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MOUNT LYELL REMEDIATION

Remediation options to reduce acid drainage from historical mining operations at Mount Lyell, Western Tasmania

John Miedecke and Partners Pty Ltd

Mount Lyell Remediation Research and Demonstration Program

a Tasmanian and Commonwealth Government initiative *supervising scientist report* **108**

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Department of Environment and Land Management

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

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

This report was prepared by John Miedecke and Partners Pty Ltd, in association with Environmental Geochemistry International (EGi) Pty Ltd, Golder Associates Pty Ltd and Australian Nuclear Science and Technology Organisation (ANSTO).

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Executive summary

The former Mount Lyell Mining and Railway Company Limited (MLMRCL) lease is large and the problems associated with the mine drainage, waste rock dumps and river tailings are typical of a number of old mine sites in Australia and internationally. The magnitude of the acid drainage (AD) loads from the lease are comparable with the major acid drainage producing mines in the United States, Canada and Great Britain. By far the greatest loads are from the Haulage Creek catchment which receives the surface discharge of the mine dewatering, adit drainage from old workings and drainage from major waste rock dumps. This catchment contributes 99.3% of the total copper loads to the Queen River and 98.7% of the lease. Approximately 2.5 tonnes of copper per day is released into the Queen River from the Queen River catchment.

The remediation of the Mount Lyell lease to totally eliminate on-going acid drainage and release of copper from the site is an unrealistic objective, but it is feasible to put in place strategies that will result in a progressive reduction in the contaminant load from the site.

Previous works by the Mount Lyell Mining and Railway Company Limited (MLMRCL) and the Hydro Electric Commission (HEC) have had some effect on loads in the Linda and Comstock catchments draining to Lake Burbury and the recently recommenced mining operations by Copper Mines of Tasmania (CMT) will result in a progressive reduction in copper loads to the Queen River system due to partial treatment of waters draining from the lease. However, it is regarded as unacceptable by the Sustainable Development Advisory Council (SDAC) that the balance of the waters are left untreated and SDAC acknowledges that this is a government and community responsibility (SDAC 1995).

A review of acid drainage remediation technology has revealed that to meet water quality objectives for downstream rivers and Macquarie Harbour, the only feasible means of reducing the acid mine drainage loads is by a conventional neutralisation water treatment plant. This will require substantial capital investment and ongoing operating costs.

A pilot test of a Solvent Extraction/Electrowinning (SX/EW) plant design carried out in 1993 by the former Mount Lyell Mining and Railway Company Limited as a condition of its Licence to Operate, has shown that high grade copper can be won from the drainage from the Haulage Creek catchment. Further feasibility studies by CMT have indicated that a modern SX/EW plant could be constructed to recover copper from the high concentration streams in the Haulage Creek catchment. Financial analyses indicate that the plant with traditional neutralisation treatment of the effluent (raffinate) to remove acidity and other metals would be viable and is commercially attractive and financially robust. It therefore appears feasible to construct and operate the plant to recover copper from the major concentrated copper sources and treat the raffinate effluent as a commercial venture.

It is estimated that with the SX/EW plant and raffinate treatment of the major Haulage Creek loads, the acidity and copper loads to the Queen River could be reduced by up to approximately 95%, depending on the effectiveness of collection of AD loads and water management. Aluminium, zinc and iron loads would be reduced by similar amounts, with manganese and sulphate less affected.

The SX/EW plant could operate as long as the effluent streams coming from the dumps and the underground workings have significant metal loads and could be independent of mining operations. It could therefore represent a long-term solution to the remediation of the site.

The use of SX/EW technology in this application would be a world first and of worldwide interest and application.

The balance of the lease site has acid drainages with much lower loads and flows and other options have been identified which could remediate these sources. These include the reduction in loads by flooding and covering AD sources, the passive treatment of adit drainages by successive alkalinity producing systems, and alkalinity addition to receiving waters by anoxic limestone drains and limestone addition.

Trials are recommended for these technologies which will have worldwide application if proven successful.

It is estimated that with the remediation measures identified, the AD loads from the lease site to both the Lake Burbury and Queen River catchments can be reduced by approximately 95%, such that water quality objectives can be met downstream.

The ongoing operations of CMT have resulted in a marked improvement in the environment of the lease site and provided the impetus for ongoing remediation works. It is important that any ongoing site remediation works and future mining activities should consider the long-term planning for mine closure and site rehabilitation, otherwise at some time in the future the Tasmanian Government may again be facing an expensive solution to an ongoing long-term environmental problem.

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1 Introduction

The Mount Lyell Remediation Research and Demonstration Program (MLRRDP) was established as a joint program in 1995 by the Tasmanian and Federal Governments to develop a strategy for remediating the environmental effects of past mining at Mount Lyell, in western Tasmania. The authorities coordinating the program comprise the Tasmanian Department of Environment and Land Management, Environmental Management Division; and the Commonwealth's Environment Protection Agency, Office of the Supervising Scientist and Environmental Research Institute of the Supervising Scientist.

The program comprises a number of projects to investigate the extent and mechanisms of the environmental impacts which have resulted from mining activities at Mount Lyell over the past century. These mining activities in the Mount Lyell region have resulted in impacts on the natural environment within and about the mining leases, the rivers downstream from the lease area and Macquarie Harbour, mostly from acid air emissions and acid drainages from the lease site. Impacts have resulted on the general landscape of the Queenstown area, the physical environment, changes to hydrology and water quality, and the deposition of tailings and slag in the Queen and King rivers and downstream to 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 projects which have been carried out as part of the program cover the lease area and downstream to Macquarie Harbour. Figure 1.1 shows the location of the lease in relation to the harbour.

The list of MLRRDP projects can be seen in insert 1.

The MLRRDP included three related projects dealing with the management of the quantity and quality of effluent from the lease site (acid drainage).

Project 1 A review and presentation of historical literature and data for the characterisation of sources of effluent from the lease site.

Project 2 Identification of the potential options for managing effluent water from the lease and recommendations for construction and operation of demonstration/evaluation trials.

Project 3 Construction and evaluation of test cases.

Project 1 presented a consolidation of available information and provided an introduction to the site with a brief history of the mining and processing operations undertaken over the past century (McQuade et al 1996). The environmental impacts resulting from these operations were presented with an overview of available information on the current quantity and quality of effluent water from the lease site.

It formed the basis for the completion of Project 2—the subject of this report. Project 3 involved the construction and evaluation of some of the options identified in Project 2.

2 Scope and conduct of study

2.1 Scope

The consultancy brief set out by the MLRRDP was as follows:

1 Identify and characterise (both in quantity and quality) the point sources of effluent water for the lease site. This should include an estimation/prediction of the rate and contaminant load in the short term (20 years) and the long term (500 years).

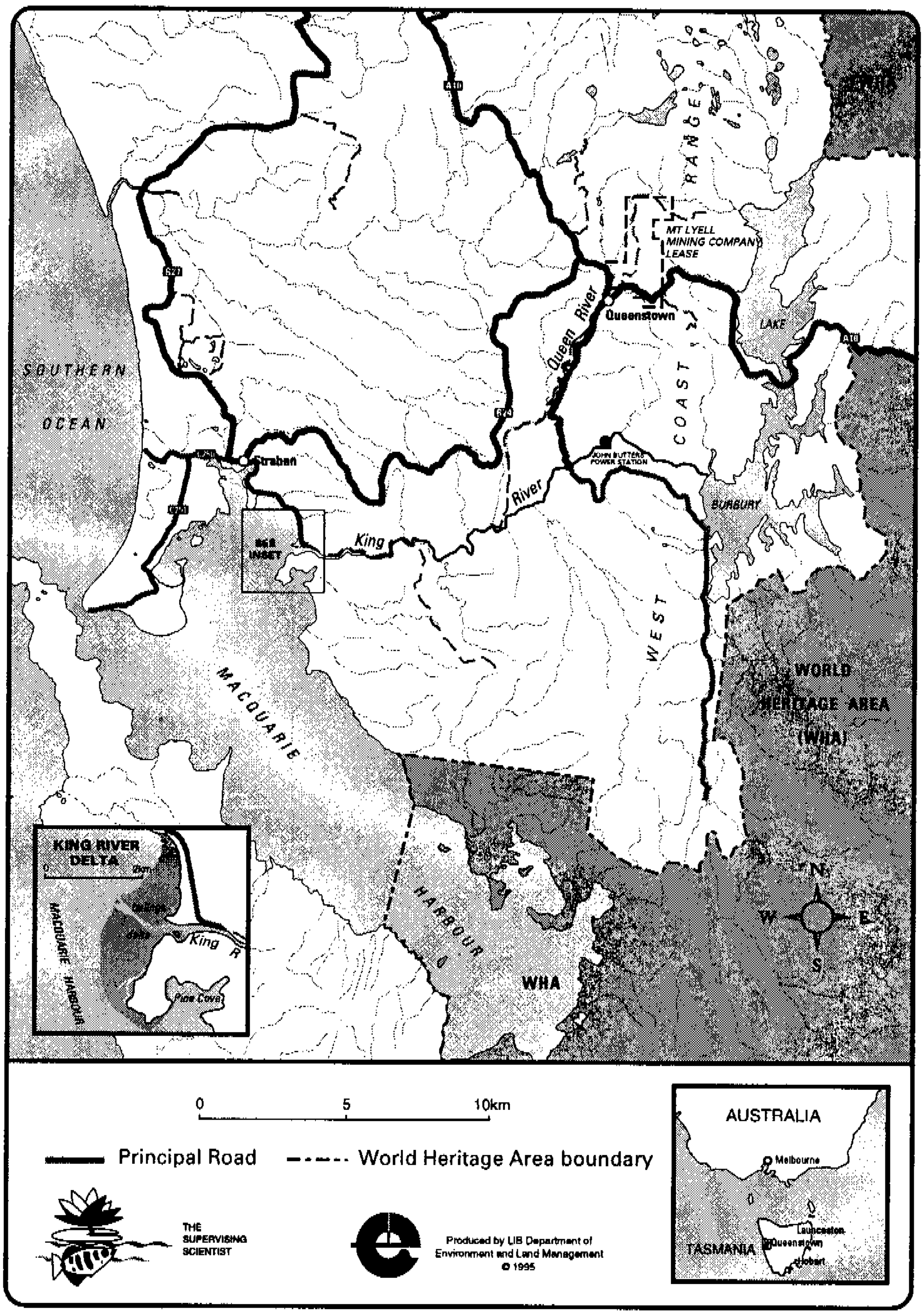


Figure 1.1 Regional map

2 Propose short and long-term options for remediating the quality and quantity of the effluent water from the lease site. Preference should be given to passive/minimum management systems or cost-neutral systems. Consideration should be given to potential benefits associated with the copper mining and recovery program proposed by Copper Mines of Tasmania.

The proposed options must include:

- critical evaluation presenting the positive and negative points of each proposed option
- estimated establishment cost (+ 30%) for the entire site

- ongoing maintenance and consumable costs where applicable, prescriptions for ongoing maintenance
- the probable degree of environmental amelioration (quantity and quality of the effluent water)
- the expected life of each option

3 Through discussions with the project managers select test sites and cost the construction of the most promising management options to remediate the effluent water. The supply and installation of instrumentation to assess the performance of the management strategy should be separately itemised and costed.

4 Present the information in a report that will form the basis of Project 3.

The program brief stipulated that prescriptions for treatment of discharges resulting from historical site impacts need not meet existing water quality objectives required of a new mining operation. Thus, the net result of remedial measures should be substantial reduction of the effluent discharge from the mine lease, thereby improving the health of the downstream environment and protecting the aquatic ecosystems in Macquarie Harbour. The long-term aim of site prescriptions should be the restoration of a sustainable, though modified, aquatic ecosystem in the receiving waters for site emissions.

2.2 Study team

The study was conducted by a project team consisting of John Miedecke and Partners Pty Ltd (JMP), Environmental Geochemistry International Pty Ltd (EGi), Golder Associates and the Australian Nuclear Science and Technology Organisation (ANSTO). John Miedecke and Partners Pty Ltd was the primary consultant and project manager.

The Project Team consisted of:

John Miedecke (JMP), Project Manager—hydrology, environmental engineering, remediation options, reporting.

Dr Stuart Miller, Dr John Jeffrey, Clayton Rumble, EGi—chemistry, geochemistry, control options, water quality benefits.

Mike Gowan and Roger Parker, Golder Associates—hydrology, mine waste management, geotechnical and groundwater engineering, mine and process options, costing.

Dr Ian Ritchie, Dr J Bennett and Andrew Garvie (plus others), ANSTO—AD processes, generation rates, control options.

In addition, during the course of the study additional expertise was supplied as follows:

Joe Keene, KD Engineering Co Inc, Tucson USA—SX/EW review.

Copper Mines of Tasmania (CMT)—information on solvent extraction/electrowinning feasibility studies.

MINPROC Engineers—water treatment engineering cost estimates.

Doug Keppler and Eric McCleary, Damariscotta, Pennsylvania USA—design advice on successive alkalinity producing systems.

Dr Robert Hedin (Hedin Environmental)—advice on anoxic limestone drains and alkalinity producing systems.

2.3 Conduct of the study

The study was conducted over a 7 month period and included site visits by the study team, additional sample collection to identify acid drainage sources and to quantify loads from the site, and project team meetings including the program managers to review remediation options and the study program.

In addition, the opportunity was taken to inspect a number of sites and visit overseas practitioners in the United States and Canada (by John Miedecke as part of a United States visit). Sites in the eastern and western United States were inspected including the Tennessee Valley Authority works, the latest advances in acid drainage passive treatment in Pennsylvania, and passive and active mine water treatment sites in the western USA. In Canada, the remediation works which had involved active mine water treatment and major site works at the Equity Mine, British Columbia, were inspected. Site visits and discussions were held with a number of government and industry professionals, including Mr Pat Wiram (Cypress Amax) and Dr Robert Klienmann (US Bureau of Mines). This provided access to the latest developments in AD remediation in the United States and Canada. In addition, information provided by the Canadian Mine Environment Neutral Drainage study (MEND) provided direct access to international experience in acid drainage.

The assistance of the OSS and DELM personnel was invaluable during the conduct of the study. In particular, the assistance of John Johnston, Shelly Innes, Karen Johnston and Chris McQuade is gratefully acknowledged. DELM LIB Department assisted with figure production.

3 Lease area acid drainage loads

3.1 Introduction

Water quality and flow data have been collected from numerous locations at Mount Lyell since early 1974. These data have been summarised and presented in previous reports prepared by EGi, HEC, CMT and DELM. In addition, single event samples and ongoing monitoring data are continually being collected and documented.

The major compilations of data are contained in the following reports:

- Acid mine drainage interim report, May 1991 (EGi 1991)
- Modelling of water quality in the Queen and King Rivers below the Mount Lyell Mine, October 1993 (EGi 1993)
- Mount Lyell redevelopment environmental management plan, March 1995 (CMT 1995)
- DELM and OSS Project 1: Review of historical literature and data on the sources and quality of effluent from the Mount Lyell lease site, December 1995 (Supervising Scientist Report 104, McQuade et al 1995)
- Modelling of pollutant loads in the Linda and Comstock catchments (Mounter 1993)

In addition, computer databases have been compiled by JMP, EGi and DELM which contain data currently available on water quality and flows for the lease site. CMT also maintains a database of monitoring information being collected as part of its current operations.

Much of the data (in particular the early flow data) are unreliable. However, in most assessments which have been published, only the major outliers have been omitted from the analysis and interpretation of the data. It is not intended to reproduce the information contained in previous documents in this report or to critically evaluate the data. The purpose of this section of the report is to present the findings of the detailed evaluation of the available data to provide a best-estimate of the pollutant sources and loads and to allow the effect of previous and proposed control strategies to be evaluated.

3.2 Pollutant sources

Figure 3.1 is a conceptual drainage model of the Queen and King River system which incorporates the Mount Lyell lease site. All relevant monitoring sites are shown on this figure.

This report focuses on the lease site and immediate surrounds. This area consists of four main catchments (fig 3.2):

- Haulage Creek
- East Queen River
- Comstock Creek
- Linda Creek

3.3 Water quality and pollutant indicators

The historical water quality data were limited in the elements analysed. Very few complete analyses were carried out. However, from the results of the few complete analyses, the data confirm that aluminium, iron, copper, manganese and zinc are the main soluble metals and sulphate is the dominant anion. Calcium and magnesium are also major cations with magnesium generally occurring at higher concentrations than calcium.

The concentration of other elements of potential environmental concern such as Cd, Pb, As and Hg are generally below detection or at very low concentrations.

The data confirm that the primary indicators of acid drainage and sulphide oxidation at Mount Lyell are pH, aluminium, copper, iron and sulphate. Manganese and Zn are secondary indicators.

The acidity in drainage waters is due mainly to iron, aluminium and copper.

3.4 Pollutant loads and source evaluation

The monitoring data have been analysed to provide median and 90th percentile values for flows and median values for quality data. At many locations the flow data have been estimated from the available hydrological data and catchment characteristics. This has been based on information previously provided by the HEC. The 90th percentile values are only provided where continuous records are available.

Where acidity has not been directly measured, it has been calculated from the dissolved metal concentrations and pH. The acidity data are critical for evaluating the alkalinity requirement for treatment of acid drainage sources.

Load estimates for copper, iron, sulphate and acidity have been calculated and are discussed below for each major lease site catchment. The 90th percentile load values provide an estimate of upper values since at higher flows, lower concentrations would be expected than the median values used in the calculations.

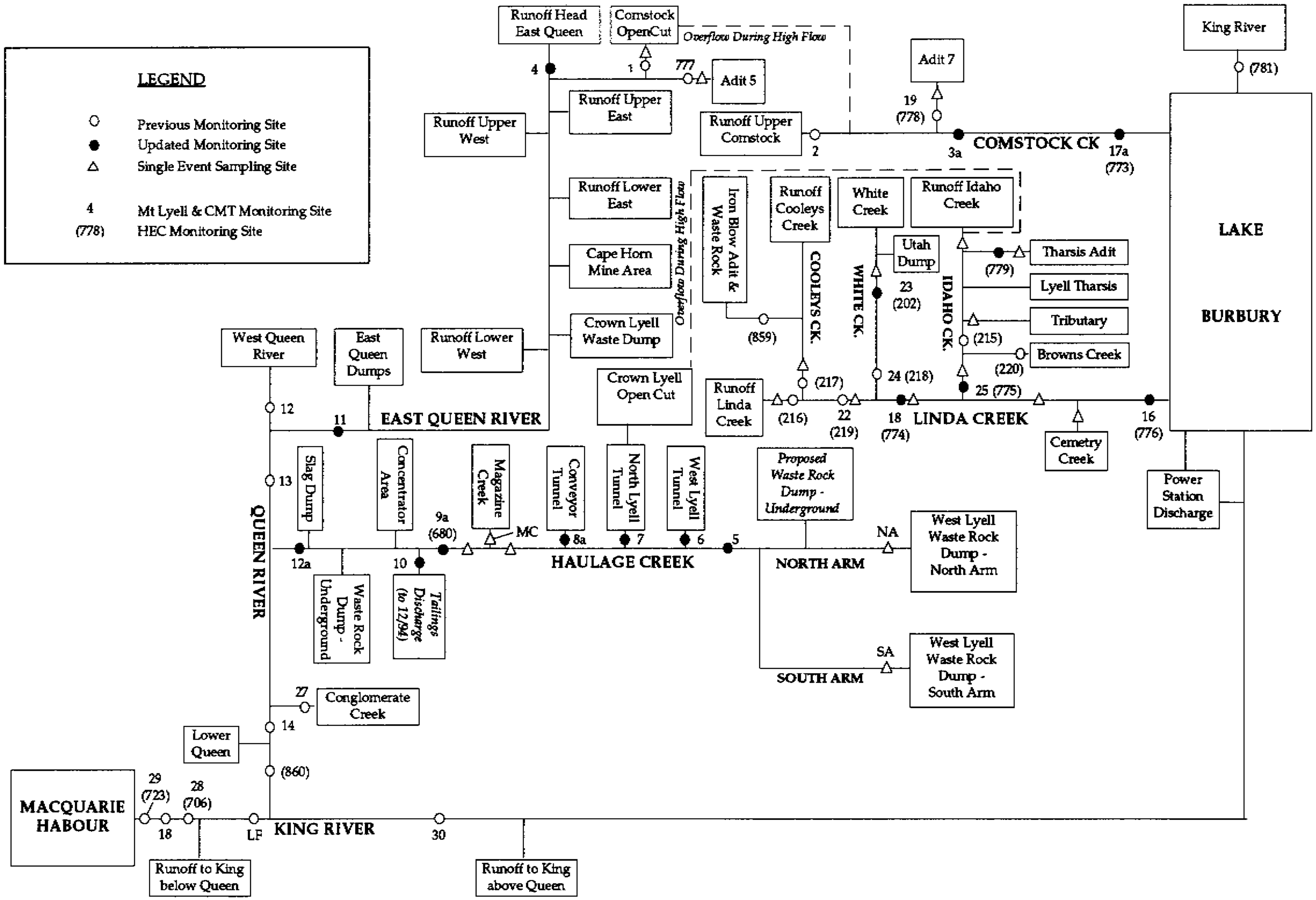


Figure 3.1 Conceptual drainage model of the King and Queen River system

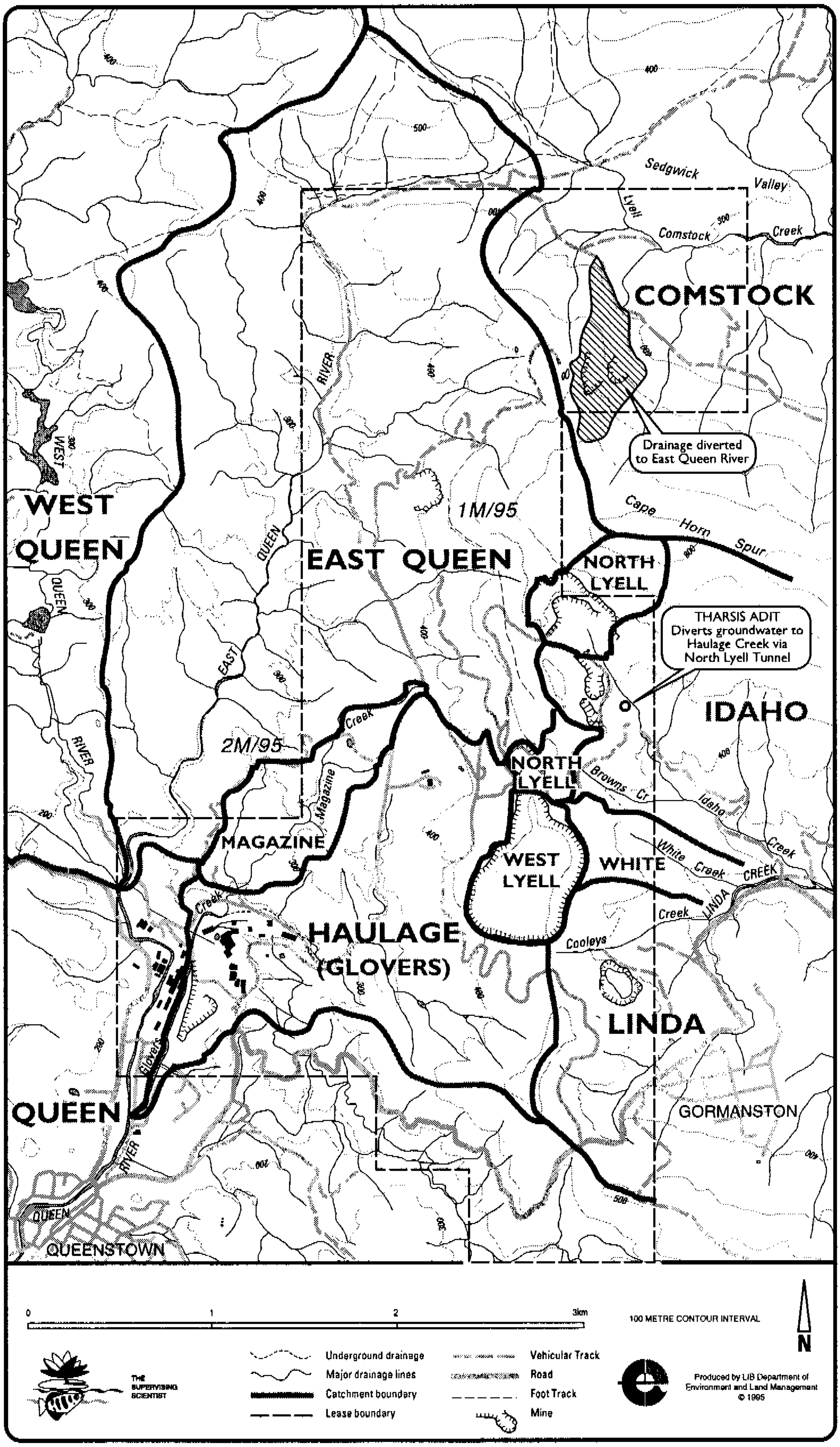


Figure 3.2 Drainage catchments in the Mount Lyell lease site

3.4.1 Haulage Creek

The Haulage Creek catchment comprises the main acid drainage sources. These are the West Lyell, Magazine Creek and underground mine waste rock dumps, West Lyell Tunnel, North Lyell Tunnel, and mine dewatering discharge via the Conveyor Tunnel. Prior to December 1994, the process tailings were also discharged into Haulage Creek and transported by the Queen and King Rivers to Macquarie Harbour.

Table 3.1 gives the median water quality values for each monitoring site along Haulage Creek. These sites are shown on figure 3.3 which is an enlarged scale of the Haulage Creek section from figure 3.1. The monitoring period for each data set is shown in the table and it is important to note that the data for Site 10 (tailings discharge) and Site 12a are only relevant to the pre-December 1994 period since tailings are no longer discharged from the site.

Figure 3.4 is a plot of the sulphate concentration verses the dissolved copper concentration for Haulage Creek sites 5, 6, 7 and 8a. These sites represent the waste rock dumps (Site 5), disused tunnels (Sites 6 and 7) and the mine water (Site 8a). The data show a very good correlation between sulphate and copper concentrations at all sites, however at Site 8a the data are significantly more scattered than at the other sites. Three different relationships are identified on figure 3.4 and reflected by the regression lines for sites 5, 6 and 7/8a. The data show that for a given sulphate concentration, the copper concentration is highest at site 7/8a and lowest at site 6. For example, at a sulphate concentration of 4000 mg/L, the copper concentration at sites 6, 5 and 8a could be expected to be 25, 60 and 100–150 mg/L, respectively.

These different relationships are possibly due to a combination of mineralogy, exposure time and flow effects. Site 8a reflects the active mining area and higher Cu/S ratio in exposed rocks. Site 5 is the waste rock with a lower Cu/S ratio and a direct flow dilution response within the catchment of Site 5. Site 6 is the West Lyell Tunnel which drains old workings.

The estimated acidity, copper, iron and sulphate loads within Haulage Creek for the period up to December 1994 and post-December 1994 are shown in tables 3.2a and 3.2b, respectively. Loads are shown for median flows and the 90th percentile flows, where available. The copper loads for these two periods are also shown on figure 3.3.

The data confirm that the major copper loads are from the underground mine dewatering (site 8a) and the waste rock dumps (site 5). An increase in the dissolved copper concentration in the mine water since December 1994 is indicated by the load increase at Site 8a (Conveyor Tunnel). Prior to this period the copper concentration was about 150 mg/L which increased to a median value of 282 mg/L during the intensive daily monitoring from April 1995 to September 1995. Prior to December 1994 the copper load from Haulage Creek was about 1.7 tonnes per day which increased to about 2.5 tonnes per day during the period April 1995 to September 1995. The reason for this increase is not known, but may reflect the unusual climatic conditions in 1994, the improved monitoring program that was established post-December 1994 or an increase in copper solubility as a result of the current development works. Ongoing monitoring will confirm if the recent increase is sustained. At present, Haulage Creek contributes about 99% of the total dissolved copper load from the lease site.

All load estimates shown in tables 3.2a and 3.2b are based on measured or estimated flows and measured concentrations. The metal balances achieved in these estimates are consistent and suitable for pollution control planning and assessment.

