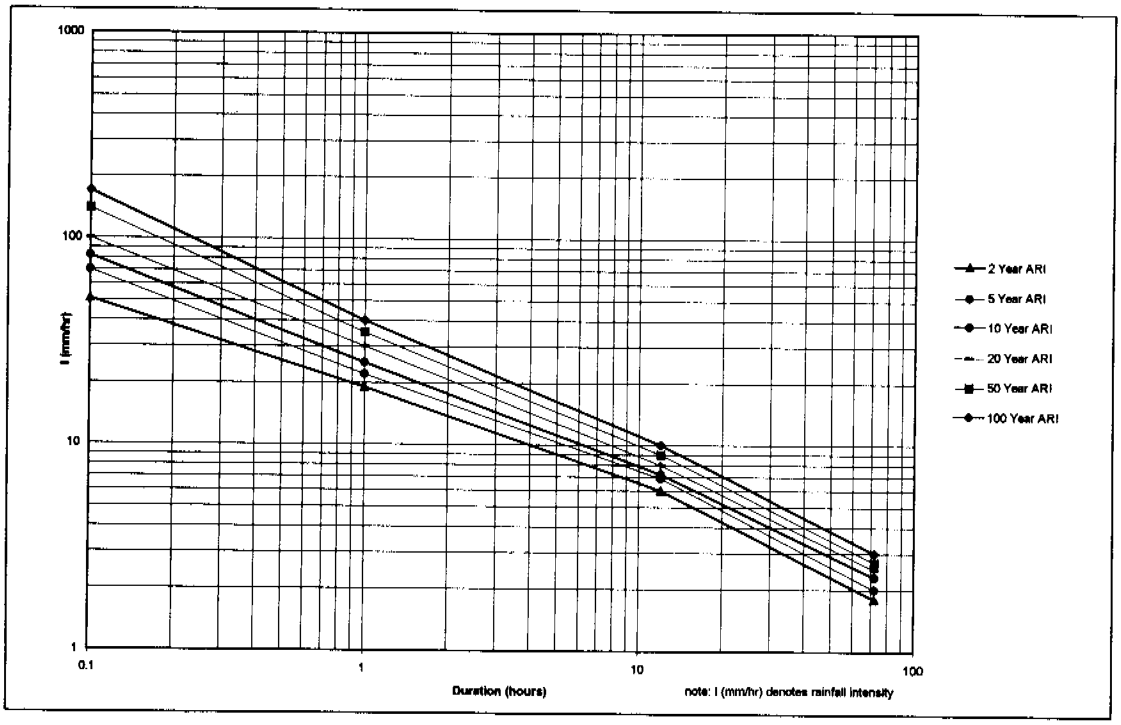

Figure 2.5 Annual recurrence interval intensity/duration chart for Queenstown (Pilgrim 1987)

Rainfall usually occurs as light rain or as a mist interspersed with less frequent heavier rain; winter rainfall generally exceeds summer rainfall. For an annual recurrence interval of two years, the one hour duration storm has an intensity of around 18 mm/h. The annual recurrence interval intensity/duration chart for Queenstown is shown in figure 2.5.

The pan evaporation record for the district is poor, providing only a few good years of continuous record; based on these data annual average pan evaporation is estimated to be around 750 mm, with daily evaporation ranging from less than 0.5 mm in June/July to 3.5 mm in January/February. Evaporation may exceed precipitation for only one or two months in the year. Annual potential evaporation of the region is considerably less than the annual rainfall with excess water being lost to groundwater or surface water discharging via the surface drainage network to Macquarie Harbour.

Although rainfall is the principal means of precipitation, snow and hail frequently occur above the 600 m level. Snow mainly falls in winter but may occur in any month at altitude. At lower elevations snow rarely persists, and there is no permanent snowline.

2.4 Geology

The host rocks of the Mount Lyell ore field lie towards the southern end of a 10–15 km wide belt of volcanic rocks which extends in a north-south direction from Hellyer in the north to South Darwin Peak about 25 km south of Queenstown (figure 2.6). This belt, known as the Mount Read Volcanics, is altered, folded and cleaved to varying degrees and comprises predominantly rhyolites, dacites and andesites, with basalts being relatively rare. The volcanic belt hosts not only the disseminated to massive copper rich ore bodies at Mount Lyell but also the massive polymetallic sulphide ore bodies at Hellyer, Que River, Rosebery and Hercules. Although relatively small in area, the high grade ores of the major deposits in the Mount Read volcanic belt make this belt one of the richest provinces of its type in the world.

The geology of the Queenstown area is dominated by feldspar–phyric lavas, and intrusive rhyolite and dacite of the Mount Read Volcanics. Several lenses of shale, sandstone and tuff are present, the largest being about 80 m thick (Corbett 1981). Overlying the groups of the Mount Read Volcanics are the siliciclastics of the Owen Conglomerate and the Gordon Limestone, periodically outcropping in the vicinity of Mount Lyell and Mount Owen.

The Mount Lyell ore field lies north-east of Queenstown in a complex sequence of felsic lava, breccias and tuff which are strongly altered and cleaved. The ore field is defined by a zone of sericitic and chloritic alteration and is up to 800 m thick (Soloman and Carswell 1989). There are several main ore types in the Mount Lyell ore field, including:

- disseminated pyrite and chalcopyrite in a silicate assemblage of mainly quartz, sericite, and chlorite;
- massive pyrite and chalcopyrite;
- lenses of pyrite, sphalerite, galena and chalcopyrite;
- bornite, chalcopyrite, chalcocite and phyllosilicate replacement; and
- native copper in goethite and clays.

The minerals in the ore field are believed to represent two main periods of mineralisation, Cambrian and post-Cambrian. Cambrian mineralisation probably resulted from fluids circulating at the junction of two major fault systems (Great Lyell Fault and Linda Fault Zone). Post-Cambrian mineralisation is believed to have been derived from solutions more

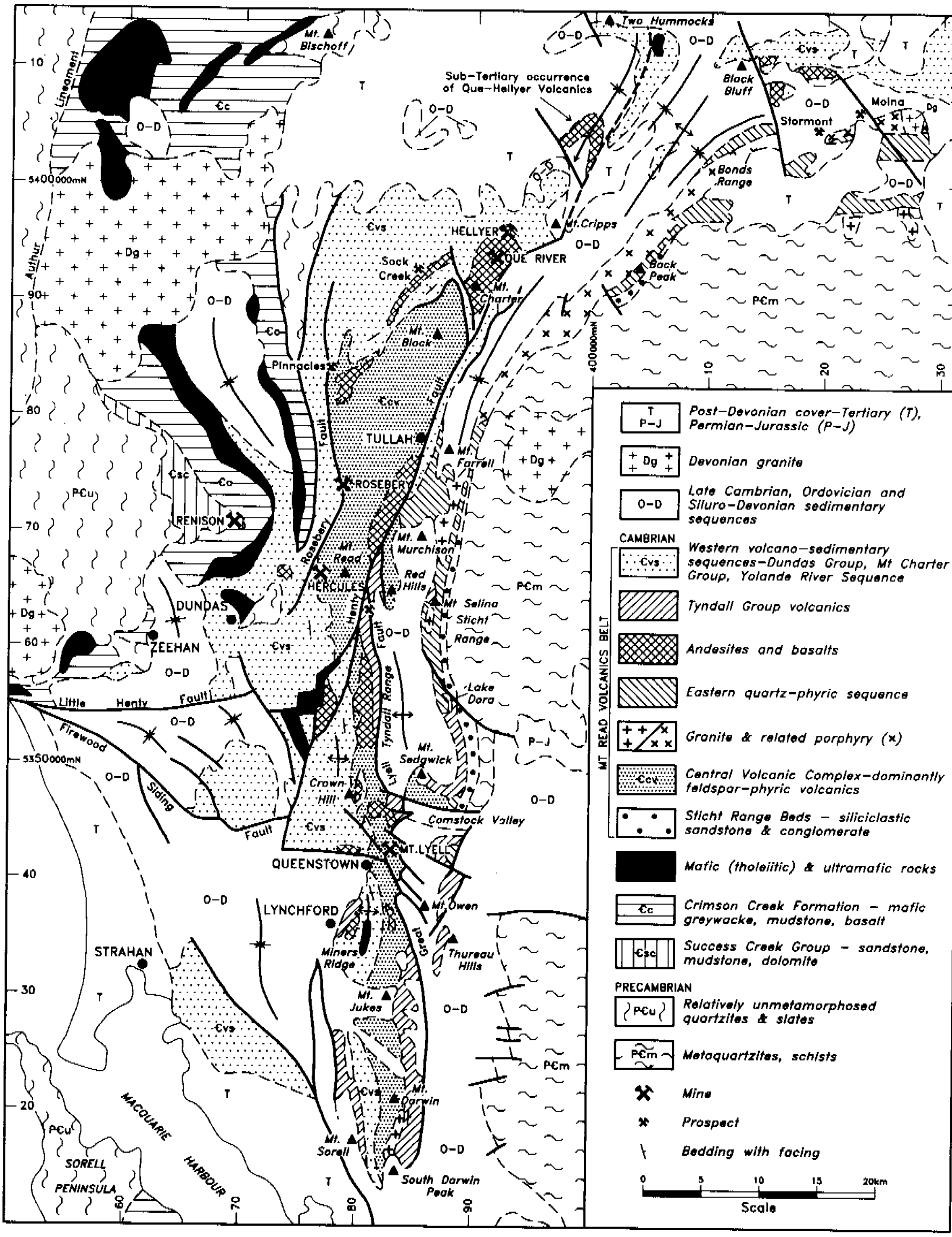

Figure 2.6 Geological setting of the Mount Lyell mining region (after Corbett and Soloman 1989) (reproduced with permission of the Geological Society of Australia Inc)

acidic and oxidised than those forming the Cambrian ores. The acid oxidising fluids are thought to be Devonian in age and are believed to have selectively dissolved copper from the Cambrian sulphide assemblages of the Mount Read Volcanics.

Some of the mineralised zones at Mount Lyell contain up to 49% pyrite. The high sulphidic nature of the mineralised assemblages represents a source of short and long-term environmental impact as a consequence of oxidation and acidic leaching.

3 A century of mining

Mining and processing operations had a considerable impact on the local and regional environment. This section briefly outlines the historical mining and processing operations and presents an overview of the environmental impacts.

3.1 Mining

The Mount Lyell region was the site of copper mining and processing on a continuous basis for 102 years from early 1893 to late 1994. Table 3.1 presents a summary of principal operations since 1896. The locations are shown in figure 3.1. The Mount Lyell Mining and Railway Company Limited (MLMRCL), a wholly owned subsidiary of Renison Goldfields Consolidated Limited, ceased operations on 15 December 1994. Mining recommenced in early 1995 when the Tasmanian Government awarded the Mount Lyell leases to a new operator, Copper Mines of Tasmania Pty Ltd (CMT), a wholly owned subsidiary of Gold Mines of Australia. CMT subsequently commenced re-development of the remaining ore resource. Processing ore recommenced in November 1995, with the objective of progressively increasing production to 3.5 million tonnes per annum. The results of pre-development exploration estimate the remaining resource to 1.3 million tonnes of copper and 1 million ounces of gold. Further exploration of the lease site is likely to increase the reserve of remaining resources.

In the early 1900s there were more than 40 companies operating in the Mount Lyell mining field. The mining operations were both surface and underground, resulting in six large open pits and over 100 adits. Support infrastructure included the townships of Queenstown, Linda, Gormanston, Crotty and Darwin, railways to Teepookana, Strahan and Kelly Basin on Macquarie Harbour, and smelting operations at Mount Lyell and Crotty.

In 1903, The Mount Lyell Mining and Railway Company Limited became the sole mining company in the region through the acquisition of its major rival, The North Mount Lyell Company and its associated assets (Crotty smelters, rail system to Kelly Basin and the Port of Pillinger). These facilities were subsequently closed in favour of the Mount Lyell smelters and the Abt railway to Teepookana and Strahan.

In recent years mining has been focused on the Prince Lyell orebody. Initially mined in the West Lyell open-cut, this near vertical ore body has been mined since 1978 below the open-cut using sub-level open stoping, with pillar extraction under cave mining method (figure 3.2). The ore was funnelled down ore passes to lower levels for road haulage to the crusher station situated on mining level 18. Primary crushed ore was transported to the surface via the Prince Lyell Shaft. An overland conveyor transported ore from the shaft to the mill for concentrating.

The Mount Lyell Mining and Railway Company Limited ceased its mining operation at the sixty series stoping level in the Prince Lyell Mine 300 m below sea level. In June 1995, Copper Mines of Tasmania committed to developing the remaining resource, with an estimated ten year mine life at a processing rate of 3.5 million tonnes per annum and a head grade of 1.45% copper and 0.5 g/t gold.

Open stoping of the Prince Lyell ore body promoted the percolation of rainfall falling within the catchment of the West Lyell open-cut, down through the caved material and broken ore to lower levels of the underground operation.

Table 3.1 The period of operation of the principal mines in the Mount Lyell mining region (estimates to 1991 from Flitcroft & McKeown (1992) updated to 1994 by Snowden (1994))

Mine	Period of operation	Mining type	Production				
			Ore (10^6 t)	Waste (10^6 t)	Copper (%)	Gold (g/t)	Silver (g/t)
Mount Lyell (Iron Blow) and South Lyell	1896–1929	open-cut	5.6	4.5	1.29	1.99	61.22
North Lyell	1896–1972	open-cut and underground	4.7	N/A	5.28	0.40	34.29
Royal Tharsis	1902–1905 1930–1937 1940–1959 1964–1966 1968 1972–1974 1976 1981 1985–1994	underground	2.0	none	1.56	0.49	2.77
Lyell Comstock	1913–1921 1929–1959	open-cut and underground	1.3	N/A	2.38	0.67	5.23
Crown Lyell & Twelve West	1931–1942 1953–1954 1959–1978 1980–1985	open-cut and underground	4.0	N/A	1.62	0.37	6.67
West Lyell open-cut	1934–1972	open-cut (largest above ground operation in the area)	58.3	47	0.72	0.25	1.66
Razorback	1964–1969		0.2	N/A	1.10	0.24	1.48
Cape Horn	1969–1987	open-cut	4.1	N/A	1.43	0.42	3.30
Prince Lyell	1969–1994	underground (continuation of the West Lyell open-cut operation)	31.0	none	1.29	0.40	2.91
Lyell Tharsis	1970–1977	open-cut and underground	0.7	N/A	0.94	0.27	4.85

Waste rock was generally placed around the perimeter of the open-cut mines and is present within most sub-catchments (see figure 3.3). These dumps contribute acidic drainage products, primarily heavy metals and sulphate, to the effluent water. The 47 million tonnes of waste surrounding the West Lyell open-cut is estimated to contain 0.17% copper, giving around 80 000 tonnes of copper metal resource (Gunn Metallurgy 1993).

The waste material from the West Lyell open-cut contains approximately 10% pyrite. The most significant metal contaminants are copper and iron with less significant quantities of aluminium, magnesium and manganese. Preliminary modelling has indicated that oxidation of the waste material is occurring throughout the dumps (ANSTO 1994a, 1994b). There appears to be no factor limiting the oxidation process, which continues at the maximum possible rate. ANSTO estimated that acid generation will continue for more than 600 years. Measurements have shown that approximately 130 tonnes of copper and 1300 tonnes of sulphate per year leach from a single 25 ha waste rock dump below the West Lyell open-cut. These loads

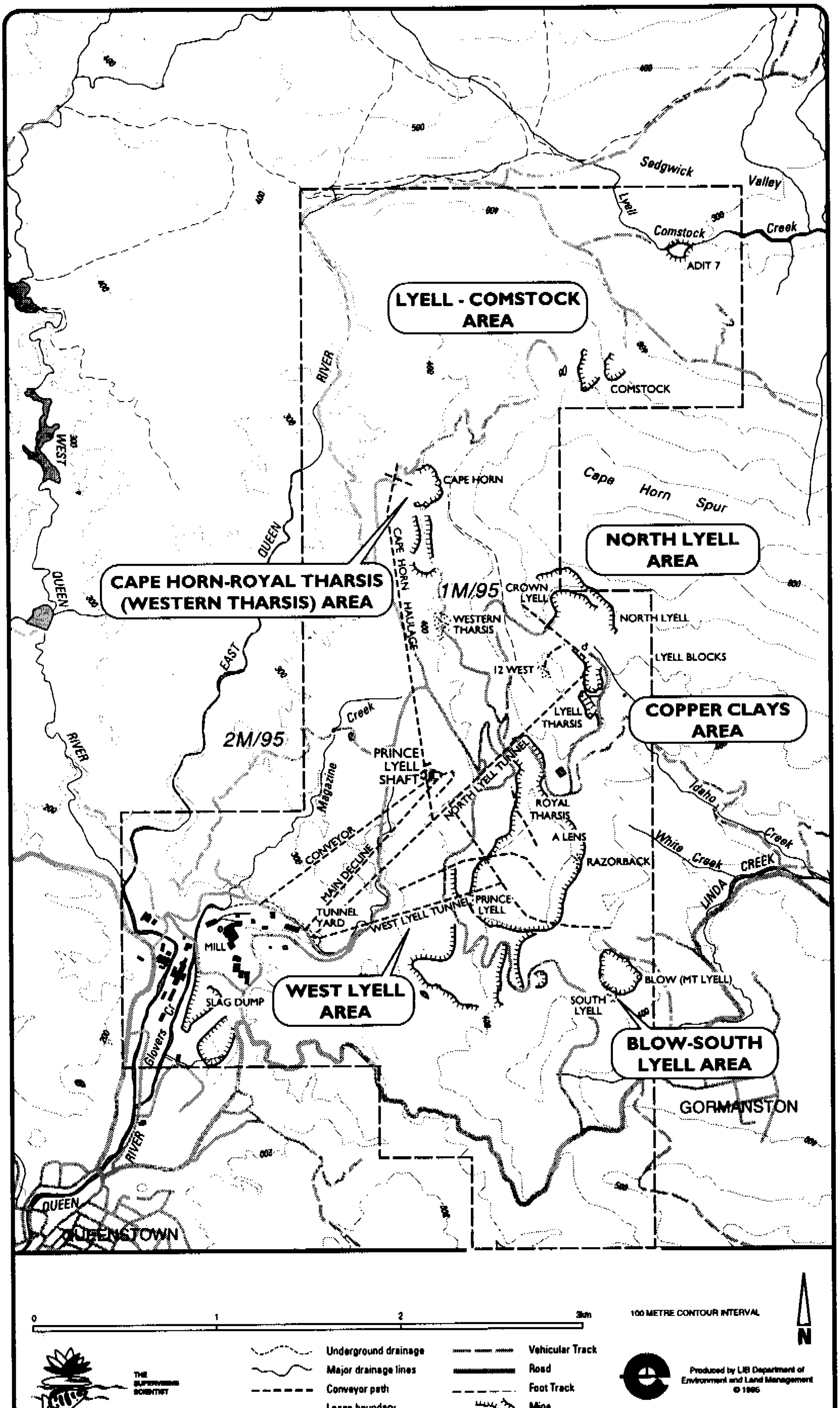

Figure 3.1 The principal historical mining operations in the Mount Lyell mining region

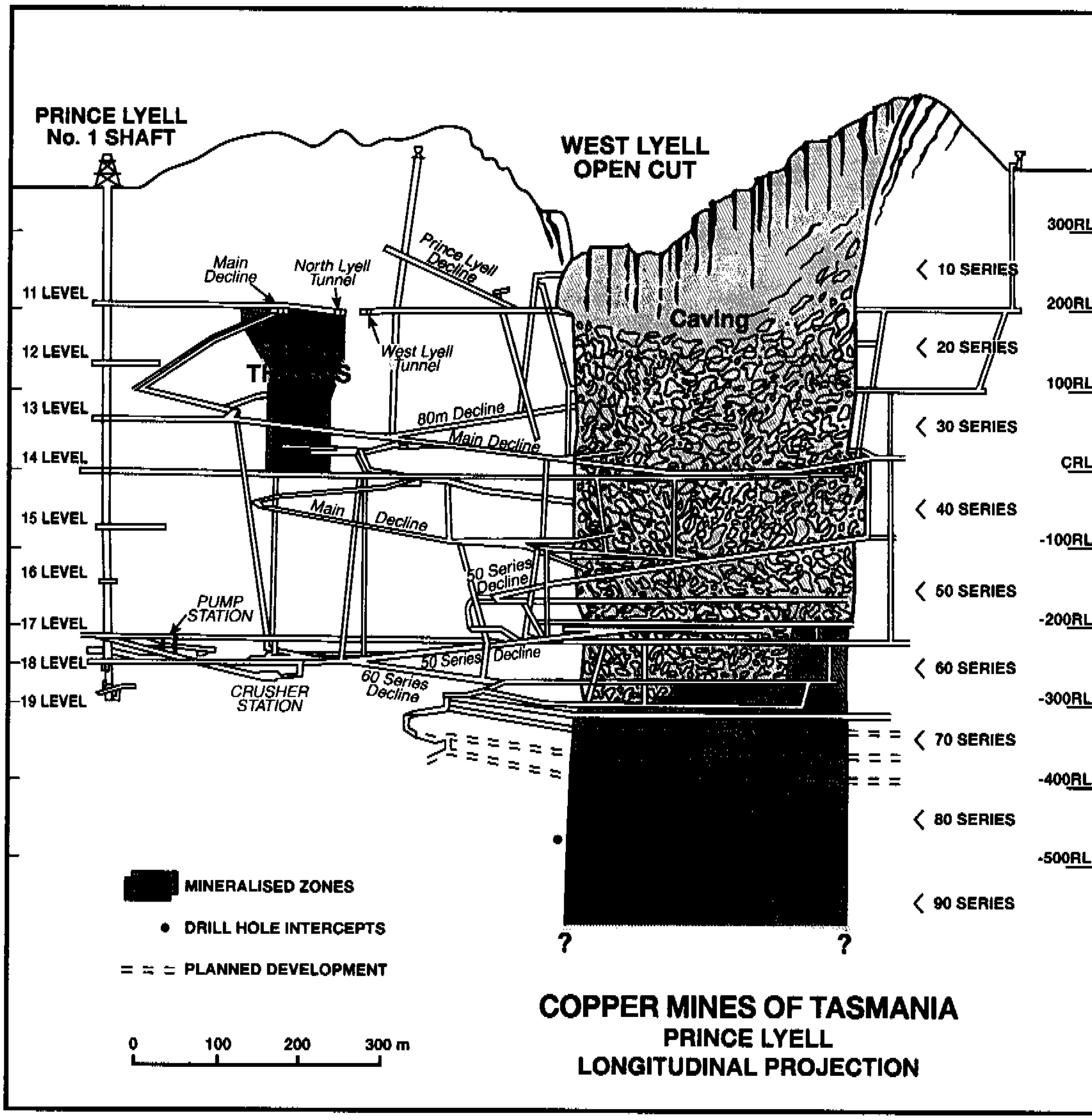

Figure 3.2 Longitudinal schematic of mining areas showing sub-level open stoping with pillar extraction under cave mining methods (after Atkinson 1982)

are expected to continue for around 20 years, after which they will gradually decrease to around 10% for an estimated 600 years. There are in excess of ten individual rock dumps over the lease area covering around 50 ha and containing approximately 53 million tonnes of rock material (EGI 1993).

3.2 Processing

In the early years of mining, appropriate technology for concentrating the copper minerals was unavailable, leading to the mining of high grade ore that could be shipped to Europe for direct smelting. Pyritic smelting, through the combustion of the iron pyrite contained within the ore, was developed and successfully implemented for the first time by the American metallurgist Robert Sticht with the commissioning of the first Queenstown furnace in 1896. Wood (1991) estimated that 200 000 tonnes of sulphur dioxide was discharged to the atmosphere annually during this phase of processing. An estimated six million tonnes of black siliceous slag was produced and stockpiled on site or discharged with tailings into the river system.

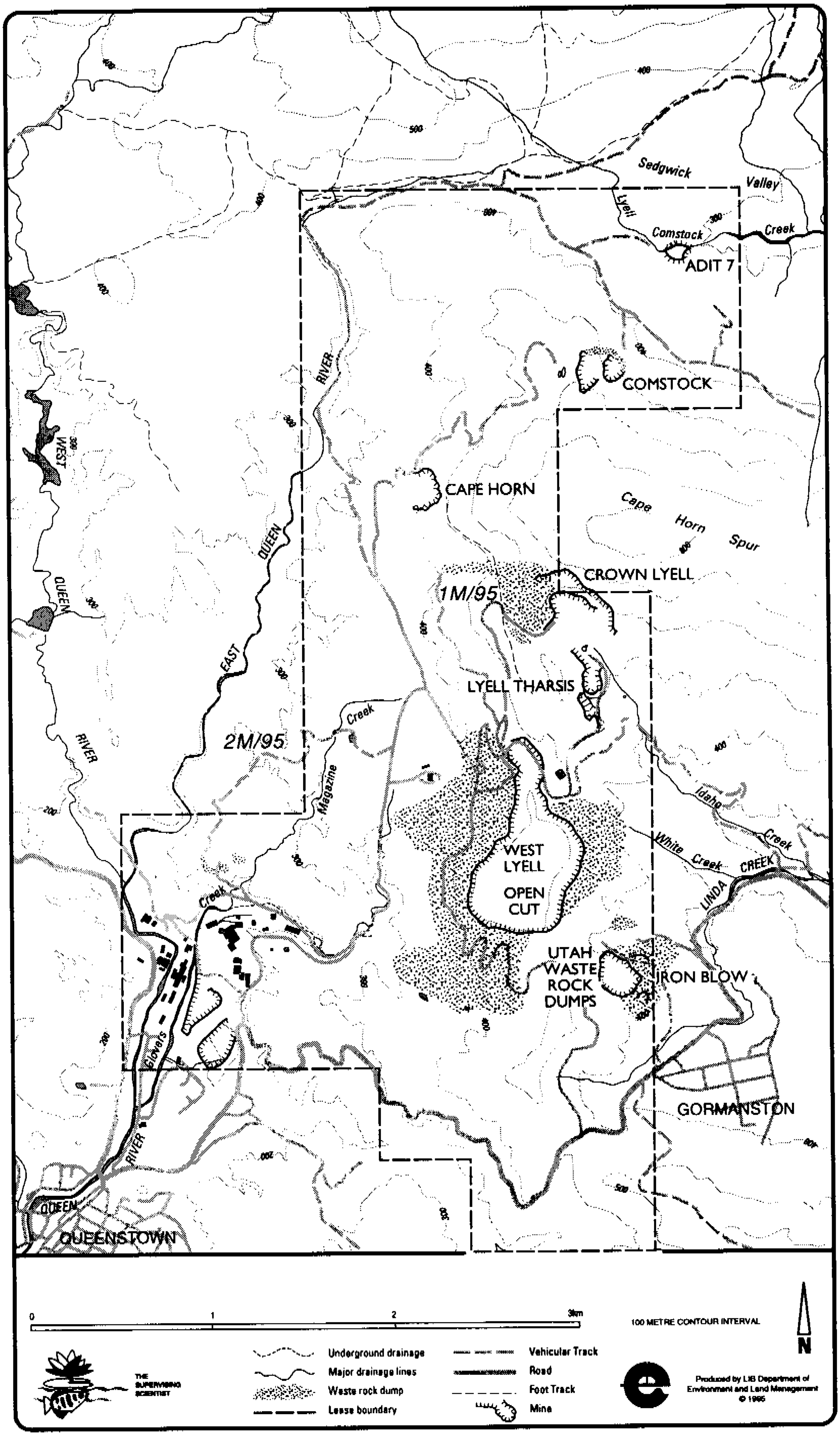

Figure 3.3 Location of waste rock dumps on the Mount Lyell Mining lease site

As pyrite grades in the host ore began to decline, alternative fuels were required to supplement the pyritic process and timber and coal replaced pyrite in 1904. Preconcentration of copper became necessary to maintain the viability of on-site smelting as the higher grade ore deposits were depleted. This was achieved through the introduction of flotation technology in 1922. Smelting operations at Mount Lyell ceased in 1969, after which concentrates of copper and pyrite were transported by rail to Strahan and later to Burnie (north coast of Tasmania) from where they were shipped to Japan for smelting. The ore processing methods are summarised in table 3.2 and tailings production is summarised in table 3.3.

Table 3.2 Ore process methods at Mount Lyell over the life of operations

Process	Period of application	Process	Period of application
Direct smelting	1893–1895	sintering plant to roast sulphur from the copper concentrate to fuel the smelters	1916–1934
Pyritic method	1896–1903	pre-concentration of ore via flotation followed by sintering before smelting	1922–1934
Semi-pyritic incorporating coal as the main fuel source	1904–1916	copper concentrate charged into the furnace in the raw state	1934–1969

Table 3.3 Tailings production rates (MLMRCL 1990)

Period	Tailings production rates (t/yr)
1922	commenced discharge to Queen River at 100 000
1928–1935	increased from 100 000 to 500 000
1935	increased from 500 000 to 1 500 000
1935–1980	fluctuated between 1 500 000 and 2 000 000
1980–1994	steady at 1 500 000
Total	approximately 97 000 000

The absence of other downstream water users, combined with difficult topography and high rainfall, resulted in tailings being discharged into Haulage Creek from where they were transported down the Queen and King Rivers to Macquarie Harbour. Co-disposal of slag to the river system also commenced, as the tailings were able to mobilise the slag which had previously been disposed of on site. Figure 3.4 shows the history of tailings and slag discharge to the Queen River. The slag dump is located adjacent to Haulage Creek and contains around seven million tonnes of material grading 0.4% copper. The tailings were discharged with a median solids content exceeding 300 000 mg/L and a pH around 9.5. This high pH acted to buffer the acidic mine water, surface waters discharging from the remainder of the site, and the acidic leachate generated from tailings beaches in the riverine systems. The tailings also provided a large surface area for the adsorption of metals leaching from the site. Approximately 100 million tonnes of tailings were disposed of to the riverine environment in this manner. The new mining operator, CMT, constructed a tailings dam located in the Princess Creek catchment with sufficient capacity to contain all the tailings generated from a processing through-put of 3.5 million tonnes per year for 60 years.

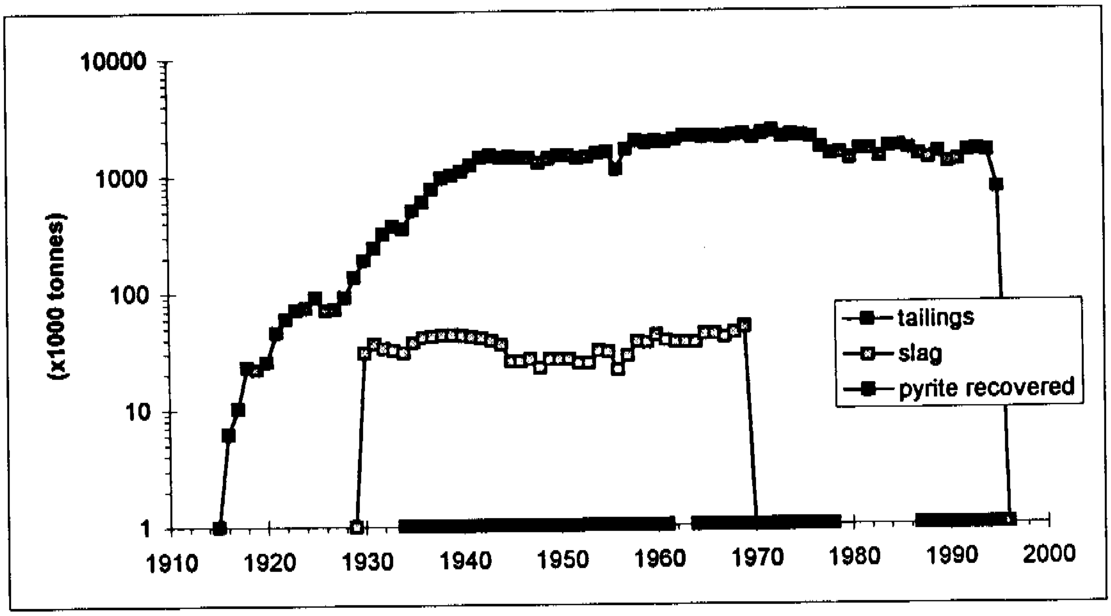

Figure 3.4 History of tailings and slag discharge to the Queen River (after Locher 1995) (reproduced with permission of the CRC for Catchment Hydrology)

The specific gravity of the tailings was measured by Locher (1995) and found to be approximately 2.9. A chemical analysis of tailings material derived from the Prince Lyell load is given in table 3.4 (MLMRCL 1990). Note that pyrite was removed from the tailings for varying lengths of time during the mining operation, depending on market demand. The recovery rate of pyrite was about 50% at peak efficiency, thereby reducing the iron and sulphur content percentage presented in table 3.4 by half.

Table 3.4 Chemical analyses of Mount Lyell tailings (when pyrite was not being removed from the ore)

Analyte	Percentage	Analyte	Percentage
SiO_2	58	S	6.0
Al_2O_3	10	CaO	0.6
Fe	11	others	14.4

The median tailings particle size determined by the MLMRCL (1990) using the hydrometer method was 26 microns which is over double that determined from a sample collected in 1993 by Locher (1995) using a Malvern Laser Scatterer. Generally, as milling technologies improved the particle size of the tailings decreased – from a median size of around 70 microns in 1916–1944 to 30 microns in 1980–1995. Slag was discharged to the river system at a reasonably consistent median particle size of around 1.6 mm (Locher 1995). Slag disposal ceased in 1969 with the cessation of smelting at the site.

3.3 Water management

Water management is a critical component for mine operation as well as for environmental protection, water being the primary medium for the transport of pollutants and a necessary component in acid generation. The median tailings discharge rate was about 200 L/s with the water for processing being sourced from the three dams on the West Queen River. In dry periods the West Queen River supply was supplemented through controlled discharge from

Lake Margaret. Water used within the mine was pumped from the East Queen River at 30 to 40 L/s into two mine head tanks above the Prince Lyell Shaft. Additional storage capacity was provided by the Utah Tanks which stored overflow from the Prince Lyell head tanks. From the head tanks water was directed underground for use throughout the mine for production purposes (MLMRCL 1994b). Mine water is also derived from precipitation falling in the West Lyell open-cut and percolating down into the underground workings. Mine de-watering pump discharge from the Conveyor Tunnel shows a relationship with rainfall with an approximate 24 hour delay.

Mine dewatering was, and will continue to be, an essential component of the mining operation allowing access to ore at depth and is a significant component of the overall water and solute balance for the site. Rainfall drains through fractures in the country rock and the mine workings where contact with pyritic material (at around ten percent sulphide) produces water with an acidity ranging between pH 2.5 and pH 3.5 and median concentrations of copper of 150 mg/L. The intensity of vehicular traffic within the mine, blasting and cave collapse, and high flows of water, result in a high solids content with particle sizes ranging from colloidal to around 6 mm. Water within the mine drains to mining level 18 (RL–246.5) from where it is transferred to settlers to remove the suspended solids through the addition of anionic flocculants at approximately 1 kg of flocculant per 1000 m^3 of mine water. Settled 'mud' is evacuated via a displacement system using water pressure from the Prince Lyell head tanks to push settled mud to RL200 and out of the Conveyor Tunnel. During MLMRCL operations mud was displaced up to eight times per day. Clear water overflows the settlers into a 4 million litre storage pond from where it is pumped via a rising main to the Conveyor Tunnel and discharged into Haulage Creek.

Historical average discharge data are considered poor, with estimates derived from pump hours. The pumps have variable performance with a theoretical maximum of 120 L/s and recorded flows to 65 L/s. Reported mean pump rates vary from 50 L/s (GH&D 1994) to 85L/s (MLMRCL 1994b). The current system comprises four pumps each with a design capacity of 120 L/s. Projections of solute loads to the Queen River are critically dependent on good flow estimates. Recently measured flow data by CMT suggest that the previous estimates were significant underestimates, with a more appropriate average annual discharge rate approaching 90 L/s and flows following heavy rainfall approaching 240 L/s. Typical discharge rates in response to rainfall for the North Lyell tunnel are shown in figure 3.5.

Mud collected within the settlers during active mining was displaced at a maximum rate of 20 L/s into the Conveyor Tunnel from where it flowed with the mine dewatering water into Haulage Creek. The solid component of the mud is estimated to be generated at an average rate of 130 t/d (CMT 1995). After the MLMRCL ceased its operations mud displacement occurred on average two to three times per day.

The mud contains considerable quantities of copper and other heavy metals, sufficient for CMT to propose processing the mud as a resource. The historical monitoring program undertaken by MLMRCL to estimate both concentrations and loads leaving the Conveyor Tunnel comprised a monthly grab sample and an estimation of flow. Due to the variability in heavy metal concentrations, depending if mud was being displaced or not, grab sampling and an estimation of flow would be unlikely to provide sufficient information to truly estimate load or concentration over time. The Conveyor Tunnel discharge represents the single greatest point source of pollution discharging from the lease site comprising in excess of 60% of the mass discharge of copper from the site. The variability of concentrations over time are addressed more fully below.

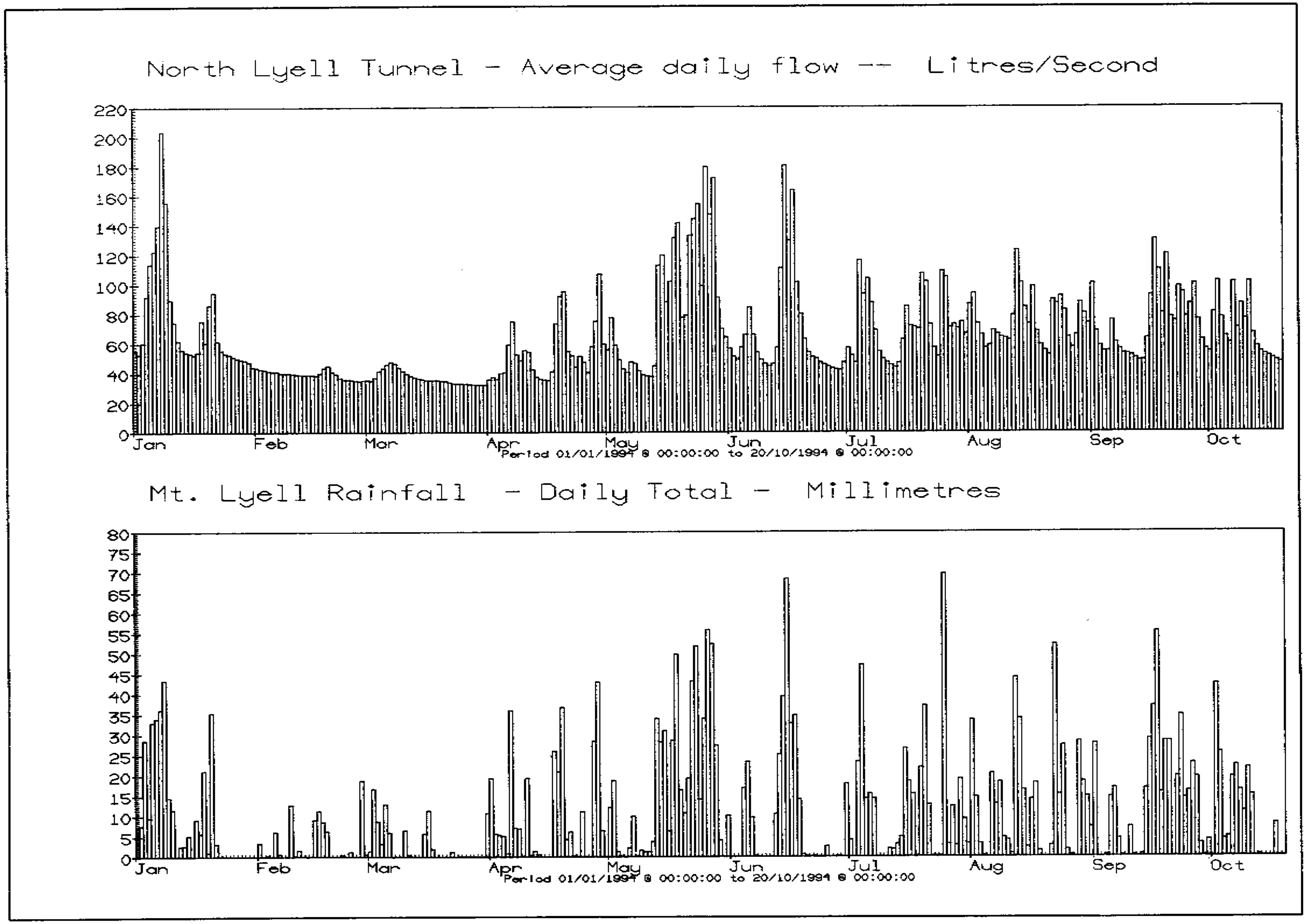

Figure 3.5 Site rainfall and discharge rate from the North Lyell Tunnel (HEC supplied data)

4.0 Environmental impacts

A century of mining development caused substantial disturbances within the Mount Lyell lease site and surrounding areas, downstream riverine systems and Macquarie Harbour. In the initial years, impacts to the environment resulted from mine access, harvesting timber for fuel, mine support and housing, dramatically increased incidence of bushfires, smelter gasses and the discharge of process waste into the Queen and King Rivers system. When operations closed in 1994 an estimated 100 million tonnes of tailings and smelter slag had been discharged into the Queen River with impacts downstream to Macquarie Harbour. Pyritic smelting resulted in an estimated annual discharge of around 200 000 tonnes of sulphur dioxide into the atmosphere. Acidic rainfall, which had a devastating effect on surrounding vegetation, was the direct result of high rainfall of the region, the position of the smelters at the bottom of a steep sided valley, and frequent temperature inversions within the valley. This section summarises the regional and site impacts of the mining operation.

4.1 Land and vegetation disturbance

The lease site contains large open-cut voids, substantial quantities of overburden and unconsolidated waste rock dumps and slag from smelting (figure 3.3). Support infrastructure for mining was installed and included the towns of Linda, Gormanston, Queenstown and Crotty, with associated roads and railways linking this area to the coast and towns to the north. The Lyell highway to Hobart was completed in 1932 and the Murchison highway through to Burnie was completed in 1963. Prior to the completion of the roads the only access to this region was via the rail system from Macquarie Harbour. In 1914 Lake Margaret hydro-electric power station was built to supply the mining operations with power.

Prior to mining, the region supported temperate rainforest dominated by Myrtle (*Nothofagus cunninghammii*), with Sassafras (*Atherosperma moschatum*), Leatherwood (*Eucryphia lucida*) and Celery Top Pine (*Phyllocladus aspleniifolius*) being of secondary importance. At higher altitudes, King Billy Pine (*Athrotaxis selaginoides*) may become a co-dominant species with Huon Pine (*Lagarostrobus franklinii*) dominant in the riverine areas (Kirkpatrick 1977). Temperate rainforest is characterised by a relatively low species diversity and limited understorey, comprising Laurel (*Anopterus glandulosus*), Musk (*Olearia argophylla*), Native Pepper (*Drimys lanceolata*), Waratah (*Telopea truncata*) and Horizontal (*Andopetalum biglandulosum*). Groundcover is typically moss and ferns of which the dominant species is *Dicksonia antarctica.*

Blackwood (*Acacia melanoxylon*) and Eucalyptus species (principally *Eucalyptus obliqua* and *Eucalyptus nitida)* tend to dominate in more frequently disturbed areas, particularly drier ridges subject to fire. Temperate rainforest has not developed the recovery and reproductive features of fire tolerant species and is consequently susceptible to the effects of fire and unable to easily re-establish. A particularly hot burn may destroy the rainforest, particularly at higher altitudes where more fire resistant sclerophyllous and acacia species dominate after burning.

Vegetation coverage has been dramatically altered over large areas in the Queenstown region due to the combined effects of logging, wild fires and sulphur dioxide emissions. Once the vegetation was cleared, the high rainfall and steep topography resulted in the erosion of soil and sub soil horizons. An estimated 10 million tonnes of topsoil has washed from the mine site into the Queen and King Rivers (MLMRCL 1990). The acidic mist formed from sulphur dioxide and the light rains of the region, combined with regular fires and a lack of soil, suppressed regeneration of vegetative cover. Immediately around Mount Lyell, both tree and understorey vegetation was removed, producing a 'lunar landscape' of bare hills displaying the colours of the primary rock and weathered soils. Wood (1991) estimated from aerial photographs that around 15 km^2 were completely devoid of vegetation in the early 1950s with a further 25 km^2 substantially denuded (figure 4.1). The bare hills were vulnerable to erosion and little top soil remains outside valleys today.

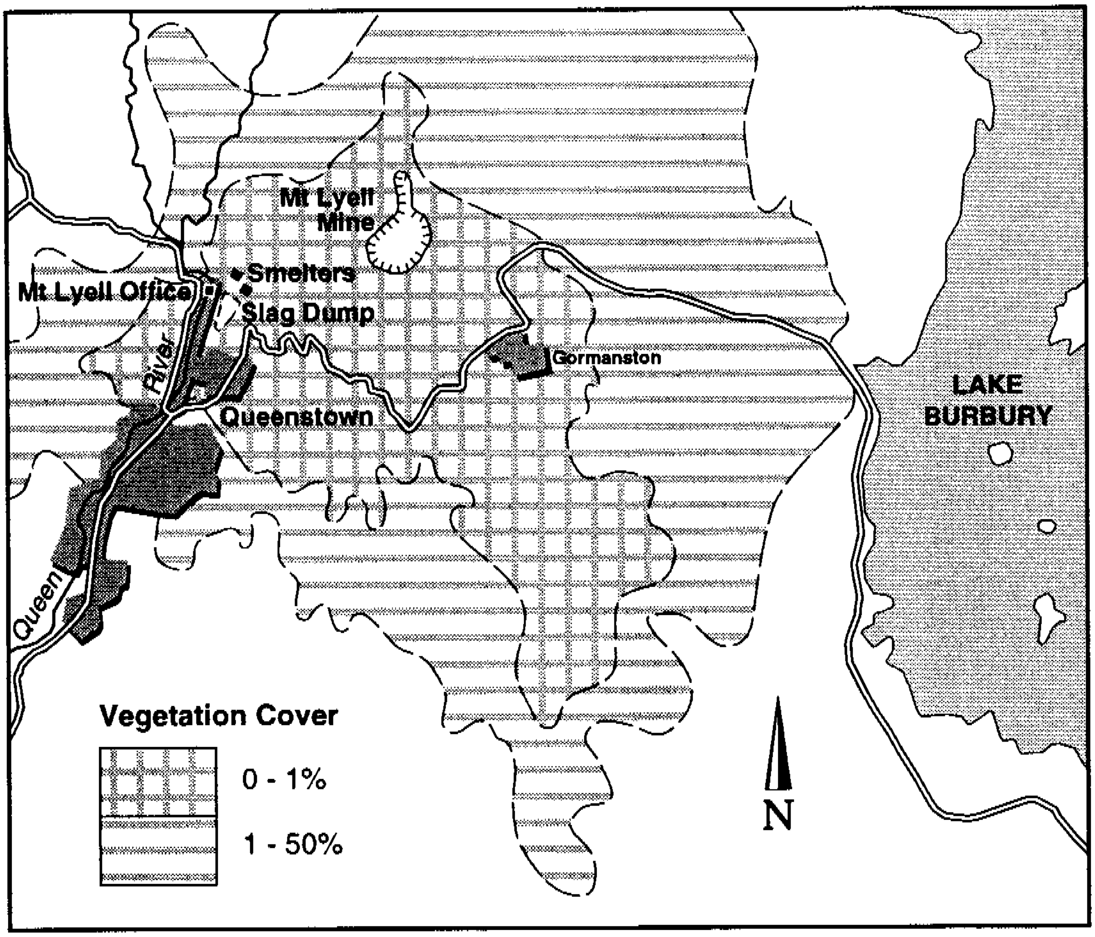

Figure 4.1 The extent of vegetation impact in 1953 (after Wood 1991)

The local community has lived with this environment for many years, in some cases third generations, and feel that the environment has unique aesthetic qualities worthy of preservation. This is reflected in the nominating of the landscape on the interim register of the National Estate as the 'Queenstown Hills Cultural Landscape'. The feeling is so strong that on 14 October 1993, through direct lobbying by the community, the Premier of Tasmania instructed MLMRCL to cease its revegetation program (Hay 1994). MLMRCL Annual Site Plan 1994/95 states that the re-implementation of a revegetation program is imperative to:

- enhance the aesthetics of the lease site environment;
- establish a stable vegetative cover to reduce the potential for pest plant invasion;
- reduce the erosion potential thereby improving the stability of the landscape;
- reduce the long-term sediment loads to the rivers;
- decrease the acid generating potential for diffuse (pyritic outcrop) sources.