Table 3.1 Median water quality data for the Haulage Creek monitoring sites

Station	Data collection		pH	#Acidity	TDS	TSS	EC	Dissolved constituents (mg/L)						
	From	To		(mg $CaCO_3$/L)	(mg/L)	(mg/L)	(µS/cm)	Al	Cl	Cu	Fe	Mn	SO_4	Zn
† NA	–	Nov 95	2.6	10000	–	–	8850	870	–	127.0	2230	64.9	13900	16.6
† SA	–	Nov 95	2.5	8300	–	–	8360	880	–	180.0	948	149	11700	15.5
5	Apr 74	Aug 90	2.6	–	18250	10	6800	–	16.0	139.0	####	69.0	8600	13.1
	Sep 90	Dec 94	2.5	5271	10250	14	5370	500	11.0	82.9	788.5	46.7	6550	6.7
6	Apr 74	Aug 90	2.9	–	3880	237	3220	–	12.0	70.0	920.0	40.0	4700	6.8
	Sep 90	Dec 94	2.9	1952	4305	65	3220	128	12.0	16.9	399.0	43.2	2798	3.7
7	Apr 74	Aug 90	2.7	–	2265	230	2550	–	7.0	80.0	420.0	21.5	2100	7.6
	Sep 90	Dec 94	2.7	1495	2860	8	2200	70	10.0	56.7	327.0	20.0	1661	4.3
8a	Jul 84	Aug 90	2.9	–	4183	200	–	–	12.0	160.0	370.0	40.0	3660	7.0
	Sep 90	Dec 94	2.9	2598	7022	853	5200	197	13.0	141.0	326.0	173.0	4285	25.0
	Apr 95	Sep 95	–	–	–	–	–	–	–	282.0	–	–	**8000	–
† MC	–	Jul 95	2.9	–	–	–	1450	40	–	9.2	52.6	8.1	643	–
9a	Aug 92	Dec 94	2.7	3175	6890	674	4050	*275	–	103.5	422.0	131.0	4090	14.2
10	Apr 75	Aug 90	10.7	–	–	####	870	–	–	0.1	0.1	0.1	285	0.01
	Sep 90	Dec 94	9.7	4	511	####	–	*0.1	–	0.1	0.2	0.1	311	0.02
12a	Aug 92	Dec 94	3.9	1036	3915	95050	3240	*75	–	58.2	146.5	65.6	2050	8.3

\# Acidity calculated from median pH and metal concentration values

* Concentration estimated from SO4 and Fe concentrations

** Concentration estimated using Cu–SO4 correlation

† Data based on single event sampling

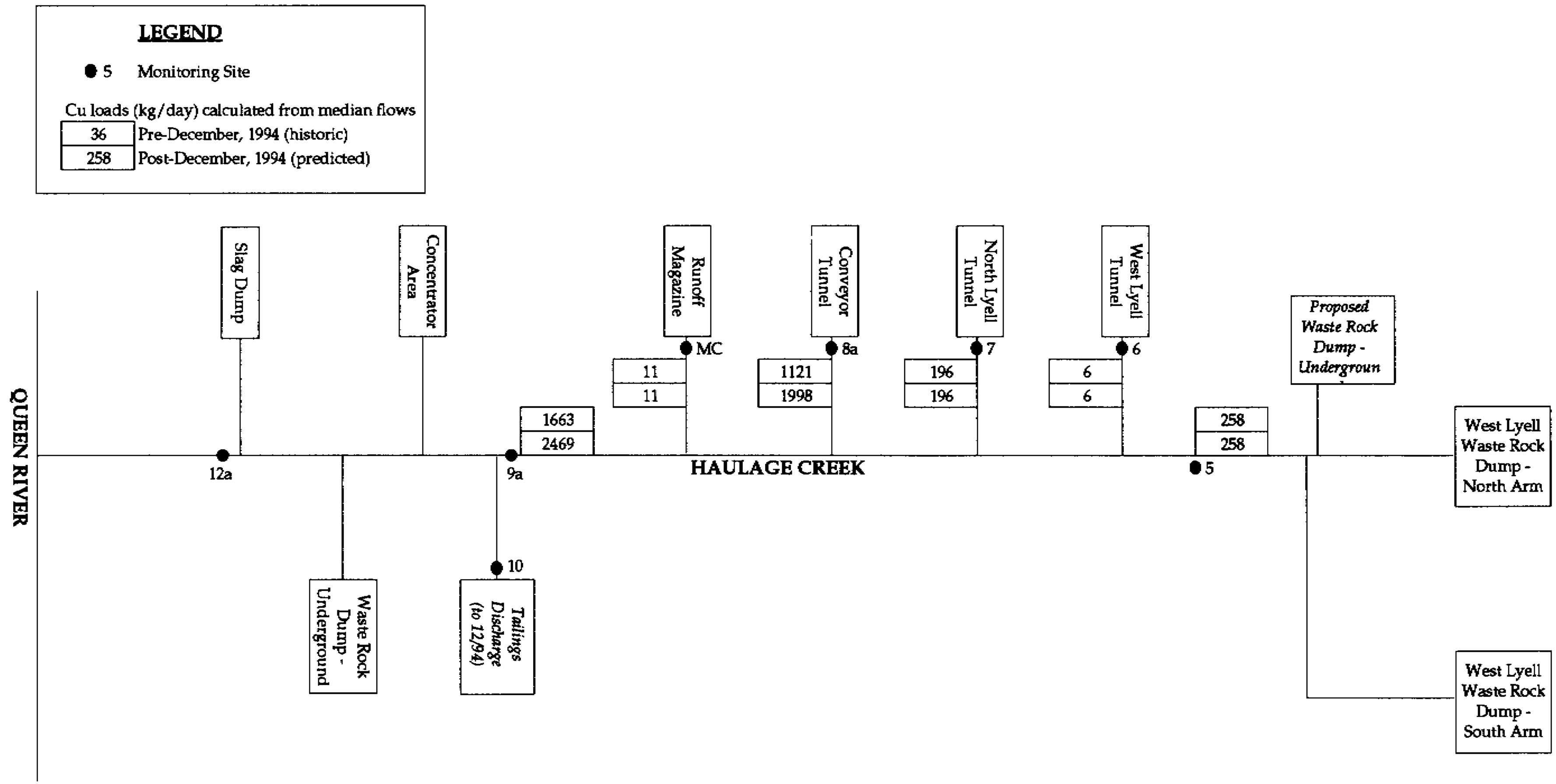


Figure 3.3 Pre-December 1994 (historic) and post-December (predicted) copper loads for Haulage Creek catchment

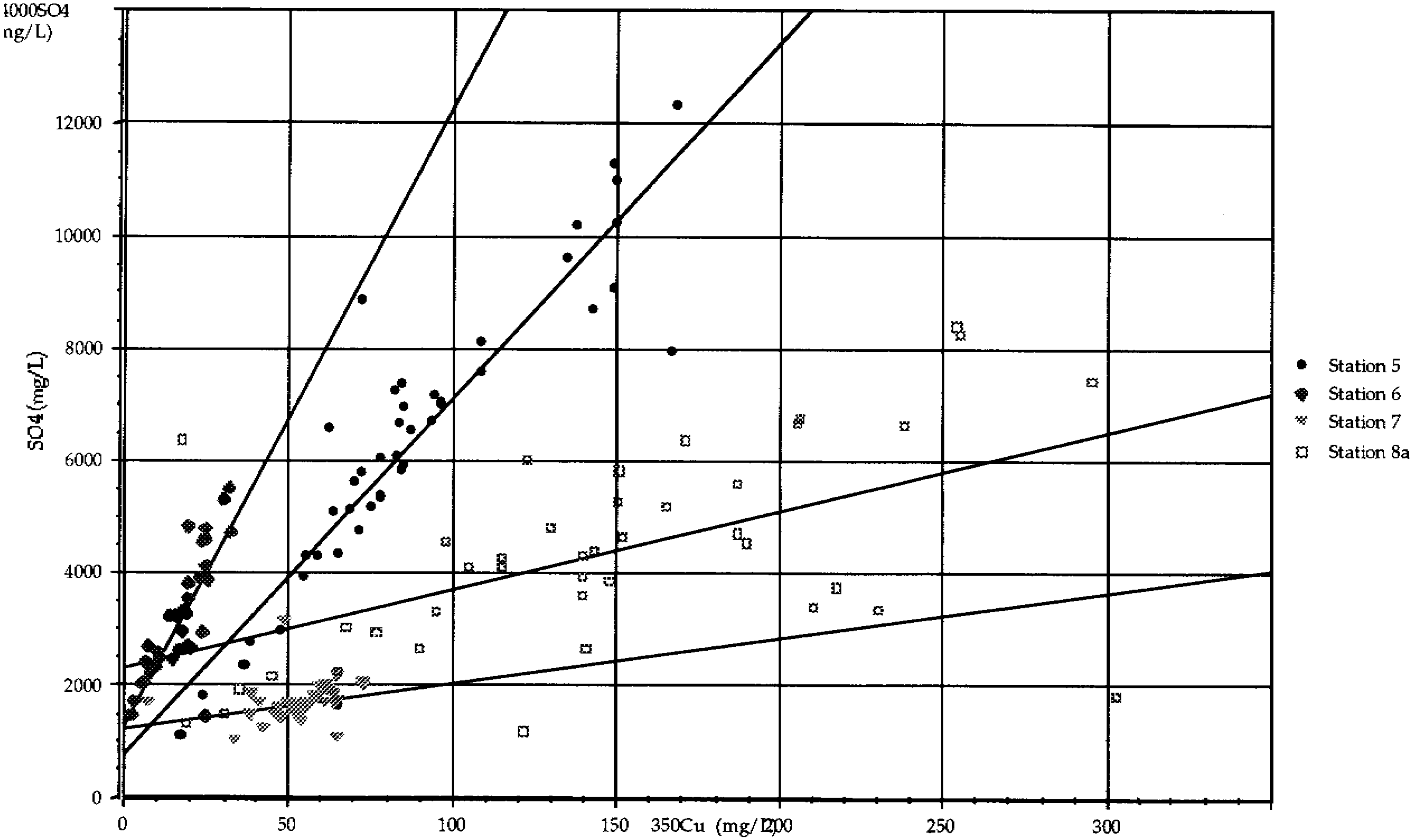


Figure 3.4 Sulphate versus copper concentrations for MLMRCL monitoring stations 5, 6, 7 and 8a

Table 3.2a Monitoring periods and estimated acidity, copper, iron and sulphate loads from Haulage Creek

Station	Data collection		Measured flow (L/sec)		Calculated loads for median flow (kg/day)				Calculated loads for 90th percentile flow (kg/day)			
	From	To	Median	90th percentile	Acidity	Cu	Fe	SO4	Acidity	Cu	Fe	SO4
5	Sep 90	Dec 94	36A	133A	16395	258	2453	20373	60570	952	9061	75267
6	Sep 90	Dec 94	4A	10A	675	6	138	967	1687	15	345	2417
7	Sep 90	Dec 94	40A	76A	5167	196	1130	5739	9817	372	2147	10903
8a	Sep 90	Dec 94	92B	–	20651	1121	2591	34061	–	–	–	–
† MC	–	Jul 95	14C	–	–	11	64	778	–	–	–	–
9a	Aug 92	Dec 94	186D	–	51023	1663	6782	65728	–	–	–	–

† Data based on single event sampling

FLOW DATA SOURCES: A Range of 50th to 90th percentile from CMT supplied data; B Recent continuous monitoring; C Recent HEC direct measurement; D Sum of stations 5, 6, 7, 8a and MC flows

Table 3.2b Monitoring periods and predicted acidity, copper, iron and sulphate loads from Haulage Creek monitoring station 8a (post December 1994)

Station	Data collection		Measured flow (L/sec)		Calculated loads for median flow (kg/day)				Calculated loads for 90th percentile flow (kg/day)			
	From	To	Median	90th percentile	Acidity	Cu	Fe	SO4	Acidity	Cu	Fe	SO4
5	–	–	36A	133	16395	258	2453	20373	60570	952	9061	75267
6	–	–	4A	10	675	6	138	967	1687	15	345	2417
7	–	–	40A	76	5167	196	1130	5739	9817	372	2147	10903
8a	Apr 95	Sep 95	82E	102E	–	1998	–	63590	–	2485	–	–
† MC	–	Jul 95	14C	–	–	11	64	778	–	–	–	–
9a	–	–	186D	–	–	2469	–	91447	–	–	–	–

† Data based on single event sampling

FLOW DATA SOURCES: A Range of 50th to 90th percentile from CMT supplied data; B Recent continuous monitoring; C Recent HEC direct measurement; D Sum of stations 5, 6, 7, 8a and MC flows; E Range of 50th to 90th percentile from DELM supplied data

The data also indicate that the median sulphate load from the waste rock dumps is about 20 tonnes per day. Assuming this sulphate originates from the 50 million tonnes of waste rock placed in the catchment, the estimated average intrinsic oxidation rate for the waste rock is about 4 x 10^{-9} kg $O_2m^{-3}s^{-1}$. This is consistent with the measured intrinsic oxidation (IOR) rates determined by ANSTO which are discussed in section 5.2.2 of this report. This low IOR value indicates that oxidation is likely to proceed at the current rate for a long period of time (many decades at least) before a significant reduction in the sulphate or copper load from this source is observed. This aspect is discussed further later in this report.

3.4.2 East Queen River

The East Queen River catchment is shown on figs 3.1 and 3.2 and extends from MLMRCL monitoring site 4 at the head of the catchment to monitoring site 11 near the confluence with the West Queen which forms the Queen River. The East Queen receives acid drainage from the Crown Lyell waste dumps, Cape Horn mine and waste dumps, East Queen dumps and from Adit 5 and the Comstock Open Cut, which were both diverted to the East Queen during mid 1991.

Table 3.3 gives the median concentrations and estimated loads for acidity, iron, copper and sulphate within the East Queen catchment

The data indicate that the current copper load from this catchment is 17 kg/d with about 8 kg/d originating from the diverted Adit 5 and Comstock open cut. No data are available for the East Queen dumps but the copper load balance indicates this area is likely to be only a minor source.

Overall the pollutant load from the East Queen catchment is only about 0.7% of the total pollutant load from the lease. The acidity load is also relatively low and possibly amenable to in situ treatment.

3.4.3 Comstock Creek

The main acid drainage sources in the Comstock Creek catchment were Adit 5, Adit 7 and runoff from the Comstock open cut and associated minor waste rock dumps. However, as discussed in section 3.4.2 above, in July 1991 drainage from Adit 5 and all but high flow drainage from the Comstock open cut were diverted to the East Queen catchment. Adit 7 in the only remaining acid drainage source that is known to drain to Lake Burbury via Comstock Creek.

Table 3.4 gives the median concentrations and estimated loads for acidity, iron, copper and sulphate from Adit 7 and indicates that the total copper load entering Lake Burbury was reduced by approximately 50% by the 1991 diversion works. The data also suggest that some attenuation of the copper load occurs downstream of Adit 7 prior to the water entering Lake Burbury, however given the high and variable flows in this area, the difference observed could be accounted for by errors in flow and load estimates.

The copper load entering Lake Burbury via Comstock Creek is currently only 3 kg/d which is only about 0.2% of the total copper load from the lease area.

3.4.4 Linda Creek

The Linda Creek catchment receives acid drainage from disused adits, old waste rock dumps and drainage from sections of the Crown Lyell and Lyell Tharsis open cuts. As indicated on figures 3.1 and 3.2 most surface drainage from the Crown Lyell (including the Lyell Tharsis) open cut is currently directed back through the old workings to the North Lyell Tunnel and hence to Haulage Creek. However, during periods of high flow, the diversion works spill to the Linda catchment. Works were also carried out in 1991 and 1992 to cover part of the Utah dumps and to seal the Tharsis Adit.

Table 3.3 Selected metal and acidity concentrations and estimated acidity, copper, iron and sulphate loads from East Queen monitoring data

Monitoring site			Data collection		pH	Concentration in solution (mg/L)				Estimated loads (kg/day)			
	Monitoring station code	Median flows (L/sec)	From	To		Fe	Cu	SO_4	#Acidity ($CaCO_3$)	Fe	Cu	SO_4	#Acidity ($CaCO_3$)
Adit 5	[777]	2A	Sep 78	May 90	3.3	217	43.9	961	–	37	8	166	–
†		2A	–	Sep 95	2.9	85.5	44.7	1120	660	15	8	194	114
† Comstock Open Cut	1	2B	–	Nov 95	3.1	5.42	2.28	90	80	1	0.4	16	14
East Queen River Head Water	4	51B	Jul 91	May 93	3.7	1.7	1.1	28	25	7	5	123	110
† Cape Horn Mine Area	–	18B	–	May 90	3.8	3	0.6	39	–	5	1	61	–
† Crown Lyell Waste Dump	–	30B	–	May 90	3.0	50	4	260	–	130	10	674	–
East Queen Dumps	No data available	–	–	–	–	–	–	–	–	–	–	–	–
Lower East Queen River	11	150B	May 91	Dec 94	3.4	6.4	1.3	68.5	–	83	17	888	–

Acidity calculated from pH and metal concentrations

† Data from single event sampling

FLOW DATA SOURCES: A - Continuous Record; B Calculated from catchment area (EGi, 1993)

Table 3.4 Selected metal and acidity concentrations and estimated loads from Comstock and Linda Creek monitoring data

Monitoring site	Monitoring station code		** Median flows L/sec	Data collection From	Data collection To	pH	Concentration in solution (mg/L) Fe	Cu	SO_4	#Acidity ($CaCO_3$)	Estimated loads (kg/day) Fe	Cu	SO_4	Acidity ($CaCO_3$)
Comstock Creek														
Upper Comstock Creek	2		–	Apr 74	Mar 75	4.1	0.21	0.1	–	6	–	–	–	–
Adit 7	19[778]		7	Oct 78	Aug 90	3.4	132	24	892	895	80	15	539	541
Comstock Creek below Adit 7	3a		98	Aug 92	Dec 94	3.5	5.7	1.1	47.5	59	48	9	402	500
Lower Comstock Creek	17a[773]	Pre diversion	150	Aug 75	Aug 90	4.1	3.2	0.5	34.9	29	41	6	452	376
		Post diversion	150	Jul 91	Apr 93	4.1	0.98	0.23	10	12	13	3	130	156
Linda Creek														
* Linda Creek above White Creek	22[219]		49	–	–	2.9	30	1.13	185	180	127	4.8	783	762
White Creek below Utah Dumps	23[202]	Post works	2	Jul 91	Apr 93	2.3	1430	93.2	4836	7267	247	16.1	836	1256
* White Creek above Linda	24[218]		8	–	–	2.5	411	28	2170	2455	284	19	1500	1697
Linda Creek below White Creek	[774]	Pre works	80	Sep 78	Aug 90	3.4	57.8	3.6	277	319	400	25	1915	2205
Tharsis Adit	[779]	Pre adit sealing	1	Sep 78	May 90	2.9	482	139	3617	3812	42	12	313	329
		Post adit sealing	1	Feb 94	Oct 95	2.7	84	37.1	1365	890	7	3	118	77
Idaho Creek above Linda Creek	25[775]	Pre diversion	61	Sep 78	Aug 90	3.4	24.4	5.2	174	184	129	27	917	970
		Post diversion	61	Feb 93	Nov 94	3.2	4.1	1.7	63	75	21	9	332	395
Linda Creek below Idaho Creek	18	Post works	140	Jul 91	Apr 93	3.0	27.9	2.42	178	196	337	29	2153	2371
Lower Linda Creek	16[776]	Pre works	352	Aug 75	Feb 87	3.5	11.5	2.00	97	89	350	61	2950	2707
		Post works	352	Jul 91	Apr 93	3.6	4.76	0.94	69	56	145	29	2098	1703

\# cidity calculated from pH and metal concentrations

* Data from CMT Mt Lyell Redevelopment EMP Report, March 1995

** Median flows from continuous record except for Station 3a and 16

Station 3a: from HEC flow calculation (DELM, Project No. 1, November 1995); Station 16: estimated mean divided by 3 (EGi, 1993)

The Linda Creek monitoring sites are shown on figure 3.1 and table 3.4 shows the median concentrations and estimated pollutant loads. The data indicate that the waste rock dumps in Whites Creek and Idaho Creek are currently the main pollutant sources. The data indicate that the Tharsis Adit was a major source prior to sealing when the copper load was about 12 kg/d. This was reduced to about 3 kg/d following sealing. Overall, the data indicates that the pollutant load from the Linda catchment (Site 16) was reduced by about 50% after completion of the control works in 1991 and 1992. Prior to these works, the copper load at Site 16 was estimated to be 26 kg/d which was reduced to 12 kg/d by the works. This load of 12 kg/d is about 0.5% of the total copper load currently discharging from the lease site.

3.4.5 Pollutant load summary

Table 3.5 and figure 3.5 summarise the copper, sulphate and acidity load data for each source within each catchment and the total lease site. The data confirm that Haulage Creek is the major pollutant source and contributes about 99% of the total copper load from the lease. Within Haulage Creek the major source is the Conveyor Tunnel (80%) with significant contributions from the waste rock dumps (10%) and the North Lyell Tunnel (8%). The Magazine Dump catchment and the West Lyell Tunnel are only minor sources (less than 0.5%).

The copper loads from the East Queen, Comstock and Linda catchments are only 17, 3 and 12 kg/d compared with 2469 kg/d from Haulage Creek. The total copper load from these catchments combined is only 1.4% of the total from the lease.

The previous works carried out in the Comstock and Linda catchments in 1991/92 have resulted in about a 50% reduction in the loads entering Lake Burbury. The major sources remaining in these catchments are Adit 7 in Comstock catchment and the waste rock dumps in Whites Creek and Idaho Creek in the Linda catchment. In the East Queen, the main point source is Adit 5 which has been diverted from the Comstock catchment.

The acidity data suggest that following treatment or collection and diversion to Haulage Creek of these point source sites, passive input of alkalinity could be highly effective in ameliorating the residual acid drainage impacts in the East Queen, Comstock and Linda catchments.

4 General screening of remedial technologies

4.1 Introduction

The elimination of acid drainage from exposed pyritic material is virtually impossible. However, it is possible to reduce the rate of AD generation to an environmentally acceptable level by controlling the process rate and the transportation mechanism such that the loads can be assimilated by the downstream receiving aquatic environment.

In general terms the strategies available to minimise the long-term environmental impact of drainage from pyritic mine wastes are:

- Reduce the pollutant load to an environmentally accepted level by control of the acid generating process and/or control of acid drainage migration (**load reduction**).
- Treat the acid drainage until the load in mine drainage drops to a level where drainage can be released without treatment (**acid drainage treatment**).
- Speed up the overall oxidation rate to such an extent that little pyrite is left at or after mine closure and recover and treat the mine drainage.

Table 3.5 Summary of copper, iron and sulphate loads for the Mount Lyell lease area

Location	Cu load (kg/day)				SO_4 load (kg/day)				Acidity load (kg/day)			
	pre works	post works	% of total post works		pre works	post works	% of total post works		pre works	post works	% of total post works	
			pre Dec 94	post Dec 94			pre Dec 94	post Dec 94			pre Dec 94	post Dec 94
Haulage Creek												
West Lyell Waste Rock (5)	258	NR	15.2	10.3	20373	NR	30.1	21.8	16395	NR	24.2	17.6
West Lyell Tunnel (6)	6	NR	0.4	0.2	967	NR	1.4	1.0	675	NR	1.0	0.7
North Lyell Tunnel (7)	196	NR	11.6	7.8	5739	NR	8.5	6.1	5167	NR	7.6	5.5
Conveyor Tunnel (8a) pre Dec'94	[1121]	NR	66.1	–	[34061]	NR	50.4	–	[20651]	NR	30.5	–
Conveyor Tunnel (8a) post Dec'94	1998	NR	–	79.9	63590	NR	–	68.1	* 45340	NR	–	48.6
Magazine Creek (MC)	11	NR	0.6	0.4	778	NR	1.2	0.8	* 620	NR	0.9	0.7
Total Haulage Creek (9a) pre Dec'94	[1663]	NR	98.1	–	[65728]	NR	97.2	–	[51023]	NR	75.4	–
Total Haulage Creek (9a) post Dec'94	2469	NR	–	98.7	91447	NR	–	98.0	* 68200	NR	–	73.1
East Queen River												
Adit 5 [777]	8	NR	0.5	0.3	194	NR	0.3	0.2	114	NR	0.2	0.1
Comstock Open Cut (1)	0.4	NR	0.1	0.1	16	NR	0.1	0.1	14	NR	0.1	0.1
East Queen Head Water (4)	5	NR	0.3	0.2	123	NR	0.2	0.1	110	NR	0.2	0.1
Cape Horn Mine Area	1	NR	0.1	0.1	61	NR	0.1	0.1	* 50	NR	0.1	0.1
Crown Lyell Waste Dump	10	NR	0.6	0.4	674	NR	1.0	0.7	* 540	NR	0.8	0.6
East Queen Dumps	–	–	–	–	–	–	–	–	–	–	–	–
Total East Queen River (11)	17	NR	1.0	0.7	888	NR	1.3	1.0	* 710	NR	1.0	0.8

Table 3.5 cont'd

Location	Cu load (kg/day)				SO_4 load (kg/day)				Acidity load (kg/day)			
	pre works	post works	% of total post works		pre works	post works	% of total post works		pre works	post works	% of total post works	
			pre Dec 94	post Dec 94			pre Dec 94	post Dec 94			pre Dec 94	post Dec 94
Comstock Creek												
Adit 7 (19)	15	NR	0.9	0.6	539	NR	0.8	0.6	541	NR	0.8	0.6
Comstock below Adit 7 (3a)	9	NR	0.5	0.4	402	NR	0.6	0.4	500	NR	0.7	0.5
Total Comstock Creek (17a)	6	3	0.4	0.2	452	130	0.2	0.1	376	156	0.2	0.2
Linda Creek												
Linda above White Creek (22)	4.8	NR	0.3	0.2	783	NR	1.2	0.8	762	NR	1.1	0.8
White Ck below Utah Dumps (23)	–	16	0.9	0.6	–	836	1.2	0.9	–	1256	1.9	1.3
White Creek above Linda (24)	19	NR	1.1	0.8	1500	NR	2.2	1.6	1697	NR	2.5	1.8
Linda below White Creek (18)	25	17	1.0	0.7	1915	1230	1.8	1.3	2205	1355	2.0	1.5
Tharsis Adit [779]	12	3	0.2	0.1	313	118	0.2	0.1	329	77	0.1	0.1
Idaho Creek above Linda (25)	27	9	0.5	0.4	917	332	0.5	0.4	970	395	0.6	0.4
Total Linda Creek (16)	26	12	0.7	0.5	1257	894	1.3	1.0	1153	726	1.1	0.8
Total lease area (pre Dec 94)	1712	1695	100	–	68325	67640	100		53262	52615	100	–
Total lease area (post Dec 94)	2518	2501	–	100	94044	93359	–	100	70439	69792	–	100

NR – No remediation work carried out

* Based on estimate of acidity only

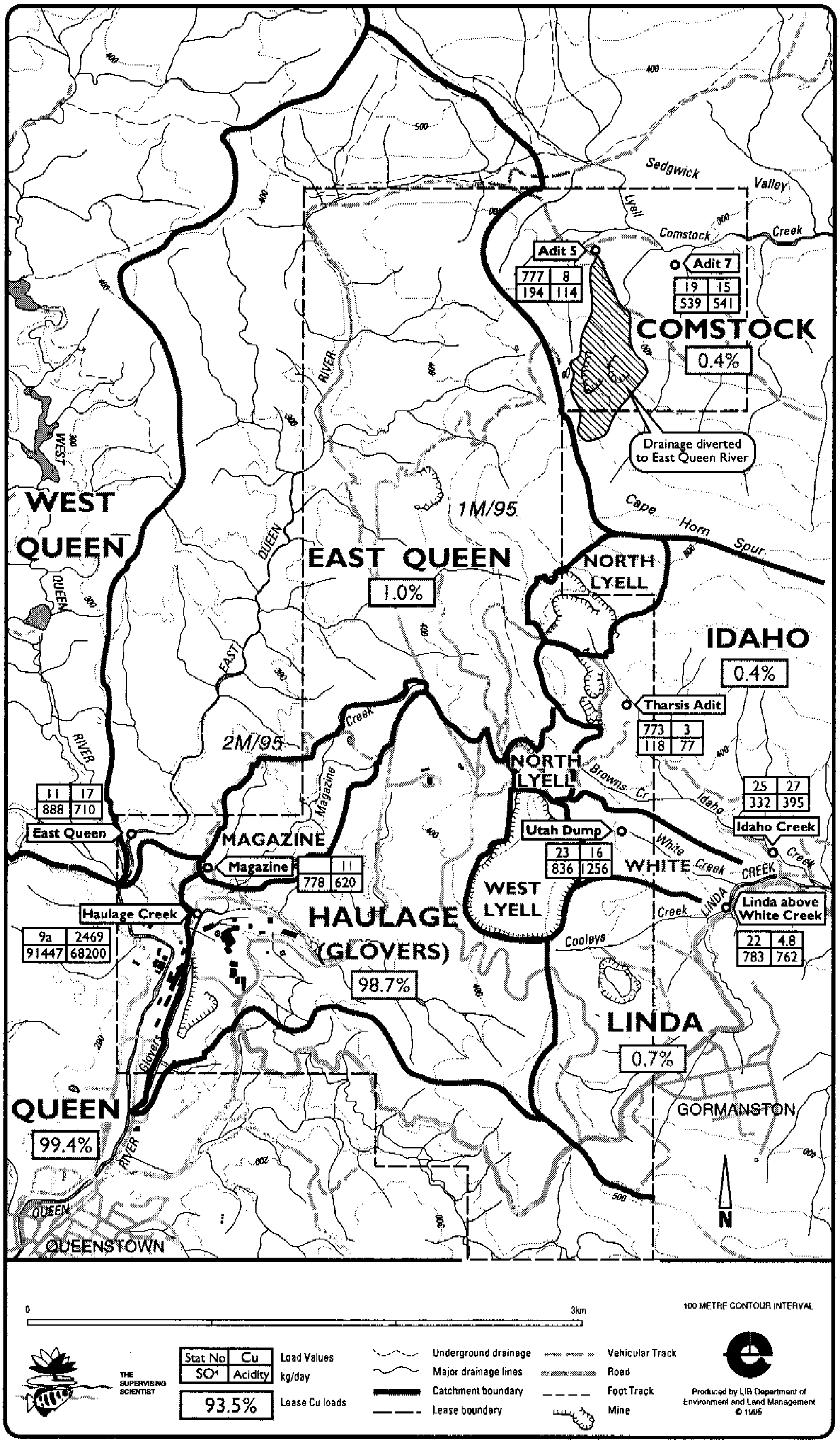


Figure 3.5 Summary of sulphate, copper and acidity loads within Queen, Linda and Comstock catchments

A discussion of the acid mine generation process is presented in section 4.2, together with a description of rate control processes as a basis for the screening of remediation options.

Within the framework of each of the general strategies outlined above are technologies which have potential application to the lease site. Technologies were first screened to assure their potential application to the various AD sources as described in section 3. In the subsequent screening process (detailed in section 4.3) these technologies are sufficiently defined to provide information on their expected effectiveness and their use on the lease site.

The screening is presented in terms of site and source characteristics and potential applications. Technologies which have potential application are identified for further evaluation in section 5. Some of these, though potentially applicable, are also in a development stage and unproven.

4.2 Acid drainage generation

4.2.1 Acid drainage generation process

The heart of the primary pollutant generation process in waste rock, ore or exposed materials containing sulphides, is the oxidation of pyrite which leads to the formation of sulphuric acid and iron sulphate. In the first instance the iron is ferrous iron. However, depending on conditions this can be oxidised up to ferric iron, which in acid conditions is a strong oxidising agent and oxidises metal sulphides to more soluble metal sulphates. Water infiltrating the material picks up the soluble oxidation products and transports them through the pyritic materials. This water, some of which appears as drainage, is typically low pH and contains high concentrations of sulphate, of major ions such as calcium, magnesium and aluminium, and of trace metals such as copper, iron, manganese, zinc, cadmium and lead. The detailed composition of this drainage depends on the chemical composition of the material.

4.2.2 Generation rate controls

It has been concluded in a number of studies including those by MEND (Mine Environment Neutral Drainage) that the most important control on pyrite oxidation is the availability of oxygen, which influences production of ferric iron and bacterial population density.

This oxidation process, which is the primary pollutant generation process, requires large volumes of oxygen. Although a small amount of oxygen enters the acid generating materials dissolved in infiltrating rainwater, the vast majority of the oxygen requirements come from the gas in the gas filled pore space. The overall oxidation rate is generally limited by the rate at which oxygen is transported to oxidation sites; the water flux is usually more than enough to supply all the water demands in the oxidation process.

4.2.3 Controlling the primary pollutant generation process

Controlling the rate of oxygen ingress therefore controls the overall sulphide oxidation rate and offers a first order control of the primary pollutant production rate.

Since the oxygen source is external, reducing the diffusive flux (rate of movement) entails reducing the oxygen diffusion coefficient of a layer on the outside surface of the acid producing source. To be effective, this reduction in flux must be typically between a factor of ten and a hundred. A cover layer can be designed to have an acceptably low diffusion coefficient. In fact any cover system designed to have low water transmissivity or low diffusion coefficient will have an acceptably low gas permeability.

4.2.4 Control of water flux

The water flux into the acid producing material is derived from precipitation or water flowing onto or through the surface or rock.

The water flux required to sustain oxidation rates for materials is only rate limiting if the infiltration rate is very low. Therefore, designing a cover to shed water from the source might not reduce the water flux to an adequately low level to reduce oxidation. However, this water demand relates only to the oxidation of pyrite. Reduction in water flux may be advantageous for other reasons. At high overall oxidation rates or at low infiltration rates the concentration of a particular pollutant may be such that it reaches its solubility limit. The solubility limit depends on the details of the chemical environment in the pore space but it does mean that in some situations oxidation products or the products from secondary reactions are stored within the material, rather than being transported as acid drainage loads. In these cases the reduction of the water flows through the pyritic material will result in a reduction of loads.

4.3 Evaluation and screening of applicable technologies

4.3.1 Load reduction

The control of AD at source and reduction of the AD load can involve a number of techniques which are intended to reduce the oxidation rate of the source and/or the water flux through the system, including:

- isolation of sources to control oxygen
- removal of source
- treatment at source
- water management (diversion of surface water and/or groundwater upgradient of AD sources)
- revegetation

These technologies are discussed in general terms below.

(i) Isolation of source

Isolation by covering with natural or synthetic materials or hydraulic (water) encapsulation (flooding) of the source to control the primary pollutant generation process and transportation of the AD loads is one technique that has been widely adopted world wide and was considered for further analysis.

MEND consider that the disposal of acid generating material under a water cover prevents sulphide oxidation (MEND 1994), and the disposal of sulphide mine wastes underwater is regarded by the mining industry as best practice technology to prevent acid drainage.

(ii) Removal of source

Removal involves mining the in-place acid producing sources—ore and waste rock—for reprocessing or relocation. While acknowledged as expensive and only feasible in the long term this has also been passed for further consideration as it has long-term potential in conjunction with future CMT operations and possible longer term mining plans.

(iii) Treatment at source

A number of technologies have been developed at a laboratory and trial stage which attempt to control the AD source. These include formation of an iron hardpan (layer which limits oxygen and water flux), electrochemical oxidation/passivation of sulphides and detergent and bacterial additives to slow or halt the oxidation process and limit the rate of acid production.

MEND studies have considered the first two technologies (among others) and found them either impractical or of no economic potential.

Detergent and bacterial additives are water soluble and the application must be repeated in high acidity situations. Although trialled in the United States they have not had widespread use. Because of the cost, lack of proven experience elsewhere and the high rainfall which would make repeated application necessary, this technology was not considered further.

(iv) Water management

Water management includes the construction of diversion structures to reduce surface water and groundwater infiltration and the contamination of clean water by the AD sources (ie to control the water flux). This technology has been adopted for further analysis. However, due to limited effectiveness, this alternative must be used in combination with other technologies—principally covering and water treatment.

The diversion of groundwaters includes the construction of barriers or extraction wells. Because of the nature of the terrain, groundwater inflows are only small, except where mine workings and fractured bedrock allow surface infiltration. The use of barriers or extraction wells is not considered further. The diversion of adits and the rerouting of mine drainage has been adopted for further analysis.

(v) Revegetation

Revegetation is often considered in AD remediation because of the ability in some circumstances to stabilise the surface and to reduce infiltration into mine waste components and to reduce runoff of acid drainage. At Mount Lyell, the main source of AD is from underground workings and waste rock dumps; loads from exposed acid producing materials such as exposed rock are relatively insignificant. Therefore, though revegetation is an important part of the stabilisation of covers over waste rock dumps, there is no evidence that the vegetation cover will act as a significant barrier to either oxygen or water transport into acid producing wastes. Therefore, other than for stabilising the cover on waste rock dumps, revegetation of other areas is not considered further.

4.3.2 Acid drainage treatment

The potential technologies for the treatment of the acid drainage include on-site containment, on-site treatment and release of treated water into the Queen and King River catchments, and disposal off site to an environment which could possibly better assimilate the acid and metal loads.

(i) On-site containment

This would involve the collection and storage of AD on site, thereby allowing evaporation of the waters. This is not a viable option at the site because the evaporation rate is far less than annual precipitation and a net discharge is required.

(ii) On-site treatment

Treatment of the AD to remove the metal loads and acidity potentially involves a number of technologies, including:

- metal recovery
- traditional neutralisation and precipitation
- passive treatment methods

Metals recovery from acid drainage has received considerable attention worldwide in recent years as attention has been focussed on the problem of acid drainage and the costs of treatment to meet environmental standards. A number of studies have investigated possible recovery technologies including:

- biological adsorption of metals by plants and algae
- sulphide reduction
- copper cementation
- solvent extraction
- electrowinning
- ion exchange

CANMET (Energy Mines and Resources Canada), as part of the MEND studies has investigated a number of alternative treatments to conventional neutralisation (MEND 1991), including a review of most of the above technologies. These are briefly reviewed below. A number of mining companies are actively researching metal recovery as part of environmental compliance studies. One of the most advanced is the Kennecott Utah Copper Corporation (Plant Projects Group) at its Bingham Canyon operations in the United States. The corporation is actively researching most technologies with emphasis on metal recovery and sulphate concentration reduction.

Biological systems Biological systems which accumulate metals have been investigated; though technically feasible, they are neither practical nor economic and have not been considered further.

Sulphide reduction Precipitation of trace metals in AD by sulphate reduction catalysed by sulphate reducing bacteria (SRB) offers a method of treating AD. It can lead to a saleable product which can defray the overall cost of installation and operation. The technology is still largely at the laboratory stage of development but is considered further under Emergent Technologies.

Copper cementation Copper cementation with iron has been used successfully in hydrometallurgical processes for copper production for several centuries. However, research and development has mostly been confined to concentrated solutions. High concentrations of ferric iron also interfere with the recovery and economics. MEND studies have considered this technology (MEND 1991) and recent efforts have been directed towards the development of reactors to treat dilute copper solutions efficiently. Though potentially interesting, this technology was not considered further; however it is a technology which warrants longer term consideration should other metal recovery technologies be unsuccessful.

Solvent extraction Solvent extraction uses an organic solvent to remove metals from the liquid stream where the solvent solubility is higher than water. It has received little interest as a technique for treating AD, probably because it becomes highly energy (and reagent) intensive if the concentration of the target metal is low. The loss of organic extractant into the effluent solution is also an issue. However, in recent years the continued improvement in the selectivity of SX reagents in conjunction with technology of electrowinning and production of London Metal Exchange (LME) grade 'A' cathode copper from solutions has been widely developed. This technology was considered for further analysis in conjunction with electrowinning.

Electrowinning This technology uses electrolytic processes for the removal/recovery of metals from process streams. Increased consideration is being given to electrolytic processes for the removal/recovery of metals from dilute process streams. In comparison with the various physical and chemical waste water treatment methods, electrowinning systems offer several advantages: low capital costs with high return rates; low operating costs; no chemicals are required; saleable products are generated and combination with other techniques such as ion exchange to more economically recover metals is feasible.

However, AD solutions that contain a considerable concentration of iron as compared with other metal contaminants can cause problems. Though it will have reduced copper concentrations, the treated effluent will also have similar loads of other metals and acidities to the untreated AD and will require further treatment.

This technology was considered for further analysis with solvent extraction.

Ion exchange In ion exchange, ions are interchanged between an aqueous solution and a solid medium (ion exchange resin). This technology is a well established method for removing metal ions from contaminated water, producing drinking water, but usually at low flow rates.

Its application to AD has been limited due to costs and maintenance considerations. Anion and cation resin beads replace metal ions and 'loaded' resin beads are regenerated by acid washing or caustic soda. Metals may be recovered from the acid or caustic solution by solvent extraction or electrowinning. As part of the MEND studies, CANMET have conducted bench scale tests on ion exchange and no further tests will be conducted, presumably because this technology has been found to be uneconomic for AD treatment (MEND 1991, 1994b). This technology was not considered further but future development warrant monitoring.

Conventional neutralisation and metal precipitation technology AD neutralisation/precipitation is used world wide for treatment of high load high flow AD. It consists of:

- neutralisation of the effluent with lime or other alkaline material
- oxidation of ferrous iron under alkaline conditions by aeration
- precipitation of ferric iron and base metals
- clarification following coagulant/flocculant addition

In the MEND 1994 Annual Report, it is concluded that after the consideration of a number of technologies, the major emphasis for the balance of the MEND Treatment Review component of the study was to concentrate on conventional neutralisation and precipitation technology. This technology has also been adopted as the 'Best Available Technology Economically Achievable in the USA and Canada'. It is a well proven and a reliable method of treating AD.

It has been adopted as the most proven and feasible method for treatment of high flow and high load AD from the lease site.

Passive treatment of AD Passive treatment methods have attracted a great deal of research in recent years and number of passive treatment systems have been constructed in the United States. The pioneering work has been carried out in the eastern US where wetlands have been constructed to treat acid drainage from coal mines. This technology has now been well developed and has been advanced to a stage where the removal processes and any pretreatment needs are now well understood. However, this technology is currently only proven for low flows and low acidity coal mine drainage and its capability to treat high acidity, high metal concentration from metal mine drainage such as Mount Lyell is yet to be proven. However, recent advances in inducing alkalinity have developed in conjunction with wetlands and this technology is considered further in treating low flows and the lower acidity load drainage.

(iii) Off-site disposal

The collection, piping and disposal of AD to an environment which is more capable of assimilating the contaminant loads was considered for further analysis, given the high cost of treatment on site.

5 Remediation technologies and selection of site-specific options

5.1 Introduction

Section 4 presented results of a preliminary screening of potential remediation options carried out to ensure that a range of options were identified and developed, and that relevant information concerning potential options was presented.

The remediation options passing the screening evaluation were identified in terms of load reduction and AD treatment. The load reduction technologies which could be implemented include isolation by flooding or covering, relocation/removal of AD sources, and diversion of upgradient surface water and groundwater. The treatment technologies which could be implemented at the site include collection and treatment of acid drainage with copper removal by solvent extraction/electrowinning (SX/EW), conventional neutralisation, passive treatment and emergent technologies, and offsite disposal to the ocean.

These technologies are further evaluated in this section, according to the following criteria:

- overall potential reduction in AD loads
- long-term effectiveness and permanence
- short-term effectiveness
- implementability
- cost

The metal load reduction technologies that have passed through the general screening presented in section 4 are discussed in section 5.2 and the metal load treatment in section 5.3.

Site-specific applications for the lease site are considered in section 6 and the most appropriate remediation measures for the various AD sources are selected.

5.2 Load reduction technologies

Flooding or capping AD sources to control oxygen input and/or water flux through the system is a technology which has been used effectively for site remediation. The flooding of exposed and backfilled sulphide rock/spent ore within the old workings and the capping of waste rock dumps with low-permeability single or multi-layer covers, are technologies that may be employed to control oxygen and water flux.

Surface water runoff and infiltration (and to lesser extent groundwater flow), are the pathways responsible for the movement of large metal loads. Diversions are technologies that may be employed to reduce the interaction of site waters and conveyance of metal loads offsite.

The removal of the acid generating sources to another location where acid generation could be minimised or acid drainage migration could be controlled is also applicable.

5.2.1 Flooding of old workings

Orebodies on the lease have been mined for approximately 100 years using both surface and underground methods. This mining has left an extensive network of adits, drives, workings and stopes which extend from Comstock and Cape Horn in the north west, to the West Lyell open cut, and north to the Crown Lyell workings. Access to these workings was generally via horizontal adits driven into the hillside. The West Lyell open cut drains through caved material into the Prince Lyell mine workings underneath, and the mine is dewatered via pumps discharging to the surface at Haulage Creek.

The principal remaining accesses to the Prince Lyell and Tharsis underground workings are via the Conveyor Tunnel, the Main Decline, the North Lyell Tunnel and the West Lyell Tunnel, all of which are accessed from the Haulage Creek area. Other adits are the Tharsis Adit and the Comstock 5 and 7 Adits (see fig 5.1) which access the Tharsis and Comstock orebodies respectively.

The adit system which provided access to the underground mine workings during their active periods today provides drainage from the main Prince Lyell workings and the old workings to the north and north west. Reaction of infiltrating surface water with residual mineralisation, particularly under the desaturated conditions of the drained adit system and via rainfall and runoff direct to the surface of the West Lyell open cut, has produced high acid, high-metals waters that are currently discharging from one or other of the tunnels to surrounding catchments and comprise by far the majority of the metal and acid loading of the lease. The old workings cannot be effectively isolated by any form of dry cover, however they could potentially be flooded which would reduce any continued oxidation of sulphides and thereby reduce the AD loads.

The blocking of the Tharsis Adit, though not effective in achieving a complete seal, has been successful in reducing metal loads (see section 3.4)

The North Lyell Tunnel extends to the north under the Crown Lyell workings and also includes a connection to the Tharsis Adit. The Cape Horn workings are also connected to the main workings via a drainage tunnel. The Comstock workings are independent and drain via either the Comstock 5 or 7 Adit. Diversion of adits and the rerouting of mine drainage has already been carried out on the lease, with attempts to block the Tharsis Adit and the redirection of surface waters via a dam at the Crown Lyell workings where surface waters are diverted via drill holes into the North Lyell workings and then to the North Lyell Tunnel. The Comstock 5 Adit drainage has also been diverted by surface drains into the East Queen catchment. CMT are also understood to have done some diversion works both underground and on the surface.

Further modification of the mine hydrology could potentially include the following actions:

- Flooding of old mine workings up to a level which would be decided on geotechnical investigations, probably the Main Decline or West Lyell Tunnel
- Plugging of the Tharsis Adit
- Plugging of the Comstock 7 Adit

Because of the active mining plans of CMT which include the Royal Tharsis orebody and the continued mining of the Prince Lyell orebody at depth, the plugging and flooding of any of these mine workings cannot be considered in the short term and can only be considered after final mine closure. However, the flooding of the mine workings after closure is a practical solution after mining finally closes. This could allow flooding to at least the Main Decline level and effectively limit pyrite oxidation in workings below this level (see figure 5.2).

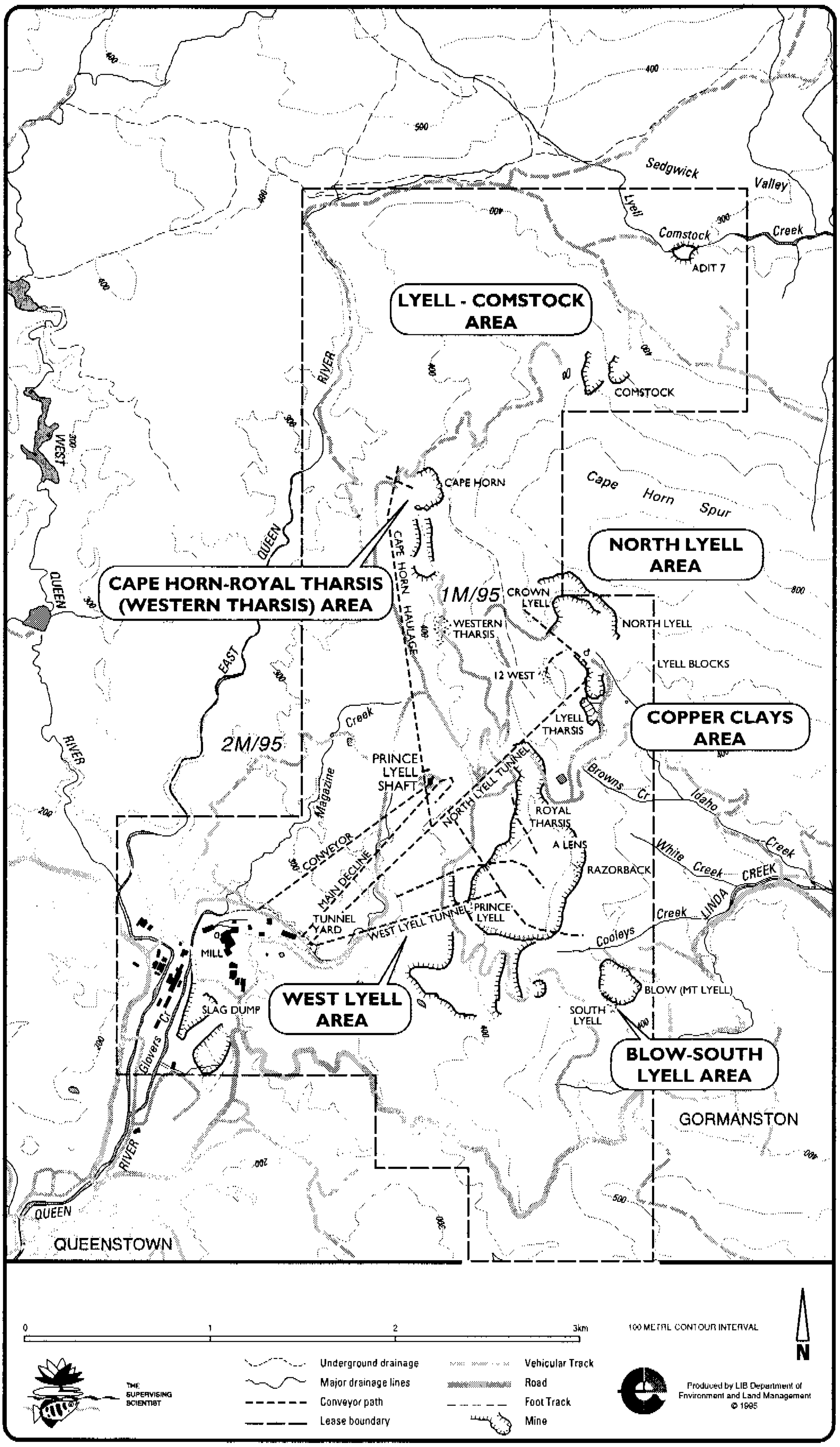


Figure 5.1 Historic mining operations on the Mount Lyell lease site

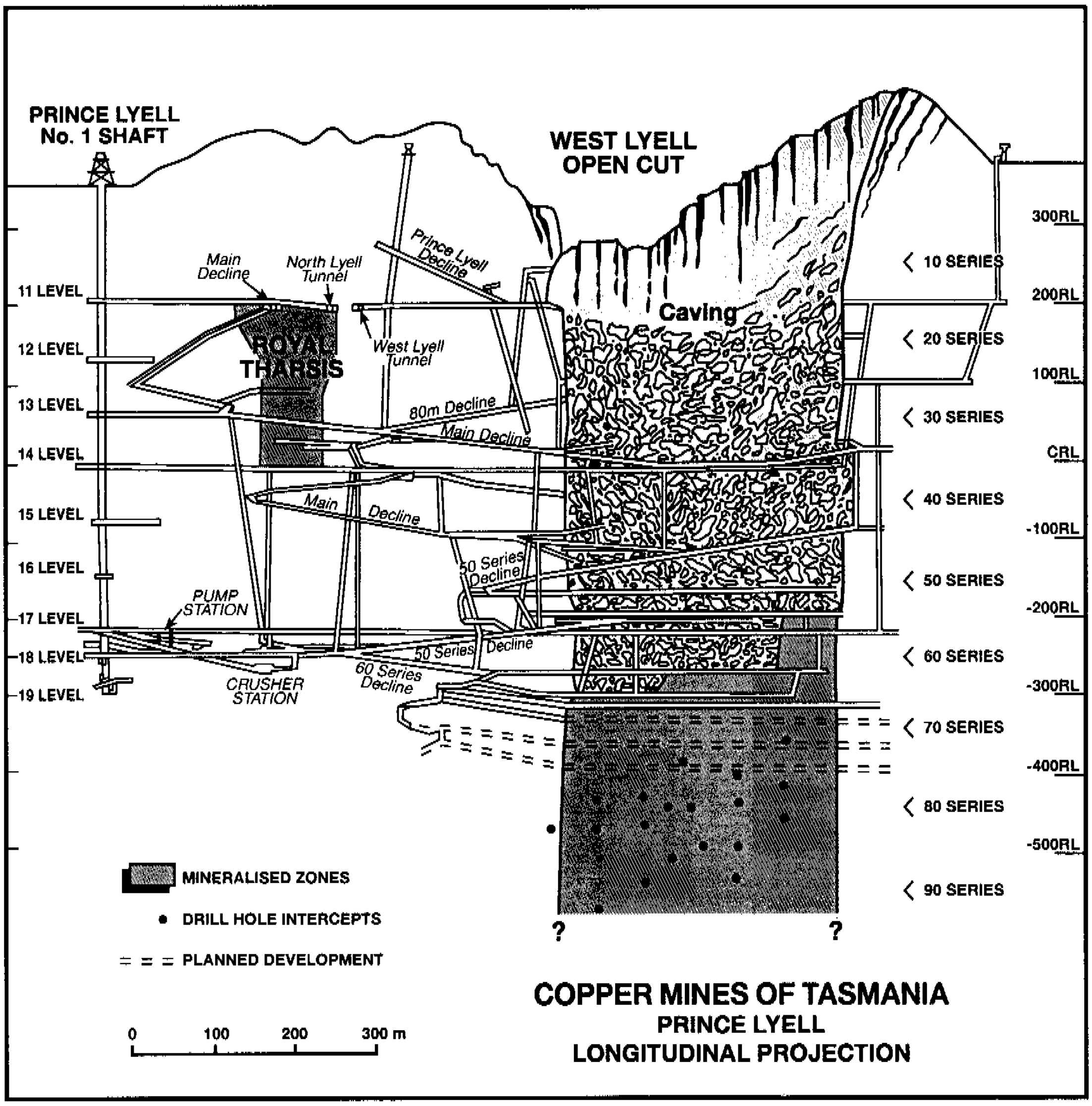


Figure 5.2 Prince Lyell Mine longitudinal section (source MLMRCL 1994)

The plugging of the Comstock 7 Adit could be considered as this is a separate hydrologic regime.

The success of plugging the adits to reduce metal loading will depend on many factors including locating the plug within competent bedrock. Recent experience in the United States and United Kingdom indicates that adit plugs within fractured bedrock and at conditions where hydraulic pressures exceed lithostatic pressure may not resaturate and encapsulate the sulphide materials but may instead discharge groundwater at the surface through a myriad of new seeps and springs. The flooding of the Tharsis Adit resulted in leakage around the concrete plug and attempts to flood the Eagle Mine in Colorado resulted in surface seeps and springs. At Wheal Jane in Cornwall a catastrophic failure of a plug resulted in a mass release of acid waters into the local streams.

Analysis of the Eagle Mine experience indicates that the plugging of adits is not likely to be effective where:

- there are multiple adits;
- the adit plugs are close to the ground surface;
- the workings extend close to the ground surface; and
- there are direct geological and structural pathways to the surface.

These all indicate that any additional plugging and attempts to flood old workings on the lease will need to be carefully considered and engineered Nevertheless, the success in the reduction in loads from Tharsis Adit indicate that the effort may be worthwhile.

5.2.2 Covering of waste rock dumps

Introduction

There are a number of waste rock dumps on the lease. Their location and approximate size are shown in fig 5.3.

The most significant dumps in order of size and AD loads are the West Lyell Dumps, the Utah, Magazine Creek and the Crown Lyell. Other smaller dumps which have been identified include the unnamed dumps in the East Queen catchment and the pyrite dump.

The West Lyell Dumps draining to Haulage Creek are the most significant and contribute approximately 10% of the AD loads from the lease to the Queen River. The Utah, Magazine and the Crown Lyell dumps contribute 0.6%, 0.4% and 0.4% respectively. Additional sampling and load estimation is required to establish the loads from each dump and the actual proportion of the catchment being affected.

Results from instrumentation installed by ANSTO in one of the West Lyell dumps near the Prince Lyell shaft indicate that pollutant loads in drainage are likely to remain at current levels for about 20 years at which time pollutant loads are expected to drop by about a factor of ten and continue at this reduced level for about a further 600 years or so (ANSTO 1994). It is expected that this is the case for most of the waste dumps on the lease which have been developed from the West Lyell open pit.

Reducing AD by controlling the rate of generation of the process and the transport of the loads is possible by covering the dumps.

It is noted that these objectives will conflict with the recovery of copper from the dump leachate by SX/EW and the implications are considered in section 6.

Generation rate controls

General The oxidation process, which is the primary pollutant generation process in a waste rock dump, requires large volumes of oxygen. Although a small amount of oxygen enters a dump dissolved in rainwater infiltrating the dump, the vast majority of the oxygen requirements come from the gas in the gas filled pore space of the dump. It is readily shown (see for example Ritchie 1994) that the oxygen demand of sulphide oxidation requires transport of oxygen from the atmosphere on the outer surface of the dump to oxidation sites within the dump. It is also readily shown that in many circumstances the overall oxidation rate in the dump is limited by the rate at which oxygen is transported to oxidation sites; the water flux into a dump is usually more than enough to supply all the water demands in the oxidation process.

The oxygen flux into a dump can arise from:

- diffusion—driven by oxygen concentration gradients in the dump pore space
- advection—driven by gas pressure gradients in the dump pore space

Oxygen concentration gradients arise because oxygen is used up in the oxidation of sulphides. Pressure gradients can arise from temperature gradients induced by heat released in the exothermic pyrite oxidation reaction. Pressure gradients can also be induced by wind moving air over the surface of the dump. It is likely, however, that the wind direction has to be reasonably persistent for this to be an effective gas transport mechanism.

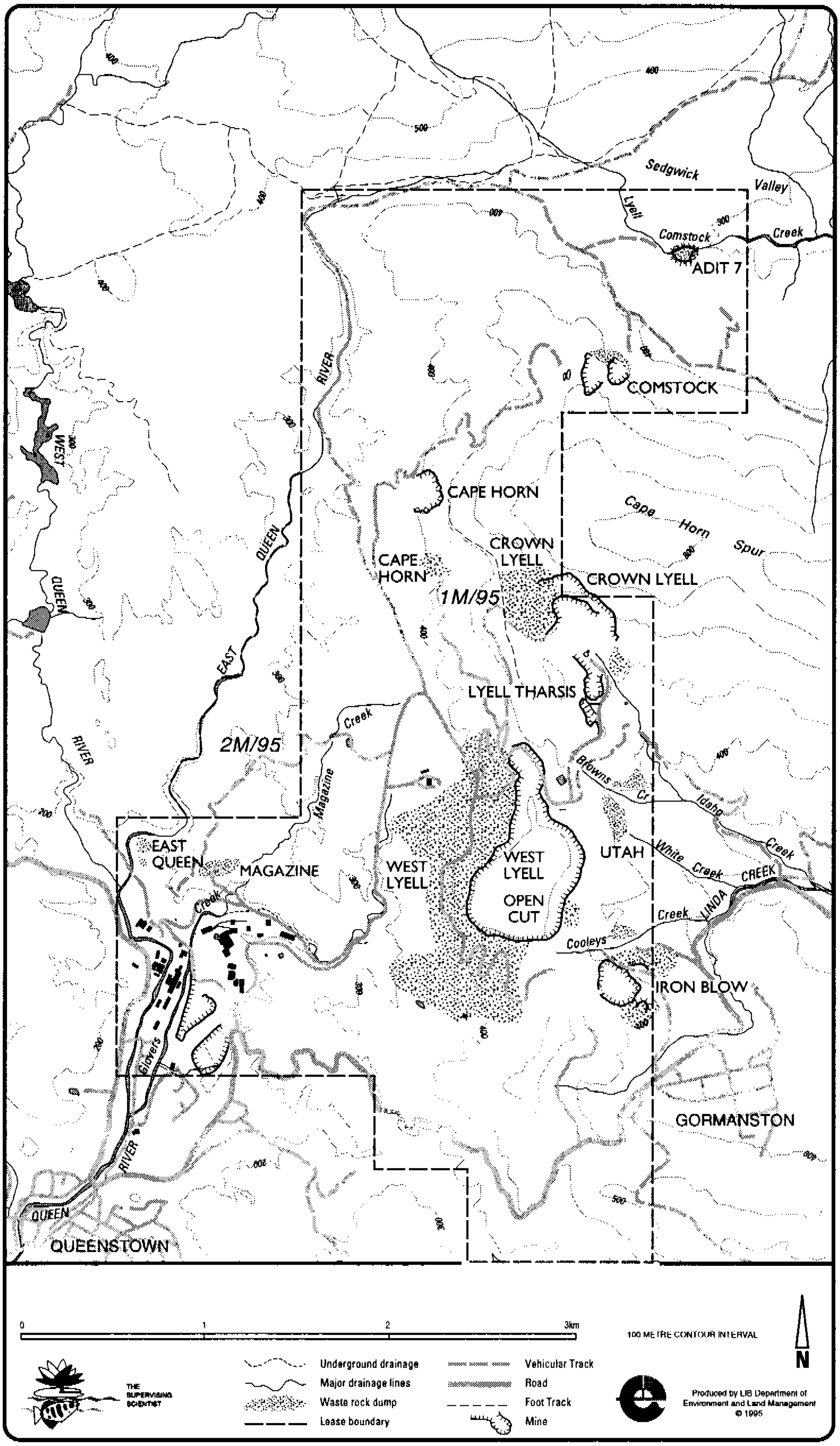


Figure 5.3 Location of waste rock dumps on the Mount Lyell lease site

The magnitude of the diffusive flux also depends on the size of the oxygen diffusion coefficient, which measurements within a number of waste rock dumps have shown, varies very little within a waste rock dump and between one waste rock dump and another (Ritchie 1994). Similarly, the magnitude of the advective flux depends on the size of the gas permeability of the waste material. In situ measurements have shown that this property is highly variable within a waste rock dump with generally the same range of variability between waste dumps (Ritchie 1994).

The West Lyell dump Measurements of temperature and oxygen profiles within one of the West Lyell dumps have been conducted by ANSTO as part of the MLMRCL investigations. These measurements have been interpreted to conclude (ANSTO 1994):

- wind driven advection is a significant gas transport mechanism
- most (about 70% by volume) of the dump material has a relatively low intrinsic oxidation rate (estimated to be (2 to 6) x 10^{-9} kg(O_2) m^{-3} s^{-1})
- there are pods of material with a much higher intrinsic oxidation rate (estimated to be about 6 x 10^{-7} kg(O_2) m^{-3} s^{-1} imbedded in the dump)
- the oxygen flux into the dump is high enough to maintain pore gas oxygen concentrations close to atmospheric in most parts of the dump
- in most of the dump oxidation proceeds at a rate determined by the oxidation rate of the dump material
- the oxygen flux is not high enough to maintain oxidation throughout the pods

These conclusions are regarded as preliminary since:

- good quality data were not and are not available on dump drainage flow rates and pollutant concentrations
- no in-situ measurements were made of gas permeability and oxygen diffusion coefficient in this dump
- no follow up measurements have been done to confirm that wind driven gas transport is a dominant process

These conclusions are assumed to be representative of all the dumps on the lease.

Controlling the oxygen ingress

Controlling the rate of oxygen ingress in a waste rock dump controls the overall sulphide oxidation rate in the dump and offers a first order control of the primary pollutant production rate.

Since the oxygen source is on the outside of the dump, reducing the diffusive flux entails reducing the oxygen diffusion coefficient of a layer on the outside surface of the dump. To be effective, this reduction in flux must be typically between a factor of ten and a hundred—a factor unachievable by working the material of the dump by, for example, compaction. A cover layer, as discussed below, can be designed to have an acceptably low diffusion coefficient.