Revegetation trials were conducted on the Mount Lyell lease site by MLMRCL together with an assessment of soil condition on the site and its relationship to revegetation. Prescriptions for establishing native species on the site were determined through these trials (MLMRCL

1991), although this is poorly documented. A PhD study assessing soil contamination and researching potential revegetation methods for the lease site is currently being finalised (Dawson submitted) and will provide more scientifically-based prescriptions for revegetation on the lease site.

Over a century of mining, approximately 37 million cubic metres of tailings and slag were discharged into the Queen River. Due to its relatively steep grade of 0.011 the Queen River is essentially a conduit for the transport of tailings to the King River with little or no long-term storage of tailings. This material in-filled the valleys of the King River, to a depth of four metres at Teepookana and nine metres at a location half way between Teepookana and the river mouth giving a total estimated storage of 7–10 million tonnes of mine waste (Locher 1995), and produced a delta-like formation at its mouth. When tailings discharge stopped in 1994, the delta had a surface area of 250 ha above mean sea level in the Harbour (its development is shown in figure 4.2) and is estimated to contain 100 million tonnes of material comprising erosion products and 85% of all mine wastes discharged over its century of operation. The deposited tailings have also reduced the navigability of the King River at its mouth, allowing access only to shallow drafted small boats. This is a significant change from the days when all equipment for the Mount Lyell mining operation was transported by sea going vessels six kilometres up the King River to the port of Teepookana. During the first six months after tailings discharge ceased, most of the tailings in the Queen River were washed into the King River.

The discharge of tailings material also produced point bars and sediment banks along the lower reaches of the King River. Locher (1995) estimated that sediment banks contained 3.5 million tonnes of material in 1993. A large portion of the vegetation of these areas is now dead, as a result of the deposition of sediment. The tailings material also represents a considerable source of leachable copper, iron, aluminium, manganese and zinc. The impact of these metals on aquatic life within the Harbour is being examined through projects 9 and 13 within the MLRRDP (Appendix A).

4.2 Aquatic ecosystem

The undisturbed portions of the Queen and King River catchments support a diversity of organisms including drifting invertebrates. Lake et al (1977), Swain et al (1981) and Fulton (1989) recorded Nematoda, Arachnida, Crustacea and Insecta, 59 taxa of benthic invertebrates, fish and platypus in the King River, upstream of the confluence with the Queen River. All these studies concluded that macro invertebrate fauna were reduced in both diversity and abundance below pollution inputs of Comstock Creek and Linda Creek.

Project 7 (Appendix A) of the MLRRDP program was designed to assess the status of the aquatic ecosystem of the Queen and King Rivers downstream of mining operations. Preliminary surveys have identified extremely limited populations of aquatic invertebrates within areas disturbed by tailings disposal and acid drainage, with only three taxa being identified.

4.3 Water quality

4.3.1 Introduction

This section summarises in tabular form the flow and water quality data available from the mine site, the Queen and King Rivers, and Macquarie Harbour. The data available for each station are listed in Appendix B.

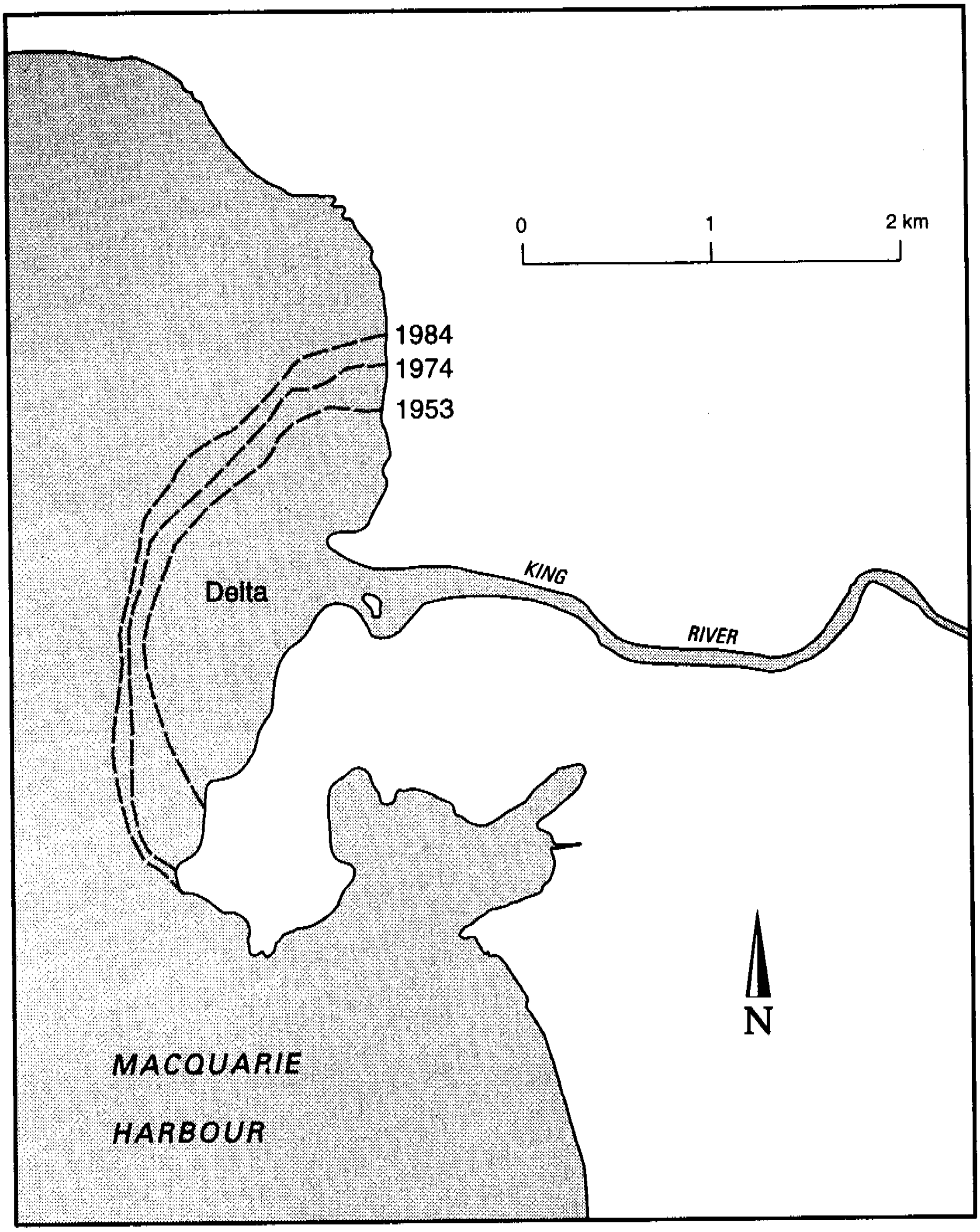

Figure 4.2 Delta development over a thirty year period (after EGI 1993)

The water quality in streams draining undisturbed catchments of the region is slightly acidic within the range pH 4.5–5.5, with a low alkalinity, very low soluble salts, low metals, suspended solids and sulphate, and a high organic content that gives the water a brown coloration, like tea. Water quality data for the King River above Comstock Creek prior to any contamination from mining activity, and the Upper Southwell River to the north, are representative of catchments free of mining activities and are presented in table 4.1. Only analysis for total metal concentrations are available for the King River above Comstock, however, in these undisturbed catchments it is likely that total and dissolved metal concentrations are generally similar. Comparisons by the HEC indicate 90% of the total metal is in the dissolved state (Mounter 1993).

Table 4.1 Typical water quality for streams draining undisturbed catchments (derived from HEC and DELM data)

Parameter	King above Comstock (total metal–mg/L)			Upper Southwell River (dissolved metal–mg/L)		
	Mean	Max	Min	Mean	Max	Min
Copper	0.002	0.005	<0.001	<0.0005	0.0006	<0.0005
Iron	0.2	0.35	0.07	0.16	0.25	0.06
Sulphate	<1	2	<1	<2	5	<2
Zinc	0.002	0.003	0.001	<0.02	0.09	<0.02
Manganese	0.015	0.018	0.003	<0.03	0.08	<0.03
Lead		0.005	<0.001	0.003	0.01	0.001
Suspended solids	2	5	1	4	7	2.5
pH	6.4	7.3	5.9	6.9	7.9	6.1
Conductivity (μS/cm)	39	64	29	45	56	28

The Mount Lyell mining operation has had a dramatic impact on the water quality of both the mine area and catchments downstream of the mine. Effluent that discharges from the mine site consist of discrete point sources and diffuse surface contributions to runoff and can be generally grouped into the following categories:

- abandoned underground and surface mine workings;
- drainage from waste rock dumps;
- mine dewatering from the active Prince Lyell Mine;
- tailings discharge; and
- miscellaneous point sources such as sewage, and waste disposal sites.

Apart from tailings and the few miscellaneous sources, most of the effluent sources have a pH ranging between 2.5 and 3.5 with elevated concentrations of toxic heavy metals, particularly aluminium and copper. If concentrations of metals are not reduced, they will continue to impede the establishment of aquatic ecosystems in the downstream river system.

Of interest in determining the potential for recovery of the affected catchments is the maximum concentrations of toxicants and the period that concentrations of contaminants exceed toxic threshold limits for aquatic organisms. Total loads of contaminants to the river–harbour system are also an indicator of the potential continuing threat to this system and is discussed in section 4.3.4.

4.3.2 Flow data

Both the local and regional hydrology have been altered by mining within the Queenstown area, in particular, land clearance which created the greatest impact on the local hydrography. Less water is retained in the catchment to infiltrate into the soils. The increased runoff has greater erosive energy and is able to carry greater suspended loads than storm runoff events prior to land clearance and mining.

On a regional scale the environmental impacts of the increased water runoff are expected to be small. The disturbed area of around 50 km^2 represents approximately 40% of the Queen River catchment and less than five percent of the King River catchment (area above confluence with Sailor Jack Creek).

Two hydro-electric power schemes have been constructed in the area which also influence regional hydrology. Lake Margaret was constructed on the Yolande River in 1914 to power mining and processing operations at Mount Lyell. Water is periodically directed to the West Queen mill supply dams from Lake Margaret in times of drought.

Modifications to the flows in the King River have occurred through by construction of the Crotty Dam to create Lake Burbury in 1991. The King River power scheme provides power to the Tasmanian grid which is generated at John Butters Power Station. The Power Station generally releases water during daylight hours at an optimum rate of between 70 and 80 m^3/s.

The total annual discharge for the King River has remained about the same (56 m^3/s), however, controlled discharges from Lake Burbury have modified the flow duration characteristics of the King River downstream of Crotty Dam. Flow duration information calculated at the Sailor Jack Creek monitoring station on the King River is presented in figure 4.3. The data comprise of four years prior to construction of Crotty Dam and six years post construction. Although the period of record is short and therefore unlikely to demonstrate the true magnitude of the change, the data show that the minimum flow rate increased (from around 1 m^3/s to 3 m^3/s) and the period of high flows decreased (flows greater than 1000 m^3/s have reduced from 0.3% to 0.1% of the period of record). Flood frequency data for Crotty prior to the dam construction are provided in figure 4.4.

The Queen River is the largest sub-catchment of the King River with a mean annual discharge of 5.2 m^3/s. Based on six years of data from the Queen River, five kilometres south of Queenstown, the 1:5 year flood is around 100 m^3/s and the 1:100 year flood is between 100 and 300 m^3/s (confidence intervals for the relationship are wide due to the limited data).

Until 1993, there was no continuous measurement of the flow rate within the Queen River catchment on the mine lease site. Previously, MLMRCL obtained visual estimates for flow on a monthly basis for a number of sites (see figures 4.5 and 4.6), although the accuracy of this method is limited. In 1993, the HEC (on behalf of MLMRCL) installed flow monitors at four sites comprising Haulage Creek, above the West Lyell Tunnel (station 5); East Queen River, above West Queen River (station 11); Haulage Creek, below Magazine Creek and prior to tailing discharge (station 9a); and West Lyell Tunnel (station 7). Flow monitoring was undertaken at these sites by MLMRCL until mine closure in December 1994 and subsequently continued by DELM and CMT.

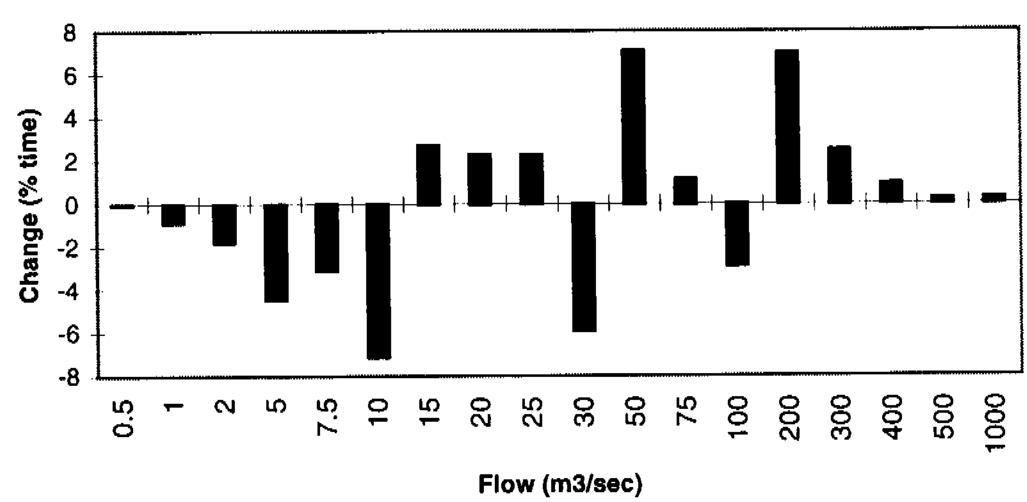

Figure 4.3 Difference in percentage of time that flow was within a given range (pre-construction minus post-construction data) at Sailor Jack Creek (HEC supplied data)

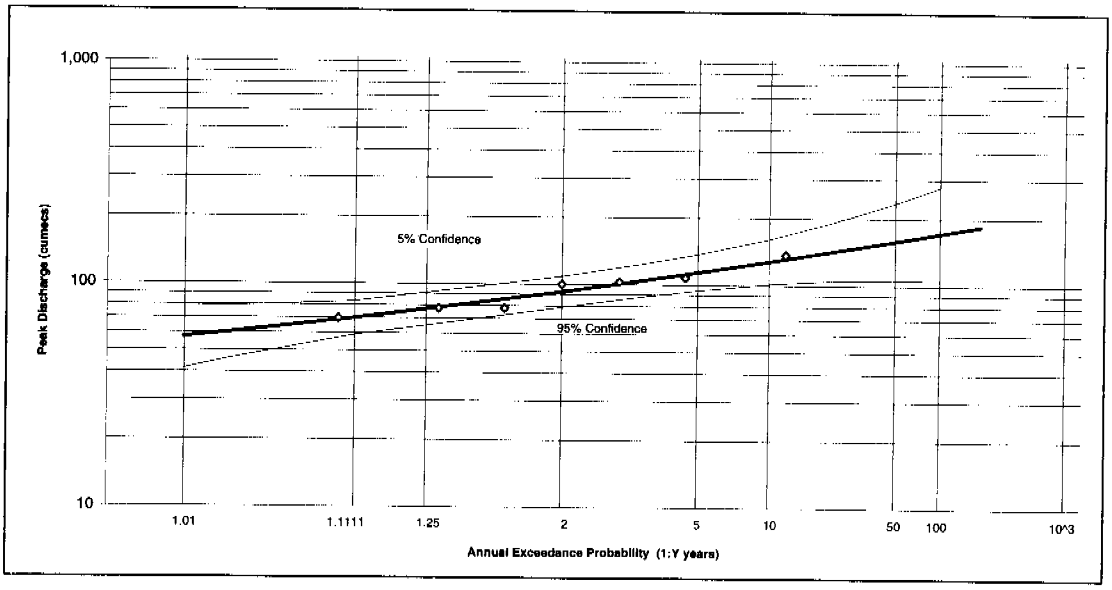

Figure 4.4 Flood frequency curve for the King River at Crotty, prior to dam construction (HEC supplied data)

Of these continuously monitored stations, a generally reliable dataset has been established with the exception of station 9a, one of the most important stations in respect to determining mass load contributions to the Queen River. The HEC recorded median flow for station 9a is 397 L/s (8/93–8/95), but this figure may be an over-estimate, as the actual flow derived from totalling respective inputs into Haulage Creek at this site gives a median value of 225 L/s (table 4.2).

Table 4.2 Water balance for Haulage Creek

Monitoring station	Median Flow (L/s)
Haulage Creek above tunnels (st 5)	54[1]
West Lyell Tunnel (st 6)	4[2]
North Lyell Tunnel (st 7)	56[3]
Conveyor Tunnel (st 8a)	92[4]
Magazine Creek	19[5]
Haulage Creek below Tunnels (st 9a)	225[6]

1 median flow from continuous record (5/93–10/94)
2 median of visually estimated MLMRCL flow data; flow is consistently low with little variation
3 median flow from continuous record (5/93–10/94)
4 continuous record (4/95–10/95)
5 EGI flow determined from catchment area
6 derived from sum of all median flow inputs listed above

GH&D (1994) estimated the median flow for Haulage Creek at station 9a to be 227 L/s, which is calculated by subtracting the contribution of tailings discharge (177 L/s) from the recorded median flow between May 1993 and October 1993 (404 L/s). However, this figure is in fact under-estimated because tailings were actually discharged into Haulage Creek below station 9a and thus the tailings discharge value should not have been subtracted from the recorded value. Coincidentally, the altered median flow of 227 L/s approximates to the flow estimated from totalling respective inputs into Haulage Creek.

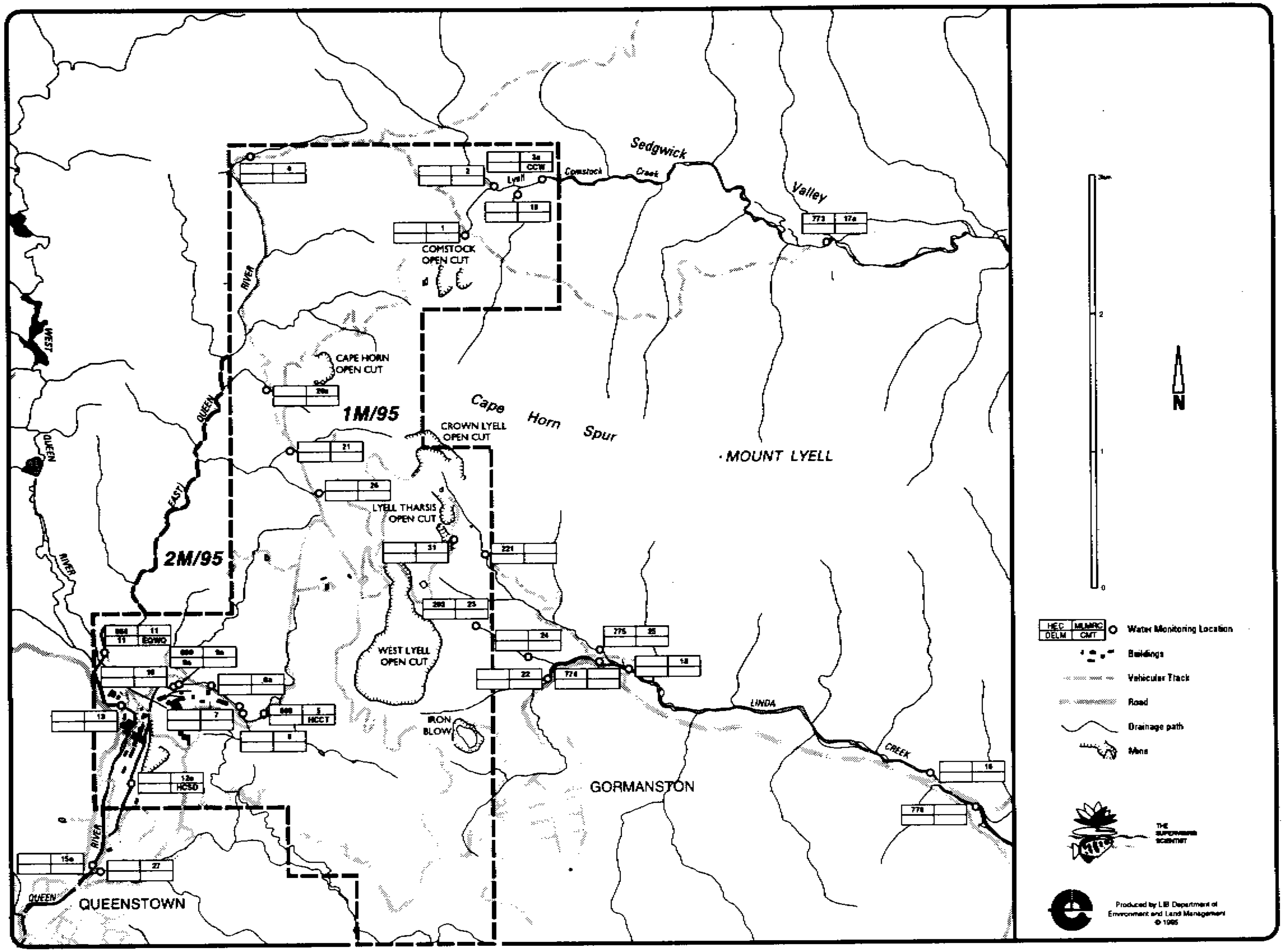

Figure 4.5 Monitoring stations in the Queenstown area

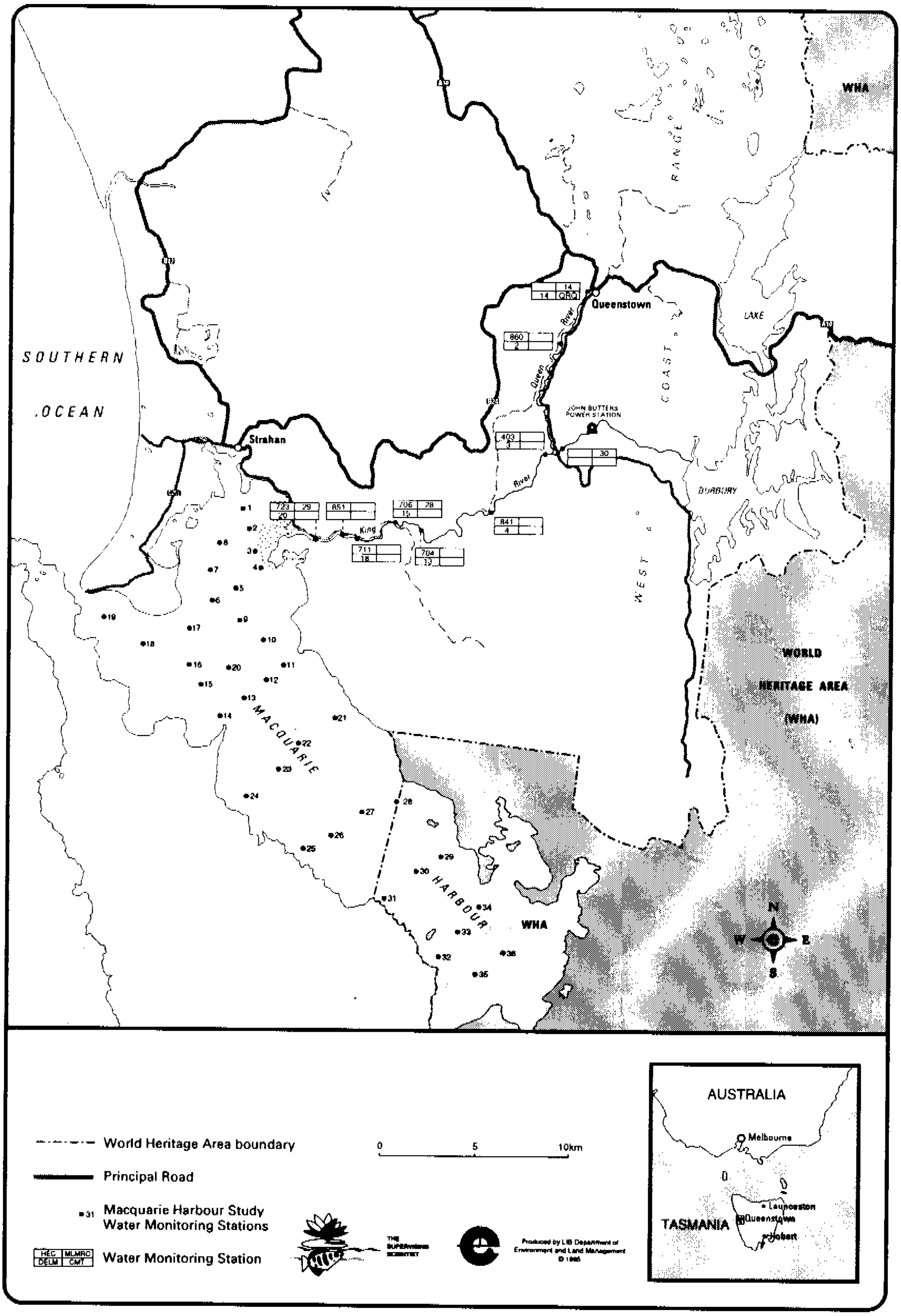

Figure 4.6 Regional water monitoring stations

Given the discrepancy in the flow rates for station 9a, the HEC Water Resources Department conducted a water balance on Haulage Creek in order to recalibrate the flow monitoring stations. This balance is reproduced in table 4.3. The recordings verify that the record at station 9a is reading approximately half the existing rating. It has been suggested that flow readings at station 9a have been consistently difficult to quantify due to the high velocities in the discharge pipe and the possible diversion of drains in the catchment.