Reducing the advective flux entails reducing the gas permeability of some layer on the outside of the dump by the required factor. Modelling studies (Pantelis & Ritchie 1991) have shown that if a dump has a gas permeability of $10^{-9}/m^2$, convective transport in the form of convection adds significantly to the overall oxidation rate in the dump, but at a permeability of $10^{-10}/m^2$, gas transport by diffusion dominates. Modelling of the West Lyell dump confirms this observation. As $10^{-9}/m^2$ is close to the top of the range of gas permeabilities measured in waste rock dumps it seems likely that reduction of the advective component of the oxygen flux into a dump should be readily achievable. Moreover, any process (such as compaction) which reduces the pore space decreases the gas permeability greatly. Indeed any cover system designed to have low water transmissivity or low diffusion coefficient will have an acceptably low gas permeability. Modelling studies by ANSTO indicate that a layer with a gas permeability of $10^{-13}/m^2$ should reduce the advective component of the oxygen flux into the dump to an insignificant level. A gas permeability of $10^{-13}/m^2$ translates to a hydraulic conductivity of 10^{-6} m/s, which is that of a fine sand.

Control of water flux

The water flux into the waste rock dumps is derived from precipitation on the outer surface of the dump. The rough and uneven texture on the surface of a waste rock dump maximises infiltration. The fraction of rainfall which infiltrates will of course vary from location to location but can be about 50%. The infiltration rate is expected to be high at Mount Lyell, due to the nature of the rainfall.

The water flux required to sustain oxidation rates for materials is only rate limiting if the infiltration rate is very low. Therefore, designing a cover to shed water from a waste rock dump may well not reduce the water flux to an adequately low level to reduce oxidation.

However, this water demand relates only to the oxidation of pyrite. Reduction in water flux may be advantageous for other reasons. At high overall oxidation rates or at low infiltration rates the concentration of a particular pollutant may be such that it reaches its solubility limit. The solubility limit depends on the details of the chemical environment in the pore space but it does mean that in some situations oxidation products or the products from secondary reactions are stored within the waste rock dump.

Such a mechanism can prove useful in limiting the pollutant load in drainage. It does mean that when oxidation stops or the oxidation rate slows down the stored pollutants tend to resolubilise with the result that pollutant levels in drainage can remain for some considerable time after oxidation has stopped or slowed significantly. The process may have most impact with such pollutants as sulphates, calcium, magnesium, aluminium, sodium and potassium but has less effect on trace metals such as copper, manganese, zinc, cadmium and so on.

Reduction of the water flux is a strategy which is being applied at a large number of mine sites in Australia and in Canada and USA, with varied results. More monitoring needs to be done to quantify the effectiveness of the technique in reducing the overall environmental impact of effluent from the pyritic wastes. Recent reports of covering major waste dumps with an 0.8 m thick till cover at the closed Equity Silver Mine in British Columbia have provided encouraging results (Wilson 1995, Murray et al 1995, Equity Silver pers comm). Early trends indicate that lime quantities for the treatment of acid drainage have decreased by 30%. Measurements and modelling of the results of the cover indicate that the cover maintained a high degree of saturation, oxygen flux rates have decreased by 98% and infiltration was 4% of precipitation. Indications are that the Equity dumps will take up to 15 years to drain.

ANSTO believes that considerable care needs to be exercised in interpreting the results of reducing the water flux, particularly in a 'mature' dump which has been producing polluted effluent for some time. The immediate effect of reducing the water flux tends to be a reduction in load since concentrations of pollutants in the pore space near the base of the dump reflect a pseudo steady state interaction between pollutant generation in the dump and pollutant transport by water infiltrating the dump pore space. With the new, reduced water flux regime the whole system will re-equilibrate with a time constant which is likely to be tens of years. Re-equilibration will tend to lead to higher concentrations of pollutants in the pore water at the base of the dump if the overall pollutant generation rates has been unaffected by the reduction in water flux.

The works carried out by the MLMRCL on the top of the Utah dumps at the head of White Creek have been successful in reducing the AD loads in White Creek by approximately 33%. It is not known if this is due to reduction in the oxygen flux or the water flux. However, the results are encouraging.

Cover layer design

Cover layers have been used in landfill operations and in mining for the rehabilitation of tailings dams and waste rock dumps. Thus there is considerable expertise and documentation available on the design and installation of layered cover systems. In many of these applications, the goal is to reduce the amount of water infiltrating the cover system and, at the same time, avoid erosion of the cover when runoff is high during high rainfall rate events. The design and installation of such covers can be considered standard engineering practice. In the present application an additional goal is to reduce the amount of oxygen diffusing through the cover system. This is a much newer problem and tools for the design of such systems are less common, although the Equity experience provides a good guide.

Imported soil cover Generally soil covers consist of a layer of well compacted low permeability imported clays, overlain by protection layers of imported soil and or rock, depending on the final rehabilitation requirement. The thickness of the layers are determined by the performance requirements of the cover and are site specific. At Rum Jungle in the Northern Territory, three layers were used in the cover layer, consisting of a compacted clay seal 225 mm thick, overlain by a moisture retention layer of 250 mm. On this was placed a 150 mm thick erosion protection cover of gravelly sand (Applegate 1993). At Equity Silver, the cover consisted of glacial till (with a clay content) with 0.5 m compacted overlain by an uncompacted rooting medium.

To achieve a cover layer with a very low oxygen diffusion coefficient, it is necessary for some portion of the cover system to be close to saturation under varying rainfall conditions. This layer is usually the 'clay' layer which needs to have high capillarity as well as low hydraulic conductivity. The need to ensure low oxygen flux during varying rainfall conditions is much harder to achieve than ensuring low water flux under the same conditions. For example the cover system at Rum Jungle which was designed primarily to reduce infiltration and which has met this design criterion for more than ten years, works well in reducing the oxygen flux during the wet season but does not work well during the dry season. To work well during the dry season the two lower layers would have to be substantially thicker, or need a capillary break layer.

In many Australian environments where the rainfall is light or highly variable it will prove difficult to design a cover system which is effective in maintaining a low oxygen flux into the waste dump at all times. The problem of designing a cover system for the Mount Lyell dumps that have a low oxygen diffusion coefficient for most of the time, is expected to be comparatively easily resolved given the high rainfall characteristic of the Queenstown area.

Artificial membranes (geomembranes) Where there is no source of suitable cover layer materials, artificial membranes have to be used. These are called geomembranes, and may be made of PVC, HDPE or some similar materials. The choice of geomembrane and its thickness will depend on the duty it has to perform, whether it needs to be protected from ultraviolet light, mechanical damage, etc.

It is normally necessary to prepare the surface to be covered by the membrane, to remove sharp or high protrusions that can puncture the geomembrane and result in leakage. However, the degree to which the surface needs to be prepared will depend on both the thickness of the geomembrane used and the duty it has to perform.

Kelian Equatorial Gold has recently covered a 20 ha waste rock dump with an artificial membrane which has been highly successful in reducing AD loads by reducing the water flux.

Geomembranes deteriorate in sunlight. The rate of deterioration depends on the material type and its thickness, improving from PVC through to HDPE and Butyl, and with thickness. Thus to improve the life of the geomembrane and to minimise its thickness, it is advisable to provide a soil protection cover over the geomembrane. It is likely though that a soil cover placed over a geomembrane installed on a slope will not be stable under wet conditions unless the slope is at a very shallow angle (probably less than 14°).

In situ compaction The large size of most of the rock in a waste dump generally precludes it being used for the cover layers. Mines such as Mount Leyshon (Orr 1995) have overcome this problem by using an innovative compaction technique to form a low water transmissivity cover layer from the in situ waste rock. They are using an 8 tonne flat sided roller, commonly called the *square* or *impact* roller. This roller was designed to compact thick layers of collapsing sands and is capable of producing uniformly compacted layers up to 1 m thick in waste rock.

For in situ compaction to work, the dump rock has to be capable of fracture under compaction, and there has to be sufficient moisture in the rock to produce the desired compaction density (water for compaction can be added if required). Compaction by the *square* roller ensures that some fracture of most rocks will occur under the impact, and due to its high impact force the moisture content is not too critical.

The roller supplier has indicated that the roller will compact about 1500 to 2000 m² per hour. At Mount Leyshon the area being compacted is about 40 ha of new waste rock dump surface every year, and though the tops of the dumps present no problems, the sides of the dumps have to be reduced to a 4H:1V slope (about 14°) to allow the roller to traverse successfully. Equity regraded dump slopes to 20–22° to apply a compacted clay cover.

Waste dump geometry

Waste rock dumps are generally just geotechnically stable, and as long as water is not allowed to dam up within the dump, they should remain so. Thus, there is generally no need to modify the outer slopes of a waste rock dump for geotechnical reasons.

However, there are a number of other reasons that generally dictate the need to flatten the steep outer slopes of a waste rock dump (generally in the order of 35° to 39°):

- They will tend to erode over time to much flatter slopes, as exhibited in nature.
- It is not possible to place and compact cover layers mechanically on slopes much steeper than 22° and they may need to be as flat as 14°, as stated above.
- It may not be possible to get safe access to place geomembranes on long steep slopes.

For instance, at Rum Jungle the outer slopes were reduced to a batter of 3H:1V (about 17.5°) and the top surface grades were minimised. In addition the slope lengths were kept short by introducing berms at regular intervals (Applegate 1993).

Mount Lyell waste rock dumps

Potential for AD control Construction of an engineered cover on the dumps would dramatically reduce the advective oxygen flux and, with proper design, reduce the diffusive oxygen flux and water infiltration even during periods of low rainfall. The results of the Utah dump works indicate that covers are feasible and effective.

If the ANSTO interpretation of the oxidation process and oxygen transport mechanisms in the West Lyell dump is correct, then reduction of the advective flux means that:

- the contribution from the pods or layers of high intrinsic oxidation rate imbedded within the dump will be greatly reduced and probably eliminated
- a relatively small portion of the dump volume will contribute to the overall oxidation rate rather than the bulk of the dump as is the case currently

With a dramatic reduction of the advective oxygen flux achieved, the overall oxidation rate will be determined by the magnitude of the diffusive flux through the cover. This then becomes a design criterion for the cover.

A conclusion from the ANSTO investigations on the West Lyell dump was that currently the pods or layers contribute 90% of the overall oxidation rate in this dump. If a dramatic reduction of the advective flux eliminates the contribution from these pods then the overall oxidation rate will drop by a factor of ten. Estimates based on the dump model developed during the ANSTO investigations indicate that if diffusive transport is the dominant oxygen transport mechanism then the overall oxidation rate in the dumps would be about 20% of that where convection occurs and adds to the overall oxidation rate. Wind driven advective transport can be incorporated in this model but such incorporation requires data on wind persistence and local topography.

The geometry of the other dumps (the other West Lyell dump, Utah and Magazine Creek) are similar to that of the West Lyell dump and as it is reasonable to assume that the material in the other dumps is similar to that in the West Lyell dump and on the assumption that the gas and water transport mechanisms and overall oxidation rates in these dumps are similar to those in the West Lyell dump.

Timescale for reduction in overall oxidation rate If the engineered cover effectively cuts off advective gas flow to the interior of the dump then the oxygen concentration in the pore space will decrease as it is used up in sulphide oxidation. Assuming an intrinsic oxidation rate of 4×10^{-9} kg(O_2) $m^{-3}s^{-1}$ for the bulk of the dump material the pore space oxygen will be used up in about 7.5 months. The existence of pods of higher intrinsic oxidation rate will decrease this time. Since many parts of the interior of the West Lyell dump have pore gas oxygen concentrations close to atmospheric (21% oxygen mole fraction) a decrease to 15% is significant and readily measured. ANSTO therefore expects to detect this immediate effect of the engineered cover in a period of about 2 months or possibly less.

Surface runoff control There is little control exercised over surface runoff from the surrounding countryside onto and through the dumps at present. This is in part due to the very steep topography uphill of the dumps and also due to the fact that the dumps run across valleys, effectively damming streams and forcing them to percolate through the dump material to get downgrade. This means that the AD flows are greater than they need to be, due to the additional runoff passing through them and there is scope here for improved water management and reduction in contaminant flows (see section 5.2.4).

5.2.3 Removal of AD sources

The removal of the AD sources which consist of waste rock and ore, would be effective in eliminating the load. Approximately 47 million tonnes of waste rock was dumped around the West Lyell open cut during the open pit mining in the 1930–70s and this material, together with the walls and caved material in the open cut and the upper levels of the mine workings, form the main acid producing sources on the lease. All of this material forms a low grade copper resource which could potentially be recovered by a large open pit mine operation at some stage in the future.

The possibility of this occurring will depend on economics and is being actively considered as a long-term plan by CMT. If this were to occur, it would remove many of the AD sources and be an effective solution. The disposal of any waste rock and tailings which are generated could then be managed in a way which minimises any potential AD.

Removal of waste dumps can be a cost effective measure where they are accessible and small, and the cost of covering is high compared with removal.

5.2.4 Surface water diversion

The current metal loading sources which may be directly or indirectly influenced by surface water flow include:

- West Lyell waste rock dumps
- other waste rock dumps—Utah, Crown Lyell, Magazine Creek, Pyrite, East Queen
- West Lyell Pit
- Crown Lyell, Comstock and Cape Horn open cuts
- general exposed surfaces

Surface water may come in contact with these potential source areas either as direct precipitation or by surface runoff flowing over or through the surface.

The load reduction measures could include construction of surface water diversion structures in conjunction with clay covers over waste rock dumps to minimise infiltration (see section 5.2.2). Diversion structures can be constructed to collect and convey surface water runoff around the acid generating materials in dumps and away from open pits to reduce water flows. These structures would be constructed along the upper edge and around the sides of the potential source areas in order to prevent contact between the acid producing materials and surface water runoff from the surrounding natural catchment areas.

Studies conducted for CMT show that the contribution of groundwater to the mine dewatering is insignificant and that mine dewatering can be accounted for by rainfall falling on the open cut catchment and any mine water use (drilling etc). This is also expected to be the case for other workings (such as Comstock, Tharsis etc). Therefore, if surface waters can be excluded, flows and probably loads from underground workings can also be expected to be reduced.

The diversion of surface waters has been part of the remedial works to date and surface waters have been diverted by the MLMRCL and the current operator (CMT) has carried out works to divert surface flows from the West Lyell open cut.

Other works have been carried out around the Crown Lyell open cut workings so that surface flows are directed in the old underground workings and flow to the Haulage Creek catchment via the North Lyell Tunnel. These works were effective in reducing loads to Idaho Creek (see section 3.4). The HEC in 1991 used a system of drains and pipes to remove the Comstock 5 drainage from the Comstock catchment and divert this into the East Queen River just below the mine water intake and this also was successful (see section 3.4). The future of these diversions has to be considered.

There are potentially only limited additional works in combination with other technologies which can be effectively adopted. These are mostly associated with the waste rock dumps. The steep topography makes the construction of diversions upslope impractical in many areas. If the dumps are either to be used for copper recovery, where the collection of concentrated leachate is important, or to be covered, more surface water diversion works will be required. The collection and diversion/removal of the Utah dump drainage from the Linda catchment would remove a major source of contamination.

The potential of diversion structures and recontoured vegetated covers for the various mine components are described in section 6.2.5 and 6.2.6.

A strategy of surface water diversion and waste rock dump covering can be expected to result in a substantial reduction in contact between surface water flow and the acid generating materials. Additionally, infiltration due to precipitation falling directly on the project components will be reduced. Upon completion, these load reduction measures can be expected to be effective in reducing contamination of storm water runoff. Typically, a well-graded single soil-type cover could reduce the amount of residual infiltration to approximately 10 to 20% of the total amount of precipitation falling or accumulating on the material. This reduction in infiltration can be offset somewhat by the increase in concentration of the resulting seepage. Consequently, the metal load reduction at each source area may range from a total of 80 to 30% depending on the various contributions of groundwater and surface water.

Some of these activities have been carried out on site and have included regrading of the top surface of the Utah waste rock dumps to promote rapid runoff, placement of alluvial soil, and revegetation. These simple works have achieved an approximately 33% reduction in metal and sulphate loadings.

5.3 Load treatment technologies

5.3.1 Copper recovery from acid drainage using SX/EW technology

Introduction

Copper loads in the drainage from the lease are large and can be regarded as a resource which is likely to continue for at least twenty years (based on ANSTO's estimates for the West Lyell waste rock dump). Estimates are that the loads are in the vicinity of 1.6 to 2.5 tonnes per day from the Haulage Creek catchment alone (approximately 99% of the lease) (see section 3.4). If feasible to recover for sale, the copper could provide funding for at least the treatment of the effluent from the plant and potentially other remedial actions on the lease.

As part of the *Continuation of Operations Act 1992* (Annexure C), the Mount Lyell Mining and Railway Company Ltd (MLMRCL), the former lease holder and operator of the mine, operated under an exemption from sections 15 and 17 of the *Environment Protection Act 1973*. These exemptions were in respect of the discharge of tailings and contaminated drainage waters from the lease. This exemption was issued on the condition that the

Company was to monitor technological developments and techniques for the removal of heavy metals from the mine discharge water and to examine and test such developments or techniques wherever feasible.

As part of this work (and funded under Annexure B of the Continuation of Operations Act), Mount Lyell invited Euralba Mining Ltd (Euralba) to test its technology for copper recovery from solutions in the period 1991–1993.

Euralba Mining Ltd (now called Electrometals Mining Limited (EML)) had developed an electrowinning technology (the EMEW cell) which was capable of plating metals over a broad range of concentrations from aqueous solutions, at high current densities and efficiencies. This technology is compact and relatively low in capital cost. An application to which it is well suited is the extraction of metals from waste streams, where the concentration of the target metal is often very low relative to that required for conventional electrowinning plant.

A series of trials has been carried out by EML on Mount Lyell acid drainage (and partly funded by EML). This work culminated in a pilot scale solvent extraction (SX) plant with copper recovery by EMEW cells operating at the site in November and December 1993. A report of the study and a feasibility study was completed by Gunn Metallurgy, who considered that the EMEW cell was engineered to a point where commercial application could be undertaken (Gunn Metallurgy 1993).

This feasibility study formed part of the AD treatment technology investigations carried out by MLMRCL and has been reviewed and investigated as part of this study. CMT has undertaken to review its potential as part of their ongoing operations.

There have also been recent advances in SX/EW technology which have resulted in its application to a number of projects in recent years.

The technology if successfully adopted, offers the potential to remove copper from the waste stream, with the copper sales and operating revenue generating funds which could be used to treat the remaining pollutants in the waters flowing from the lease.

Technology background

Solvent Extraction (SX) and Electrowinning (EW) are established and commercially viable technologies which are being used widely in the mining industry in copper recovery from leaching of copper ores. The SX/EW process is always preceded by some kind of leaching step. The leaching step at Mount Lyell is the process of acid drainage.

The combined process consists of three solution loops.

In the first loop, the copper bearing pregnant leach solution produced by leaching flows to the extraction section of the SX plant. Here it is contacted with a synthetic organic solution which selectively extracts the copper. The barren leach solution (raffinate) completes the loop back to leach more copper (where the water balance allows). The second loop is within the SX plant proper. The loaded organic solution from extraction goes to the stripping section. Highly acidic spent electrolyte solution from electrowinning strips the copper from the organic, which flows back around the loop to the extraction section. Finally, in the third loop the strong electrolyte is sent to electrowinning. High purity cathode copper is deposited by electrolysis and the spent electrolyte completes its loop back to the SX section or is discharged after neutralisation. If applied at Mount Lyell, the raffinate would be discharged, with perhaps some recirculation to leach waste rock dumps. This raffinate is basically acid drainage (slightly more acid—typically an additional 0.1 pH unit lower) with most of the copper removed. Therefore, for AD remediation it requires further treatment to remove other metal loads and to increase its pH.

Typical flow sheets for SX and EW are shown in figure 5.4. The SX process is carried out in mixer-settlers, usually comprising two or more mix boxes in series followed by a settling tank to separate the organic and aqueous phases. The flow sheet shows two extraction stages and one stripping. Traces of residual organic must be removed from the strong electrolyte prior to electrowinning. The flowsheet shows this being recovered by flotation columns, but filters can also be used.

Typically there is a build up of solids/organic crud which must be removed for treatment by decantation centrifuging or filtration to recover the valuable organic. Small quantities of organic extractant (kerosene) are lost from the circuit by entrainment in the raffinate or evaporation.

Electrowinning is carried out in a number of cells through which the electrolyte is circulated. The cells can be PVC lined concrete, or recently they have been constructed with polymer concrete. The cells contain the lead based anode and the cathode plates on which the copper is deposited. Recent developments include stainless steel cathodes. At about 7 day intervals, the cathode plates loaded with copper are transferred by crane to a washing and stripping facility where the copper is physically removed.

Generally for the SX/EW process to be economic, the concentrations of copper in the incoming effluent and outgoing electrowinning liquors need to be high and are often quoted in the range of 500–2500 mg/L. Thus, normally, SX/EW plants could not be used for the recovery of copper from the AD runoff streams at Mount Lyell, although recent advances in solvent extraction and electrowinning have resulted in this being reconsidered. This includes the EMEW cell.

EMEW cell technology and trials at Mount Lyell

Electrometals Mining Limited (EML, formally known as Euralba) has developed an electrowinning cell (the EMEW cell) that can recover copper economically from very low concentration liquors, such as those found at Mount Lyell. This cell overcomes the need for a high copper concentration feed liquor to the cathode, by continuously replacing the electrolyte around it. The cells are small and easily handled, so that copper stripping is easy and can be automated.

The EML technology for electrowinning base metals from solutions carrying very low concentrations of the target metal was developed over the 1980s and early 1990s. A pilot scale trial was undertaken in 1991 and 1992 at Mount Lyell, with copper being recovered by direct electrowinning from a combination of waste dump drainage and surface runoff. The trials were successful, both in achieving copper extraction to levels below 1 ppm; and in demonstrating application of the cell for commercial removal of the copper.

The resultant preliminary feasibility study (by EML) examined the potential application of both direct treatment of the solutions through the EMEW cell and potential for linking the technology with a solution purification step (namely solvent extraction). Although indicated to be economically viable, the size of plant that would be required for the direct electrowinning option was relatively large (in the number of cells required) and the route was shown to be sensitive to significant changes in power cost. These features are a direct result of the extremely high iron to copper ratios in the waste streams, therefore prompting inclusion in the study of a conceptual design and cost estimate for incorporating solvent extraction (SX) in the circuit.

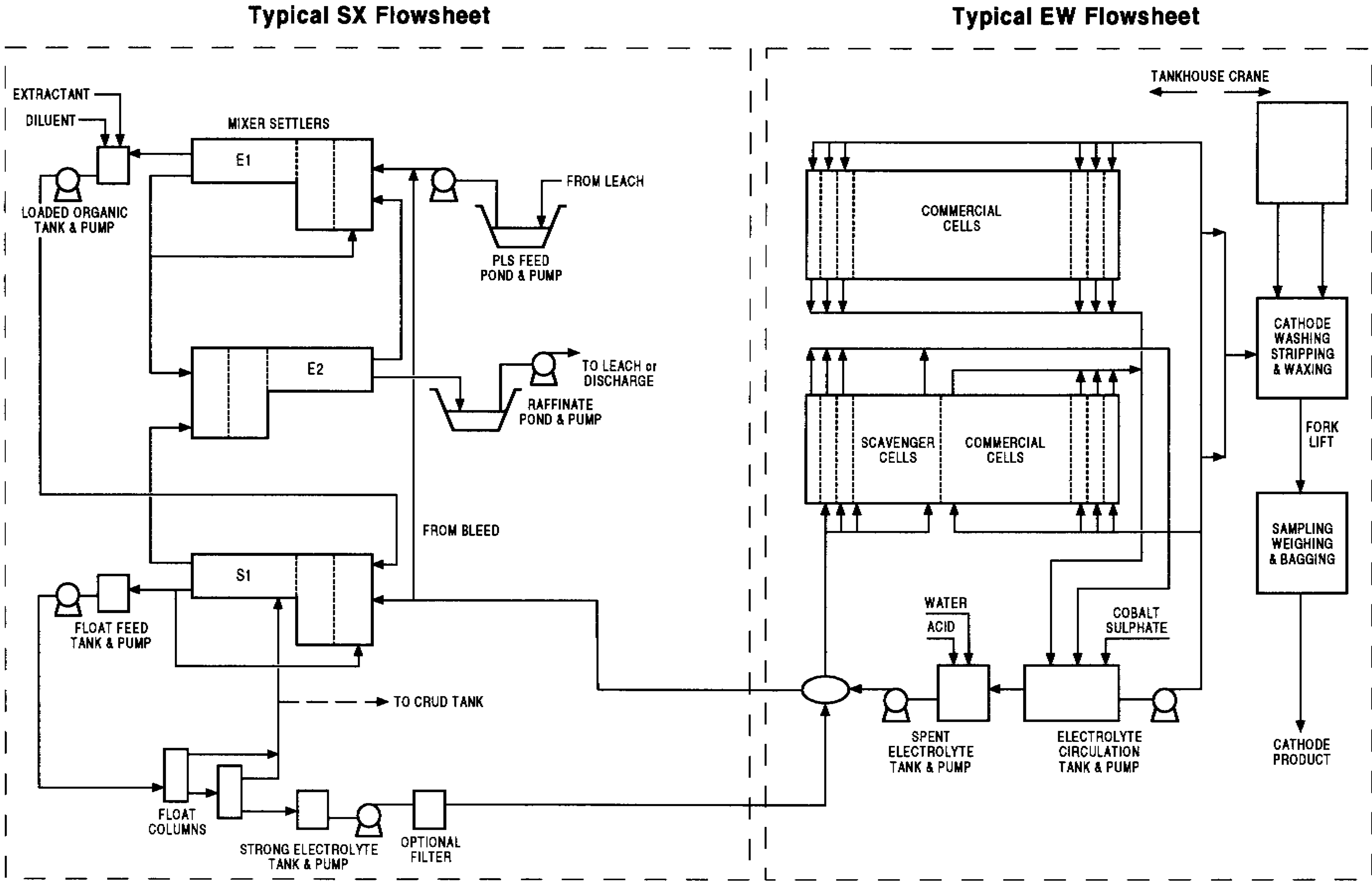


Figure 5.4 Typical flow sheets for the SX/EW process

The study demonstrated potential for significant capital cost savings, and lower sensitivity to electricity charges, when SX is used in conjunction with the EMEW cell. In effect the impact of the high iron to copper ratio on electrowinning efficiency was eliminated and the size of the EMEW plant was significantly decreased.

In November and December of 1993 a pilot scale SX plant was run on a variety of drainage streams at the Mount Lyell site, with copper from the upgraded solution recovered by EMEW cells. Sufficient data were collected to enable both the design and cost estimation of a full scale process plant, and the commercial analysis of a full scale operation.

EML has since commissioned an EW plant of its own (the design did not call for the SX stage) at the Young Australia mine (copper heap leach) near Cloncurry. From all reports this plant is working very effectively. The EMEW cell is receiving widespread industry attention and is now regarded as viable technology.

The application of SX/EW copper recovery to the Haulage Creek loads is considered in detail in section 6.2.2.

5.3.2 Conventional neutralisation/precipitation treatment of acid drainage

Introduction

The adoption or otherwise of a SX/EW plant to remove copper will not eliminate the need for a conventional neutralisation/precipitation plant to raise the pH and remove the other metal loads from the lease site. These loads are mainly from the mine dewatering, underground mine drainage and waste dump drainage within the Haulage Creek catchment and a conventional plant is seen as the only proven technology which can cope with the high loads and acidities.

Technology description

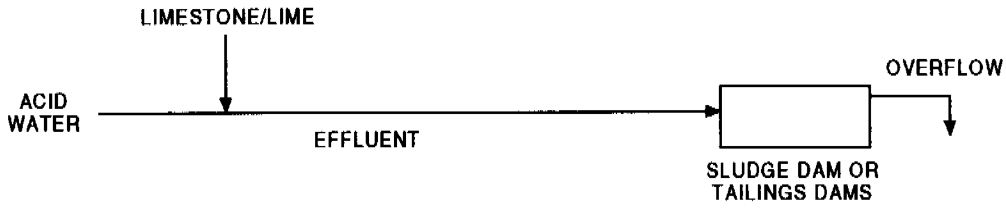
The chemistry of the waters is dominated by metals including aluminium, iron, copper, manganese and zinc, the concentrations of which can range from several tens to hundreds of mg/L. There are four primary issues relating to the efficiency and success of long-term active water treatment:

- current and future water chemistry
- current and future water volumes
- type and degree of water treatment
- volume and nature of the sludges produced during treatment

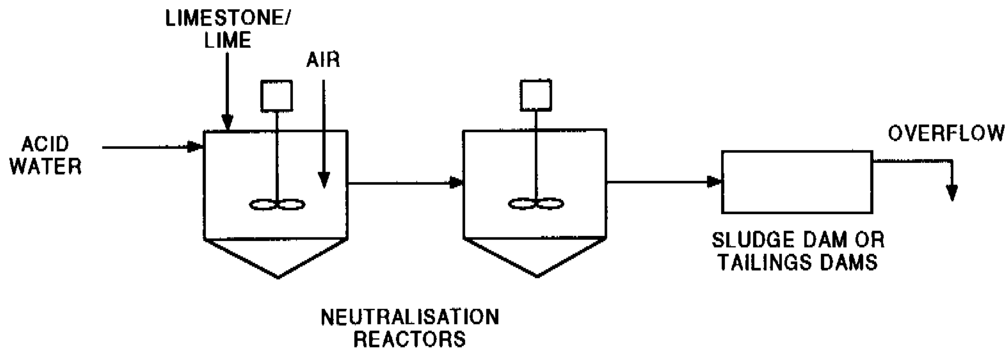
The range of water chemistry and flows determine the design capacity of an active treatment system. The design and construction also requires a consideration of storage or flow equalisation to accommodate flows generated during the short runoff period. Otherwise it would require a large flow capacity while only a fraction of the capacity would be needed during the remainder of the year.

Figure 5.5 shows a range of plant flow sheets from simple neutralisation and disposal of effluent to a dam to a high density sludge recirculation plant which is state of the art technology.

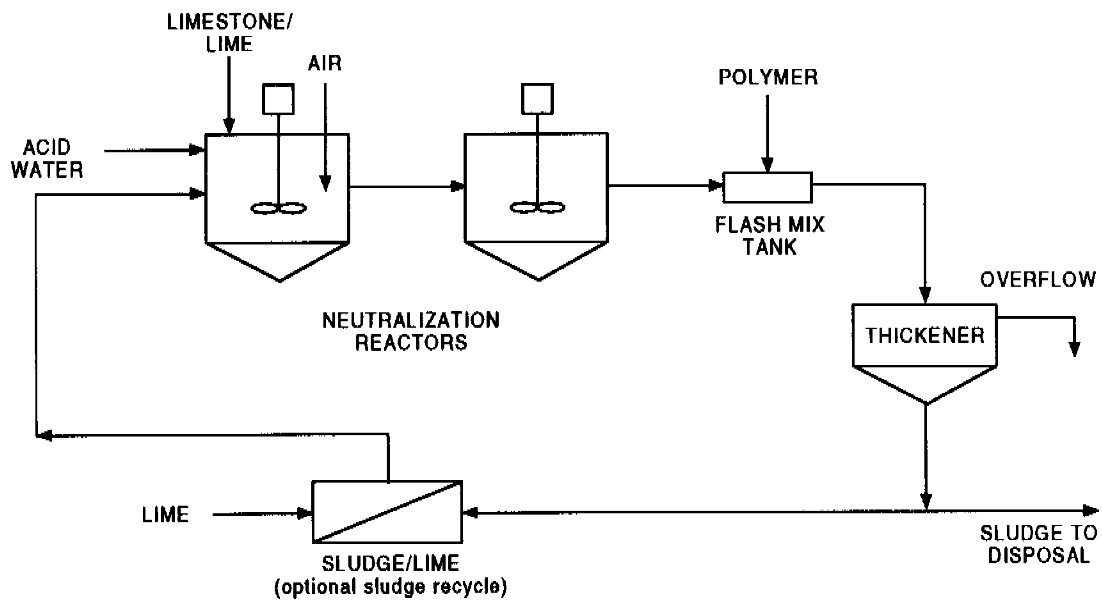
A conventional neutralisation and metals precipitation plant generally can achieve a 95–98% reduction in metal load. However, for some metals like copper the reduction efficiencies attained can be above 99%.



Type 1 Limestone/Lime addition to effluent or tailings lines.



Type 2 Limestone/Lime addition to neutralisation reactors. Solid/liquid separation in dams.



Type 3 Limestone/Lime addition to neutralization reactors. Solid/liquid separation in thickener.

Figure 5.5 Flow charts for various neutralisation treatments

A treatment plant would consist of:

- limestone/lime preparation storage and transfer equipment
- neutralising tanks
- thickener, flocculant dosing
- sludge disposal

The final pH of the AD before solids separation will determine the metal load, together with the solids/liquid separation efficiency. Trials carried out by CMT (CMT 1995) indicate that a final pH in the range of 6–6.5 was efficient in removing the toxic metals, however a pH less than this range may be acceptable. Manganese will remain in solution at these pHs and if manganese removal is required a pH of approximately 9 would be required, associated with increased neutralisation costs.

The plant will require an initial capital cost for construction, plus ongoing operating costs for the period of treatment. The major cost is usually the neutralisation agent. Typically neutralisation is achieved by the addition of lime. However, fine ground limestone can be used, but may not be very effective at raising the pH above about 5–5.5. Because of the cost of lime delivered to the site, the use of limestone is recommended, with lime being used only as a final pH adjustor. CMT has identified a high grade limestone resource at Lynchford which would be suitable if available.

The long-term active treatment of water will result in the generation of large volumes of sludge which require separation and disposal. Sludge disposal can range from containment within a dam, codisposal with tailings, to sludge drying and water separation by a belt separator. The sludge has significant neutralisation capacity and contains high levels of metals. The recovery of metals by smelting is seldom economic and is usually only used as a disposal option (MEND 1994b, ASARCO pers comm; Cominco pers comm; Kennecot pers comm).

5.3.3 Passive treatment of acid drainages

Background

Passive treatment, like active treatment with chemicals, requires that the metal contaminants be precipitated and that the acidity associated with these ions be neutralised. In conventional treatment systems these two treatment objectives are combined by the addition of basic chemicals (usually lime) that simultaneously cause the rapid precipitation of metal contaminants and the neutralisation of acidity. Passive treatment makes a distinction between these two treatment objectives.

Passive treatment options are discussed below and include engineered anoxic systems, alkalinity producing systems and wetlands. These options are considered passive due to their increased reliance upon natural versus manufactured components as the centre of the treatment system. Although these systems are not maintenance free, their operational costs are generally less than those associated with conventional or advanced treatment systems and are of value in treating small water flows of moderate acidities. In general, the operational lives of these systems are finite but are believed to be in the vicinity of tens of years. Once the alkalinity and metals loading capacity of the systems is exhausted, the alkaline source and/or organic matter must be replaced if continued use of the systems is desired.

Most applications of passive treatment have been at sites where the mine water is net alkaline and there are many examples where mine drainage has been successfully treated—such as at Beaconsfield in northern Tasmania and Hellyer in western Tasmania—when waters are alkaline. However, when mine water is acidic, enough alkalinity must be generated by the passive treatment system to neutralise the acidity. Attempts to use limestone have generally failed because of the clogging and armouring of the limestone with iron oxides which reduce effectiveness. However, there have been projects recently which have involved the addition of limestone as sands in areas of steep topography which are worthy of consideration.

Until recently, the most common method used to passively generate alkalinity is the construction of a wetland that contains an organic substrate in which alkalinity-generating microbial processes occur. If the substrate contains limestone, as spent mushroom compost does (this is the most common material used in the US), then alkalinity will be generated by both calcite dissolution and bacterial sulfate reduction reactions. These alkalinity generating processes are slow relative to processes that remove iron, therefore the performance of the constructed wetlands that receive acidic water is usually limited by the rate at which alkalinity is generated within the substrate.

Although wetlands can significantly improve water quality, and have proven to be effective at moderately acidic sites such as at many coal mine sites in the eastern United States, no wetland systems that consistently and completely transform highly acidic water to compliance quality are known. High flows, high acidities (>300 mg/L), and aluminium are serious impediments to passive treatment success. In many cases inconsistent or partial treatment indicates undersizing and indicates just how much larger wetlands constructed to treat acidic water must be than ones constructed to treat alkaline water. The US Bureau of Mines (USBM 1994) has conducted studies which indicate that wetlands constructed to treat acidic water need to be six times larger than ones constructed to treat similarly contaminated alkaline water.

However, there have been recent developments of limestone pretreatment systems, such as the anoxic limestone drain (ALD), which are a significant advancement in passive treatment technology. When successful, ALDs can lower acidities or actually transform acidic water into alkaline water, and markedly decrease the sizing demands of the wetlands constructed to precipitate the metal contaminants at a cost much less than compost wetlands. Thus, when the influent water is appropriate, ALDs are the preferred method for generating alkalinity in passive treatment systems. Anoxic limestone drains have also been used to increase the performance of existing constructed wetlands in the United States. However, aluminium and iron can limit their effectiveness.

There have been further advances in Pennsylvania, Virginia and West Virginia in the United States testing 'hybrid' ALD-compost wetland systems. In these, organic substrates are used to reduce ferric iron to ferrous iron and strip dissolved oxygen from the water so that the mine water is suitable for flow through an anoxic limestone drain, which otherwise would not be suitable. Indications are that these systems will treat highly acidic water by cycling it between anoxic alkalinity-generating environments and aerobic metal-removal environments. Systems using this design have recently been constructed in western Pennsylvania and these were inspected as part of the study.

Consultants who have developed this technology (Damiscotta) have been engaged to provide design advice on the potential application at Mount Lyell, as have consultants who have experience with ALDs and limestone application (Hedin Environmental).

Though the specific tools of passive treatment are likely to evolve in the coming years, the fundamental mechanisms of passive treatment that have been identified will probably not change markedly, but the performance and cost-effectiveness of passive treatment systems are rapidly improving. At Mount Lyell, the application of passive treatment is regarded as a practical solution for the low load and volume point sources and a properly designed passive treatment system can be expected to rapidly recoup the cost of investment through decreased water treatment costs.

Passive treatment systems cannot be expected to perform indefinitely. In the long term, wetland systems will fill up with metal precipitates or the conditions that facilitate contaminant removal may be compromised. However, when properly designed they can expect to last for at least tens of years.

Aerobic wetlands

In aerobic wetland systems, oxidation systems can occur, and metals can precipitate as oxides and hydroxides by bacterial catalysis and abiotic reactions. They are generally constructed at sites where the mine water naturally contains sufficient alkalinity to buffer the acidity generated by the metal hydrolysis reactions. Because the Mount Lyell waters are acidic, they require pretreatment to make the water alkaline before aerobic wetlands are effective.

Limestone addition

Water flowing over limestone creates alkalinity when the acidic water contacts the limestone. The limestone is subject to armouring and passivation but recent studies indicate that even in this condition the limestone still produces alkalinity. There have been recent trials constructed in Pennsylvania which were inspected.

Limestone in the form of sands which are mobilised and dispersed under high flow conditions has also been successfully applied. The rates of alkalinity generated in an atmospheric environment are not large, but open drain systems and limestone sands are cheap, easily applied and suitable to steep topography. They are therefore potentially applicable on the lease site.

Anoxic limestone drains (ALDs)

In an ALD, alkalinity is produced when the acidic water contacts the limestone in an anoxic, closed environment. ALDs are now widely used in the United States for inducing alkalinity into mine drainages (mainly coal mines) and their design parameters and operating requirements are becoming well understood.

However, not all water is suitable for pretreatment with ALDs. The primary chemical factors believed to limit the utility of ALDs are the presence of ferric iron (Fe^{3+}), aluminium (Al) and dissolved oxygen (DO). When acidic water containing any Fe^{3+} or aluminium contacts limestone, metal hydroxide particulates (FeOH or $Al(OH)_3$) will form. No oxygen is necessary. Ferric hydroxide can armour the limestone, limiting its further dissolution. The build-up of both precipitates within the ALD can eventually decrease the drain permeability and cause plugging. The presence of dissolved oxygen in mine water will promote the oxidation of ferrous iron to ferric iron within the ALD, and thus potentially cause armouring and plugging. Mine water that contains very low concentrations of DO, Fe^{3+} and Al (all <1 mg/L) is ideally suited for pretreatment with an ALD. As concentrations of these parameters rise above 1 mg/L, the risk that the ALD will fail prematurely also increases.

The limestones used in most successful ALDs have 80 to 95% $CaCO_3$ content. Most effective systems have used number 3 or 4 (baseball-size) limestone. Some systems constructed with limestone fines and small gravel have failed, apparently because of plugging problems. The ALD must be sealed so that inputs of atmospheric oxygen are minimised and the accumulation of CO_2 within the ALD is maximised. This is usually accomplished by burying the ALD under several feet of clay. Plastic is commonly placed between the limestone and clay as an additional gas barrier and designed so that the limestone is inundated with water at all times. The dimensions of existing ALDs vary considerably. Most older ALDs were

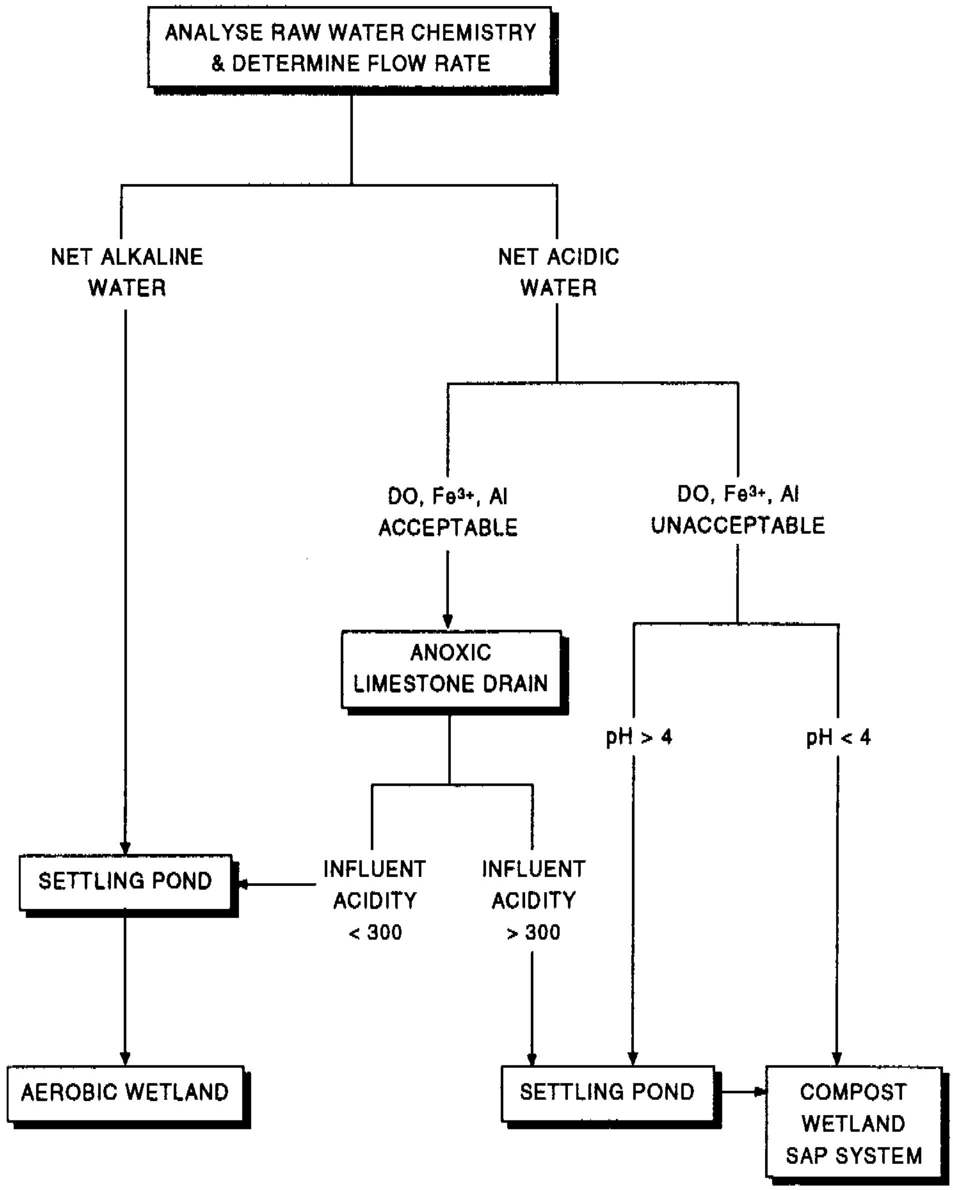


Figure 5.6 Flow chart for the characterisation of mine drainages showing chemical characteristics and suitability for the design of passive treatment systems (modified after USBM 1994)

The ability to develop SAPS as alkalinity generating systems capable of producing an essentially infinite amount of alkalinity broadens the scope of passive treatment and it is believed will allow the treatment of acid drainage at Mount Lyell.

Characterisation of Mount Lyell mine drainage and application of passive treatments

The USBM has developed a flow chart for the characterisation of mine drainages showing chemical characteristics and suitability for the design of passive treatment systems (USBM 1994). This chart, modified, is shown in figure 5.6. Based on the Mount Lyell water quality, all mine site drainages are acidic, with total acidities varying from 100 to approximately 10 000 mg/L.

Most of the drainages have dissolved oxygen, ferric iron and aluminium concentrations too high for ALDs and the only treatment based on the flow chart is via anaerobic compost wetland and/or SAPS. The application of ALDs, however, could be considered for the alkaline recharge of 'clean drainages' if they can be demonstrated to generate sufficient alkalinity.

5.3.4 Emergent technologies

Sulphate reduction

Precipitation of trace metals by sulphate reduction catalysed by sulphate reducing bacteria (SRB) offers an alternative method of treating AD. As with SW/EW technology it can lead to a saleable product which can defray the overall cost of installation and operation. The advantage of SRB technology is that metals other than just copper can be recovered. The disadvantage is that the technology is still largely at the laboratory stage of development.

Sulphate reduction is the inverse of sulphate oxidation, converting soluble sulphate to largely insoluble sulphides. There are, however, important differences with respect to mine site rehabilitation. Firstly the sulphides in the mine wastes are solids while the sulphates in drainage are in solution which makes understanding and quantification of mechanisms easier. Secondly, while the bacteria involved in sulphate reducing bacteria are aerobic they need an organic carbon source. A wide range of organic material including alcohols and sugars are suitable sources of organic carbon; material such as straw, hay, compost and so on has to be degraded to produce substrates suitable for SRB.

Sulphate reduction is one of the processes which remove trace metals from acid drainage as it flows through a wetland.

The use of sulphate reduction in the mine site rehabilitation has generally been limited in application to low flow rate drainage. In such cases recovery of the metals as sulphides is not an objective. A biogenic sulphide plant, where sulphate reduction takes place in a reactor from which H_2S is fed to a second reactor in which metal sulphides are precipitated, provides a way to extract metals in a saleable form from drainage which has a high flow rate and contains concentration of trace metals in the tens to hundreds of mg/L range.

A commercial biogenic sulphide plant began operation in 1992 (Scheeren 1993) treating contaminated ground water with high zinc concentrations. In this case the recovered zinc sulphide was sent for metal recovery at an on-site roaster.

The US Bureau of Mines (Hammack et al 1993) has conducted some bench scale test work to apply the biogenic sulphide plant concept to low pH mine drainage water containing concentrations of about 2000 mg/L zinc, 150–300 mg/L copper, about 20 mg/L manganese and sulphate levels of about 90 000 mg/L. In the metal precipitating reactor, the Bureau investigated both variable pH control, where precipitation of different metals is controlled by the solution pH, and constant pH where the least soluble metal sulphides precipitate first and separation can occur by sequential recovery of the precipitates. The conclusion was that, while both techniques were effective in separation, the variable pH technique allowed for more efficient and easier metal selectivity. A pilot scale plant has been constructed and is in operation at the Bureau in Pennsylvania. Kennecott Copper are also trialling this technology at Bingham Canyon.

The application of SRB technology at Mount Lyell at some time in the future could offer an alternative to the SX/EW technique in that metals other than copper are removed from the waste stream. Moreover, the process introduces alkalinity which, unlike SX/EW process, means that the pH of discharge liquor is higher than the input. The technology is, however, nowhere nearly as well developed as SX/EW and has only been utilised for low flows.

As indicated above, in many applications the substrates for SRB come from the degradation of plant material. It is more effective to use organic material which can be accessed directly by the bacteria. In the Tasmanian context a suitable substrate would be lactose which is often a waste product in the dairy industry. The attraction here is the use of a waste stream with associated disposal costs in reducing the environmental impact of another waste stream and at the same time producing a saleable product.

Other technologies
There are other technologies which have been discussed previously which are being trialled at laboratory scale in the MEND studies and by mining companies. These include Kennecott Copper which is devoting large resources to investigating a wide range of techniques to treating acid drainage and the recovery of metals in groundwater and surface waters. There is a need to monitor these for possible future application.

5.4 Remediation work to date

5.4.1 Previous operations (Mount Lyell Mining and Railway Company Ltd)

Remediation works carried out by the previous operator as part of the site rehabilitation works and the HEC as part of the Lake Burbury diversion works have included:

- levelling and revegetation of the surface of the Utah dumps (1989–1991)
- surface water diversions (mainly around the West Lyell open cut and the Tharsis waste dumps Crown Lyell workings)
- underground drainage diversions from the Crown Lyell area to the North Lyell Tunnel (June 1991)
- blocking of the Tharsis Adit (August 1992)
- diversion of Comstock 5 drainage from Comstock to East Queen catchments (July 1991)
- trial of bioreactors on the Tharsis Adit drainage (1994)
- attempts to fill the Stope 3 surface hole (1994)
- investigations of the West Lyell waste rock dumps (ANSTO 1994)

The location of these works is shown in figure 5.7.

Surface water diversions around the West Lyell open pit were constructed by the MLMRCL to reduce inflows into mine workings. These were successful and reduced inflows during heavy rainfall periods. A diversion drain was also constructed to divert surface runoff from the vicinity of the Tharsis waste rock dumps to the Crown Lyell diversion dam which diverts water from the Crown Lyell area to the North Lyell Tunnel via drill holes into old workings.

This dam was build by the HEC as part of the program of works to remove acid drainage loads from the Lake Burbury catchment. Other works were also constructed on Comstock Creek where Comstock Adit 5 and drainage from the Comstock open cut were diverted by an open drain system to the East Queen catchment.

In 1982 the MLMRCL constructed a concrete plug in the Tharsis Adit to divert this drainage (of approx 1 L/s) back to the underground workings. Seepage around the edge of the blockage in fractures in the adit walls rendered this attempt to redirect flows unsuccessful, but the concentrations have reduced, probably by reduction in oxidation.

Most of these works have been effective; the results of load reductions are shown in table 5.1.

In the Linda Creek catchment, the levelling and covering of the Utah dumps has reduced the AD loads in Linda Creek downstream by 33%. The Tharsis flooding has reduced the Tharsis source by 75% and with the Crown Lyell diversion loads in Idaho Creek have reduced by 67%. Downstream at Linda just before Lake Burbury, all of these works have been effective in reducing the loads to the Lake by 53%.

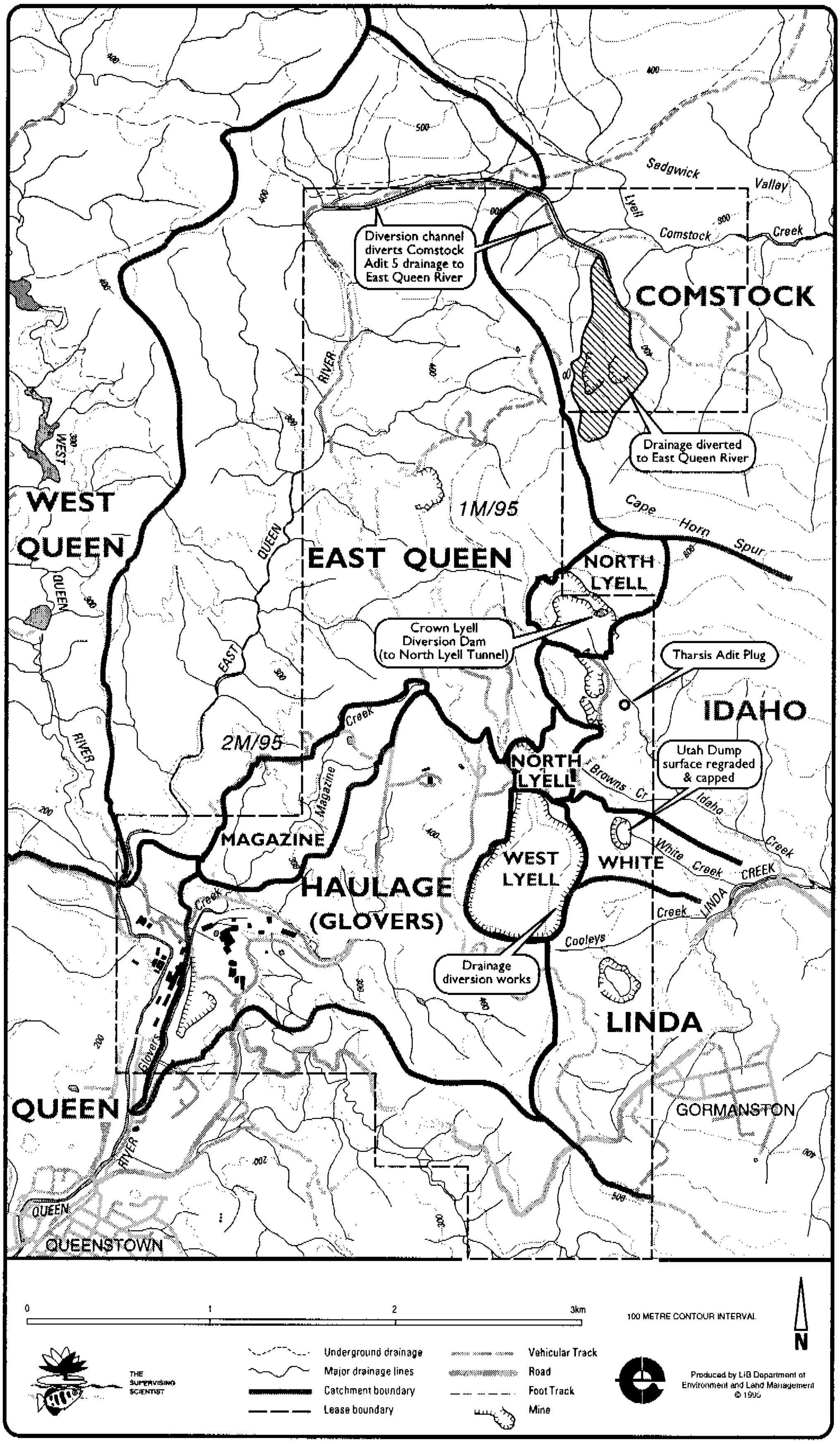


Figure 5.7 Location of remediation works on the Mount Lyell lease site

Table 5.1 AD loads before and after MLMRCL/HEC load reduction works (kg/d)

Location	Before diversion			After diversion		
	Cu	SO_4	Acidity	Cu	SO_4	Acidity
Lower Comstock Creek	6	454	376	3	156	
East Queen River	17	888	710	NR	NR	NR
Tharsis Adit	12	313	329	3	118	77
Linda Creek below White Creek	25	1915	2205	17	1230	1355
Idaho Creek above Linda	27	917	970	9	332	395
Lower Linda Creek	26	31257	1153	12	894	726

At Comstock Creek, the diversion of Adit 5 has reduced the loads in Lower Comstock by 50%. These loads were transferred to East Queen River.

The MLMRCL also undertook a trial of bioreactors (anaerobic) on the Tharsis Adit drainage in 1994. These trials were of an upflow system through mushroom compost and peat, with limestone. The compost proved successful in removing the acidity, raising the pH and adsorbing most of the metals (A. Hayter pers comm.) These would not be a long-term solution with the system clogging up with precipitates. The results of this trial have been used in the development of a SAPS for a trial treatment of the Tharsis Adit drainage, with the equipment being reused (see section 6.4).

ANSTO conducted investigations of the West Lyell waste rock dumps. A total of nine investigation holes were drilled, and instrumented with monitoring equipment (ANSTO 1994). These data were then used to estimate the pollutant load, the time frame for pollutant generation and develop a model for predicting pollutant generation. The model has been used in this current study to assess the effects of covering the waste rock dumps.

5.4.2 Copper Mines of Tasmania (CMT) operations

CMT commenced mining operations in 1995 with concentrate production in December 1995 in accordance with an approved environmental management plan (EMP). These operations will result in the reduction of AD loads discharged to Haulage Creek and are described in section 6.2.

It is expected that there will be a progressive improvement in AD drainages from the lease as the mine increases production over the next three years to a planned 3.5 million tonnes per annum in 1998, as CMT treats mine dewatering flows by cotreatment with alkaline tailings.

Figure 5.8 shows the proposed water management of the CMT operations.

However, under the EMP and approvals, AD discharge via mine dewatering will continue when tailings neutralising capacity is inadequate to treat the mine drainage, when the concentrator is not operating, and under high flow conditions.

In the longer term it is possible that CMT may develop an open pit mining operation which would result in the mining of the low grade ore outside the confines of the existing pit and encompassing the existing waste rock dumps.

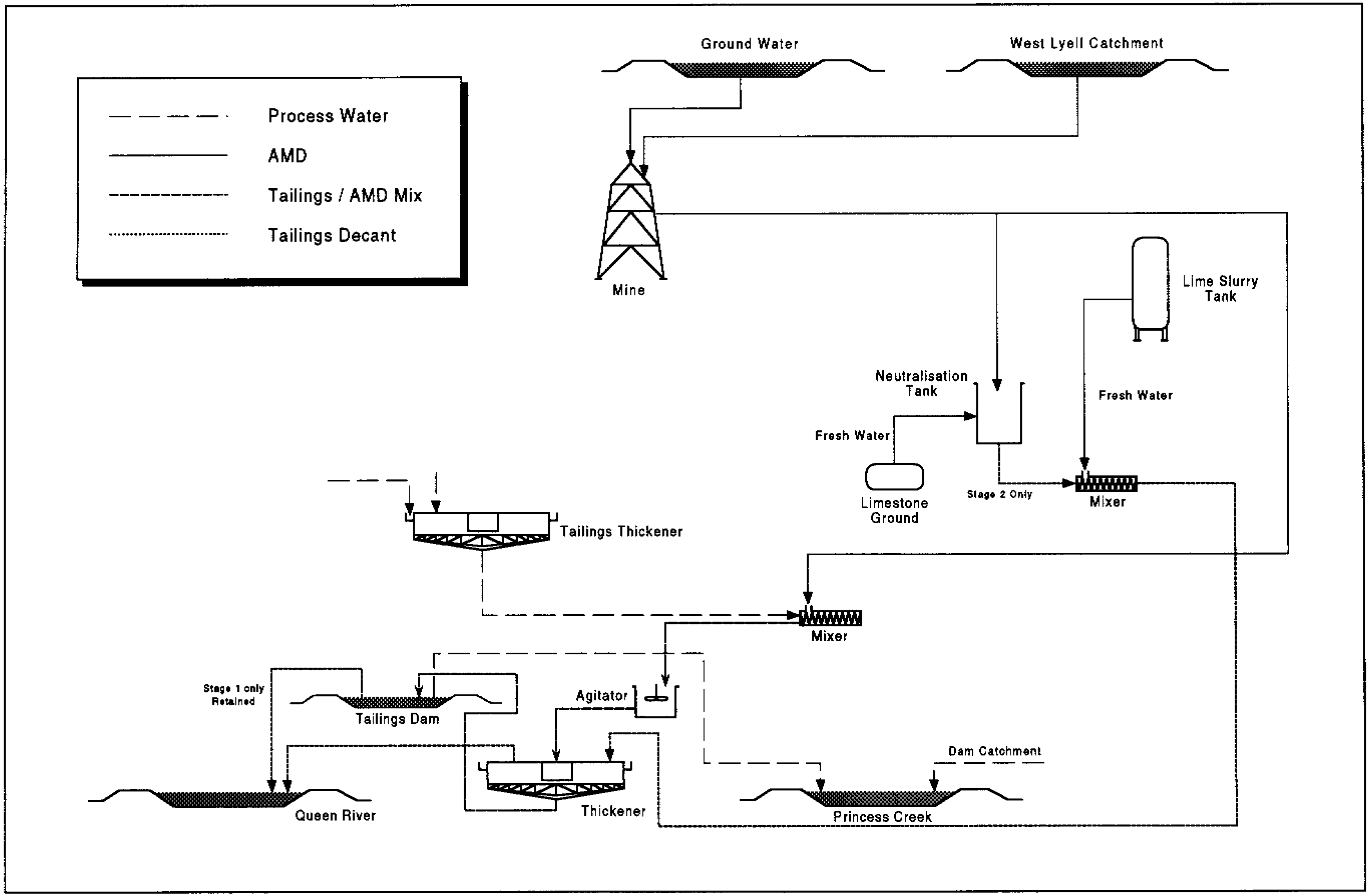


Figure 5.8 Proposed water management of the CMT operations (after CMT 1995)

5.5 Summary and applicability to the lease

A review of technologies for the remediation of the acid drainage from the lease has identified a number of technologies which are potentially applicable. The site, with a high rainfall, low evaporation and steep topography, results in high runoff volumes with high concentrations of metals in solution. Because the majority of the loads come from underground sources and active mining areas, the use of load reduction remediation options such as flooding or covering are not expected to be effective for these major loads and in any case cannot be considered because of ongoing mining operations.

Consequently, there are no options other than to treat the major AD sources and the only proven technology able to cope with the high loads and flows is conventional acid neutralisation metal precipitation technology.