Table 4.3 HEC water balance for Haulage Creek (October 1995)

Monitoring station	HEC station number	Flow (L/s)	Flow (%)
Haulage Creek above tunnels (st 5)	669	29	12
West Lyell Tunnel (st 6)	10670	5	2.1
North Lyell Tunnel (st 7)	670	63	26.1
Conveyor Tunnel	11670	99	41.1
Magazine Creek		14	5.8
Leakage and Pickup (estimated)		20	8.3
Unaccounted		11	4.4
Haulage Creek below tunnels (st 9a)	680	241	100

A continuous flow record was established at the Conveyor Tunnel (station 8a) by the HEC on behalf of CMT in April 1995. This has provided the most accurate quantification of underground mine water discharges to date. The median and mean flows have been calculated at 92 L/s (4/95–10/95) and 81 L/s (4/95–6/95) (CMT 1995). Although the period of record is short, these figures provide the most accurate representation of the actual flow from the Conveyor Tunnel. The fluctuating flow is buffered by a 4 ML storage tank on mining level 18. The storage tank is serviced by three pumps, usually only two of which are operational.

Previously, MLMRCL flow values from the Conveyor Tunnel were estimated from limited pump operational times and the likely pump rates. The latter could vary between 120 L/s and 70 L/s depending on the period since the pumps were last overhauled. MLMRCL records since 1990 suggest an average pump rate of 40 L/s. EGI (1993) and GH&D (1994) both estimated 50 L/s as the median discharge from the Conveyor Tunnel while a mean discharge rate of 83 L/s has been noted by MLMRCL (1994a).

Flows from the Conveyor Tunnel are typically a function of a number of variables including:

- period since pump overhaul and pumping efficiency;
- frequency of mud displacement;
- duration of pump downtime; and
- period of single or dual pump operation.

As a result of the above variables and the short record of accurate monitoring, a typical flow for this station is difficult to quantify.

The Hydro-Electric Commission installed continuous flow recorders at key sites within the Linda, Comstock and King River catchments in 1986. These sites comprise:

- station 775, Idaho Creek above Linda Creek;
- station 773, Comstock Creek above King River;
- station 776, Linda Creek above King River; and
- station 781, King River above Comstock.

The flow data from these sites have been used to derive a median flow catchment area relationship in the Comstock and Linda sub-catchments (equation 1 and figure 4.7).

$$\text{FLOW} = (19.3+5.4\times\log \text{AREA}) \times \text{AREA} \qquad \text{Equation 1}$$

where FLOW is in L/s and AREA in km^2

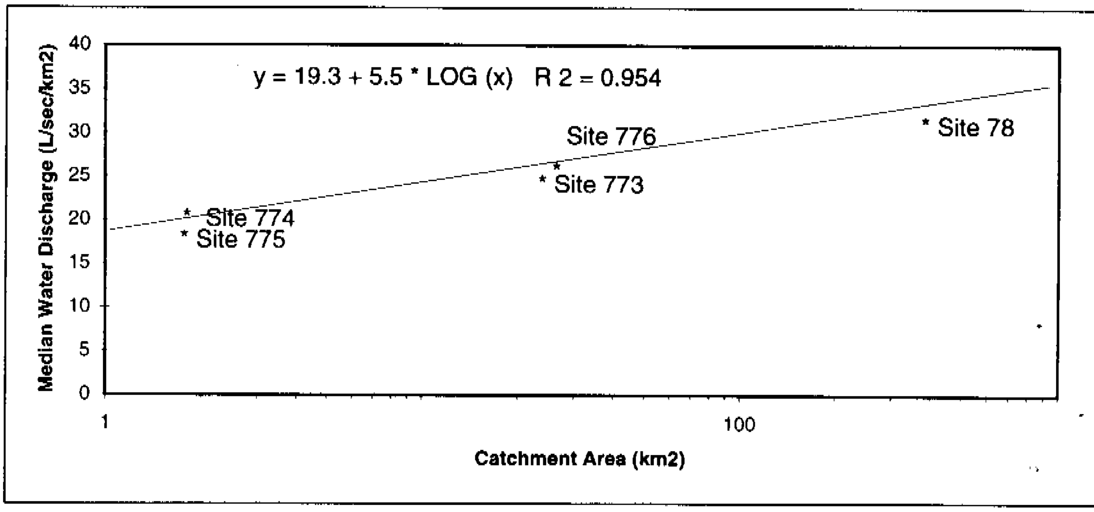

Figure 4.7 Catchment area versus median water discharge for the King River and its tributaries

The relationship indicates that as the catchment area increases the normalised median water discharge increases. In applying this relationship to catchments of the Queen River, it has been assumed that the runoff and rainfall characteristics of the King River sub-catchments are relatively consistent throughout the King River catchment. All flow data recorded by the HEC can be considered reliable and of good quality for the Comstock and Linda catchments, although the period of record is short.

The sub-catchment areas on the mine lease site were re-mapped for this study to take account of roads and drains directing water outside their topographic divides. These sub-catchments are presented in figure 4.8. The HEC flow equation mentioned above was applied to these sub-catchments and the calculated flows compared with other flow estimates (table 4.4).

Based on the size of each sub-catchment and assuming an annual rainfall of 2500 mm and 100% runoff, EGI (1993) estimated mean stream flows from each sub-catchment within the Comstock–Linda–King River system and the Haulage–Queen River system. Using a conversion factor of 0.33 (EGI 1993), the mean flows were converted to median flows. Given that discharges from adits and tunnels are not directly related to rainfall events and are more a function of groundwater inflows and pumping rates underground, EGI assumed that median flows from underground sources are the same as the mean measured flow. EGI developed this flow derivation method in response to the uncertainty associated with the existing MLMRCL data and the lack of data for some major input streams into the Haulage Creek–Queen River system

Table 4.4 shows a combination of mean and median flow values. Median flow represents the central value of a ranked flow dataset. Where the dataset has a limited number of values, the median value is not affected to the same degree as the mean value by the addition of an extremely low or high value to the dataset. However, where the dataset is non-Gaussian, the median value is not particularly useful in that it cannot be used to calculate total flow.

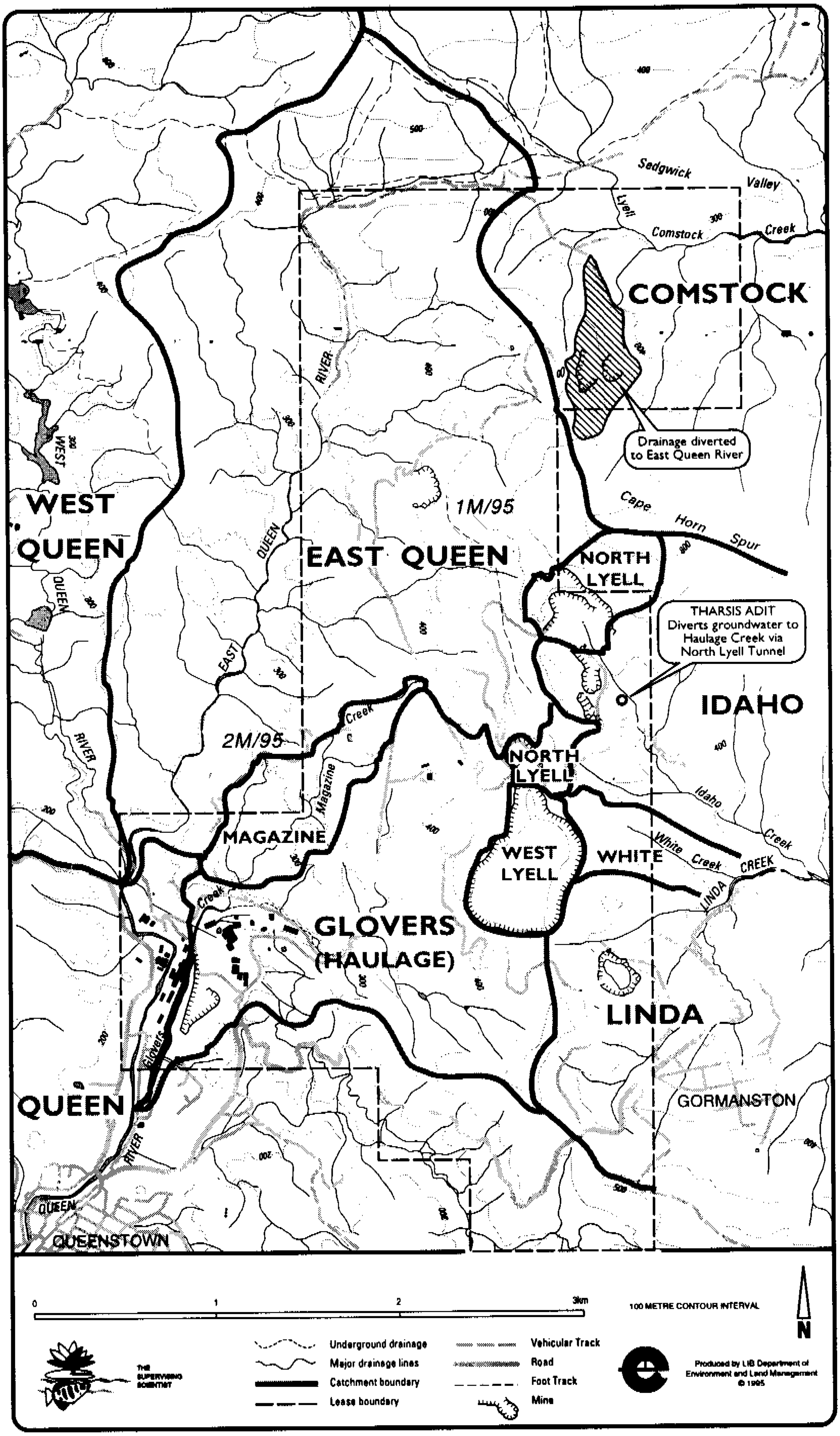

Figure 4.8 Sub-catchments of Mount Lyell

Table 4.4 Flows from sub-catchments on the Mount Lyell mining area

Sub-catchment	Area (km²)	Estimated mean flow[2] (L/s)	Estimated median flow[3] (L/s)	Estimated median flow[4] (L/s)	Measured mean flow[5] (L/s)
Linda Creek above Idaho Creek (774)	2.3	170	57	50	184
Idaho Creek above Linda Creek (st 775)	2.3	182	60	50	150
Linda Creek	14.73 14.40[6]	1165 1140	390 380	375 365	975
Lyell–Comstock Creek above King River (st 773)	13.80 13.58[6]	1095 1075	365 360	350 335	1310
Haulage Creek at Queen River	2.87	225	75	65	
East Queen River (before Comstock diversion)	8.35	660	220	200	
East Queen River (after Comstock diversion) (st 11)	8.56[6]	680	225	210	268
Haulage Creek at tailings discharge point, surface catchment (st 9a)	1.92	150	50	40	
Haulage Creek at tailings discharge point, effective catchment[1]	3.32				
Magazine Creek	0.58	58	19	10	
Haulage Creek above West Tunnel (st 5)	1.67	120	40	35	54

1 includes redirected drainage to the North and West Tunnels and Conveyor Tunnel but excludes the water sourced from the mine header tanks (30 L/s)

2 estimated flow, assuming annual rainfall of 2500 mm and 100% runoff (EGI 1993)

3 estimated mean flow divided by 3 (EGI 1993)

4 estimated from HEC FLOW equation

5 HEC installed flow monitors

6 area post Comstock diversion

EGI (1993) used median flow values on the basis that '...in terms of water quality within a river system, it is often median flow, rather than mean flow, that is more important'. It is assumed by this statement that EGI has taken the median value to represent the 'typical flow'.

Flow duration analysis data for HEC station 773 (table 4.5) was taken from Mounter (1992). These data were used to calculate median and mean flow values for the HEC stations in the Comstock valley. The following techniques were used to calculate median and mean flow values:

- median: percentage of time in each range was cumulated over the ranked ranges and the central value of the range associated with 50% of time was selected as the median value; and

- mean: the central value of the range was multiplied by the percentage of total time within the range to give a total discharge for the range. The total discharge for each range were summed and divided by 100 to give the mean.

Comparisons of median and mean flow values are found in table 4.6

The data in table 4.5 show that the flow distributions are right skewed with half of the total flow occurring in about 80% of the time. Based on these data, total flows calculated from median values would underestimate the actual total flow by up to 500%. The percentage of time in a flow range and the total flow within each range for the HEC station 775 are presented in figure 4.9.

Table 4.5 Flow duration analysis data for HEC station 773 (after Mounter 1992)

Flow range (L/s)	Flow value (L/s)	Time (%)	Cumulative time (%)	Total flow (L)	
0–30	15	2.31	2.31	35	
30–50	40	1.72	4.03	69	
50–70	60	5.22	9.25	313	
70–100	85	7.41	16.66	630	
100–150	125	10.15	26.81	1268	
150–200	175	7.72	34.53	1351	
200–300	250	10.94	45.46	2734	
300–400	350	6.88	52.34	2408	Median
400–600	500	8.45	60.80	4227	
600–800	700	5.59	66.39	3914	
800–1000	900	4.19	70.58	3774	Mean
1000–2000	1500	12.70	83.28	19053	
2000–3000	2500	6.55	89.83	16363	
3000–5000	4000	5.82	95.65	23292	
5000–7000	6000	2.20	97.85	13212	
7000–10000	8500	1.28	99.13	10880	
10000–15000	12500	0.64	99.78	8050	
15000–20000	17500	0.14	99.91	2380	
			Total	114000	

Table 4.6 Median and mean flow values for the HEC stations 773, 774 and 775

Station	Description	Catchment area (km^2)	Median flow (L/s)	Mean flow (L/s)
773	Comstock above King	14.0	350	1100
774	Linda above Idaho	2.3	50	150
775	Idaho above Linda	2.3	35	200

4.3.3 Water chemistry data

Water chemistry datasets were provided for this study by the HEC, DELM and MLMRCL. The data vary widely between datasets in terms of size, locations sampled, analytical techniques used and parameters analysed.

In its investigations for the construction of the King River Power Station, the HEC undertook detailed investigations of water quality and metal loads that would enter Lake Burbury from the Comstock and Linda Creeks. Parameters analysed by the HEC vary from station to station with generally only the major elements being analysed. There is a lack of detailed analysis of some key parameters including calcium, magnesium, sodium, potassium, aluminium and total organic carbon (TOC), all of which influence water chemistry.

The DELM data involve two discrete sets of data: one from The Macquarie Harbour–King River Study (Koenken in press) and the Mount Lyell Shutdown Intensive Monitoring Program (DELM 1995).

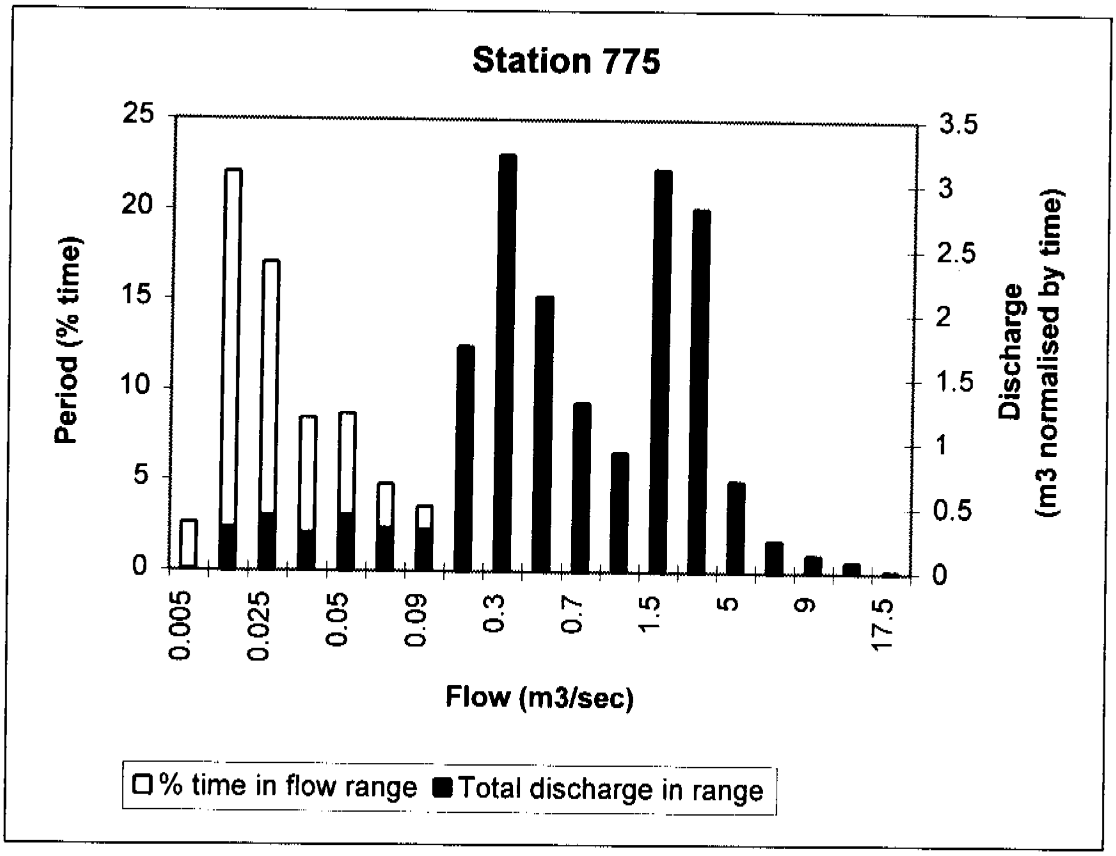

Figure 4.9 Percentage of time in a flow range and total flow within each range for HEC station 775

The Macquarie Harbour–King River Study was initiated in February 1993 and has involved periodic water and sediment sampling of 36 locations in Macquarie Harbour and three locations in the King River over a three year period (Koehnken in press). Typical parameter values for water from two locations within the Harbour during the period of tailings deposition can be seen in table 4.7 (see figure 4.6 for station locations). The last column in table 4.7 presents preliminary data for the first few months after the cessation of tailings discharge. The data are a summary from the DELM Mount Lyell Shutdown Intensive Monitoring Program (see discussion below).

Table 4.7 Macquarie Harbour water quality (total copper–mg/L)

Parameter	Macquarie Harbour station 2			Macquarie Harbour station 9			Macquarie Harbour station 27, post tailings[2]		
	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
Copper	69	464	2.3	38	166	1	23	87	2
TSS[1]	18	26	14	16	27	0.5	12	22	2.5

1 Total suspended solids

2 Post December 1994 when tailings discharge ceased at MLMRCL

The data indicate dilution of King River water in Macquarie Harbour with increasing distance from the mouth.

The DELM Mount Lyell Shutdown Intensive Monitoring Program was undertaken from December 1994 to May 1995 in response to the closure of the MLMRCL operations. A total of seven locations on the lease site and in the Queen and King Rivers were monitored either at four hourly intervals or daily over a period of five months. Samples were analysed for pH, copper, iron, manganese and aluminium.

The MLMRCL undertook a monitoring program on, and downstream of, the lease site as a part of a regulatory compliance and voluntary monitoring program. A total of 33 stations were monitored periodically (typically monthly) for a range of metal species and other parameters. Similar to the HEC dataset, key parameters such as calcium, magnesium, sodium etc were never analysed. Data from some stations show infrequent sampling and a few sites were sampled only once or twice. A number of stations were sampled on a continuous monthly cycle throughout the five year period of monitoring. A majority of these were regulatory compliance monitoring sites required by DELM. Table 4.8 shows the median and mean concentration of dissolved metal species and other parameters from these stations. See figures 4.5 and 4.6 for locations of monitoring stations.

For all stations, the mean value for zinc was found to be at least two orders of magnitude greater than the median value. A review of the data showed for consistent dates the analyses appeared to be reported as µg/L rather than the usual mg/L, although the stated units were mg/L. These values were corrected by dividing by 1000 prior to recalculating the arithmetic means.

Analyses of the tailings discharge (station 10) showed mean copper and iron values significantly greater than the median values. A review of the raw data confirmed that these values matched those in the database in which copper values prior to mid 1991 were in the order of 0.5 mg/L, after which the data became erratic with values in excess of 600 mg/L. However, after mid 1991 it would appear that total and filtered analyses were mixed in the same column under the heading 'copper'. As the data prior to mid 1991 were very inconsistent the authors approached the laboratory which analysed the samples with a query on their accuracy. The laboratory indicated that the analytical technique prior to 26/8/91 was unsuitable for analysis of tailings and all data prior to this date should be discarded.

The mean value for copper at station 11 was reduced from 4.1 to 1.3 by the removal of a single data point having a value of 135 mg/L. Cross checking with the raw data showed that this entry was incorrect. Due to the number of anomalous data values and inconsistencies in the data and in the absence of apparent trends (except for station 5), it is considered that median values are likely to be more representative of the 'typical' water quality at each monitoring station.

All waters draining the mine area (that were tailings free) contain little suspended solids; are acidic; and analyses for total and dissolved copper are in the same order of magnitude (figure 4.10). Stations 3a and 11 drain catchments that contain overburden rock associated with the mining of Comstock and Cape Horn, respectively. In 1991, water draining from adit 5 into Comstock Creek (station 3a) was redirected into the East Queen River. Just above station 11 there is an uncharacterised source of waste material that produces acidic seepage into the East Queen River. The key water quality parameters for stations 3a and 11 for the period of record are presented in figures 4.11 and 4.12.

The water quality discharging from the upper catchment area of the mine site was determined at station 5 on Haulage Creek (figure 4.13). At station 5 the suspended solids are relatively low, around 10 mg/L, with copper fluctuating around 100 mg/L. Prior to the water reaching the tailings discharge point, just below station 9a, it receives additions from the West Lyell Tunnel (station 6), North Lyell Tunnel (station 7), and mine water and mud from the Conveyor Tunnel (station 8a). The addition from Magazine Creek, the last input prior to the

Table 4.8 Median and mean concentrations of total copper, dissolved metal species (mg/L), flow (L/s) and other parameters calculated from MLMRCL data. Mean values are bracketed.