However, the high concentration and metal loads of copper from the Haulage Creek catchment, and possibly other high copper concentration sources in other catchments, which are in the vicinity of 2.5 tonnes of copper per day, are potentially amenable to copper recovery using solvent extraction and electrowinning and possibly other metal removal technologies. SX/EW has the potential to recover copper for sale and provide a revenue source for the treatment of the effluent from the plant and possibly other site drainage by conventional technology. The removal and treating of the high load sources will allow the use of passive treatment for the remaining smaller AD loads.

The balance of the lease, which includes the Magazine Creek, East Queen River, Linda Creek and Comstock Creek catchments, has lower load/volume sources within these catchments which are more amenable to other technologies.

These include:

- covering of waste rock dumps and acid producing sources to reduce AD loads
- flooding of old workings and flow diversion
- passive treatment of adit discharges and low flows
- alkalinity generation into the receiving waters to buffer AD and precipitate metals within wetlands and/or within the stream system

6 Remediation options

6.1 Introduction

The review of remediation options has identified potentially applicable technologies which could be utilised to remediate AD source on the lease. These remediation options which are applicable are described in section 6.2.

These range from the improved conditions which will result from the ongoing Copper Mines of Tasmania mining operations, recovery of copper by SX/EW from the major load streams, load reduction actions, through to passive treatment systems which could be trialled and implemented.

The ongoing CMT operations which involve the mining of the Prince Lyell and Tharsis orebodies will result in a reduction of AD loads in Haulage Creek, however, these operations also restrict some of the remediation options which could be potentially be considered. The potential application of SX/EW to recover copper and the treatment of the effluent raffinate also conflicts with some remediation options—such as covering waste rock dumps—and this also makes the consideration of options complicated.

Each of the options is considered under the following headings:

i description
ii expected effectiveness and feasibility
iii advantages/disadvantages
iv costs/financials
v additional work required

In section 6.3 the site specific remediation options for each identified source are described:

- within the Queen River catchment
- Haulage Creek
- East Queen River
- within the Lake Burbury Catchment
- Linda Creek
- Comstock Creek

6.2 Identified remediation options

6.2.1 AD treatment by existing CMT operations

(i) Description

CMT have recommenced mining operations on the Prince Lyell orebody beneath the former MLMRCL workings, in accordance with the Scheduled Premises Licence conditions and the approved EMP. The continued operation of the mine by CMT, until either mining operations cease or the nature of the mining operations changes, is therefore the baseline from which future AD remediation can be evaluated.

There will be a progressive improvement in AD drainages from the lease commencing with:

- Removal of mud discharges to the Queen River via the mine dewatering mud displacement system. In the future these will be sent to the concentrator for processing.
- Partial treatment of mine dewatering to fulfil licence requirements (this relates to an indemnity for past mining operations). This is estimated at between 0–20% of the total mine dewatering flows (see below).
- The co-treatment of mine dewatering flows up to the neutralising capacity of the tailings. The actual percentage which is treated will depend on the quantity of tailings produced and the available neutralising capacity (see below).

(ii) Expected effectiveness and feasibility

The immediate removal of the mud displacement to Haulage Creek will have an unquantifiable benefit, as water sampling in recent times has been restricted to non-mud flow periods. However, it will be significant. The treatment of mine dewatering flows by codisposal with tailings is estimated to vary from 60% at minimum flows to <54% at maximum flows (CMT 1995). This allows for mill shutdown. SDAC has estimated that, on average, perhaps as little as 50% of the mine dewatering discharge will be treated. Therefore, reduction in copper loads from Haulage Creek could vary from approximately 35 to 60%.

The balance of the AD loads from mine dewatering will continue to be discharged and under mine and mill shutdown conditions, mine water discharges to Haulage Creek could also occur.

There will be no reduction of loads from other sources in Haulage Creek and the load reduction will cease at mine closure when tailings production will cease.

(iii) Advantages/disadvantages
There will be a progressive improvement in AD drainages from Haulage Creek with initially a reduction due to mud removal and a progressive reduction in mine dewatering loads as mine and tailings production increases. However, there will be periods under concentrator shutdown when AD loads will be released untreated to Haulage Creek. The effects on downstream water quality would therefore be periodic rather than continuous. Contingency measures could be put in place by providing additional neutralisation of the mine dewatering to replace the tailings neutralisation capacity and maintain discharge to the tailings dam.

These load reductions would cease at mine closure, but would be expected to be better than the pre CMT situation if the mine was flooded on closure (due to flooding of old workings and reduction in oxidation).

(iv) Costs/financials
This is the baseline no cost option.

6.2.2 SX/EW copper recovery from main AD sources

(i) Description
A SX/EW plant could be constructed on site to treat the major copper sources and recover copper for sale.

The major sources would be the mine dewatering and the West Lyell waste rock dumps, with surface water diversions to divert clean water from the dump leachate. Depending on the cost effectiveness it may also be possible to treat the Tharsis Adit and Utah waste rock drainages as these are all high concentration sources (but low flow). The North Lyell Tunnel copper concentrations may be too low. It may also be possible to irrigate the waste rock dumps and accelerate the oxidation process similar to a heap leach.

Available copper resource. The major copper loads from the lease are from the Haulage Creek catchment, which contributes approximately 99.3% of the total copper loads to the Queen River above Conglomerate Creek and approximately 98.7% of the total loads from the lease. These copper sources are from drainage from the operating Prince Lyell Mine, the North Lyell Tunnel draining underground workings and the West Lyell waste rock dumps. Other potential sources are the high concentration Tharsis Adit and Utah waste dump drainages.

Based on the 48 million rock dump tonnage only, which grades at about 0.17% copper, it is estimated that some 64 000 tonnes of recoverable copper remains in the dumps (Gunn Metallurgy 1993). ANSTO estimates that current copper loads can be expected for a further 20 years at which time the loads are expected to decrease by about a factor of ten and stay at that level for about another 600 years. In addition there is unquantified copper resource leaching via the North Lyell Tunnel from Crown Lyell and North Lyell, the drainage from the West Lyell pit and contained cave material and the acid drainage from mining operations.

The Haulage Creek copper load source and distribution is shown in figure 6.1, and summarised below in table 6.1. These figures are based on a recent review of all data to date and are based only on median data and will require corroboration due to variations within data sources. The effect of using mean flows is likely to increase the available copper load estimates (see table 3.2 for 90th percentile data). The copper loads are in accord with the EML feasibility study (EML assumed 1821 kg/d).

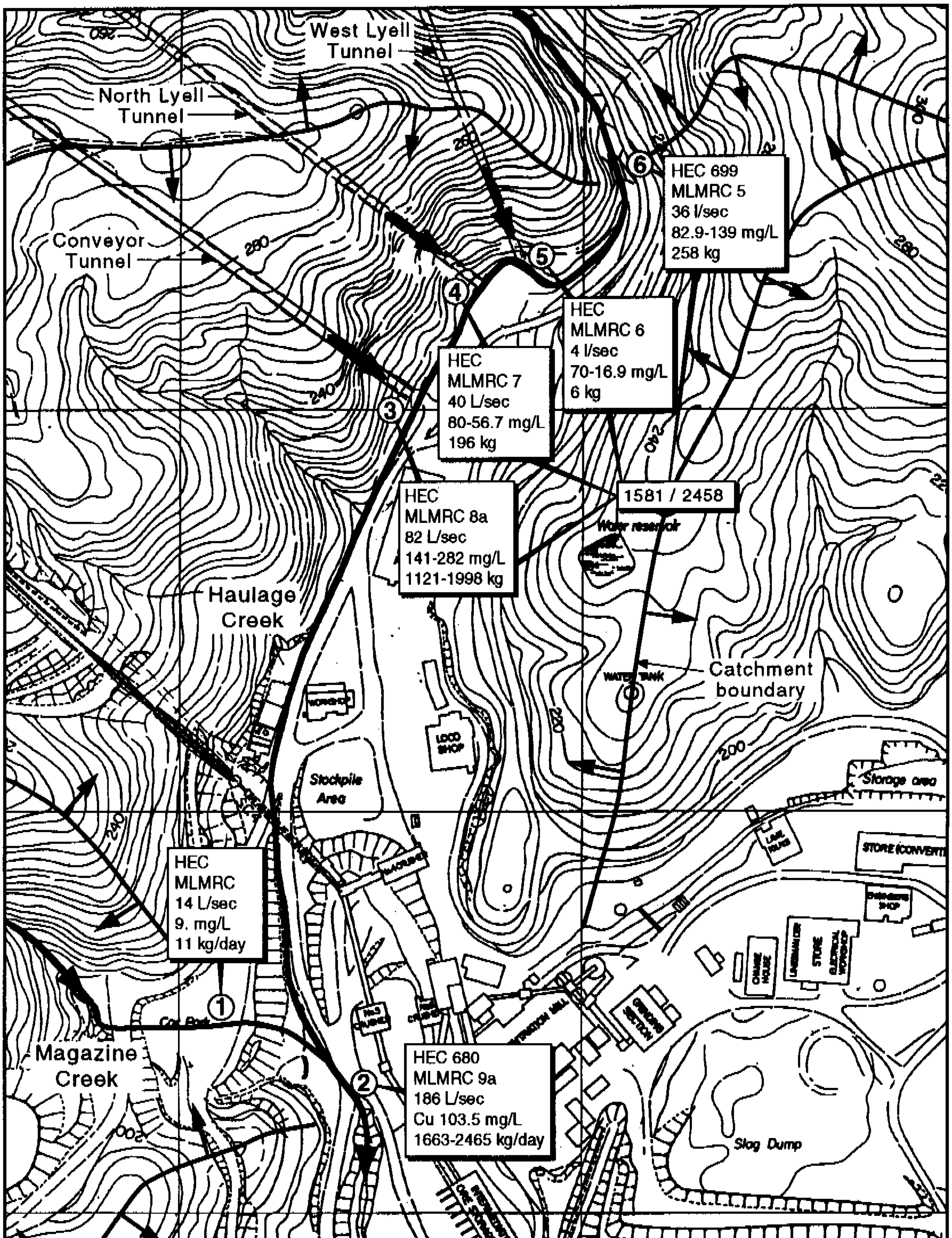


Figure 6.1 Distribution and source of the copper loads in Haulage Creek

As discussed in section 6.2.1, CMT has responsibility for the treatment of the AD flows from only its mine operations but has also undertaken to treat as much additional mine water as possible, using the acid neutralising capacity of the tailings. The copper resource which could be recovered will therefore be dependent on CMT's operations. For the purposes of the copper recovery by SX/EW it is assumed that all the copper loads from mine dewatering would be available for recovery and any treatment by CMT would be after the copper recovery by SX/EW.

Table 6.1 Haulage Creek copper resource loads

Source	Cu loads (kg/d) Pre 12/94	Cu loads (kg/d) Post 12/94	% total Post 12/94
Conveyor Tunnel (mine dewatering)	1121	1998	80.3
West Lyell waste rock	258		10.4
Utah Dumps	16		0.6
Tharsis Adit	3		0.1
North Lyell Tunnel	196		7.9
West Lyell Tunnel	6		0.2
Magazine Creek	11		0.4
Total	1611	2488	100

Any SX/EW recovery of copper from AD streams will require a consideration of the flow to be treated and the copper concentration. There will be some copper concentration where the recovery of copper will no longer be economic and the feasibility of copper recovery will be marginal. The separation of high concentration copper AD streams from relatively clean catchment waters will therefore be crucial to the plant operation.

The volume of the West Lyell waste rock dump drainage from surrounding catchments is estimated at 50% of the Haulage Creek flow at Station 5 (see next section). Other copper sources would include the collection of the mine dewatering flows.

EML SX/EW plant trials EML has indicated in its report (Gunn Metallurgy 1993) on the trials that:

- its plant would be economic for a copper concentration down to 80 ppm and at an AD effluent flow rate of 140 L/sec
- up to 1.5 tonnes of copper would be recovered a day from this stream (based on EML's load estimates)
- the plant to handle this throughput would cost about $1.1M
- this plant could have a net profit of at least $600 000 per year

These have been based on:

- a copper price of US$0.85/lb
- an exchange rate of $0.7 US
- a recovery efficiency of 80%
- a power cost not more than $0.50/kWh

Following discussions with EML and their consultant (Michael Gunn), a review of EML's report by a world SX/EW expert (Joe Keene of Tucson, USA), and discussions with metallurgists in the mining industry, the basic findings of the EML feasibility study were accepted, with the following qualifications:

- The capital and operating costs may be higher than estimated.
- The direct release of raffinate (the final liquid effluent) to Haulage Creek after copper removal would not be satisfactory because of downstream environmental effects and this effluent should be treated prior to release to remove other contaminants.
- The EML study relied on water quality and flow data provided by Mount Lyell, with some additional sampling. Additional information on flows and copper concentrations should be incorporated.
- There should be a technical review and detailed feasibility study to confirm the design.
- Changes in copper price and exchange rates should be reflected in updated financial feasibility studies, with updated capital and operating costs.

CMT SX/EW plant design During the course of this study, after discussions with CMT and DELM, CMT commissioned both a preliminary feasibility study and process plant design for a SX/EW plant located near its concentrator. This included a review of the EML process design as well as proven state of the art SX/EW plant designs.

A plant design has been developed which includes handling of acid drainage and raffinate, clarification of AD, solvent extraction and electrowinning for the production of copper cathode. The plant design is for a capacity of a nominal 100L/s to treat the mine dewatering (Conveyor Tunnel) flows, however it can be expanded with the addition of further cells.

The design is a well proven Solvent Extraction and Electrowinning process to produce a high grade copper cathode product. It does not include the EML EMEW cell. It would be fed from a storage pond which would receive the copper streams from the mine dewatering.

The economics of the plant are discussed in section 6.2.2 (iv).

Any plant expansion to treat other AD sources (such as West Lyell waste rock drainage) will require careful consideration of water management.

Water management To ensure plant feasibility, year round operation and avoid periods when untreated AD is discharged, works will be required to provide a more even flow of copper to the SX/EW plant especially if it is used to treat other drainages. This could be achieved by flow diversion to separate concentrated copper streams and clean runoff, with direction to a storage prior to the plant. During dry periods a portion of the raffinate solution could be recirculated to irrigate the dumps (see below) and maintain a minimum solution flow volume.

Haulage Creek contains drainage from the waste rock dumps and runoff from a catchment which includes the waste rock dumps. Approximately 50% of the total Haulage Creek catchment above Station 5 is affected by waste rock drainage (see figure 6.2). It will be possible to separate the relatively clean general runoff from waste rock drainage water by the construction of cut off trenches to divert clean runoff and weirs and a pipeline to take drainage to the SX/EW plant. This will lead to higher copper tenor and more even flow rates to plant. Similarly, general catchment drainage and the other sources could be kept separate.

Project 1 has demonstrated that flows on the lease are highly skewed and the use of median flows may underestimate total flows in the lease catchment where up to 80% of the flows may occur in 20% of the time. Therefore even though this means that in fact copper loads may be greater than stated, so too will flows. This requires detailed study to establish the feasibility of collection of AD and the need to divert any higher flows (such as after a certain return period storm event (eg 1:10 year storm event).

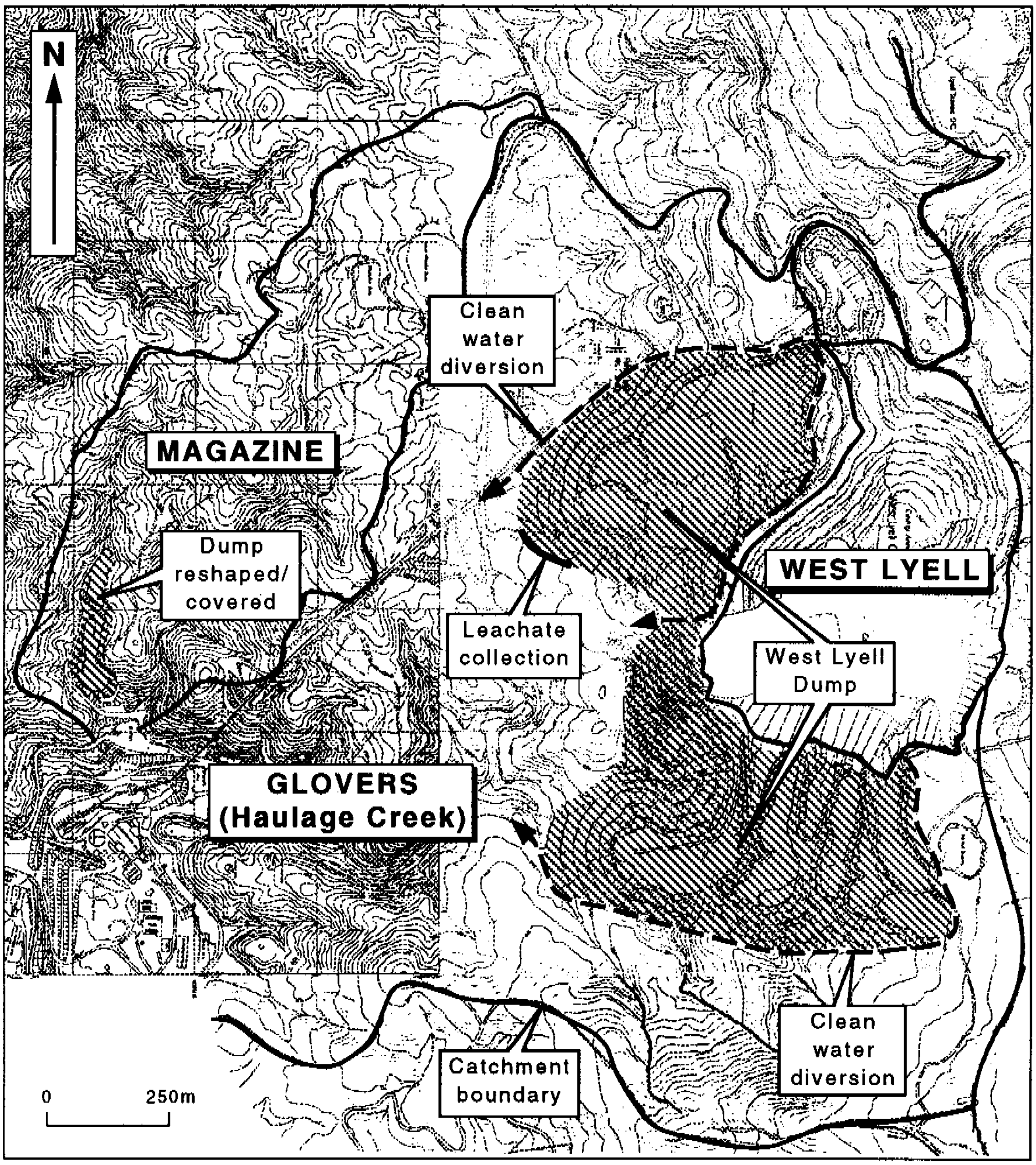


Figure 6.2 Waste rock drainage into Haulage Creek

In dry periods the flows reduce significantly and there will be a converse need to maintain flows to the plant. This may be possible by irrigating the dumps with raffinate. If the dumps were to be successfully irrigated, the average daily copper production could be increased and the plant run at a flow throughput close to the peak design flow, increasing the revenue considerably. This may also be possible with the West Lyell open pit.

However, it is not immediately clear that irrigating with low pH, high ferric iron liquor will speed up solubilisation rates. It is, however, possible that irrigation with liquor containing high concentrations of iron, aluminium and sulphate will lead to deposition of jarosites etc and consequent blocking of pores in the dump. This is a common problem in leach dumps and should be investigated.

Raffinate effluent The SX/EW plant removes copper from solution, with other cations/anions essentially unaffected. It is reported that pH will decrease by approximately 0.1 pH units.

Therefore, additional AD treatment will essentially be the same as for the influent acid drainage stream in chemical constituency and flows. The options to treat the effluent are discussed in the following sections.

(ii) Expected effectiveness and feasibility

After SX/EW treatment total copper loads would be reduced by an estimated 80–88% from the treated AD, but acid loads and other metals would not be decreased.

The reduction of copper loads from Haulage Creek are expected to be in the vicinity of 80% if the mine dewatering and West Lyell waste rock copper sources are recovered. The current CMT design is for the treatment of the mine dewatering flows only, but the plant is capable of being expanded.

Based on ANSTO's estimate for the waste rock dumps, the current loads could be expected to continue for at least twenty years and then decrease by a factor of ten. The loads from mine dewatering and drainage from the West Lyell open cut are expected to continue for a period at least as long. This period would be more than adequate to justify a plant construction.

The control of surface water and the maintenance of high copper concentrations will be critical to plant operations and the feasibility of load recovery.

(iii) Advantages/disadvantages

The SX/EW plant would remove copper from the AD stream, but the effluent (raffinate) would still require treatment if downstream effects are to be reduced. The treatment would consist of the conventional neutralisation/precipitation and would essentially be the same process as the treatment via co-disposal with tailings, or a separate treatment plant as discussed in the following sections.

However, the plant operation would generate sufficient operating revenue to pay for the treatment of the raffinate, with surplus funds to repay capital costs.

The SX/EW plant could operate as long as the effluent streams coming from the dumps and the underground workings have significant metal loads and would be independent of mining operations. The plant would thus provide employment for plant operations for the foreseeable future and provide a long-term revenue source which could fund ongoing treatment of the AD which otherwise would be released untreated.

Ideally the plant would be constructed and integrated with the existing CMT infrastructure and management but could be an independent and separate operation if required to ensure the long-term availability and use.

(iv) Financial analysis

The financial analyses which were undertaken in the feasibility study indicated that the project was cash positive with an estimated capital cost of approximately \$3.2 million, and annual operating costs of approximately \$625 000.

Table 6.2 Financial analysis of SX/EW copper recovery (based on 519 tonnes per year copper production)

	Feasibility study \$M
Annual revenue A\$1.56/lb	1.786
Annual operating cost	0.625
Net annual margin	1.161
Capital costs	3.2
Pay back years	2.75

This financial analysis indicates that the plant could operate with operating revenue exceeding costs by some $1.161 million per annum. Capital investment would be repaid in some 2.75 years. Sensitivity analyses indicate that the project is financially robust. The plant would be susceptible to copper concentration fluctuations (and therefore recoverable copper).

The recovery of copper could potentially fund the treatment of the raffinate with additional revenue sufficient to make it a commercial proposition (see section 6.2.4 for the costs of raffinate treatment).

(v) Additional work required

The construction and operation of a SX/EW plant would be most efficient if it were integrated with the existing CMT operations and discussions with CMT are required regarding the establishment of such a facility (these are current). However, careful consideration should be given to the design and operation of the plant if the maximum environmental benefits are to be gained (ie maximum copper removal), rather than the plant operated to maximise financial returns to the operator. This will require the consideration of additional copper sources suitable for treatment and the treatment of raffinate and other AD sources. The long-term future of the plant should also be considered, as it could potentially operate after mining operations cease. Some financial compensation arrangements may be required. The plant is capable of expansion.

Additional work required includes the following:

- Assessment of AD stream flows and copper concentrations, including seasonal variations and catchment hydrology, diversion requirements and identification of potential copper sources for treatment
- Additional testwork
- A study of the requirements for raffinate treatment
- Environmental assessment of the plant and process, including raffinate, crud and treated AD disposal
- Feasibility of leaching the waste rock dumps and speeding up oxidation processes
- Further feasibility study and design work to finalise capital and operating costs

6.2.3 AD treatment by neutralisation and disposal to storage dam

(i) Description

The simplest and most cost-effective means of treating the major AD loads and/or the raffinate from the SX/EW plant would be by limestone dosing and disposal of sludges to a storage system. This is illustrated in figure 5.5. This is similar to the co-treatment with the tailings stream, and could be carried out with the tailings, with additional neutralisation as required, similar to the method of mine dewatering treatment proposed by CMT. The major loads would be separated from the balance of the site drainage by surface water diversions and treated with the tailings, or with additional neutralisation provided by ground limestone, prior to disposal to the storage dam. This treatment could include all the major AD loads, such as mine dewatering, North Lyell and West Lyell Tunnels, West Lyell waste rock dumps, Magazine Dump and Utah Dump drainage, whether treated by SX/EW or not. It may require the provision of a dam for flood storage. The overflow would flow into receiving streams, depending on the location of the storage.

(ii) Expected effectiveness and feasibility

Total AD loads would be reduced by an estimated 95–98% depending on the efficiency of the treatment. The co-disposal would provide an effective solution to the treatment of the major AD sources.

(iii) Advantages/disadvantages

This is a relatively low cost means of treatment but would require ongoing neutralisation and a storage for disposal. Any co-disposal with the tailings would require the agreement with CMT and the consideration of the effects on the water quality of the tailings storage and water releases to the Princess Creek and may involve additional thickener capacity and discharge pipeline capital and operating costs.

These load reductions would cease at mine closure unless ongoing neutralisation sources were provided.

(iv) Costs/financials

This is probably the most cost-effective solution for AD/raffinate treatment, with possibly additional capital and the additional neutralisation costs the only ongoing costs.

(v) Additional work required

- A study of the neutralisation requirements for raffinate/AD treatment and the feasibility of using limestone
- The co-treatment of the AD would require an agreement with CMT and could involve cost subsidisation
- Assessment of AD stream flows and copper concentrations, including seasonal variations and catchment hydrology and identification of copper sources to be treated and diversion requirements
- Further feasibility study and design work to finalise capital and operating costs

6.2.4 Conventional neutralisation/precipitation treatment of main AD sources

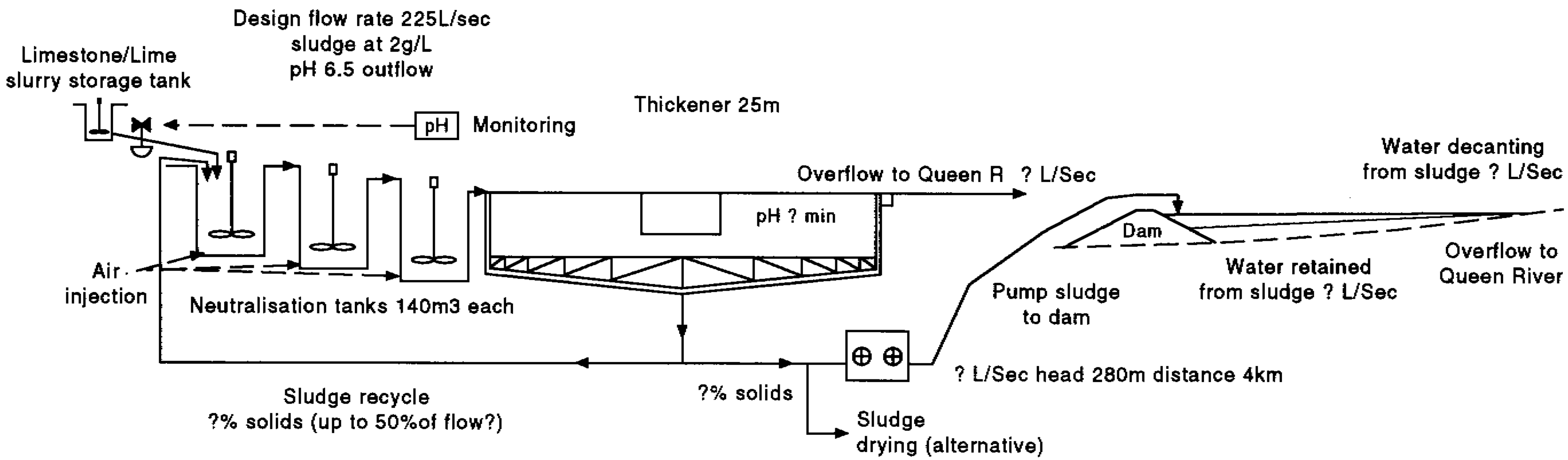
(i) Description

A conventional neutralisation/precipitation chemical treatment plant could be constructed at a location where the contaminated drainage could be collected and diverted via a storage to contain and regulate storm flows prior to treatment, and/or the raffinate from the SX/EW plant. The plant could also treat the other high load sources such as Magazine Creek dump, Utah dump etc). Surface water diversions would be required to separate clean runoff from the contaminated drainage sources.

This treatment option could be separate and independent from CMT operations.

Preliminary design The plant would be sized to treat approximately 225 L/s which could treat the main AD flows in Haulage Creek and consume ground lime at a rate of 50 tonnes per day at these flows, with additional lime to raise the final pH as required. The plant flow sheet is shown in figure 6.3.

Additional work is required to determine the required treatment rate as this will depend on the effectiveness of diversions and the storm storage capacity design. The plant would be designed to operate at a pH range from 5 to 6.5 (to be determined by trials). Sludge solids generation would be approximately 2 g/L.



High Density Sludge Process

Figure 6.3 Flow chart of neutralisation/precipitation treatment plant

Equipment Equipment requirements to treat up to 225 L/s of mine water would require the following:

- mine water collection and transfer
- water storage to cope with inflow variations
- limestone/lime storage and transfer equipment
- neutralising and precipitation tanks
- flocculant preparation and dosing equipment
- thickener
- sludge disposal

It is assumed that mine water would gravitate from the Haulage Creek catchment portal area to an approximately 10 to 20 million litre dam which would cope with storm surges.

AD would be pumped to the treatment plant so that the balance of the treatment could be gravity fed.

The treatment plant would consist of:

- limestone/lime preparation storage and transfer equipment
- neutralising tanks
- thickener, flocculant dosing
- sludge disposal

The plant would be PLC controlled with pH control of ground limestone/lime and flocculant addition. The limestone would be ground by a ball mill and stored in a tank as a slurry. An additional facility would be provided for lime storage and feed.

The AD would be directed to a series of three neutralisation tanks, mechanically agitated with air injection. These would allow for 30 minutes retention/reaction time and feed to a thickener. The thickener would consist of a 23 m diameter high rate design with provision for underflow recycling to the neutralisation tanks. This would be equipped with flocculant addition.

Overflow consisting of clarified water would be released to the Queen River. The underflow sludge would be pumped to an area for settling and decanting of surface water or to a filter press for solids separation.

Both lime and limestone have been considered for neutralisation as lime is expensive. Limestone could be quarried from a CMT quarry at Lynchford by agreement.

(ii) Expected effectiveness and feasibility

The technology is well proven and understood.

It is estimated that with the treatment plant, that total copper loads in the effluent could be reduced by approximately 98%. Aluminium, zinc and iron loads would be reduced by similar amounts, with manganese and sulphate less affected. Total metal and acidity loads would be reduced by an estimated 98% for all waters treated. Sulphates would be reduced to about 2000 mg/L.

(iii) Advantages/disadvantages

The operation of a constructed water treatment plant would achieve the removal of the majority of the high AD loads. It could be operated entirely separately from the CMT operations and would guarantee the ongoing removal of the major AD loads. The disadvantages are the capital and operating costs which would be ongoing, and sludge disposal. However, if the plant was operated in conjunction with the SX/EW plant, the revenue for this would pay for both capital and operating costs, as set out below.

(iv) Costs/financials

Capital and operating costs have been estimated by MINPROC based on the flow sheet design and a technical review.

The total capital cost of the plant (including design and construction) is $2.8 million, plus or minus 30%. The effect of reduced flows is expected to be small (ie 50% reduction in flow would result in an approximate 20% reduction in capital costs). An additional cost will be required for AD collection and storage which requires engineering (an allowance of $200 000 has been made). The capital costs include a filter press and sludge disposal on site.