Station	Fe	Cu(T)	Cu(D)	Zn	Mn	SO_4	pH	TDS[1]	TSS[2]	Flow
3a Comstock Creek below Adit 7	5.07 (12.2)	1.21 (2.9)	1.03 (2.08)	1.61 (3.7)	1.87 (3.1)	40 (95)	3.4 (3.6)	124 (193)	18 (43.8)	98[3]
5 Haulage Ck above West Lyell Tunnel	777 (995)	83 (94)	82.5 (84)	5.9 (5.2)	46 (49)	6430 (6085)	2.4 (2.5)	11350 (13750)	14 (26)	54[4]
6 West Lyell Tunnel	223 (500)	13.4 (15)	14 (13)	4.7 (4.1)	38 (38)	2100 (3770)	2.9 (2.8)	4000 (4413.1)	68 (75.2)	4[5]
7 North Lyell Tunnel	319 (335)	53 (59)	54 (54)	4.6 (3.4)	21 (21)	1655 (1840)	2.8 (2.7)	7020 (2500)	7 (31)	56[3]
8a Conveyor Tunnel	246 (394)	152 (140)	134 (140)	16.6 (11.1)	167 (175)	3995 (4030)	2.8 (2.9)	7020 (6980)	853 (4240)	50[6]
9a Haulage Ck above tailings discharge	421 (410)	107 (120)	89.6 (89.9)	9.3 (8.9)	120 (95)	3975 (3760)	2.7 (2.7)	6890 (6700)	565 (13940)	405[7]
10 Pure tailings before discharge	0.13 (22)	0.3 (76)	0.09 (0.14)	0 (0.03)	0.1 (0.1)	389 (366)	9.1 (9.5)	481 (525)	315000 (230000)	177[8]
11 East Queen River above West Queen River	6.5 (9.2)	1.4 (1.3)	1.3 (1.3)	0.4 (0.66)	0.6 (0.7)	75 (70)	3.3 (3.5)	131 (131.8)	10.5 (16.4)	268[4]
12a Haulage Ck at Slag Dump	145 (260)	137 (154)	42 (33)	5.1 (8.7)	50 (60)	1840 (2030)	3.6 (3.6)	3284 (3279)	92100 (117775)	
14 Queen River at Queenstown	51.6 (57)	10.9 (14)		1.82 (132)	20.55 (24)	769 (755)	3.8 (3.8)	1320 (1365)	7500 (33250)	890

1 total dissolved solids

2 total suspended solids

3 calculated from catchment area post diversion works

4 median flow from continuous monitoring at HEC station 664 (5/93–10/94)

5 median of visually estimated flow; data of poor quality

6 estimated from MLMRCL records

7 median flow at continuous records at HEC station 680 (5/953–10/94)

8 derived from tailings discharge at 200 L/s at 25% solids by weight

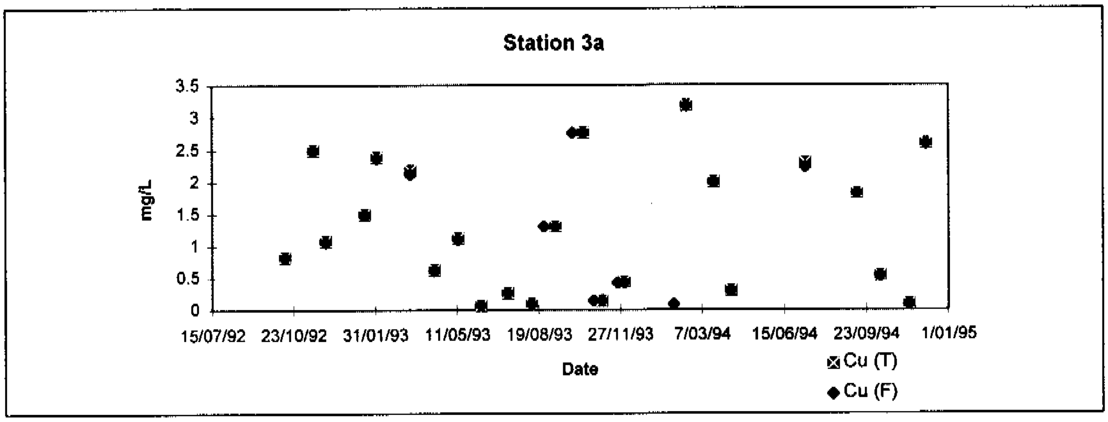

Figure 4.10 Total and filtered copper analyses for Comstock Creek below workings, station 3a (MCMRCL regulatory compliance data)

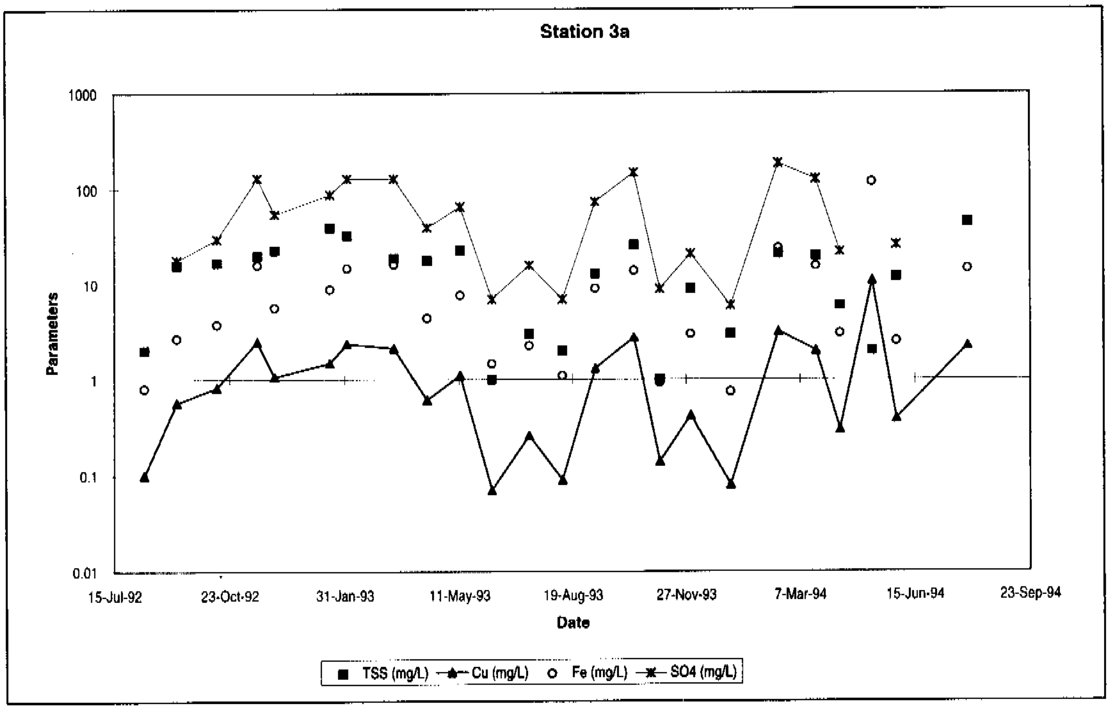

Figure 4.11 Water quality parameters for Comstock Creek below workings, station 3a (MCMRCL regulatory compliance data)

tailings discharge point, has not been monitored. Inputs from the West Lyell Tunnel (figure 4.14) and North Lyell Tunnel dilute the copper concentrations in Haulage Creek, while discharge from the Conveyor Tunnel, at approximately double the copper concentration of station 5, increases the mean total copper concentration to around 107 mg/L at station 9a (figure 4.15).

The relatively short data time series indicates no discernible trends for any station except station 6. The data presented in figure 4.14 indicate that the concentrations of copper, iron and sulphate in this water are decreasing with time. The West Lyell Tunnel drains the upper workings of the southern end of the West Lyell open-cut. This decrease cannot be attributed to dilution and is assumed to represent a decrease in available sites for acid generation.

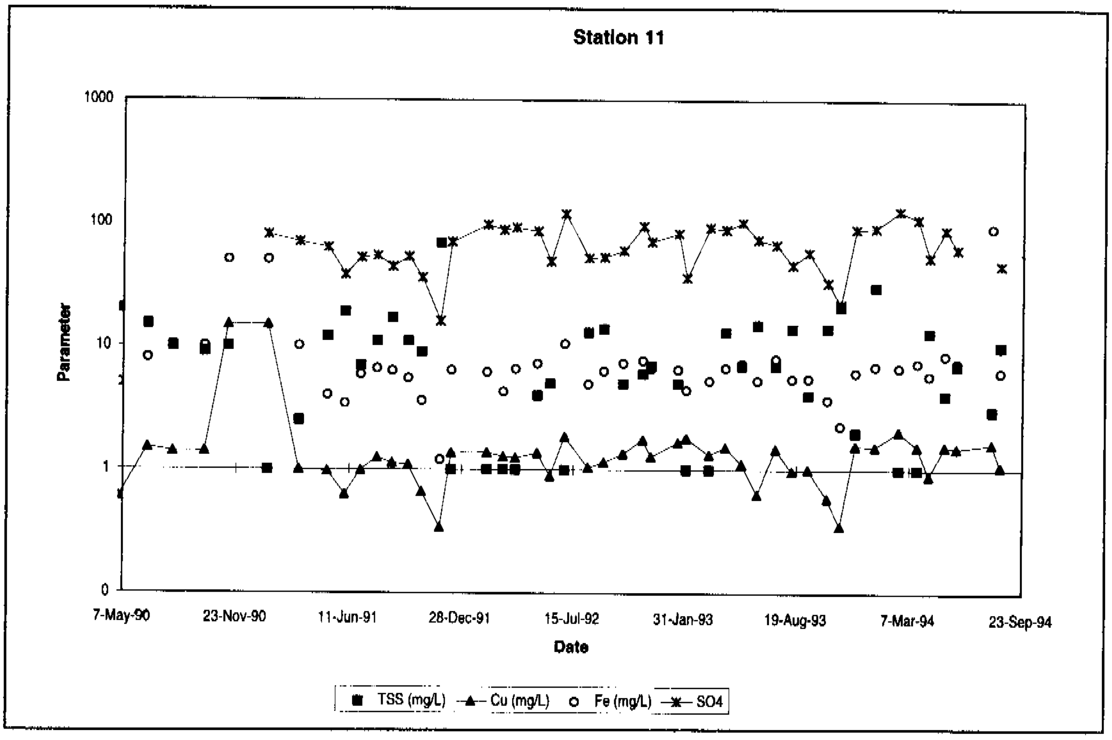

Figure 4.12 Water quality parameters for East Queen River above West Queen River, station 11 (MCMRCL regulatory compliance data)

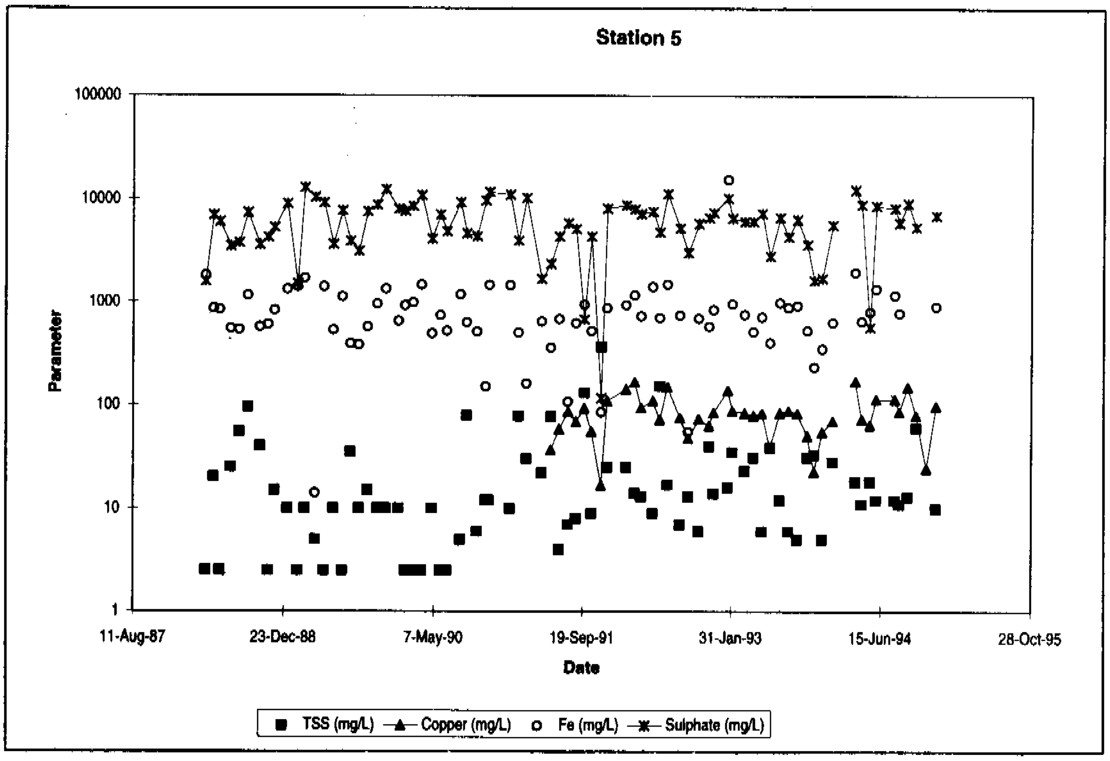

Figure 4.13 Water quality parameters for Haulage Creek above tunnels, station 5 (MCMRCL regulatory compliance data)

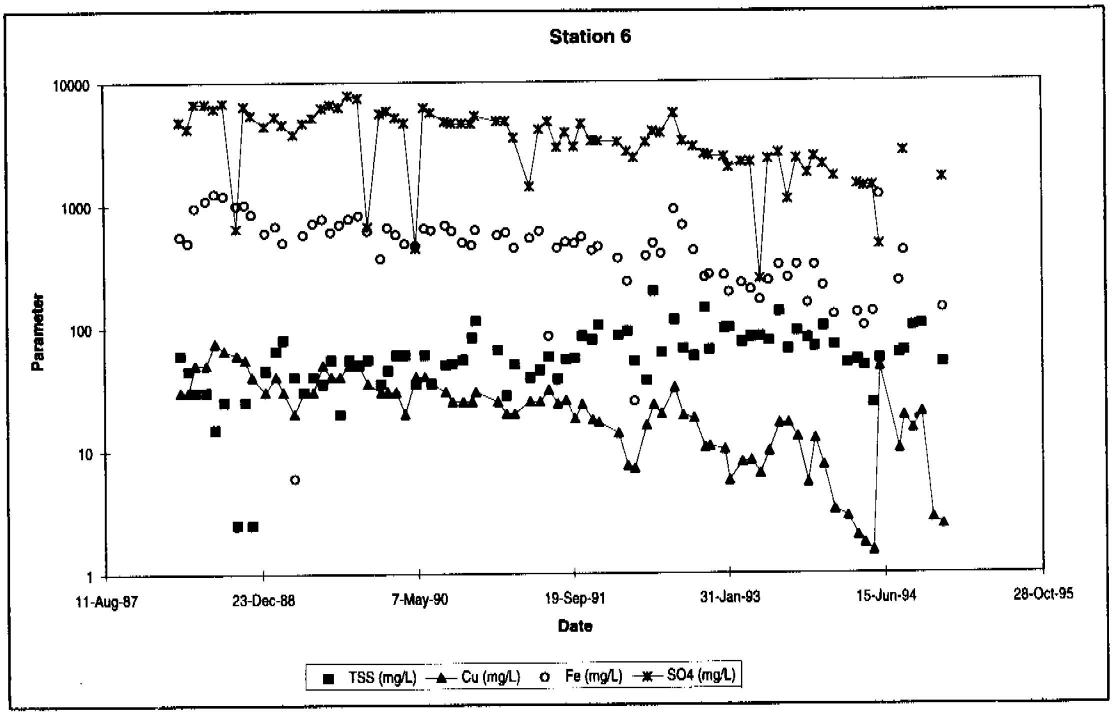

Figure 4.14 Water quality parameters for West Lyell Tunnel, station 6 (MCMRCL regulatory compliance data)

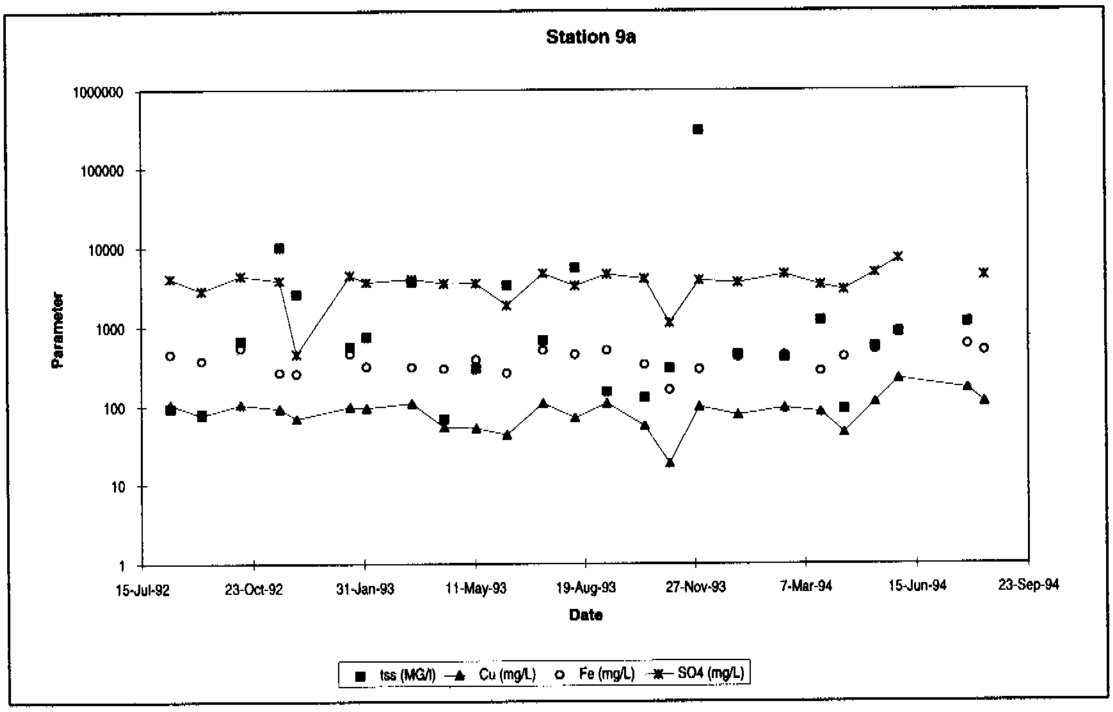

Figure 4.15 Water quality parameters for Haulage Creek at tailings discharge, station 9a (MCMRCL regulatory compliance data)

A significant change in the chemistry of the water that drains the lease site occurred with the cessation of tailings discharge to the river system. Until December 1994, tailings were discharged directly from the flotation plant into Haulage Creek, just below station 9a, at approximately 177 L/s. Median solids content was in excess of 300 000 mg/L and water content comprised around 180 L/s. MLMRCL utilised a conventional flotation process to produce two products, a copper concentrate and a pyrite concentrate, in essentially two stages:

chalcopyrite flotation: with calcium hydroxide (lime) was added in the grinding circuit at an average rate of 1.5 kg per tonne of ore, raising the pH of the process slurry from around 5.5 to 12. This pH ensured adequate depression of pyrite during copper recovery; and

- pyrite flotation: sulphuric acid was added to lower the pH to around 8.6 which increases the sulphate level from around 4 mg/L to over 300 mg/L.

Conventional flotation chemicals (commercial reagents) were used during the flotation process. The chloride content of the water is also increased from around 10 mg/L to about 60 mg/L through the dissolution of chloride containing minerals within the ore.

At station 12a, impact of discharging tailings into Haulage Creek was assessed (figure 4.16). As expected, total suspended solids were diluted from their discharge level of about 270 000 mg/L to around 100 000 mg/L, copper fluctuated around 100mg/L and pH around 3.5.

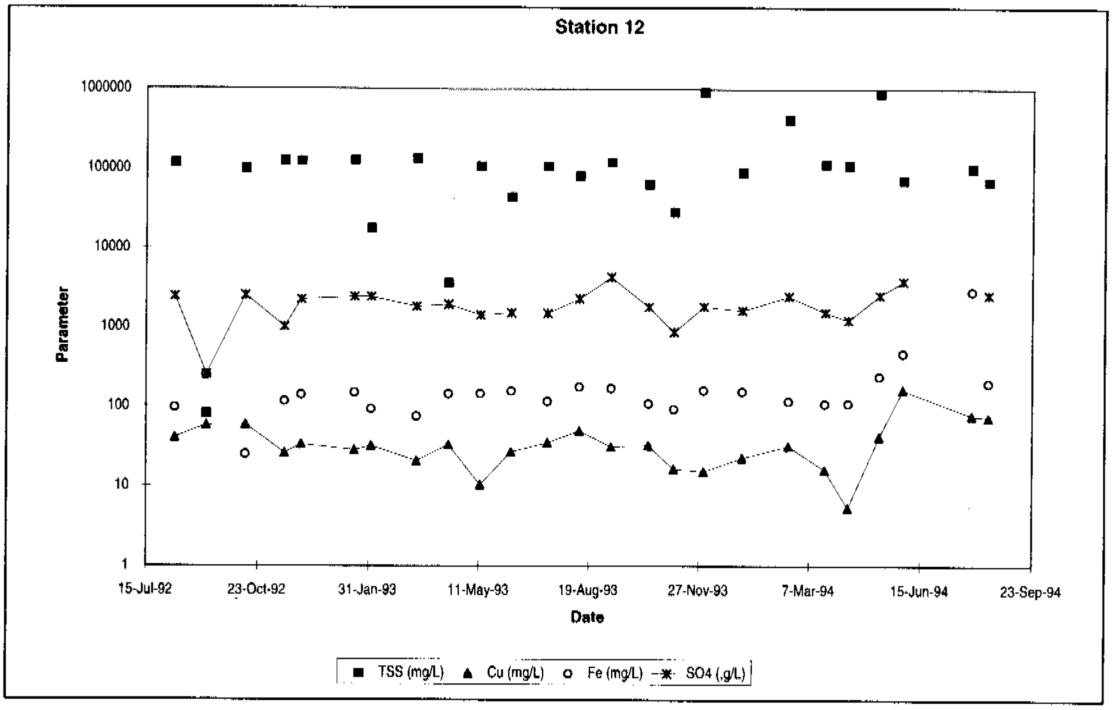

Figure 4.16 Water quality parameters for Haulage Creek at slag dump, station 12a (MCMRCL regulatory compliance data)

The contribution of tailings below site 9a to Haulage Creek had a significant impact on water chemistry. The pH increased from a median value of 2.7 to 3.6. The tailings influx to Haulage Creek also caused increased precipitation by raising the alkalinity and providing a large surface area for the adsorption of metals. From table 4.8 it is evident that station 12a, which lies below the tailings discharge, has a lower dissolved metal concentration than station 9a, and a greater difference between total and dissolved metal concentrations. EGI (1991) found the soluble copper concentrations in acid mine drainage (AMD), tailings, and Queen River water mixtures were significantly less than concentrations calculated on the basis of the individual water bodies. Also, the solubility of most common copper compounds was too high to account for the low copper concentrations reported. EGI concluded the copper concentration was controlled by adsorption reactions rather than precipitation reactions in tailings affected streams. Aluminium behaved in a similar manner to copper although precipitation occurs at a lower pH, commencing at around pH 4.0 while copper precipitation occurs closer to pH 5.0. Iron tends to precipitate at pH 3.5. The effective precipitation of iron is evident in the Queen River, where the river bed is coated with orange iron precipitate. It is expected that iron precipitates as hydroxides or oxides. Iron hydroxide (ferrihydrite) readily adsorbs heavy metals and sulphate, further removing these pollutants from solution. The adsorption of metals onto tailings particles may be controlled by ferrihydrite which coats the particles, increasing their capacity to adsorb metal ions. Tailings material is composed mainly of quartz, muscovite and chlorite which have limited ability to adsorb metals, particularly at low pH. This prompted GH&D (1994) to suggest ferrihydrite has a significant role in coating the tailings particles and increasing their metal adsorption capacity.

Appendix C shows time series plots of key water quality parameters for stations 7, 8a and 10.

Table 4.9 shows the regional water quality for the catchment downstream of the Mount Lyell mine during the period of tailings discharge (calculated from MLMRCL data). In downstream catchments, the level of metallic species and suspended solids are substantially higher and pH has decreased compared with table 4.8. Station 29 has generally a lower pH and higher level of all other parameters than station 28, which is assumed to be the result of re-mobilisation of metals from tailings stored in the delta.

Table 4.9 Water quality characteristics of regional surface water (dissolved metal species and total solids are in mg/L)

Parameter	Queen River at Queenstown MLMRCL–14			King River Teepookana MLMRCL–28			King River delta MLMRCL–29		
	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
Copper	14	45	2.1	0.6	2.2	0.04	0.93	8.2	0.08
Iron	57	156	6.6	1.6	5.7	0.05	2.44	15	0.05
Manganese	24	71	0.0	1.1	4.8	0.4	1.73	15	0.24
Zinc	132	2530	0.3	0.12	0.7	0.01	0.16	1.57	0.01
SO_4	755	1800	151	54	630	10	73	650	9
TDS[1]	1365	2940	247	90	300	36	139	884	42
TSS[2]	33250	250000	0.5	515	1890	19	800	6900	4
pH (median)	3.8	4.7	2.8	4.7	6.2	3.8	4.6	5.7	3.9
Conductivity (μS/cm)	1300	2590	390	190	760	66	274	1200	58

1 total dissolved solids (mg/L)

2 total suspended solids (mg/L)

During tailings discharge the sediment concentrations in the King River ranged around 100 mg/L with dramatic increases to 10 000 mg/L. Sudden increases in concentration are a response to gate opening and increased water flows from the John Butters Power Station below the Crotty Dam. Sudden increases in flow re-mobilise tailings settled during low flow periods and transport them downstream as a plume. Preliminary sampling in early 1995 showed a sediment concentration of the order of 10–20 mg/L in direct response to the cessation of tailings discharge to Haulage Creek (Locher 1995).

Mounter (1992) found a strong correlation ($R^2 > 0.7$) between conductivity and copper for the HEC monitoring stations in the Comstock and Linda catchments (table 4.10). The MLMRCL data also exhibit similar strong correlations. As sulphate is the major anion in the effluent water, its concentration is strongly correlated with conductivity (figure 4.17). Where the effluent water is derived from a single source there is also a strong correlation between sulphate and copper. However, for monitoring stations that reflect water mixed from a number of sources there is little correlation (figure 4.18). Continuous monitoring of copper concentrations by measurements of conductivity can be achieved relatively cheaply and efficiently where there is an acceptable relationship between conductivity, sulphate and copper.

Table 4.10 Conductivity (μS/cm) and total copper (mg/L) relationships (Mounter 1992)

Monitoring station	Regression equation	R^2
773	Cu=-0133+0.00525×Conductivity	0.77
774	Cu=-0.784+0.00568×Conductivity	0.91
775	Cu=-0.654+0.000976×Conductivity	0.93

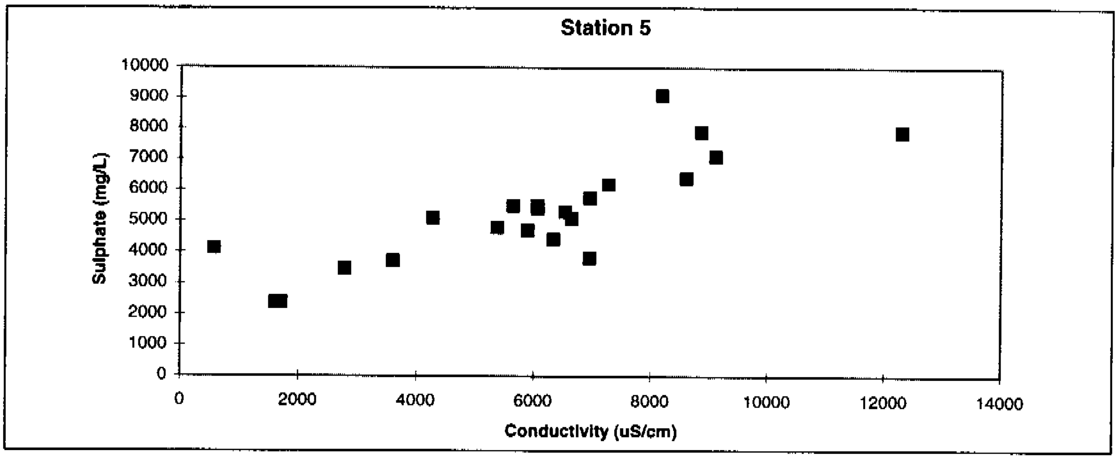

Figure 4.17 Sulphate versus conductivity for Haulage Creek above tunnels, station 5

Typically the MLMRCL dataset show that as flow increases water quality parameter concentrations decrease, however, on occasions this pattern may vary. Both Mounter (1992) and GH&D (1994) showed with HEC rated flow data that there is an inverse relationship between the concentrations of the various water quality parameters and flow. This relationship also suggests that the effluent is diluted by rainfall runoff.

Conversely, in catchments characterised by large volumes of waste rock, seasonal factors may result in increasing concentration with flow. In December 1994, DELM began an intensive monitoring program just below MLMRCL's monitoring station 9a where four hourly water samples were collected using an auto-sampler. The dissolved copper results are plotted in figure 4.19. After 25 March, copper levels in the effluent water increased markedly from around 100 mg/L to in excess of 200 mg/L. This coincided with a period of persistent rain following an exceptionally dry summer. The increase is considered to be due to saturation of the caved area in the Prince Lyell mine and subsequent discharge, via the Conveyor Tunnel, of oxidation products which accumulated in the cave material during the dry summer period. A similar scenario would have occurred in the major waste rock dumps. Under these circumstances, typical dilution with rainfall and increased flows is delayed and preceded by a marked flushing period during which concentrations increase with flow.

4.3.4 Mass load determination

Due to the enormity of the task required to fully remediate the Mount Lyell mine site, funds will need to be directed where the greatest gains in reducing pollution loads to the river system can be derived. In determining the mass pollutant load contribution from specific sources on the mine site to the downstream environment, it is important to have an accurate flow and water chemistry dataset. Lack of quality flow data, particularly for the Conveyor Tunnel which contributes an estimated 60% of the mass pollutant load leaving the lease site, limits the accuracy of determination of mass discharge.

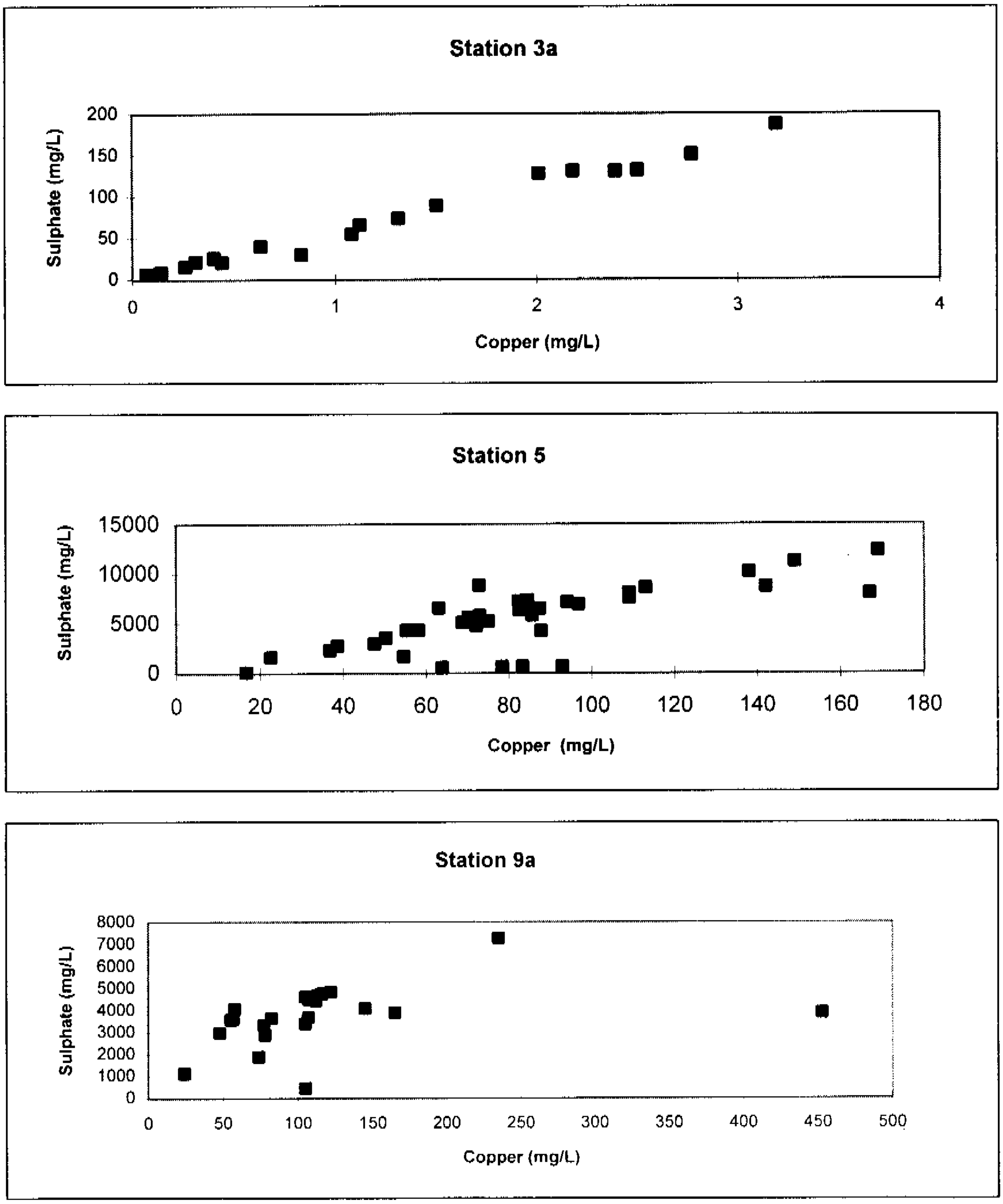

Figure 4.18 Copper (filtered) versus sulphate for stations 3a, 5 and 9a

With the exception of stations 5, 6, 9a and 11, which had flow recorders installed in 1993, all MLMRCL sampling comprised monthly grab samples with estimates of flow from a variety of stations around the lease site and downstream from the mine. The estimate of flow is not considered sufficiently reliable to be used for anything but an indicator of high or low flow.

Previous water quality studies conducted at Mount Lyell (ie EGI 1993, GH&D 1994) utilised MLMRCL recorded data to estimated flow rates for mass load calculations.

In estimating mass loads, EGI (1993) used median flows calculated from mean flow data and mean water quality values. Estimated mean flows were based on catchment size and assuming an annual rainfall of 2500 mm and 100% runoff. The estimated flows compare favourably with the mean measured flows listed in the HEC database.

GH&D (1994) used the EGI calculations for median flows with the exception of sites 5, 6, 9a and 11 which, subsequent to the EGI study, had continuous flow monitors installed. Median values were calculated for parameters of interest in the water quality data, the median being considered a more reliable estimate of the typical flow values than the mean because of the variability in the dataset.

The median flow values from EGI calculated flows, or HEC recorded flows, at these stations were applied to median water quality values to obtain median load values. It is not clear what these values represent but it is almost certainly not median loads. Table 4.11 shows a comparison of the total copper loads using mean and median flow values and median concentrations for three sites: the East Queen River (station 11); Haulage Creek, above the West Lyell Tunnel (station 5); and Haulage Creek, above tailings discharge (station 9a). It is obvious that the copper loads vary distinctly from when using different flow datasets.

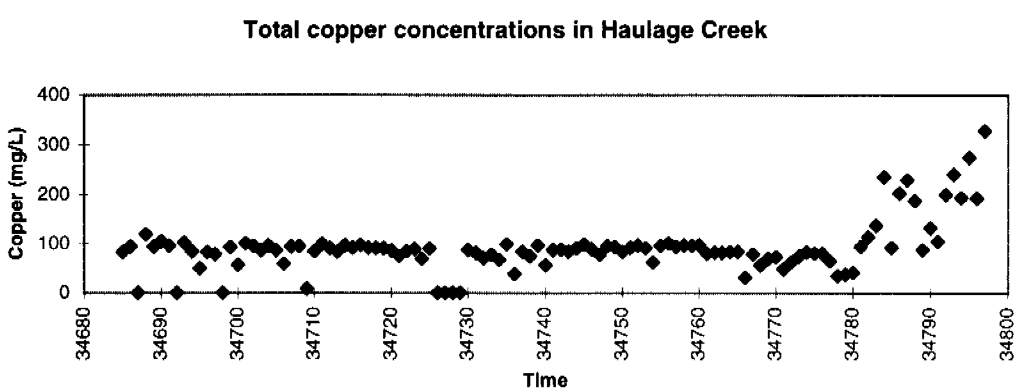

Figure 4.19 Haulage Creek copper concentrations during DELM intensive monitoring program, station 9a

Table 4.11 Dissolved copper loads (kg/d), calculated using various sources of median and mean flow data

Monitoring station	Copper loads (kg/d)[1]	Copper loads (kg/d)[2]	Copper loads (kg/d)[3]	Copper loads (kg/d)[4]
East Queen River (st 11)	348	884	295	273
Haulage Creek above tunnels (st 5)	4455	9900	295	2888
Haulage Creek below tunnels (st 9a)	21593	13440	3300	6541

1 calculated using HEC recorded median flow data

2 calculated using EGI (1993) estimated mean flow data

3 calculated using EGI (1993) estimated median flow

4 calculated using HEC flow equation

In allocating the portions of pollutants to individual sources above the Haulage Creek station 9a, just prior to the tailings discharge point, GH&D assumed that Magazine Creek, for which there are no physically recorded measurements, contributed the unknown quantity in the mass balance. Using copper as an example, table 4.12 shows the mass balance derived by GH&D at Haulage Creek, station 9a.

Table 4.12 Estimated median total copper mass load (L) at Haulage Creek, station 9a, using median concentration and median flow values (modified after GH&D 1994)

Station	Copper load (kg/day)	Copper loading (%)
Haulage Creek above Tunnels (st 5)	340	16.5
West Lyell Tunnel (st 6)	3	0.1
North Lyell Tunnel (st 7)	239	11.6
Conveyor Tunnel (st 8a)	648	31.5
Magazine Creek	829 [1]	40.3
Haulage Creek below Tunnels (9a)	2059	100

1 $L_{Magazine\ Creek} = L_{9a} - (L_5 + L_6 + L_7 + L_{8a})$

From table 4.12, approximately 40.3% of the total copper loads is attributed to the Magazine Creek catchment. A comparison of total copper loads at Haulage Creek station 9a, using median flow values and mean concentrations, is shown in table 4.13. It can be seen that when the sum of median flow inputs is used to derive a mass load for station 9a, the copper load of 2080 kg/d approximates the sum of mass loadings from all respective inputs of 1856.3 kg/d, indicating Magazine Creek is likely to be only a minor contributor of copper loading to Haulage Creek (10%).

Table 4.13 Estimated median total copper mass balance at Haulage Creek, station 9a

Monitoring station	Median flow value (L/s)	Mean copper concentration[7] (mg/L)	Copper mass load (Kg/d)	Copper loading (%)
Haulage Creek, above Tunnels (st 5)	54[1]	83	387.2	18.6
West Lyell Tunnel (st 6)	4[2]	13	4.5	0.2
North Lyell Tunnel (st 7)	56[3]	53	256.4	12.3
Conveyor Tunnel (st 8a)	92[4]	152	1208.2	58.1
Magazine Creek	19[5]	-	214 [8]	10.8
Total			1856.3	100
Haulage Creek, below Tunnels (st 9a)	225[6]	107	2080	

1 median flow from continuous record (5/93–10/94)

2 median of visually estimated flow MLMRCL; flow is consistently low with little variation

3 median flow from continuous record (5/93–10/94)

4 continuous record (4/95–10/95)

5 EGI flow determined from catchment area

6 median flow (F) of site 9a = $F_5 + F_6 + F_7 + F_{8a}$

7 derived from MLMRCL monitoring data

8 $L_{Magazine\ Creek} = L_{9a} - (L_5 + L_6 + L_7 + L_{8a})$

Water pumped from underground via the Conveyor Tunnel is by far the largest copper contributor to Haulage Creek. This reflects the high pyrite and copper content of the ore and waste rock within the active mine area below the West Lyell open-cut.

The West Lyell waste rock dumps are the second greatest contributors to pollutant loads. MLMRCL commissioned ANSTO to monitor oxygen and temperature profiles within these dumps. ANSTO (1994a, 1994b) indicated the dumps are oxidising at the maximum rate possible, with no factor limiting, and this is likely to continue for a period of up to 60 years. Preliminary modelling suggests sulphate loads may continue at a reduced rate for up to 600 years in the absence of remediation strategies.

5.0 Conclusions

A substantial volume of literature has accumulated on the environmental impacts associated with mining at Mount Lyell, with most attention focused on the discharge of acid leachates from the site. The most limiting factor in assessing these impacts is a lack of quality data, particularly in respect of water flows in catchments draining the lease site. Where good data exist they are frequently of short duration, and inadequate to fully represent the range of seasonal variation.

The Comstock–Linda catchments have good quality flow data as a result of monitoring by the Hydro-Electric Commission. Environmental monitoring in these catchments is associated with the development of Lake Burbury and the need to protect the ecological values of this lake, particularly for recreational fishing. In the Queen River catchment, acceptable water quality data are available for stations 5, 11 and the North Lyell Tunnel from 1993 to present, as a result of continuous monitoring at these stations.

EGI has developed reasonable flow estimates for other catchments on the lease site which have not been monitored. Estimates have been derived from the size of the subcatchment and assuming an annual rainfall of 2500 mm and 100% runoff to give a mean flow. Median flows were determined by applying a conversion factor to the mean, consistent with measured HEC data for similar catchments.

The Hydro-Electric Commission has demonstrated a good relationship between catchment areas and median flows. Median flow values have generally been used to calculate mass loads by EGI, HEC and GH&D.

A combination of catchment characteristics and rainfall intensities indicate that up to 80% of runoff may occur in 20% of the discharge period in small lease area catchments. Consequently, the use of median values to represent typical discharge may substantially underestimate mean or total flows. Use of median flows for determining mass loads in these catchments is likely to underestimate total discharges.

The dataset for water quality parameters is highly variable and datasets should be thoroughly checked against laboratory analytical reports where possible. Due to the inconsistencies in the concentration data, median concentrations for water quality parameters are considered appropriate.

Few trends are evident in the monitoring dataset with the exception of station 6, West Lyell Tunnel, which demonstrates a gradual decrease in sulphate, iron and copper in the past five years. The most likely cause of this is thought to be a decrease in the rate of oxidation of sulphates as available sites are oxidised and leached.

Strong correlations exist between conductivity, sulphate and copper concentrations for waters derived from a single source. Conductivity may provide a useful indicator of copper loads in point source streams on the lease site. The correlation tends to break down when effluent sources are mixed.

Both HEC and GH&D data suggest an inverse relationship between water quality parameters and flow, suggesting concentrations may be diluted by rainfall. However, this relationship is not always consistent for catchments containing large volumes of waste rock, where increasing flows associated with rainfall following long dry periods results in peak metal loads associated with flushing of oxidation products.

For streams low in suspended solids and high in acidity typical of the Mount Lyell lease site, total and dissolved parameters are very similar. However, this is not the case for tailing-contaminated waters where the abundance of adsorption sites on tailings particles results in a reduction of dissolved parameters.

For surface catchments there is an obvious relationship between the catchment characteristics related to mining activities and pollutant loads. The major pollutant source is the Conveyor Tunnel in the Haulage Creek catchment, which contributes in the order of 60% of total metal loads to the Queen River. The West Lyell waste rock dumps in this catchment are the second major source of pollutant loading (approximately 20%).

For the single West Lyell waste rock dump monitored by ANSTO (1994b) it was estimated that acid generation will continue for more than 600 years. Measurements have shown that approximately 130 tonnes of copper and 1300 tonnes of sulphate per year leach from a single 25 ha dump below the West Lyell open-cut.

The Mount Lyell mining lease sites are likely to be an ongoing source of pollution as a result of acid drainage to downstream water catchments. There have been insufficient good quality data to accurately quantify and characterise effluent discharges from the lease site, particularly in respect to flows. For environmental assessment, good quality information is required to develop time duration analyses of concentrations and loads, and the current dataset is inadequate for this application.

In order that environmental remediation strategies are effectively targeted for maximum possible benefit, it is critically important that good quality environmental monitoring data are collected. Provision of accurate monitoring data will greatly facilitate future site management decisions.

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Appendices

Appendix A The Mount Lyell Remediation, Research and Demonstration Program Projects

The Program manager was Warren Jones of the Tasmanian Department of Environment and Land Management (DELM), with the Program Implementation Committee comprising Warren Jones, Stewart Needham of the Office of the Supervising Scientist (***oss***) and Arthur Johnston of the Environmental Research Institute of the Supervising Scientist (***eriss***), branches of the Federal Environment Department. The Program was overseen by an eight member Steering Committee which included representatives of DELM, ***oss***, Copper Mines of Tasmania and the Hydro-Electric Commission of Tasmania.

A third body, the Consultative Committee, was established as a means of communicating the progress and outcomes of the projects to the relevant government and community organisations.

Environmental quality objectives

The long-term environmental quality objectives need to be defined to give the Program a clear focus, although it must be emphasised that the present Program cannot and will not achieve these objectives.

The following long-term environmental quality objectives have been compiled after discussion with the community.

Mount Lyell lease site

Subject to the requirements of ongoing and possible future mining operations on the Mount Lyell lease site, the rehabilitation of historic waste rock dumps and other historic environmental damage such that:

- emissions of acid drainage from the areas are reduced to the point that they do not compromise the environmental quality objectives for the Queen and King Rivers, and Macquarie Harbour;
- the land is stabilised to minimise erosion and effects on water quality;
- the 'lunar landscape' is maintained, particularly the field of view coming into Queenstown; and
- exotic species infestation is minimised; and culturally significant artefacts are maintained.

The Queen and King Rivers

The remediation of water quality, sediments and the banks of the Queen and King Rivers where necessary such that:

- the rivers can support a healthy, although not pristine, aquatic ecosystem;
- erosion and transport of sediments and tailings which are deposited on the banks and beds of the rivers, or the leaching of metals from these, do not pose an ongoing threat to the environmental quality objectives for Macquarie Harbour;
- restoration of the visual appearance of the rivers and banks to meet community requirements;
- navigability of the lower King River is improved;
- problems caused by a higher water table in the lower reaches of the King River are reduced;

- undamaged areas are maintained as undamaged; and
- existing heritage values are maintained.

Macquarie Harbour

The remediation of the water quality, sediments, the tailings delta and foreshore in Macquarie Harbour where necessary such that:

- the harbour will support a healthy, although not pristine, aquatic ecosystem;
- water quality throughout the harbour will be suitable for fish farming;
- fish and other aquatic life harvested from the Harbour will be suitable for consumption;
- the harbour sediments and tailings delta will not pose an ongoing threat to the water quality;
- the foreshore in the vicinity of Strahan should be safe and clean;
- dust from the delta will not pose a health risk;
- visual impact of the delta and the wharf area at Strahan will be reduced; and
- environmental quality in that part of the harbour which is in the World Heritage Area moves towards being in keeping with this designation.