Operating costs are estimated at $450 000 per annum and based on the utilisation of limestone, with some lime addition.

A summary of the financial aspects of a combined SX/EW plant and raffinate treatment is made in table 6.3. This is based on the SX/EW study results and does not take into account the additional copper loads from treatment of the West Lyell waste rock dumps. It indicates that even with the high capital cost of the neutralisation plant and the operating costs, the SX/EW is still cash positive and financially attractive.

Table 6.3 SX/EW and water treatment plant operation financial analysis

	Cost $M
SX/EW Net annual margin	1.161
WTP operation costs	0.45
Net annual margin	0.71
Capital costs SX/EW	3.2
Capital costs TP	3.0
Pay back years	8.8

(v) Additional work required

- Laboratory and pilot trials are required to determine neutralisation requirements and plant design
- Assessment of AD stream flows and copper concentrations, including seasonal variations and catchment hydrology and identification of copper sources to be treated and diversion requirements
- Further feasibility study and design work to finalise capital and operating costs

6.2.5 Covering of waste rock dumps

(i) Description

The covering of the waste rock dumps with a clay (dry) cover is an option for reducing the loads from the waste rock dumps. However, these waste rock dumps are all low grade ore, especially the dumps which are the main AD loads (West Lyell dumps and Utah dumps) and must be regarded as a possible resource. The copper loads in solution may be recovered by SX/EW recovery and the dumps may be leached to speed up the oxidation process and copper removal. They may also be mined and processed if an open pit is developed on the site. Therefore, the covering of both the West Lyell waste rock dumps may be considered in the short term, but are a long-term option. Due to the very steep side slopes of the dumps, they would need to be dozed down to much flatter angles of, say, 17.5° to 22° before a stable cover could be placed. This may also impinge on the surface workings and access routes on the mine.

However, the covering of the smaller dumps such as the Magazine Creek dump and the Utah dumps can be considered.

Dump geometry at Mount Lyell The two main dumps, the West Lyell dump and the Utah dump, cover an area of about 700 000 m^2 (refer fig 5.3). Due to the steep terrain over which they have been built, the flat top surfaces are only about 25% of this area—the balance being the dump side slopes. The dumps vary in height across the terrain up to 90 m high, and they have a series of top terraces that vary in height from 2 m to 16 m. The slope angles of the dump faces vary, but generally appear to be at the angle of repose of the rock, that is between 33^0 and 38^0, while some of the terraces have slopes flattened to angles as low as 11^0.

A thin silt layer (retrieved from the banks of the King River prior to the flooding of Lake Burbury) has been placed on the lower bench of the Utah dumps and the surface revegetated, mainly with *Acacia* species. The Utah dumps extend into both the Browns Creek and the White Creek catchments.

The other dumps include the two small dumps in Magazine Creek, Crown Lyell dumps in the East Queen Catchment and two recently identified dumps in the East Queen catchment.

Covering rock dumps without major reshaping If the major waste rock dumps could be covered without major reshaping a substantial cost saving would result. The dumps' top surfaces would probably require an approximately 1 m thick compacted soil layer covering and the slope faces would have to be covered with a geomembrane, probably a 1.5 mm HDPE.

However, before these covers are placed, certain preparatory works need to be undertaken:

- Surface regrading. The top surfaces of the dumps would need to be dozed and regraded to ensure that rain water does not pond on the surface, but is encouraged to run off the surface in a controlled manner. This may be by either sloping the surface down towards the uphill side of the dumps and collecting the runoff in prepared trenches (which would also help to collect and divert uphill runoff) or by grading the surface to allow the runoff to run over the edges and down the face of the dumps.

- Dump toe preparation. Some work will be required at the toe of the dumps to remove large rocks, and possibly the infilling of very coarse rock regions with finer materials, prior to the placing of the geomembrane.

- Runoff interception and control. Runoff interception trenches would need to be dug to prevent clean uphill runoff from entering the dumps. Separate dump surface and slope runoff trenches may also be needed. It may be necessary to line or armour some sections of these trenches.

Reshaping and covering rock dumps It is likely that investigations would determine that a geomembrane on the natural dump slopes will not perform the cover role adequately for the time period required, or that it will be too difficult to install on these very high dumps. Therefore it is likely that the dump slopes would have to be flattened to about 20^0. This would allow the mechanical placing and compaction of soil cover layers, or the easy installation of a geomembrane. This slope flattening work would be in addition to the surface reprofiling and runoff drainage listed above. Figure 6.4 shows a design for the Utah dumps reshaping and covering.

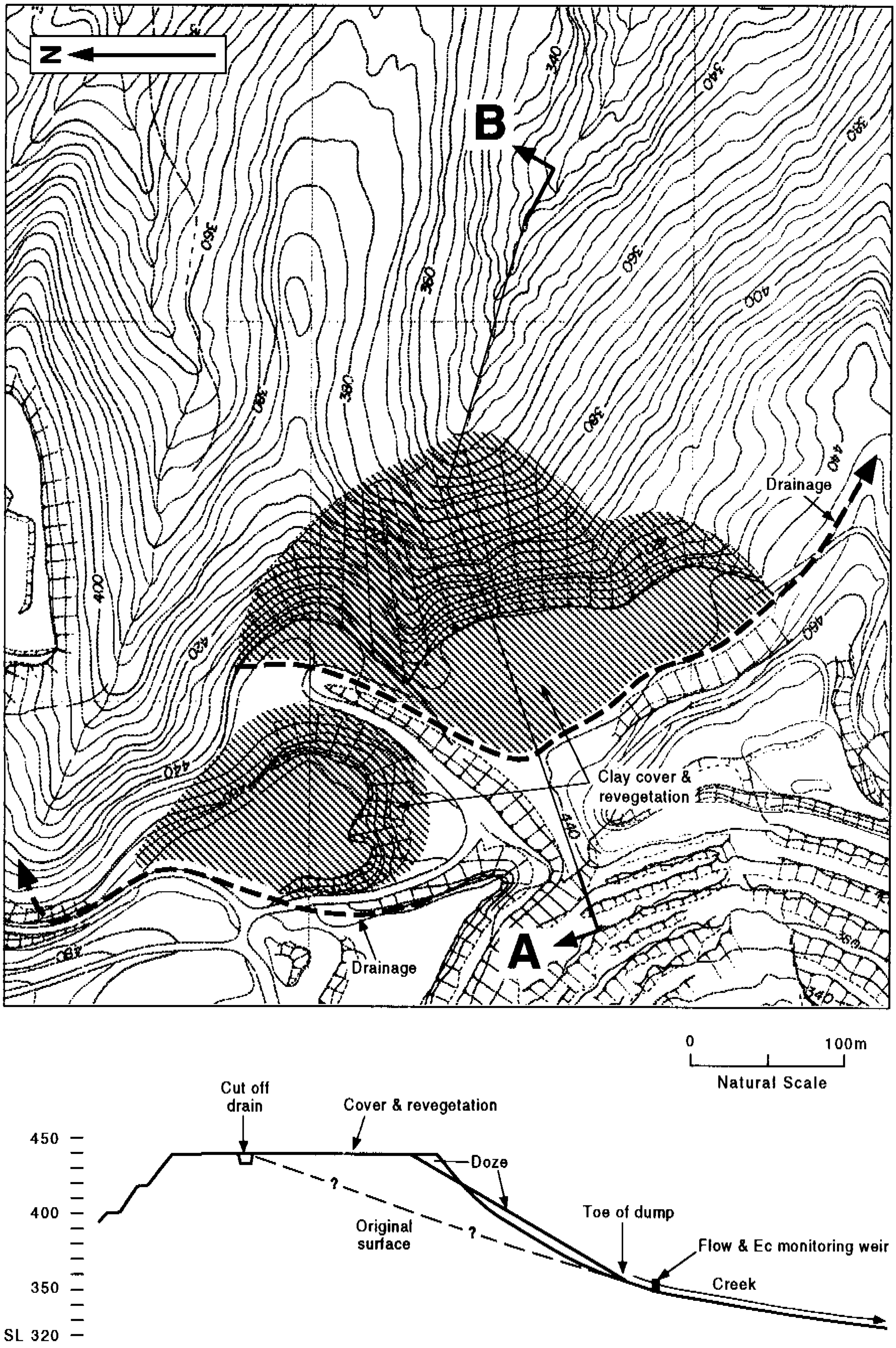


Figure 6.4 Design for reshaping and covering of the Utah dumps

The cost of covering the dumps with compacted soil layers, on the tops and slopes after regrading, is based on the assumption that sufficient suitable soils are available on the mine site.

If sufficient soils were not available, then a geomembrane would have to be used on the slopes.

Reshaping and covering Magazine Creek waste rock dump As a trial, the reshaping and covering of the small dumps in Magazine Creek catchment has been considered. The reshaping is shown in figure 6.5. The relocation and covering of the two dumps in the East Queen catchment can also be considered.

(ii) Expected effectiveness and feasibility

The major dumps (West Lyell) are being considered by CMT for remining as part of a future open pit operation. The covering of the West Lyell dumps cannot therefore be considered further until their future is decided.

Designing a cover to reduce water flux and withstand erosion is standard engineering practice. Although the indications are that such covers will remain stable for periods of longer than say 20 years, direct evidence is lacking and revegetation to stabilise the surface and long-term maintenance will be required. Such a cover would also be effective in greatly reducing advective flux of oxygen into a dump of sulphitic material.

The need to design a cover to reduce the diffusive oxygen flux is a newer requirement with the result that expertise and design tools are less common but do exist in Australia. In general such a cover would also reduce the water flux and advective oxygen flux. Application of a layered soil cover would require investigations of the quantity of suitable soil at or close to the mine site, measurements of the hydraulic properties of this material under unsaturated conditions and modelling of the layered system to ensure it meets the design criteria. It is expected that these investigations will be iterative to some extent.

Data on the effectiveness of cover systems in reducing AD are sparse. In many instances conclusions are based on speculation rather than well designed measurement programs. A contributing factor is the long timescale associated with pollutant generation and transport in sulphidic waste rock dumps. However, there are recent data on such regrading and covering of waste rock dumps at Equity Silver in British Columbia which indicate that such covers are effective in reducing AD loads as well as the success of the Utah dump works. These studies indicate that the cover maintained a high degree of saturation, oxygen flux rates have decreased by 98% and infiltration was 4% of precipitation. Indications are that the Equity dumps will take up to 15 years to drain.

The effectiveness of a cover over the waste rock dumps is calculated to vary from a 20 to 80% reduction in loads.

(iii) Advantages/disadvantages

As discussed above, the covering of waste rock dumps will conflict with the need to maximise copper loads for recovery by SX/EW and also the possible leaching to speed up the process.

There are also conflicting opinions on the effectiveness of covering dumps and the estimated reduction of loads and therefore the construction of a trial on the Magazine Creek waste rock dump is proposed with a measurement program to determine pollutant loads in drainage and the effectiveness of the cover. Covering of other dumps such as Utah can then be considered if the trials are successful.

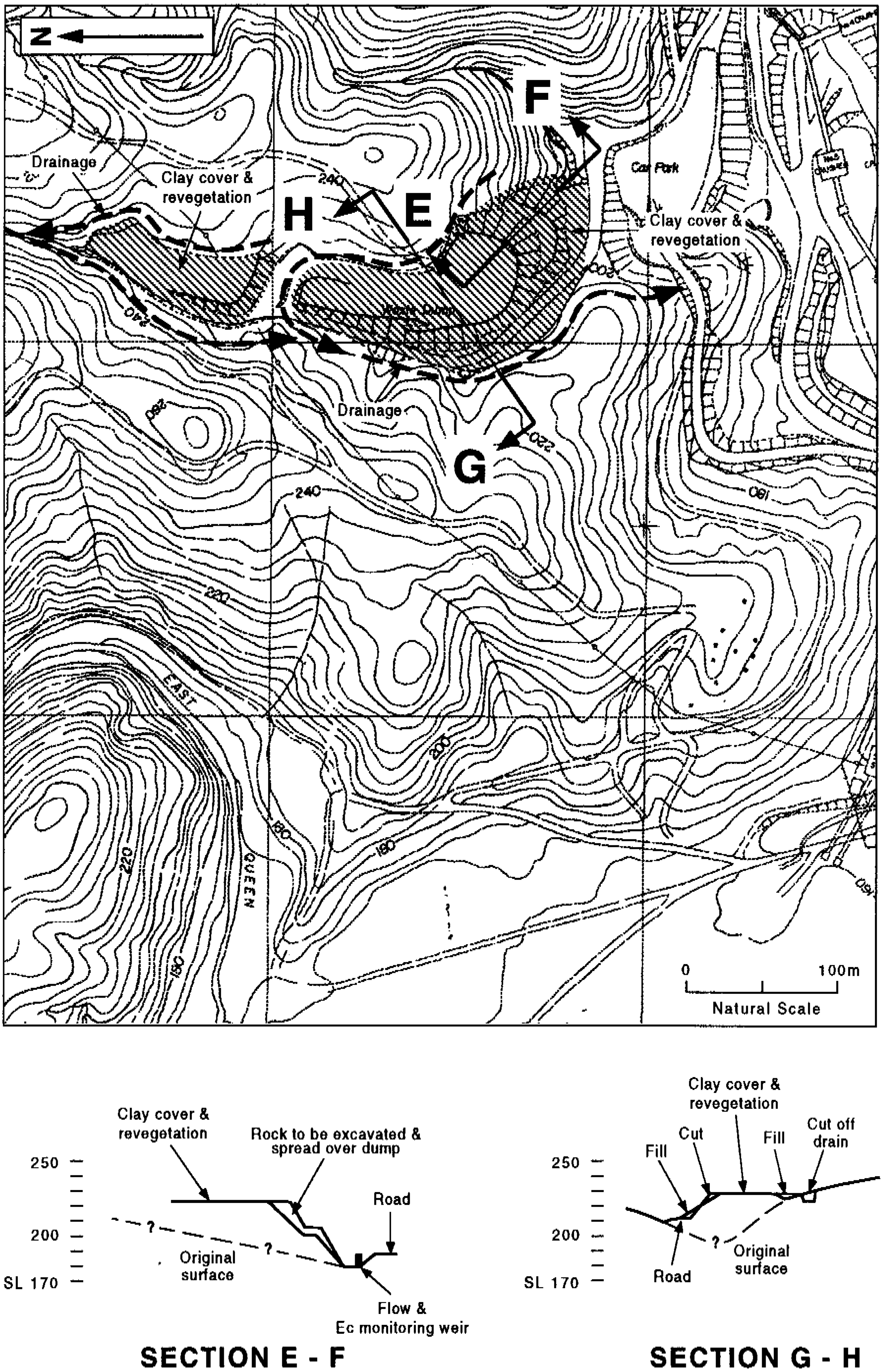


Figure 6.5 Design for reshaping the Magazine Creek waste rock dump

(iv) Costs/financials

Costs of covering the dumps are set out in table 6.4.

Table 6.4 Waste rock dump covering costs

Options	Cost ($M)
Covering without reshaping	8.5
Covering with clay	13.0
Clay top surface, HDPE slopes	19.5

The costs of the trial covering of Magazine dump is estimated at approximately $200 000.

(v) Additional work required

- Assessment of how best to increase the overall oxidation rate in the West and Utah dumps with a view to increasing copper tenors in drainage water in the short term and reducing pollutant loads in the longer term
- Source and engineering properties of clay cover materials for a magazine dump cover
- Engineering design
- Installation of flow and water quality monitoring equipment
- Assessment of results and cover design for other dumps

6.2.6 Water management (flooding of old workings, water diversions)

(i) Description

Water management options could include the flooding of old workings to stop oxidation of sulphides and the diversion of both surface and groundwaters to reduce loads. There are a number of possible diversions which could be implemented in conjunction with other remediation (mainly treatment) options.

The activities which could be considered are:

- Diversion of upslope surface waters from around both of the West Lyell waste rock dumps. This would allow the separation of the clean waters and AD and allow collection for SX/EW copper extraction and/or neutralisation treatment.
- Diversion of Comstock 5 and Comstock open cut waters to a passive treatment system (successive alkalinity producing system (SAPS), or with alkalinity generated by ALDs). The treatment is discussed in the following sections.
- The blocking of the Comstock 7 Adit to at least partially flood the workings, reduce loads and redirect the drainage at a higher level (probably from the Tasman shaft) so it could be collected and treated with a passive system. The MLMRCL investigated sealing at the portal, but additional investigation is required to see if the Adit can be sealed closer to the mine area as the flows are large and the cost of treatment high. If this is not feasible, an alternative is the collection and diversion of the drainage to another downslope location where there is sufficient room to treat the drainage.
- The removal of the Crown Lyell diversion dam and either the release into Idaho Creek for downstream alkaline treatment, or the piping and passive treatment downstream at suitable location. The reason for this action would be to remove relatively clean surface waters from the North Lyell Tunnel drainages so that concentrate sources could be treated in the SX/EW plant.

- Collection in a toe storage dam and the diversion (pumping, or drill hole) of the Utah dump drainage to the Haulage Creek catchment. Additional surface drainage control should be investigated to reduce clean water infiltration. This would allow for the copper recovery for SX/EW, or to treatment by neutralisation. This would remove the major AD source in the Linda catchment.
- Additional grouting to block the Tharsis Adit, or direct piping to SX/EW/ AD treatment.
- Diversion of Cape Horn drainage from underground workings and to a passive treatment system. This would reduce relatively clean water flows to the North Lyell Tunnel, so that copper recovery could be undertaken.
- Surface water diversions around other existing waste rock dumps, such as Magazine Creek dump and the East Queen dumps, in conjunction with covering and removal.

(ii) Expected effectiveness and feasibility

Except for flooding of old workings (Comstock 7), the diversions will only achieve a transfer of AD loads so that they can be treated and the effectiveness has to be assessed with the treatment options. However, implementation would result in an improvement to the East Queen and Linda catchments. The feasibility of blocking Adit 7 needs to be assessed, but the high flows and cost of passive treatment warrant a substantial expenditure. Similarly, the removal of Tharsis and Utah dump drainage will remove the major sources from Linda Creek (62%) and also make available the copper loads for recovery.

(iii) Advantages/disadvantages

The diversions will allow for the relocation and redirection of contamination sources, but not the reduction of loads, except for Adit 7.

(iv) Costs/financials

The cost of the flooding and diversions can only be approximately costed without a detail investigation and design.

West Lyell diversions $5000 – $100 000

Comstock 5 diversion $2000

Comstock 7 blocking $25 000 – $100 000

Crown Lyell diversion $5000 – $15 000

Utah dump drainage redirection $5000 – $50 000

Tharsis Adit grouting/redirection $5000 – $25 000

Cape Horn surface diversion $5000 – $10 000

Other surface diversions $2000 – $20 000

(v) Additional work required

- Further investigations to assess feasibility and costs
- Detailed engineering design

6.2.7 Successive alkalinity producing systems (SAPS) passive treatment of point sources

(i) Description

Successive alkalinity producing systems have been identified as the most applicable technology for the treatment of low load/low flow point sources. A number of point sources have been identified which are suitable for passive treatment. These are sources with low flows and generally low acidities, as it is not feasible to treat high acidities and high flows by passive treatment. The sources which are considered suitable are:

- Tharsis Adit
- Comstock 5
- Comstock 7
- other low flow/acidity sources (these could include the Crown Lyell diversion, Cape Horn drainage, Crown Lyell drainage etc)

The water quality from these sources generally precludes the direct treatment by anoxic limestone drains, and the only feasible direct treatment is by successive alkalinity producing systems (SAPS).

As discussed in section 5.3.3, SAPS combine both ALD and anaerobic compost wetlands technology. Treatment effectiveness within a passive treatment system is inherently based on the residence time of the drainage within the system. The SAPS would consist of a series of alkalinity producing and settlement components to progressively add alkalinity to the waters, raise the pH, remove metals from solution and precipitate as sediments. Figure 6.6 shows an illustrative plan of a SAPS. This system may be simplified after trials.

Preliminary designs have been prepared for the full scale treatment of Tharsis, Comstock 5 and Comstock 7 drainages and the details are shown in table 6.5. These designs are based on a 20 year design life. To demonstrate the effectiveness, a trial is proposed on portion of the Tharsis Adit drainage (or possibly Comstock 5), with full scale treatment after assessment of the trial.

Table 6.5 Passive treatment areas using SAPS

Source	Flow rate (L/s)	Surface area (ha)
Tharsis Adit	1.5	1
Comstock 5 Adit	2	1.2
Comstock 7 Adit	8	4.4

The treatment is sequential: pH adjustment and subsequent aluminium removal are the predecessor steps of treatment, followed by removal of iron as an oxyhydroxide. The solubility products of copper and zinc dictate that copper sulphides will form prior to zinc sulphides, completing the sequential aspect of treatment for this discharge. Manganese treatment would be by pH adjustment and further oxidation.

The first component would upwardly adjust the pH of the flow, generate alkalinity, remove aluminium, and convert the Fe^{3+} component to Fe^{2+} for later oxidation and precipitation. Aluminium removal from mine drainage is a pH dependent function—independent of dissolved oxygen concentrations. Aluminium is therefore necessarily the first contaminant removed in any passive treatment system effectively raising pH values to greater than pH 4.5. Alkalinity generation and concurrent increases in pH values produced through both limestone dissolution and sulphate reduction within passive treatment systems have proven effective in removing aluminium from acidic drainage. Though there are concerns with the physical plugging and potential failure of aluminium treatment components, particularly within anoxic limestone drains (ALDs), the accumulation of aluminium precipitate is an engineering, or operation and maintenance concern, rather than a treatment shortcoming. Successful aluminium treatment components must, however, incorporate features to accumulate aluminium while preventing flow restrictions.

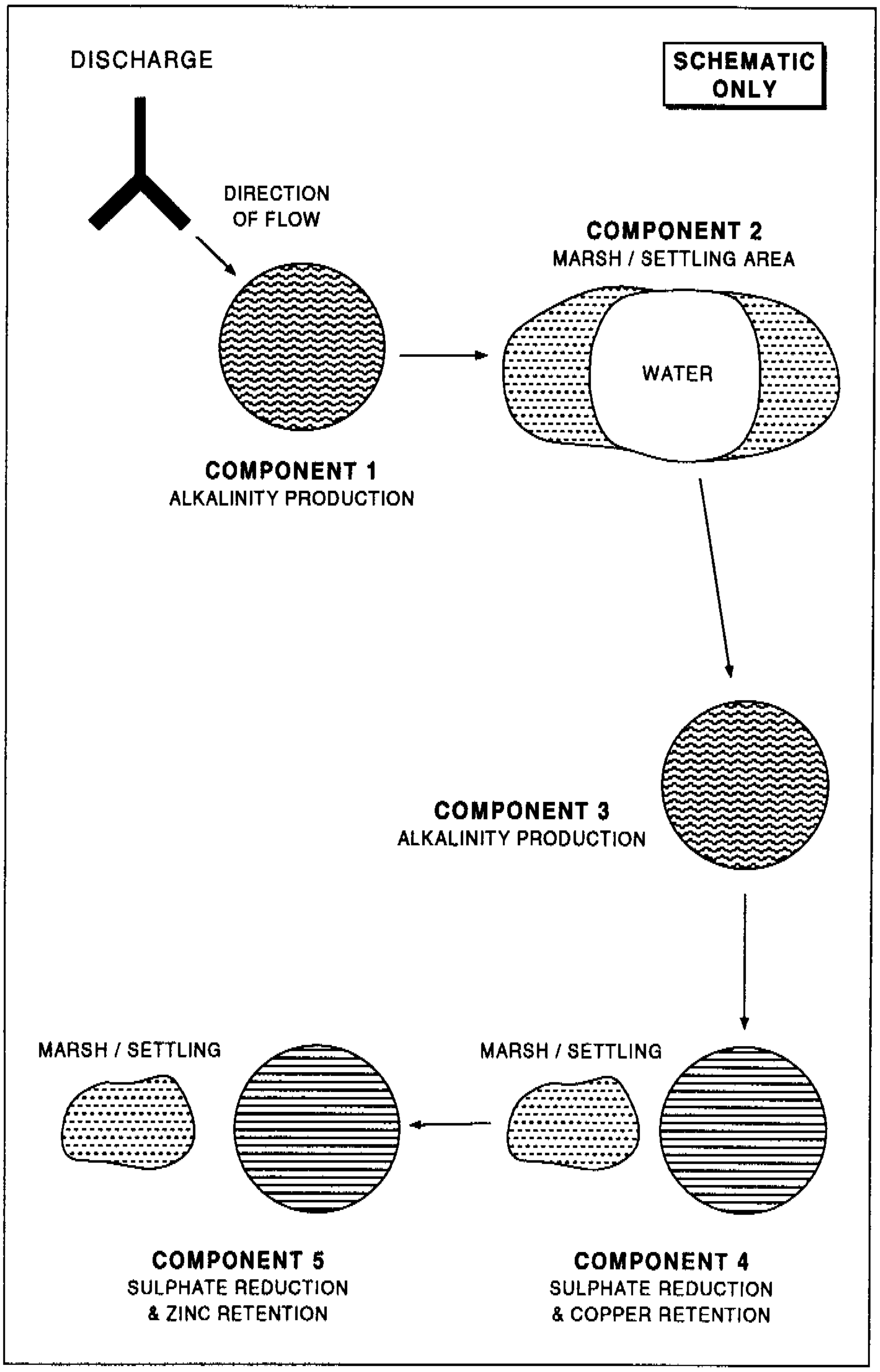


Figure 6.6 Plan of a SAPS

Damariscotta (the US consultants providing design advice on the use of SAPS) has developed and implemented an aluminium treatment design that has proven effective in meeting both the goals of actual treatment and the needs of physical integrity. Figure 6.7 shows a section through the aluminium component with layers of compost and limestone.

The compost layer in the SAPS plays several key roles; assuring that the discharge will be anoxic upon entering the limestone treatment component, altering the redox state of the iron load, and acting as a potential metal sink for sulphide precipitates. The limestone layer provides alkalinity and additional pH adjustment and is the design area for aluminium accumulation. The perforated piping system is designed to further maximise uniformity of treatment across the entire treatment system and to maintain a positive flow as aluminium is accumulated.

A large component (approximately 50% for Tharsis) of the total acidity load of the sources can be attributed to the aluminium component of the flow, and successful aluminium treatment alone will have a profound effect on the quality of the final effluent. It is anticipated that at least 80% of the aluminium load will be retained within the first treatment unit, with the remaining portion being passed through an open water settling basin. The purpose of the settling basin is to retain the remaining aluminium and a portion of iron concomitant with the alkalinity generated in the initial treatment component. The marsh portions of this component play a significant role in mineral adsorption and more importantly, flow dispersion, leading to a more effective treatment than realised with open water ponds alone. Some co-precipitation of other metals may occur here.

The next component plays two roles, one being a fail safe for ameliorating the impacts of the entire aluminium and iron complements of the discharge. The second role is to assure that circumneutral pH conditions exist which will aid in the sulphate reduction processes designed to target treatment of the metals of copper and zinc as sulphides. The final components provide for the copper and zinc treatment units. Sulphate reduction will be the key treatment mechanism here, and both copper and zinc have been successfully removed from mine drainage as sulphides under various treatment scenarios.

(ii) Expected effectiveness and feasibility

It is expected that the SAPS will remove at least 99% of all metals except manganese. The treatment systems require relatively large surface areas and ponds and as such cannot be feasibly constructed at Tharsis, or Comstock 7, because of the lack of suitable area and ground conditions. These drainages will need to be relocated if they are to be treated. Adit 5 drainage could readily be directed to suitable areas and treated. A simplified system could be trialled to add alkalinity to contaminated drainages (eg Cape Horn area).

(iii) Advantages/disadvantages

SAPS are passive treatment systems and if successful will provide a long-term solution (20+ years) to point source drainages. SAPS have been proven to be effective on a number of acid drainage sources in the eastern United States, however, their performance on metal mine AD is yet to be proven. However, they are the passive treatment system which has the most potential and their application, initially with a trial, is recommended.

If successful they would result in a long-term improvement to the East Queen, Comstock and Linda Creek catchments when applied to AD sources.

(iv) Costs/financials

The construction of the SAPS is high capital but low operating cost. They are expected to be effective for a period of 20 years or so and represent a long-term solution. The estimated cost is set out in table 6.6.

Table 6.6 Passive treatment costs using SAPS

Source	Cost ($)
Tharsis Adit	80 000–160 000
Comstock 5 Adit	85 000–190 000
Comstock 7 Adit	300 000–750 000

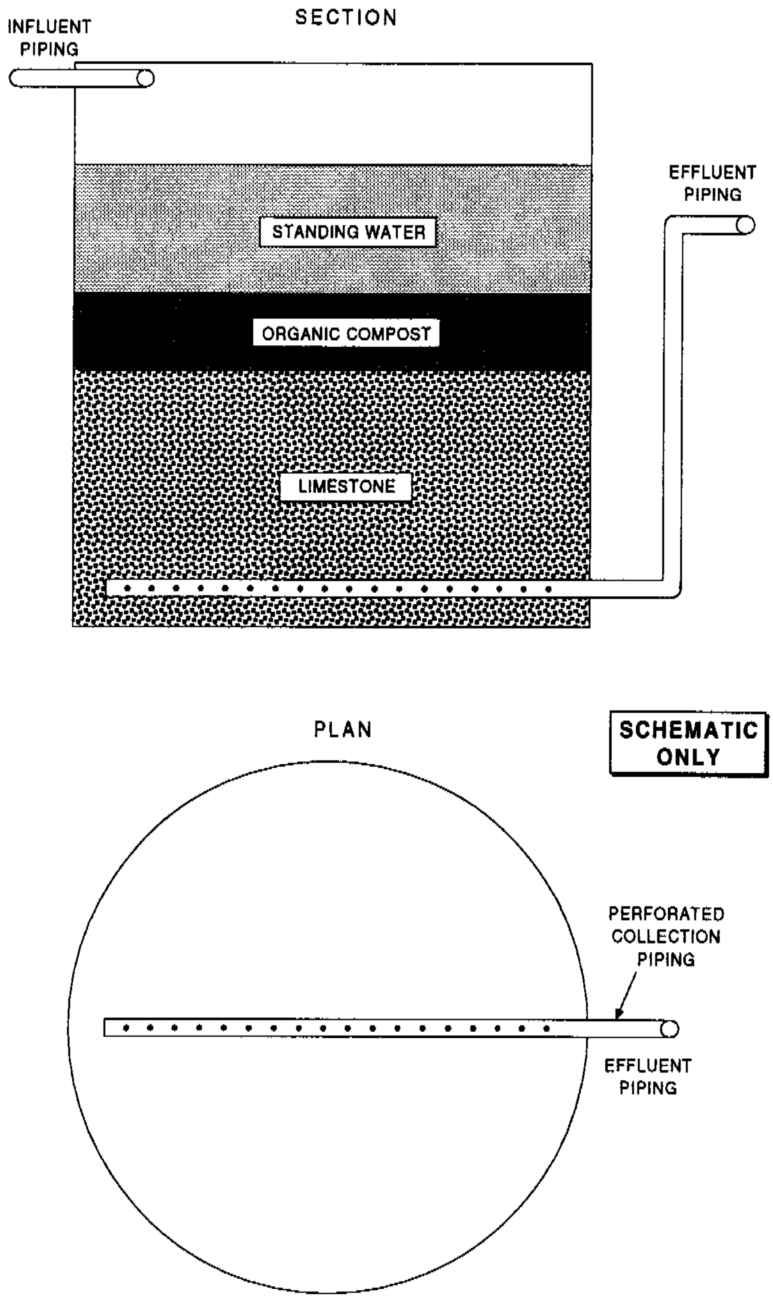


Figure 6.7 Section through the aluminium component of a SAPS

(v) Additional work required

- Trial construction and monitoring of effectiveness
- Simplified trial low cost system at Cape Horn drainage
- Construction of full scale system after assessment and design

6.2.8 ALD alkalinity addition to Linda, Idaho and Comstock catchments

(i) Description

Many of the miscellaneous AD sources in all of the catchments, though individually of low loads and flows, all impact on the water quality of the receiving waters because of their lack of alkalinity and ability to buffer AD inputs.