Project number	Project title	Project description	Project leaders	Consultants
1	Characterisation of sources of acid drainage from the Mount Lyell lease site and surrounds	Overview document detailing the current knowledge on the quantity and quality of effluent water from the lease site	Dr Chris McQuade (***oss***) John Johnston (DELM)	Dr Chris McQuade (***oss***) John Johnston (DELM) Shelley Innes (DELM)
2	Options to reduce acid drainage from the Mount Lyell lease site and surrounds	The identification of potential short and long-term options for managing effluent water from the lease site and recommendations for construction and operation of demonstration/evaluation trials	John Johnston (DELM) Dr Chris McQuade (***oss***)	John Miedecke and Partners Pty Ltd incorporating Environmental Geochemistry International and the Australian Nuclear Science and Technology Association
2b	Estimation of water quality over time at several locations in the King River	Using the RIVCHEM model rank options for site remediation against their impacts on the water quality at several locations within the King River	Dr Chris McQuade (***oss***) John Johnston (DELM)	Environmental Geochemistry International
3	Construction and evaluation of remediation options	This project involves constructing and evaluating some or all of the remediation options for the lease site as identified in project 2	John Johnston (DELM) Dr Chris McQuade (***oss***)	John Miedecke and Partners Pty Ltd
4	Tailings and fluvial processes in the Queen and King Rivers	Assess the dynamics of tailings movement within the Queen and King Rivers	Helen Locher (DELM) Dr Lois Koehnken (DELM)	Helen Locher (DELM)
5	Tailings chemistry in the Queen and King Rivers and the delta	Quantify the varying types of tailings deposits distributed along the river banks and in the delta and the effects of different physio-chemical environments to which each are exposed. The potential for the tailings to be an on-going source of metals will be determined	Dr Lois Koehnken (DELM) Dr Patrick McBride (***oss***)	Earth Systems Pty Lty incorporating Monash University Earth Science Department
6	Remediation of tailings deposits	Identify a range of options for alleviating environmental impacts arising from tailings deposits in the King Rivers and Macquarie Harbour, listing environmental, aesthetic, economic and social attributes both positive and negative for each. A small scale program of trials will be set in train as the final stage of the project.	Peter Waggitt (***oss***)	Hydro-Electric Commission in association with Coffey Partners International Pty Ltd
7	Stream monitoring	Undertake biological and water quality surveys of the fresh waters affected by the Mount Lyell operations and design a long-term monitoring program which will enable trends and patterns in biota and water quality to be assessed in relation to remediation activities and other environmental conditions.	Dr Chris Humphrey (***eriss***)	Freshwater Systems Pty Ltd

Project number	Project title	Project description	Project leaders	Consultants
9A	Toxicity testing	Estimate the levels and forms of copper which can be tolerated in Macquarie Harbour waters without causing detriment to fish and other aquatic life	Dr Patrick McBride (***oss***)	CSIRO Institute of Natural Resources and Environment
9B	Toxicity testing	Estimate the levels and forms of copper which can be tolerated by farmed fish in Macquarie Harbour	Dr Simon Stanley (DPIF)	DPIF
10	Strahan wharf rehabilitation	Rehabilitating the Macquarie Harbour foreshore between Strahan and the mouth of the King River from the environmental impacts of infrastructure or practises related to mining at Mount Lyell	Stewart Needham (***oss***) John Johnston (DELM)	Community and government sponsored groups
11	Implications on Macquarie Harbour from likely remediation measures	Determine the likely implications for the Harbour of the remediation measures which could be taken on the lease site, the rivers and the delta, and the time frame during which predicted changes will occur	Dr Lois Koehnken (DELM)	Dr Lois Koehnken (DELM)
12	Macquarie Harbour sediments	Quantify the release of metals from the sediments and the conditions that release will occur	Dr Lois Koehnken (DELM) Dr Patrick (***oss***)	CSIRO Division of Coal and Energy Technology, Centre for Advanced Analytical Chemistry
13A	Biological survey of Macquarie Harbour	Design a biological monitoring program to assess the recovery of Macquarie Harbour; and determining the concentrations and significance of trace metals in edible or potentially edible invertebrates or fish tissues	Dr Patrick McBride (***oss***)	Water Ecoscience
13B	Monitoring biological indicators	Assess the recovery of Macquarie Harbour	Dr Patrick McBride (***oss***)	Nick O'Conner, Water Ecoscience
14	Hydraulic and chemical modelling of Macquarie Harbour	Develop a Hydraulic and chemical modelling to quantify the impacts of the Mt Lyell operation on the Harbour and to provide input to the management of the Harbour	Dr Lois Koehnken (DELM) Dr David Klessa (***eriss***)	Computational Fluid Dynamics Pty Ltd

oss Office of the Supervising Scientist (Federal)

eriss Environmental Research Institute of the Supervising Scientist (Federal)

DELM Department of Environment and Land Management (Tasmanian)

DPIF Department of Primary Industries and Fisheries (Tasmanian)

Appendix B Monitoring stations and parameters in the Queen–King River catchment area

Haulage Creek

Source	Site no	Latitude	Longitude	Easting	Northing	Description	Catchment area (km²)	Parameter	Variable	Parameter name	Units	Qualifier	Start	End
Haulage Creek above Conveyor Tunnel and below West and North Lyell Tunnels														
HEC	670	-42:04:03.7	145:34:10.0	381650.000	5341700.000			100	1	Flow	L/s	Continuous	14/05/93 @ 12:15:00	28/03/95 @ 14:00:00
CMT	HCWL	-42:04:03.7	145:34:10.0	381650.000	5341700.000					pH	mg/L	Periodic	26/04/95 @ 00:00:00	Current
	HCWL									TSS, Fe, Mn, Zn, Cu, Pb, Al, Hg (T&D)	mg/L	Periodic	26/04/95 @ 00:00:00	Current
	HCWL									SO_4, Fl	mg/L	Periodic	26/04/95 @ 00:00:00	Current
	HCWL									Flow	cumecs	Periodic	26/04/95 @ 00:00:00	Current
Haulage Creek above Conveyor, North and West Tunnels														
HEC	669	42:04:03.9	145:34:18.7	381850.000	5341700.003	Weir above north and west tunnels		100	1	Flow	L/s	Continuous	14/05/93 @ 09:00:00	Current
MLMRCL	5	42:04:03.9	145:34:18.7	381850.000	5341700.003					Flow	L/s	Continuous	1/05/93	1/10/94
	5									Fe, Cu (T), Al, Zn, Mn, SO_4, Cl, As (T), Hg (T), Ni, Cd, Cr, TDS, TSS	mg/L	Periodic	1/05/91 @ 00:00:00	1/12/94 @ 00:00:00
	5									pH		Periodic	1/12/79	1/12/94
	5									Temperature	^{o}C	Periodic	1/12/79	1/12/94
CMT	HCCT	42:04:03.9	145:34:18.7	381850.000	5341700.003					pH		Periodic	26/04/95 @ 00:00:00	Current
	HCCT									TSS, Fe, Mn, Zn, Cu, Pb, Al, Hg (T&D)	mg/L	Periodic	26/04/95 @ 00:00:00	Current
	HCCT									SO_4, Fl	mg/L	Periodic	26/04/95 @ 00:00:00	Current
	HCCT									Flow	cumecs	Periodic	26/04/95 @ 00:00:00	Current

Source	Site no	Latitude	Longitude	Easting	Northing	Description	Catchment	Parameter	Variable	Parameter name	Units	Qualifier	Start	End
Haulage Creek at Tailings Discharge														
HEC	680	-42:03:54.9	145:33:33.3	380800.000	5341960.001	Ultrasonic flow meter in culvert juxtaposed to old tailings outlet pipe		100	1	Flow	L/s	Continuous	23/08/93 @ 14:45:00	28/03/95 @ 15:45:00
MLMRCL	9a	-42:03:54.9	145:33:33.3	380800.000	5341960.001					Fe, Cu (T), Al, Zn, Mn, SO_4, Cl, As (T), Hg (T), Ni, Cd, Cr, TDS, TSS	mg/L	Periodic	1/05/91 @ 00:00:00	1/12/94 @ 00:00:00
	9a									pH		Periodic	1/05/91 @ 00:00:00	1/12/94 @ 00:00:00
	9a									Temperature	°C	Periodic	1/05/91 @ 00:00:00	1/12/94 @ 00:00:00
DELM	9a	-42:03:54.9	145:33:33.3	380800.000	5341960.001					Cu, Fe, Mn, Al (D)	mg/L	Daily	17/12/94	26/01/95
	9a									Cu, Fe, Mn, Al (D)	mg/L	Periodic	27/01/95 @ 00:00:00	10/04/95 @ 08:00:00
	9a									Flow	L/s	Daily	17/12/94	26/01/95
	9a									Flow	L/s	Periodic	27/01/95 @ 00:00:00	10/04/95 @ 08:00:00
West Lyell Tunnel														
MLMRCL	6			381700.000	5341780.000					Fe, Cu (T), Al, Zn, Mn, SO_4, Cl, As (T), Hg (T), Ni, Cd, Cr, TDS, TSS	mg/L	Monthly	1/07/93	1/12/94
	6									pH		Monthly	1/07/93	1/12/94
	6									Temperature	°C	Monthly	1/07/93	1/12/94
HEC	10670			381700.000	5341780.000	Flow meter at tunnel mouth				Flow	L/s	Continuous	Apr 95	Current
North Lyell Tunnel														
MLMRCL	7			381680.000	5341780.000	Recorded runoff from Crown Lyell diversion (since July 1991) and northern end of West Lyell open-cut				Fe, Cu (T), Al, Zn, Mn, SO_4, Cl, As (T), Hg (T), Ni, Cd, Cr, TDS, TSS	mg/L	Monthly	1/07/93	1/12/94
	7									pH		Monthly	1/07/93	1/12/94
	7									Temperature	°C	Monthly	1/07/93	1/12/94
HEC	670			3816800.000	5341780.000	Flow meter at tunnel mouth				flow L/sec		Continuous	Apr 95	Current

Source	Site no	Latitude	Longitude	Easting	Northing	Description	Catchment	Parameter	Variable	Parameter name	Units	Qualifier	Start	End
Conveyor Tunnel														
MLMRCL	8a			381250.000	5341960.000	Mine water from Level 17 pump station in Prince Lyell mine. Includes catchment from the majority of the West Lyell open-cut				Fe, Cu (T), Al, Zn, Mn, SO_4, Cl, As (T), Hg (T), Ni, Cd, Cr, TDS, TSS	mg/L	Monthly	1/05/91 @ 00:00:00	1/12/94 @ 00:00:00
	8a									pH			1/05/91 @ 00:00:00	1/12/94 @ 00:00:00
										Temperature	^oC		1/05/91 @ 00:00:00	1/12/94 @ 00:00:00
HEC	11670			381400.000	5341960.000	Flow meter at tunnel mouth				Flow	L/s	Continuous	Apr 95	Current
CMT	CTW									Flow, pH, TSS, Fe, Mn, Zn, Cu, Pb, Al (T&D), SO_4, F (D)		Daily	Apr 95	Nov 95
Pure Tailings before Discharge														
MLMRCL	10	-42:03:54.9	145:33:33.3	380800.000	5341960.001	Sampled from discharge pipe at Haulage Creek				Fe, Cu (T), Al, Zn, Mn, SO_4, Cl, As (T), Hg (T), Ni, Cd, Cr, TDS, TSS	mg/L	Monthly	1/05/91 @ 00:00:00	1/12/94 @ 00:00:00
	10									pH		Monthly	1/05/91 @ 00:00:00	1/12/94 @ 00:00:00
	10									Temperature	^oC	Monthly	1/05/91 @ 00:00:00	1/12/94 @ 00:00:00

Source	Site no	Latitude	Longitude	Easting	Northing	Description	Catchment	Parameter	Variable	Parameter name	Units	Qualifier	Start	End
Haulage Creek at Slag Dump														
MLMRCL	12a			380850.000	5341210.000	Adjacent shed in lay down area				Fe, Cu (T), Al, Zn, Mn, SO_4, Cl, As (T), Hg (T), Ni, Cd, Cr, TDS, TSS	mg/L	Monthly	1/05/91 @ 00:00:00	1/12/94 @ 00:00:00
	12a									pH		Monthly	1/05/91 @ 00:00:00	1/12/94 @ 00:00:00
	12a			380850.000	5341210.000					Temperature	^{o}C	Monthly	1/05/91 @ 00:00:00	1/12/94 @ 00:00:00
DELM	12a									Cu, Fe, Mn, Al (D)	mg/L	Daily	20/12/94	26/01/95
	12a									Cu, Fe, Mn, Al (D)	mg/L	Periodic	31/01/95 @ 20:00:00	08/03/95@ 00:00:00
	12a									Flow	L/s	Daily	20/12/94	26/01/95
	12a									Flow	L/s	Periodic	31/01/95 @ 20:00:00	08/03/95 @ 00:00:00
CMT	HCSD			380850.000	5341210.000					pH		Periodic	26/04/95 @ 00:00:00	Current
	HCSD									Fe, Mn, Zn, Cu, Pb, Al, Hg (T&D), TSS	mg/L	Periodic	26/04/95 @ 00:00:00	Current
	HCSD									SO_4, Fl	mg/L	Periodic	26/04/95 @ 00:00:00	Current
	HCSD									Flow	cumecs	Periodic	26/04/95 @ 00:00:00	Current
Waste Rock Dump														
MLMRCL	32			381950.000	5341710.000	Toe of waste rock dump that ANSTO conducted work on				Temperature	^{o}C	Monthly	8/09/93	1/12/94
	32									pH		Monthly	8/09/93	1/12/94
	32									TSS	mg/L	Monthly	8/09/93	1/12/94
										Conductivity	µS/cm	Monthly	8/09/93	1/12/94
	32									Cu (T), Mn, Fe, SO_4, Cl	mg/L	Monthly	8/09/93	1/12/94

East Queen River

Source	Site no	Latitude	Longitude	Easting	Northing	Description	Catchment	Parameter	Variable	Parameter name	Units	Qualifier	Start	End
Head East Queen River														
MLMRCL	4			381800.000	5345850.000	Sampled at mine water intake from East Queen River prior to introduction of water from Comstock diversion works				Fe, Cu (T), Al, Zn, Mn, SO_4, Cl, As (T), Hg (T), Ni, Cd, Cr, TDS, TSS	mg/L	Monthly	1/07/91	1/06/92
	4									pH		Monthly	1/07/91	1/06/92
										Conductivity	µS/cm	Monthly	1/07/91	1/12/94
	4									Temperature	^oC	Monthly	1/07/91	1/06/92
East Queen River above West Queen River														
HEC	664	-42:03:48.6	145:33:28.0	380674.998	5342150.003	East Queen River at bridge to hockey oval		100	1	Flow	L/s	Continuous	14/05/93 @ 10:00:00	28/03/95 @ 14:45:00
CMT	EQWQ	-42:03:48.6	145:33:28.0	380674.998	5342150.003					pH		Periodic	26/04/95 @ 00:00:00	Current
	EQWQ									TSS, Fe, Mn, Zn, Cu, Pb, Al, Hg (T&D)	mg/L	Periodic	26/04/95 @ 00:00:00	Current
	EQWQ									SO_4, Fl	mg/L	Periodic	26/04/95 @ 00:00:00	Current
	EQWQ									Flow	cumecs	Periodic	26/04/95 @ 00:00:00	Current
MLMRCL	11	-42:03:48.6	145:33:28.0	380674.998	5342150.003					Fe, Cu (T), Al, Zn, Mn, SO_4, Cl, As (T), Hg (T), Ni, Cd, Cr, TDS, TSS	mg/L	Monthly	1/05/91 @ 00:00:00	1/12/94 @ 00:00:00
										Conductivity	µS/cm	Monthly	1/05/91 @ 00:00:00	1/12/94 @ 00:00:00
	11									pH		Monthly	1/05/91 @ 00:00:00	1/12/94 @ 00:00:00
	11									Temperature	^oC	Monthly	1/05/91 @ 00:00:00	1/12/94 @ 00:00:00

Source	Site no	Latitude	Longitude	Easting	Northing	Description	Catchment	Parameter	Variable	Parameter name	Units	Qualifier	Start	End
East Queen River above West Queen River (cont'd)														
DELM	11	-42:03:48.6	145:33:28.0	380674.998	5342150.003					Cu, Fe, Mn, Al (D)	mg/L	Daily	20/12/94	26/01/95
	11									Cu, Fe, Mn, Al (D)	mg/L	Periodic	31/01/95 @ 20:00:00	14/03/95 @00:00:00
	11									Flow	L/s	Daily	20/12/94	26/01/95
	11									Flow	L/s	Periodic	31/01/95 @ 20:00:00	14/03/95 @00:00:00
Below Cape Horn Workings Area														
MLMRCL	20a			381950.000	5343900.000					Temperature	^{o}C	Periodic	20/5/91	14/12/92
	20a									pH		Periodic	20/5/91	14/12/92
	20a									Conductivity	µS/cm	Periodic	20/5/91	14/12/92
	20a									Fe, Cu (T), Al, Zn, Mn, SO_4, Cl, As (T), Hg (T), Ni, Cd, Cr, TDS, TSS	mg/L	Periodic	20/5/91	14/12/92
Above Cape Horn workings area														
MLMRCL	21			382050.000	5343595.000					Temperature	^{o}C	Periodic	20/05/91	14/12/92
	21									pH		Periodic	20/05/91	14/12/92
	21									Conductivity	µS/cm	Periodic	20/05/91	14/12/92
	21									Fe, Cu (T), Al, Zn, Mn, SO_4, Cl, As (T), Hg (T), Ni, Cd, Cr, TDS, TSS	mg/L	Periodic	20/05/91	14/12/92
Miscellaneous waste rock dumps														
MLMRCL	26			382275.000	5343090.000	In culvert, beginning of the road to Comstock and Cape Horn workings				Temperature	^{o}C	Periodic	20/05/91	14/12/92
	26									pH		Periodic	20/05/91	14/12/92
	26									Conductivity	µS/cm	Periodic	20/05/91	14/12/92
	26									Fe, Cu (T), Al, Zn, Mn, SO_4, Cl, As (T), Hg (T), Ni, Cd, Cr, TDS, TSS	mg/L	Periodic	20/05/91	14/12/92

Idaho Creek

Source	Site no	Latitude	Longitude	Easting	Northing	Description	Catchment	Parameter	Variable	Parameter name	Units	Qualifier	Start	End
Idaho Creek above Linda Creek														
HEC	775	-42:03:48.9	145:36:03.5	384249.999	5342200.000	Natural watercourse	2.3 km^2	100	1	Flow	L/s	Continuous	05/08/68 @ 11:26:58	13/01/95 @ 10:00:00
	775							450	1	Water temp lower	^{o}C		19/02/92 @ 14:00:00	13/01/95 @ 09:30:00
	775							822	1	Conductivity	µS/cm		05/08/86 @ 11:27:00	25/10/94 @ 16:00:00
	775							823	1	Conductivity	µS/cm uncomp		19/02/92 @ 14:00:00	13/01/95 @ 10:00:00
	775							30822	1	Conductivity	Counts	Uni log	05/08/86 @ 11:26:58	19/02/92 @ 11:00:00
	775							30822	2	Conductivity	Counts	Digitised	05/08/86 @ 11:27:00	19/02/92 @ 11:15:00
MLMRCL	25	-42:03:48.9	145:36:03.5	384249.999	5342200.000					Fe, Cu (T), Al, Zn, Mn, SO_4, Cl, As (T), Hg (T), Ni, Cd, Cr, TDS, TSS	mg/L	Periodic	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
	25									pH		Periodic	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
	25									Temperature	^{o}C	Periodic	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
	25									Conductivity	µS/cm	Periodic	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00

Comstock

Source	Site no	Latitude	Longitude	Easting	Northing	Description	Catchment	Parameter	Variable	Parameter name	Units	Qualifier	Start	End
Comstock Creek above King River														
HEC	773	-42:02:12.5	145:37:08.7	385700.001	5345200.000	Controlled watercourse - drainage from Comstock Adit 5 diverted to East Queen Riv. King Riv now inundated by Lake Burbury	13.3 km^2	100	1	Flow	L/s	Continuous	04/10/78 @ 09:25:00	28/03/95 @ 18:00:00
	773							23600	40	Copper (T)	mg/l	Periodic	01/03/91 @ 00:00:00	01/08/94 @ 00:00:00
	773							30822	1	Conductivity	Counts	Continuous	06/08/86 @ 14:48:00	28/03/95 @ 18:00:00
	773							30822	2	Conductivity	Counts	Digitised	06/08/86 @ 14:48:00	28/03/95 @ 18:00:00
Head of Comstock Creek														
MLMRCL	2			383515.000	5345500.000					Temperature	^oC	Periodic	20/5/91	14/12/92
										pH		Periodic	20/5/91	14/12/92
										Conductivity	µS/cm	Periodic	20/5/91	14/12/92
										Fe, Cu (T), Al, Zn, Mn, SO_4, Cl, As (T), Hg (T), Ni, Cd, Cr, TDS, TSS	mg/L	Periodic	20/5/91	14/12/92
King River above Comstock														
HEC	781	-42:03:24.1	145:39:50.3	389450.002	5343050.001	Natural watercourse. King River now inundated by Lake Burbury	270.7 km^2	100	1	Flow	L/s	Continuous	05/10/78 @ 09:10:00	03/03/87 @ 12:22:58
	781							30822	1	Conductivity	Counts	Uni Log	05/09/86 @ 09:17:00	03/03/87 @ 12:22:58

Source	Site no	Latitude	Longitude	Easting	Northing	Description	Catchment	Parameter	Variable	Parameter name	Units	Qualifier	Start	End
Comstock Mine Water														
MLMRCL	1					Below Comstock open-cut workings				Fe, Cu (T), Al, Zn, Mn, SO_4, Cl, As (T), Hg (T), Ni, Cd, Cr, TDS, TSS	mg/L	Monthly	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
	1									pH		Monthly	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
	1									Temperature	^oC	Monthly	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
	1									Conductivity	µS/cm	Monthly	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
Comstock Creek below workings														
MLMRCL	3a			383800.000	5345510.000	Runoff from Comstock workings minus adit 5 diversion (discharges to East Queen River from July 1991)				Temperature	^oC		01/06/74	01/11/76
	3a									Conductivity	µS/cm		01/06/74	01/11/76
	3a									Al, As, Cd, Cl, Cr, Cu, Fe, Hg, Mn, Ni, Pb, SO_4, Zn, (all T&D) TDS, TSS	mg/L	Monthly	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
	3a									Temperature	^oC	Monthly	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
	3a									Conductivity	µS/cm	Monthly	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
CMT	CCW									pH		Periodic	26/04/95 @ 00:00:00	Current
	CCW									TSS, Fe, Mn, Zn, Cu, Pb, Al, Hg (T&D)	mg/L	Periodic	26/04/95 @ 00:00:00	Current
	CCW									SO_4, Fl	mg/L	Periodic	26/04/95 @ 00:00:00	Current
	CCW									Flow	cumecs	Periodic	26/04/95 @ 00:00:00	Current

Source	Site no	Latitude	Longitude	Easting	Northing	Description	Catchment	Parameter	Variable	Parameter name	Units	Qualifier	Start	End
Comstock Creek above Lake Burbury														
MLMRCL	17a					Controlled watercourse				Fe, Cu (T), Al, Zn, Mn, SO_4, Cl, As (T), Hg (T), Ni, Cd, Cr, TDS, TSS	mg/L	Monthly	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
	17a									pH		Monthly	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
	17a									Conductivity	µS/cm	Monthly	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
	17a									Temperature	^oC	Monthly	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
Comstock adit 7														
MLMRCL	19			383710.000	5345460.000	Controlled watercourse				Fe, Cu (T), Al, Zn, Mn, SO_4, Cl, As (T), Hg (T), Ni, Cd, Cr, TDS, TSS	mg/L	Monthly	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
	19									pH		Monthly	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
	19									Conductivity	µS/cm	Monthly	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
	19									Temperature	^oC	Monthly	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00

Linda Creek

Source	Site no	Latitude	Longitude	Easting	Northing	Description	Catchment	Parameter	Variable	Parameter name	Units	Qualifier	Start	End
Linda Creek above King River														
HEC	776	-42:04:29.3	145:38:04.5	387050.000	5341000.002	Natural watercourse. King River now inundated by Lake Burbury	Currently 4.6 km^2. Prior to diversion 14.6 km^2	100	1	Flow	L/s	Continuous	04/10/78 @ 11:00:00	19/06/79 @ 00:07:00
	776							14010	1	Flow (estimate)	m^3/sec	Calculated	26/08/86 @ 14:00:00	15/08/94 @ 00:00:00
	776							23600	40	Cu (T)	mg/l	Periodic	01/03/91 @ 00:00:00	01/08/94 @ 00:00:00
Linda Creek above Lake Burbury														
MLMRCL	16									Fe, Cu (T), Al, Zn, Mn, SO_4, Cl, As (T), Hg (T), Ni, Cd, Cr, TDS, TSS	mg/L	Monthly	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
	16									pH		Monthly	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
	16									Conductivity	µS/cm	Monthly	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
	16									Temperature	^oC	Monthly	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00

Source	Site no	Latitude	Longitude	Easting	Northing	Description	Catchment	Parameter	Variable	Parameter name	Units	Qualifier	Start	End
Linda Creek below White Creek														
MLMRCL	18					Incorporating runoff from E areas of the lease site, including Linda Creek (apart from Linda Creek diversions into the North Lyell Tunnel), Brown Creek, White Creek, Idaho Creek and Iron Blow seepage				Temperature	°C	Periodic	01/06/74	01/11/76
	18									Conductivity	µS/cm	Periodic	01/06/74	01/11/76
	18									Fe, Cu (T), Al, Zn, Mn, SO_4, Cl, As (T), Hg (T), Ni, Cd, Cr, TDS, TSS	mg/L	Periodic	01/05/91	01/12/94
	18									Temperature	°C	Periodic	1/05/91 @ 00:00:00	01/12/94 @ 00:00:00
	18									pH		Periodic	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
	18									Conductivity	µS/cm	Periodic	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
Linda Creek above White Creek														
MLMRCL	22									Fe, Cu (T), Al, Zn, Mn, SO_4, Cl, As (T), Hg (T), Ni, Cd, Cr, TDS, TSS	mg/L		01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
	22									pH		Periodic	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
	22									Conductivity	µS/cm	Periodic	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
	22									Temperature	°C	Periodic	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00

Source	Site no	Latitude	Longitude	Easting	Northing	Description	Catchment	Parameter	Variable	Parameter name	Units	Qualifier	Start	End
Head of White Creek														
MLMRCL	23									Fe, Cu (T), Al, Zn, Mn, SO_4, Cl, As (T), Hg (T), Ni, Cd, Cr, TDS, TSS	mg/L	Periodic	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
	23									pH		Periodic	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
	23									Conductivity	µS/cm	Periodic	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
	23									Temperature	^oC	Periodic	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
White Creek above Linda Creek														
MLMRCL	24									Fe, Cu (T), Al, Zn, Mn, SO_4, Cl, As (T), Hg (T), Ni, Cd, Cr, TDS, TSS	mg/L	Periodic	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
	24									pH		Periodic	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
	24									Conductivity	µS/cm	Periodic	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
	24									Temperature	^oC	Periodic	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
Tharsis Adit														
MLMRCL	31			383305.000	5343000.000					Temperature	^oC	Periodic	08/09/93 @ 00:00:00	05/01/94 @ 00:00:00
	31									pH		Periodic	08/09/93	05/01/94
	31									Conductivity	µS/cm	Periodic	08/09/93	05/01/94
	31									Fe, Cu (T), Al, Zn, Mn, SO_4, Cl, As (T), Hg (T), Ni, Cd, Cr, TDS, TSS	mg/L	Periodic	08/09/93	05/01/94

Queen River

Source	Site no	Latitude	Longitude	Easting	Northing	Description	Catchment	Parameter	Variable	Parameter name	Units	Qualifier	Start	End
Queen River at Queenstown														
MLMRCL	14					Represents a composite of runoff from NW and W areas of the lease site and Haulage Creek discharge (incorporating tailings, waste rock dump seepage, Lyell tharsis and adit 5 diversion waters)				Temperature	^oC		01/06/74 @ 00:00:00	01/11/76 @ 00:00:00
	14									Conductivity	µS/cm		01/06/74 @ 00:00:00	01/11/76 @ 00:00:00
	14									Fe, Cu (T), Al, Zn, Mn, SO_4, Cl, As (T), Hg (T), Ni, Cd, Cr, TDS, TSS	mg/L	Periodic	01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
	14									Temperature	^oC		01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
	14									Conductivity	µS/cm		01/05/91 @ 00:00:00	01/12/94 @ 00:00:00
	14									Cu, Fe, Mn, Al (D)	mg/L	Daily	17/12/94 @ 00:00:00	26/01/95 @ 00:00:00
DELM	14									Cu, Fe, Mn, Al (D)	mg/L	Periodic	31/01/95 @ 00:00:00	09/03/95 @00:00:00
	14									Flow	L/s	Daily	17/12/94 @ 00:00:00	26/01/95 @ 00:00:00
	14									Flow	L/s	Periodic	31/01/95 @ 00:00:00	09/03/95 @00:00:00
	14									pH		Periodic	26/04/95 @ 00:00:00	Current
CMT	QRQ									Fe, Mn, Zn, Cu, Pb, Al, Hg, SO_4, Fl (T&D), TSS	mg/L	Periodic	26/04/95 @ 00:00:00	Current
	QRQ									Flow	cumecs	Periodic	26/04/95 @ 00:00:00	Current

Source	Site no	Latitude	Longitude	Easting	Northing	Description	Catchment	Parameter	Variable	Parameter name	Units	Qualifier	Start	End
Queen River below Filter House														
MLMRCL	13			380780.000	5342260.000					Temperature	^oC	Periodic	20/05/91	14/12/92
	13									pH		Periodic	20/05/91	14/12/92
	13									Conductivity	µS/cm	Periodic	20/05/91	14/12/92
	13									Fe, Cu (T), Al, Zn, Mn, SO_4, Cl, As (T), Hg (T), Ni, Cd, Cr, TDS, TSS	mg/L	Periodic	20/05/91	14/12/92
Queen River above Conglomerate Creek														
MLMRCL	15									Temperature	^oC	Periodic	20/5/91	14/12/92
	15									pH		Periodic	20/05/91	14/12/92
	15									Conductivity	µS/cm	Periodic	20/05/91	14/12/92
	15									Fe, Cu (T), Al, Zn, Mn, SO_4, Cl, As (T), Hg (T), Ni, Cd, Cr, TDS, TSS	mg/L	Periodic	20/05/91	14/12/92
Queen River at Lynchford														
HEC	860	-42:08:10.7	145:31:25.5	378000.000	5334020.000	Controlled watercourse	78.3 km^2	10	1	Rainfall	mm	Continuous	28/08/85 @ 14:35:00	08/05/91 @ 11:09:00
	860							100	1	Flow	L/s	Continuous	16/08/86 @ 21:00:00	16/05/95 @ 16:15:00
	860							15408	1	pH - meter installed		Continuous	03/05/95 @ 17:45:00	16/05/95 @ 16:15:00
DELM	2									Cu, Fe, Mn, Al (D)	mg/L	Daily	17/12/94 @ 00:00:00	25/01/95 @ 00:00:00
	2									Cu, Fe, Mn, Al (D)	mg/L	Periodic	26/01/95 @ 00:00:00	4/05/95 @ 00:00:00
	2									Flow	L/s	Daily	17/12/94 @ 00:00:00	25/1/95 @ 00:00:00
	2									Flow	L/s	Periodic	26/01/95 @ 00:00:00	4/05/95 @ 00:00:00

Source	Site no	Latitude	Longitude	Easting	Northing	Description	Catchment	Parameter	Variable	Parameter name	Units	Qualifier	Start	End
Conglomerate Creek														
MLMRCL	27									Fe, Cu, Al, Zn, Mn, SO_4, Cl, TDS, TSS	mg/L	Periodic	03/06/91 @ 00:00:00	01/12/92 @ 00:00:00
	27									pH		Periodic	03/06/91 @ 00:00:00	01/12/92 @ 00:00:00
	27									Temperature	^{o}C	Periodic	03/06/91 @ 00:00:00	01/12/92 @ 00:00:00
Princess Creek below tailings dam site														
CMT	PCTD									pH	mg/L	Periodic	26/04/95 @ 00:00:00	Current
	PCTD									TSS, Fe, Mn, Zn, Cu, Pb, Al, Hg (T&D)	mg/L	Periodic	26/04/95 @ 00:00:00	Current
	PCTD									SO_4, Fl	mg/L	Periodic	26/04/95 @ 00:00:00	Current
	PCTD									Flow	cumecs	Periodic	26/04/95 @ 00:00:00	Current

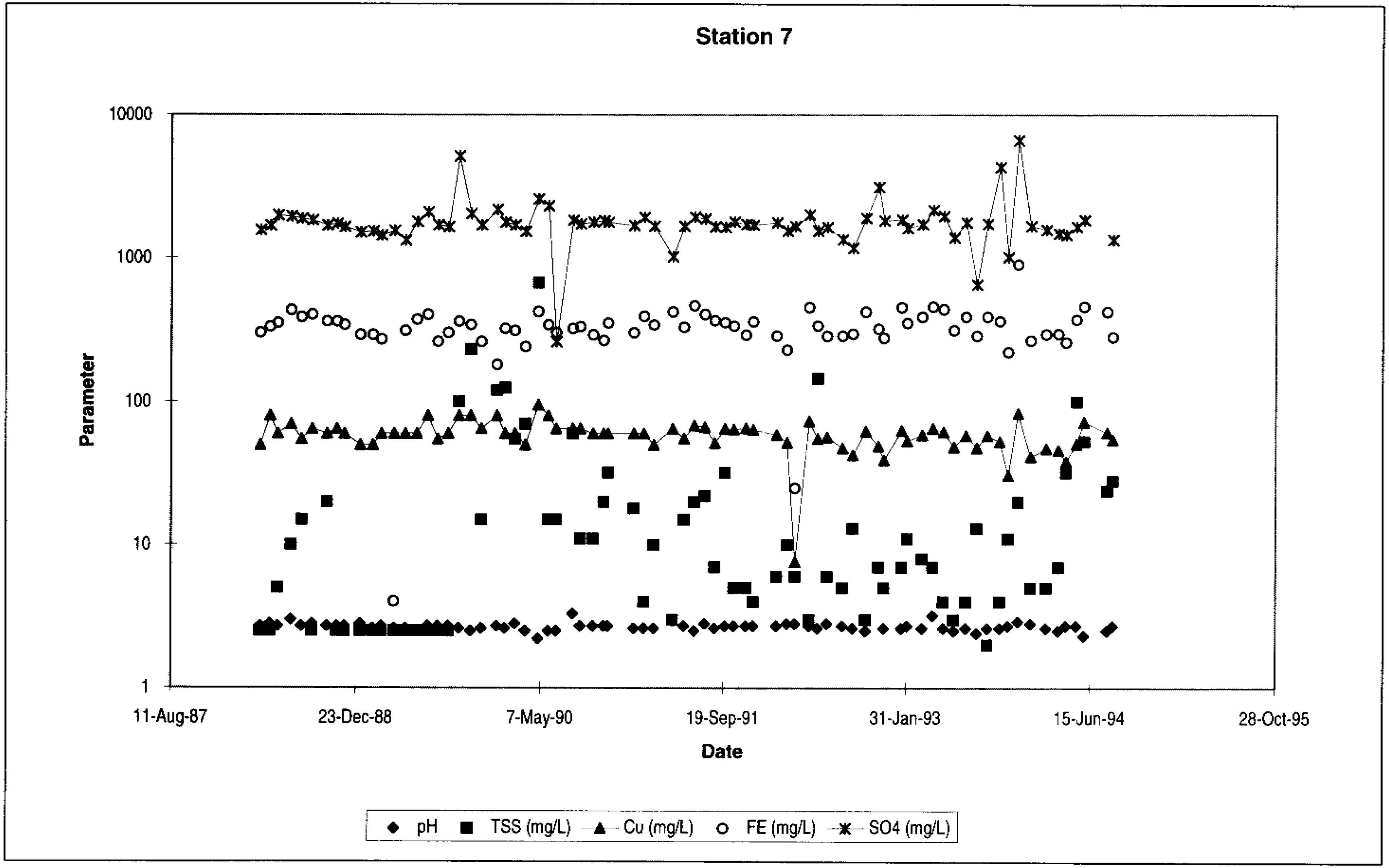
King River

Source	Site no	Latitude	Longitude	Easting	Northing	Description	Catchment	Parameter	Variable	Parameter name	Units	Qualifier	Start	End
King River above Teepookana														
HEC	704	-42:11:40.2	145:26:37.2	371500.000	5327439.999			100	1	Flow	L/s	Continuous	29/06/94 @ 12:00:00	31/03/95 @ 12:45:00
	704							405	1	Air Temp	^oC	Continuous	29/06/94 @ 12:00:00	31/03/95 @ 12:45:00
King River above mouth to Macquarie Harbour														
HEC	711	-42:11:50.4	145:24:07.0	368060.000	5327059.998	Between delta and Teepookana Bridge				Flow	L/s	Continuous	06/12/94 @ 16:00:00	13/04/95 @ 16:00:00
										Cu, Fe, Mn, Al (all D)	mg/L	Continuous	06/12/94 @ 16:00:00	13/04/95 @ 16:00:00
King River above Queen River														
MLMRCL	30									Temperature	^oC	Periodic	07/09/92	01/12/94
										pH		Periodic	07/09/92	01/12/94
										Conductivity	µS/cm	Periodic	07/09/92	01/12/94
										Al, As, Cd, Cl, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Zn, (all D), SO_4,TDS, TSS	mg/L	Periodic	07/09/92	01/12/94
King River below Queen River														
HEC	403	-42:09:27.0	145:31:45.5	378499.998	5331674.999	King River below Crotty Dam; Queen River confluence	675.8 km^2	100	1	Flow	L/s	Continuous	03/10/91 @ 12:35:10	27/03/95 @ 14:00:00
DELM	3									Flow	L/s	Continuous	03/10/91 @ 12:35:10	27/03/95 @ 14:00:00

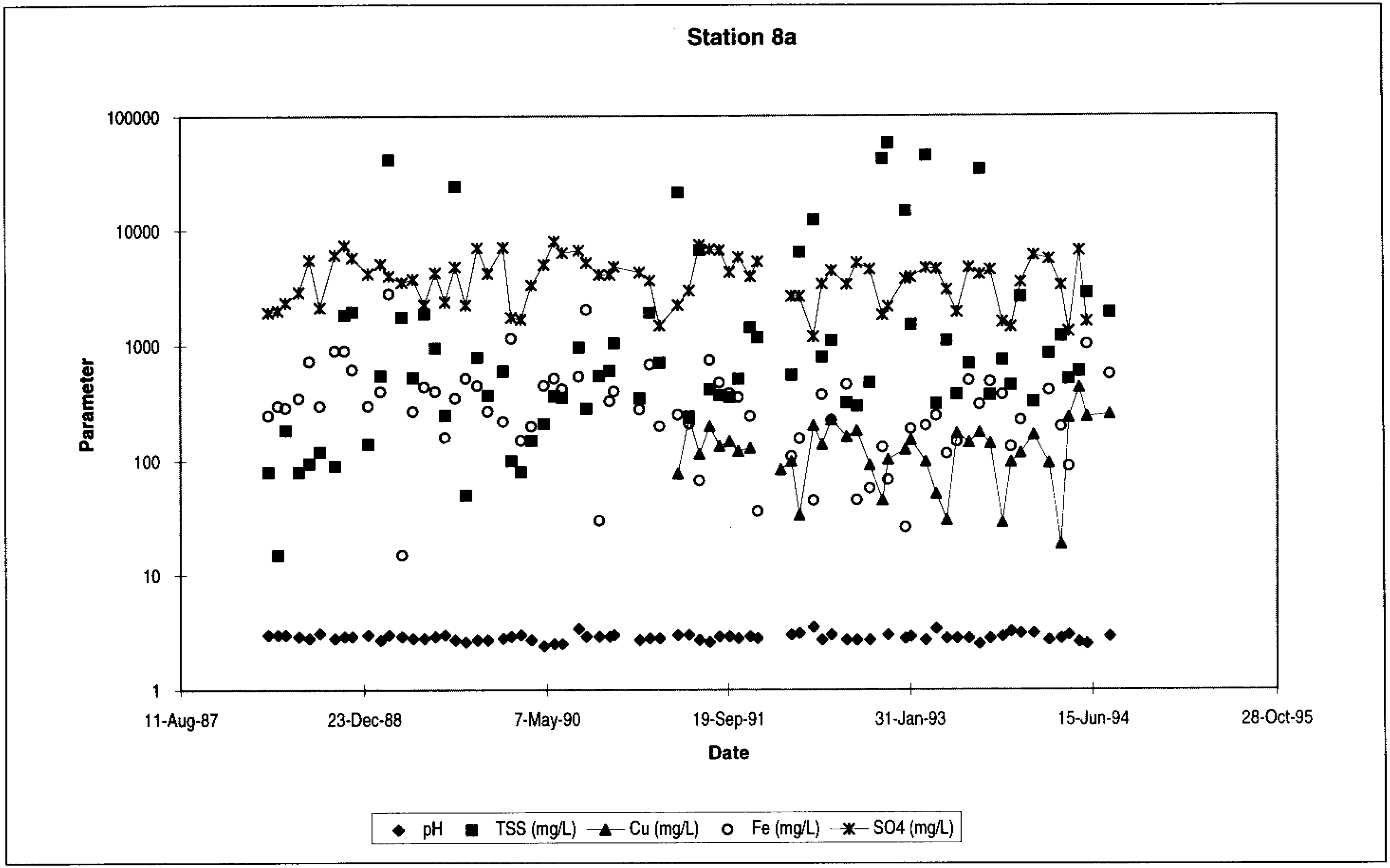
Source	Site no	Latitude	Longitude	Easting	Northing	Description	Catchment	Parameter	Variable	Parameter name	Units	Qualifier	Start	End
King River below Cutten Creek														
HEC	851	-42:11:53.5	145:24:48.1	369004.736	5326983.356	Tidal; zero gauge = -0.22 m;catchment area 71.5 km^2 between Sailor Jack and Cutten Creek	802.5 km^2	100	1	Flow	L/s	Continuous	15/01/86 @ 11:39:48	17/05/95 @ 08:45:00
	851							15408	1	pH - meter installed		Continuous	05/05/95 @ 12:15:00	17/05/95 @ 08:45:00
King River below Sailor Jack														
HEC	841	-42:10:45.4	145:29:29.4	375419.999	5329199.999	Natural watercourse controlled after 25/7/91; catchment area = 170km^2 between Crotty dam and Sailor Jack; Crotty dam to source = 561km^2	731 km^2	100	1	Flow	L/s	Continuous	23/01/85 @ 07:55:00	13/04/95 @ 10:30:00
DELM	4									Flow	L/s	Continuous	23/01/85 @ 07:55:00	13/04/95 @ 10:30:00
King River below Quarter-mile Bridge														
DELM	13					Controlled watercourse				Flow	L/s	Periodic	29/6/94 @ 00:00:00	4/5/95 @ 00:00:00
King River at Teepookana														
MLMRCL	28						792.5 km^2			Al, As (T), Cd, Cl, Cr, Cu, Fe, Hg (T), Mn, Ni, Pb, SO_4 (T), Zn, TDS, TSS	mg/L	Periodic	01/06/74	01/11/76
	28									Temperature	^oC	Periodic	01/06/74	01/11/76
	28									Conductivity	µS/cm	Periodic	01/06/74	01/11/76
	28									Al, As (T), Cd, Cl, Cr, Cu, Fe, Hg (T), Mn, Ni, Pb, SO_4 (T), TDS, TSS, Zn	mg/L	Periodic	01/05/91	01/12/94
	28									Temperature	^oC	Periodic	01/05/91	01/12/94
	28									Conductivity	µS/cm	Periodic	01/05/91	01/12/94
DELM	15									Flow	L/s	Periodic	15/10/86	04/05/65
HEC	706									Flow	L/s	Periodic	15/10/86	04/05/65

Source	Site no	Latitude	Longitude	Easting	Northing	Description	Catchment	Parameter	Variable	Parameter name	Units	Qualifier	Start	End
King River above Delta														
HEC	723	-42:11:40.7	145:21:47.3	364849.999	5327300.000	Teepookana forestry access gate above delta	813 km^2	23600	40	Cu (T)	N/A	Periodic	01/03/91 @ 00:00:00	01/08/94 @ 00:00:00
MLMRCL	29									pH		Periodic	01/06/74	01/11/76
	29									Temperature	^oC	Periodic	01/06/74	01/11/76
	29									Al, As, Cd, Cl, Cr, Cu, Fe, Hg, Mn, Ni,, Zn, Pb, SO_4,TDS, TSS	mg/L	Periodic	01/05/91	01/12/94
										Temperature	^oC	Periodic	01/05/91	01/12/94
	29									pH		Periodic	01/05/91	01/12/94

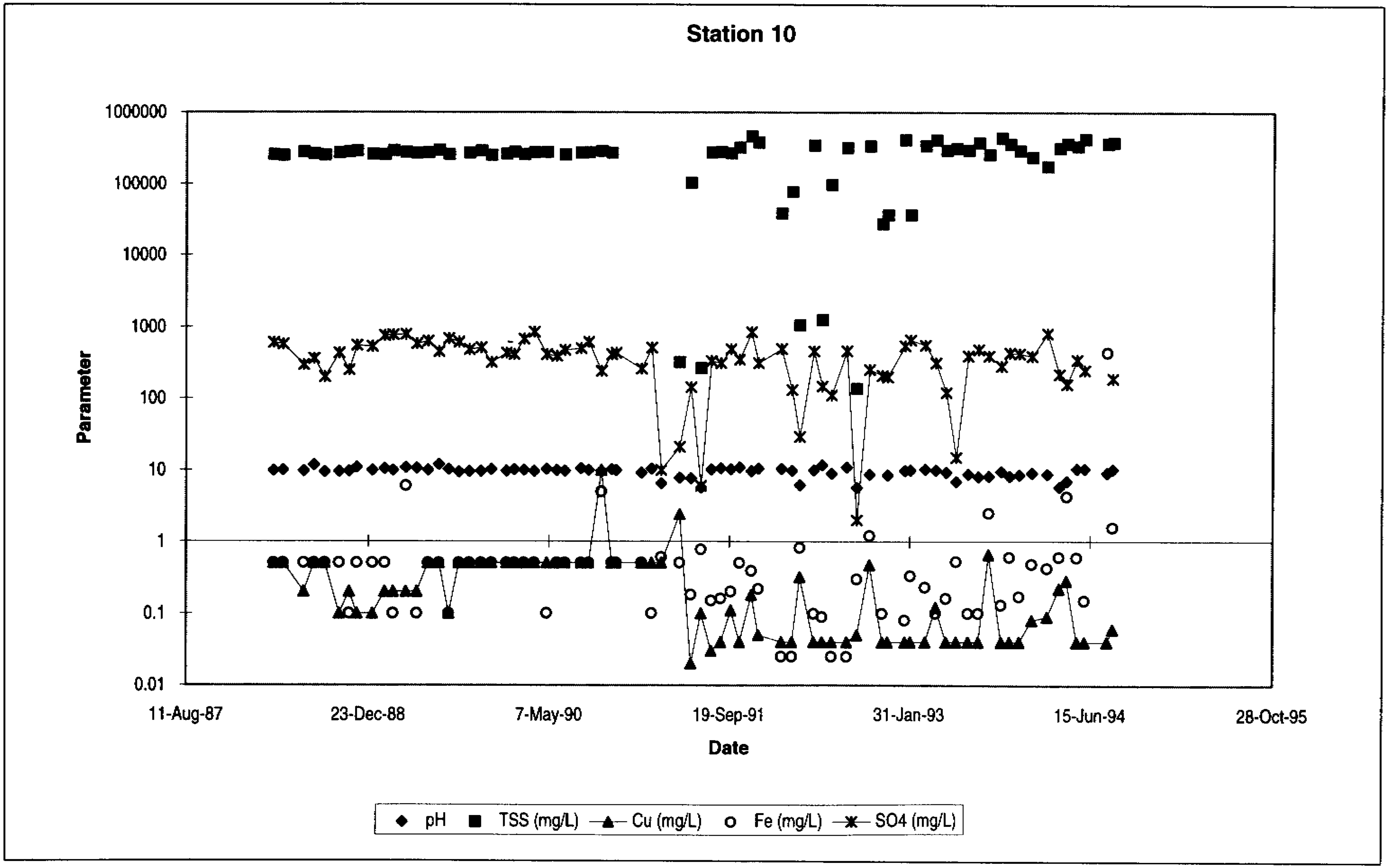
Appendix C Water quality parameters for stations 7, 8a and 10



Appendix C. Water quality parameters for station 7



Appendix C. Water quality parameters for station 8a



Appendix C. Water quality parameters for station 10