Though it is not practical or feasible to treat all of these sources, and there is a lack of space due to the topography, the use of anoxic limestone drains to recharge the catchments with alkalinity and thereby buffer the AD within the catchment drainage system is an option worth consideration. Because of the point source water quality, ALDs cannot be used directly. The raising of the pH would allow for the collection of the precipitates within the stream system or cost-effective and readily constructed aerobic wetlands downslope in areas where the topography would allow their construction.

In this system, a series of ALDs would be constructed which were sufficient to recharge the catchment with sufficient alkalinity to buffer the AD sources. These ALDs would be constructed in the East Queen, Comstock and Linda catchments. Table 6.7 shows the acidity loads within these catchments and the required size of ALDs based on tonnes of limestone required to generate the desired alkalinity. These estimates are based on the US Bureau of Mines figures which are based on ALDs generating approximately 200 mg/L of alkalinity. There are reservations regarding the ability to achieve this alkalinity and this would need to be confirmed with the limestone sourced locally and the chemistry of the waters.

Table 6.7 Acidity loads from the East Queen, Comstock and Linda catchments and the required size of ALDs to generate desired alkalinity

Catchments	Acidity loads (kg/d)	ALD size (tonnes)
East Queen catchment	710	13 000
Comstock catchment	156	3 000
Linda catchment	726	13 000

(ii) Expected effectiveness and feasibility

The ALDs would raise the pH and allow for the precipitation of metals in the sediment of the stream and/or within downstream wetlands as particulates. The reduction in loads are difficult to estimate without trials, but if the receiving water pH can be raised to approximately pH 5 to 6, most of the aluminium, iron, copper and perhaps Zn would be removed from solution, with a marked improvement in the receiving water quality. The ability of the ALD to generate the required level of alkalinity would need to be demonstrated by trials prior to full scale construction.

(iii) Advantages/disadvantages

The alkaline recharge would result in a substantial improvement in water quality and an improvement in the aquatic receiving environment. The ability of the ALDs to generate the required level of alkalinity has not been demonstrated.

(iv) Costs/financials

The costs of alkalinity addition by ALDs constructed in the relative catchments are shown in table 6.8. This assumes that alkalinity can be generated at the required rate and a 20 year design life.

Table 6.8 Alkalinity costs using ALDs

Source	Cost ($)
Idaho Creek above Linda Creek	150 000
Linda Creek above White Creek	300 000
Linda Creek above Lake Burbury	300 000
East Queen above Haulage Creek	300 000
Comstock above Lake Burbury	60 000

NB after diversions, 20 yr design life

(v) Additional work required

- Trial ALD construction in Idaho Creek catchment
- Construction of full scale ALD after design

6.2.9 In-stream acid neutralisation and alkalinity generation by limestone addition

(i) Description

This would consist of the addition of limestone to catchment streams to generate alkalinity, raise the pH and precipitate metals within the stream system, as an alternative to ALDs. Limestone could be added in crushed form, as sand or by dosing as ground material with proprietary dosing equipment.

Limestone added as crushed rock would be added to the stream bed and the stream allowed to flow over it. It could be expected that the limestone would be coated and armoured with precipitates and its effectiveness would be reduced over time, however, sufficient alkalinity may continue to be generated, particularly in steep turbulent flow areas.

The addition of limestone sand has recently been trialled in the eastern United States. Because of the small particle size, armouring is believed to be less of a problem and the sand is agitated and transported under high flow conditions downstream. Sand would be added annually.

Dosing with fine ground limestone (similar to the AD treatment plant) could be achieved by purpose built equipment. The Swedish designed and built Boxholm Lime Doser is powered by running water and can contain up to 60 tonnes of lime/limestone. It has a dispensing mechanism which maintains the required dosing flow (see fig 6.8).

Aerobic wetlands could be constructed downstream to collect precipitated metals or they would precipitate onto the stream sediments.

(ii) Expected effectiveness and feasibility

The addition of sufficient alkalinity by limestone addition should raise the pH and allow for the precipitation of metals in the sediment of the stream and/or within the wetlands as particulates. The reduction in loads is difficult to estimate without trials, but if the receiving water pH can be raised to approximately pH 5 to 6, most of the aluminium, iron, copper and perhaps Zinc would be removed from solution. The limestone could be added quite easily at constructed access points.

(iii) Advantages/disadvantages

The process is relatively simple with a nearby limestone source located at the Lynchford Quarry (CMT lease). The armouring of crushed limestone could be expected to reduce effectiveness. Periodic additions of limestone sand and ground limestone would be required, probably annually.

(iv) Costs/financials

Cost are expected to be in the vicinity of \$10 to \$20 per tonne for crushed and ground limestone. The capital cost of the Boxholm doser is approximately \$80 000. Costs are based on expected effectiveness and are after the diversions.

(v) Additional work required

- Trial application and monitoring of effectiveness
- Construction of full scale system after assessment and design

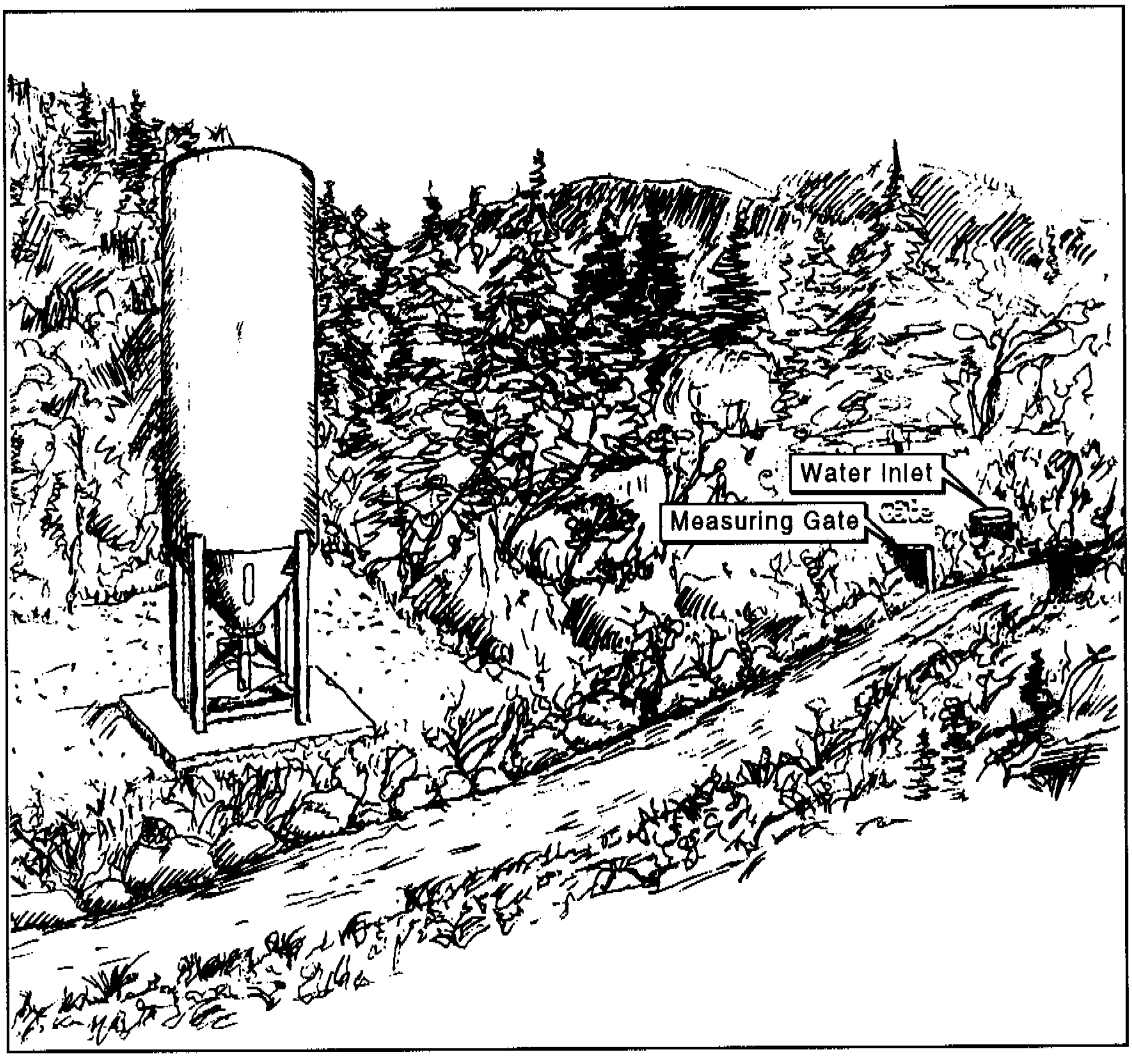


Figure 6.8 Arrangement of Boxholm Lime Doser (source BOXHOLMKALKAREN AB)

Table 6.9 Alkalinity costs using limestone addition

Source	Cost (annual) $
Idaho Creek above Linda Creek	25 000
Linda Creek above White Creek	20 000
Linda Creek above Lake Burbury	20 000
East Queen above Haulage Creek	20 000

6.2.10 Offsite disposal

(i) Description

The major effluent streams could be collected and directed to a storage dam prior to a pipeline which would be constructed to discharge at a location off Ocean Beach via an ocean outfall and diffuser.

As is unlikely that a pipeline to cater for the extreme rainstorm condition could be constructed, clean waters would need to be diverted or the dam would need to be designed with an adequate spillway and discharge to the Queen River.

The pipeline to the sea would be about 40 km long, have a fall of about 200 m, and will need to cater for a peak storm flow of about 240 L/s.

There is a suitable route for the pipeline as far as Strahan along the alignment of the old Abt railway line. Although bridges are missing, suitable pipe bridges can be built at a reasonable cost. A route through Strahan and on to the coast would have to be surveyed and approved.

The outlet of the pipe would be a purpose designed ocean outfall, probably taken 200 to 300 m beyond the surf line. The outlet would need to be designed to diffuse the effluent quickly and completely in the surrounding sea to reduce the concentrations.

A 450 mm diameter pipe flowing at 1.7 m/s would meet the flow requirement.

A moderate duty *BLACKBRUTE* HDPE pipe would be suitable.

(ii) Expected effectiveness and feasibility

The pipeline would be effective in removing the AD loads from the Queen and King River system, depending on the size of pipe and any storm flow diversions required.

(iii) Advantages /disadvantages

The pipeline solution would be cost effective in that after the initial capital costs, operating costs are expected to be minimal and this is likely to be the most cost-effective remediation measure for the lease.

The disadvantages are that the AD would be discharged untreated to the marine environment with potential for contamination of ocean waters and effects on marine habitats. These environmental effects would need to be determined. However, the ocean waters would have significantly greater capacity to assimilate the AD loads compared with Macquarie Harbour. A diffuser would be required to ensure there was sufficient dilution if receiving water objectives were to be met. Some pretreatment may be needed.

(iv) Costs/financials

The cost of supplying and installing the pipeline to the sea would be about $7 million. There would be minimal ongoing operating and maintenance costs.

6.3 Site specific remediation options

The remediation options are further discussed in this section, with a recommended work plan should the option be considered further. Figure 6.9 illustrates the possible works and table 6.10 is a summary table.

Table 6.10 Summary of potential remediation works

Location	Treatment	
Mine dewatering	SX/EW	AD neut/pptation
West Lyell Waste Rock	Drainage diversion Collection SX/EW	AD neut/pptation
North Lyell Tunnel	Collection	AD neut/pptation
West Lyell Tunnel	Collection	AD neut/pptation
Magazine Creek dumps	Regrade cover drainage collection	AD neut/pptation
Utah waste rock	Drainage diversion Collection SX/EW	AD neut/pptation
Linda and Idaho Creeks		Alkalinity addition
Crown Lyell area	Collection	SAPS
Comstock 5 Adit open cut area	Collection	SAPS
Comstock 7 Adit	Block, flood	SAPS
Cape Horn open cut	Collection	SAPS
East Queen River		Alkalinity addition

6.3.1 Haulage Creek catchment

(i) Current load

The Haulage Creek catchment contains the majority of the AD loads into the Queen River and from the lease (99.3% and 98.7% respectively).

These sources are:

- underground mine dewatering
- West Lyell waste rock dumps
- North Lyell Tunnel
- West Lyell Tunnel
- Magazine Creek dump

(ii) Remediation works

Mine dewatering Pumping from underground comprises between 68 to 79% of the total copper loads on the lease (1121–1998 kg/d). There is considerable variation in water quality and flows which makes load estimates uncertain. Some of this water is to be treated by CMT by co-treating with tailings and mud flows removed from underground.

Recommended work plan

Ongoing water and flow monitoring is required to quantify loads

The high copper concentrations and loads make the drainage suitable for copper recovery by SX/EW and the feasibility of recovery should be determined (in conjunction with CMT). The treatment of the raffinate by neutralisation technology should also be investigated to remove this major AD load (see section 6.2.4).

West Lyell waste rock dumps The West Lyell waste rock dumps contribute approximately 258 kg/d of copper to Haulage Creek and hence the Queen River. This represents about 16% of the copper load entering the Queen River in drainage from the site. The dumps occupy approximately 50% of the total catchment above the works area. Euralba conducted trials for copper recovery and ANSTO conducted investigations on waste dumps to quantify pollutant loads and behaviour. CMT is considering the mining of the waste rock dumps as a low grade copper resource.

Recommended work plan

Given the very large scale of the West Lyell waste rock dumps and the potential for remining, it is not recommended that any earth works are conducted except as required for copper recovery by SX/EW, water treatment and clean water diversions. If copper recovery is to go ahead, it may be advantageous to promote, rather than prevent, water infiltration into the dumps, and recycle raffinate through the dump to increase the load of copper available to the plant.

North Lyell Tunnel drainage The tunnel drains a large area of old workings to the north and also receives waters from the Crown Lyell diversion dam, and the Cape Horn area. Copper concentrations are approximately 56 mg/L and with the high flows (40 L/s median) constitute approximately 12.3% of the catchment copper loads. It is the third biggest source after the mine dewatering and West Lyell waste rock dumps.

Recommended work plan

Ongoing water and flow monitoring is required to quantify loads

The copper concentrations are probably marginal for copper recovery by SX/EW and the feasibility of increasing the concentration by the separation of high concentration sources should be investigated so that the copper can be recovered. The drainage should be treated by neutralisation technology even if the copper cannot be recovered to remove this major AD load.

West Lyell Tunnel drainage The tunnel drains a small area of the West Lyell open cut. It has low flows (4 L/s) and relatively low copper concentrations (17 mg/L). Copper loads are also low and constitute 0.4% of the catchment copper loads.

Recommended work plan

The copper concentrations are unlikely to be economic for copper recovery by SX/EW. The drainage should be treated by neutralisation technology to remove this AD load as the flows are low, and conveniently located.

Magazine Creek waste rock dump This small waste rock dump is located in the lower end of the catchment, which is comparatively large with a median runoff flow of 19 L/s. 'Clean' runoff from the upper part of the catchment passes through and mixes with the dump leachate emerging at the dump toe. A water quality flow monitoring station has been constructed at the toe and diversion works carried out to separate clean water.

The dump is believed to contribute 0.7% of the Haulage Creek catchment copper loads.

Recommended work plan

A rehabilitation plan has been prepared for the waste rock dump which involves reshaping and covering with a clay cover, with runoff diversions. This will form a demonstration trial of the covering technology with monitoring to establish the effectiveness.

(iii) Load reduction

With the above works it is estimated that the total copper loads in the Queen River can be reduced by 95–98%, and from the lease by 92–96%.

6.3.2 Linda Creek catchment

(i) Current load

The Linda Creek catchment contains the majority of the AD loads into Lake Burbury from the lease (81.6%), but is only a small component of the total lease (1.9%).

These sources are:

- Utah waste rock dumps
- Tharsis Adit
- Crown Lyell area
- Iron Blow waste rock dumps

(ii) Remediation works

Utah waste rock dumps The waste rock dumps at the head of Whites Creek are the largest source of copper in the Linda River catchment. Civil works have been carried out on the upper flat surface of the dump in an attempt to reduce water input to dump by the MLMRCL. These include reshaping of the surface to shed water, soil capping, and revegetation. Estimated input to the Linda Creek during median flow is approximately 16 kg/d, which is approximately 52% of copper in the catchment. The dump also extends across into the catchment of Brown Creek and is probably the main source of copper in Brown Creek (approximately 11 kg/d).

The works on the dumps have been effective in reducing the loads in White Creek from 18 kg/d to 12 kg/d.

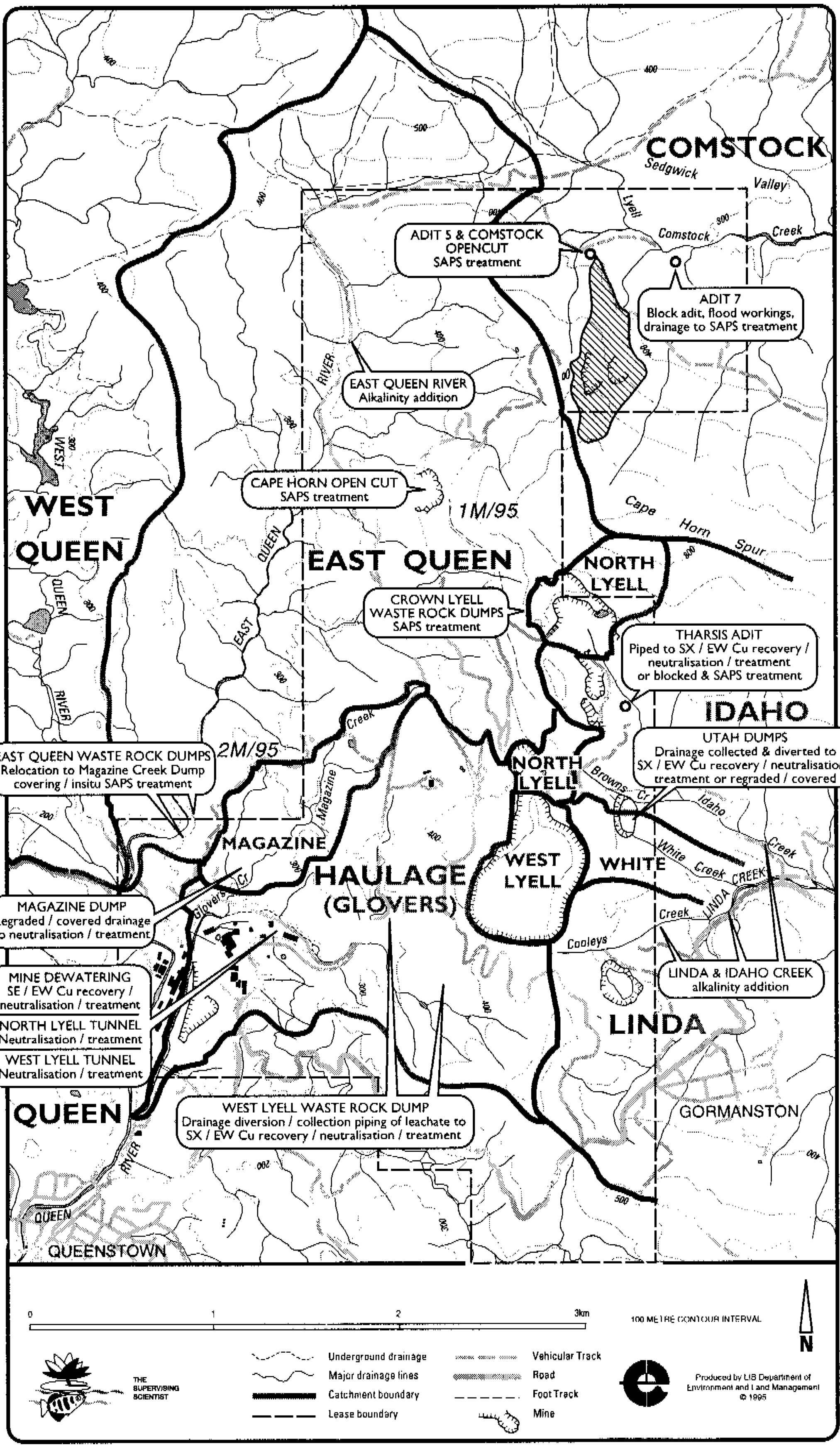


Figure 6.9 Illustration of possible remediation works

Recommended work plan

Given the high copper load being generated by the waste rock dumps, it is recommended that the drainage be collected and redirected to the SX/EW plant for copper recovery and treatment.

The drainage from the section of the dump in the Browns Creek catchment could also be collected or the dump reshaped, compacted and covered to reduce loads.

Tharsis Adit The Tharsis Adit was blocked by the MLMRCL in 1992. However, the adit seal is leaking and flows from the adit have not decreased (it is typically around 1 L/sec), and AD still flows to Idaho Creek. The Tharsis Adit currently contributes approximately 3 kg/d of copper to Idaho and Linda Creek. Even though the adit is leaking, there has been a reduction in the relatively high concentration of copper (typically 70 to 90 mg/L) to approximately 37 mg/L. It is estimated that the Tharsis Adit now represents 9.7% of the copper loads in the catchment.

Recommended work plan

The Tharsis Adit still contributed a high load to the Linda catchment. As pre blocking concentrations were high enough to make SX/EW copper recovery feasible, the piping and recovery of the copper is recommended, even though the loads are not high. This will remove the loads from the catchment. An alternative is to pipe and treat with a SAPS.

A trial SAPS could be conducted on a portion of the flow.

Crown Lyell open cut The two main sources of acidic drainage in the Idaho Creek catchment are the Tharsis Adit (see previous section) and the Crown Lyell open cut. The HEC has constructed a small dam at the opening of Crown Lyell open cut which captures most of the runoff water from the open cut as well as runoff from ridges behind the open cut. Additional diversions were installed by the MLMRCL. The captured water feeds to a series of 4 x 100 mm bore holes that connect to the old Crown Lyell underground workings. From there it gravity flows along the North Lyell Tunnel and discharges to Haulage Creek.

The reduction in copper load to the Linda Creek resulting from diversion of the Crown Lyell runoff is difficult to estimate because of the limited water quality data available for water within the open cut. However, the copper loads in Idaho have reduced from 27 kg/d to 13 kg/d as a result of this diversion and the blocking of Tharsis Adit. Assuming that Tharsis blocking has achieved a reduction in 9 kg/d, the diversion will have reduced the load by 5 kg/d. The effects on the North Tunnel drainage are difficult to quantify.

Recommended work plan

Additional water quality data will allow the load of copper being diverted underground to be quantified. If the North Lyell Tunnel copper concentration can be increased so that the waters can be treated by SX/EW, it may be feasible to remove the diversions and provide in-stream treatment of the small loads.

Iron Blow waste rock dumps and adits The estimated copper input to the Linda Creek from Cooleys Creek which drains the Blow workings is the main source of the copper to the Linda Creek above White Creek, at approximately 4.8kg/d. No works have been conducted in this catchment.

Recommended work plan

Given the relatively low copper input from waste rock and adits in this catchment, control works around the Blow should be given a low priority. The seepages at the base of the dump could in the future be collected and treated with a SAPS.

(iii) Load reduction expected

With the above works, it is estimated that the total copper loads in the Linda Creek can be reduced by 55–62%, and from the lease by 1.1%. Additional remediation works are required in the catchment. These could be in the form of alkalinity addition.

6.3.3 Comstock Creek catchment

(i) Current load

The Comstock Creek catchment contains a small amount of the AD loads into Lake Burbury from the lease (18%), and only a small component of the total lease (0.4%).

The sources within the catchment are:

- Comstock 7 Adit
- Comstock 5 Adit and open cut

(ii) Remediation works

Adit 7 Similar to Adit 5, mine drainage from Adit 7 contributes significantly to copper in Comstock Creek. Historically, the copper concentration in Adit 7 water is only about one-half of the concentration in Adit 5 water but the flow has been about 4 times greater. Assuming a mean flow of 7 L/s and a copper concentration of 24 mg/L gives a copper load from Adit 7 of approximately 15 kg/d. This load corresponds to approximately all of the total copper load now entering Lake Burbury.

Mount Lyell investigated the feasibility of sealing Adit 7 and thereby raising the water level in the underground workings up to the level of Adit 5 (or Adit 6 or Tasman Shaft). This was rejected because of the conditions of the portal.

Recommended work plan

Because of the flows and the cost of treatment, additional investigations are required to establish the feasibility of sealing the Adit further back. The flooding of the old workings may result in a reduction in AD loads (similar to Tharsis) and the diversion of flows to a higher level where waters can be treated with a SAPS system. If this is not possible, Adit 7 flows should be piped to a location where the waters can be treated.

Adit 5 and Comstock open cut Historically, water flowing from Adit 5 has added significantly to the copper load in Comstock Creek (and the open cut). The copper load from the adit is estimated to be approx 10kg/d, based on a mean flow of 2.2 L/s and a copper concentration of 50 mg/L. This load corresponds to approximately 25% of the total copper load in the catchment. The collapsed adit has been re-constructed by the HEC using concrete pipe. Mine water draining through the pipe gravity flows along an earthen canal which runs along the contour across the divide into the East Queen River catchment. Monitoring of water quality from the adit has been conducted.

Approximately 10 kg/d of copper has been diverted away from Lake Burbury but this has affected water quality in upper East Queen River. The copper concentration in the East Queen River near the pump station is approx 1.81 mg/L. The pH of East Queen water has also decreased from >6 to approx 3.5 and the iron concentration has increased to approx 2 mg/L.

Recommended work plan

Remove the diversion works and divert Adit 5 and open cut drainage waters to a SAPS system for treatment.

(iii) Load reduction expected

The flooding of Adit 7 and diverting of Adit 5 waters to be treated will reduce copper loadings in Comstock Creek and East Queen to very low levels and effectively clean up the Comstock catchment and the upper Queen.

6.3.4 Upper Queen River catchment

(i) Current load

The upper Queen River catchment is the catchment above the Haulage Creek inflow. It contains a small amount of the AD loads into the Queen River from the lease (0.7%).

The sources within the catchment are:

- Comstock 5 Adit and open cut (see previous section)
- Cape Horn drainage
- Crown Lyell waste rock.
- small unnamed waste rock dumps

(ii) Remediation works

Cape Horn open cut The Cape Horn open cut and associated waste rock dumps are a potential source of acid and copper to the East Queen River. Historic monitoring of water in the Cape Horn open cut has indicated that the copper concentration is only around 0.6 mg/L, but other sampling of drainage lines below the open cut indicates copper concentrations in the range 4 to 7 mg/L. The catchment area associated with the Cape Horn mine has been estimated at 0.68 km^2, which corresponds to a runoff of approximately 23 L/s. The copper load entering the East Queen River at this point has been tentatively estimated at around 11 kg/d. No work has been undertaken in this area.

Recommended work plan

Additional sampling is required to quantify the source of the contamination to better define the sources of copper to the East Queen River from the Cape Horn catchment. The copper could be treated with a SAPS system.

A trial SAPS consisting of only one or two alkalinity producing components could be constructed to trial the technology.

Crown Lyell waste rock dump The Crown Lyell waste rock dump is a relatively large dump, drainage from which enters the East Queen River. Only limited data are available on the quality of drainage from this dump, but the data that are available indicate relatively low concentrations of copper (ie 4 to 8 mg/L) and iron (ie 50 to 100 mg/L) in comparison with White Creek and Haulage Creek. These concentrations for the Crown Lyell dumps are very similar to the quality of water in the Crown Lyell open cut at the HEC dam. The preliminary estimate of the copper load entering the East Queen River from the Crown Lyell waste rock dump is approximately 7.8 kg/d. No work has been undertaken.

Recommended work plan

Until such time as it can be demonstrated that water infiltration into dumps can be significantly reduced (ie using Magazine Creek dump as a trial study), there is little point in any rehabilitation works on the Crown Lyell waste rock dump. A large proportion (> 70%) of the surface area of this dump is the outer steep face, hence earth works on the relatively small upper surface are unlikely to have any significant overall impact on the quality of seepage from the dump toe. If the treatment of Haulage Creek water is successful there will be an environmental benefit for the East Queen and Queen Rivers to be gained from rehabilitation works on the Crown Lyell dump.

Unnamed waste rock dumps Two small dumps have been located in the East Queen catchment and initial sampling indicates moderate levels of copper concentrations.

Recommended work plan

Additional sampling and investigations, including site survey to establish loads and possibly of covering in situ or removal to Magazine Creek dump.

(iii) Load reduction expected
The diverting of Adit 5 will effectively clean up the upper Queen above the other drainages.

6.4 Demonstration trial options

6.4.1 Covering of Magazine waste rock dump

(i) Description
This work would consist of the reprofiling of the dump, clay capping and revegetation with drainage diversions of clean water. A detail design is being prepared suitable for the calling of contracts.

The following instrumentation would be required in a program to monitor the effectiveness of a dry cover.

Table 6.11 Magazine dump monitoring

Quantity to be monitored	Instrument or technique
Rainfall	Rainfall gauge
Infiltration (water flux)	Lysimeters installed below cover
Oxygen flux	Oxygen flux meter or measurement of the oxygen diffusion coefficient in cover together with oxygen concentration profiles through cover
Drainage flow rate	Weir on dump toe drain (continuous)
Pollutant levels	pH, conductivity meter (continuous)
Pollutant concentrations	Periodic water sampling and chemical analysis

(ii) Costs
The cost of reshaping and profiling is estimated at approximately $220 000.

6.4.2 SAPS trial at Tharsis Adit or Comstock 5

(i) Description
This trial would consist of a 2 L/min trial using the existing equipment and supplemented by additional fibreglass tanks.

The trial would consist of a series of alkalinity components followed by a settling pond and marsh area. It would contain five separate components, for progressive removal of aluminium, iron, zinc, copper and manganese. Monitoring would consist of initial weekly inflow and outflow sampling, subsequently monthly.

After a 6 month period, an initial report and evaluation would be made, with a full evaluation and recommendations for extension to full scale treatment.

(ii) Costs

Engineering design (Damariscotta, JMP)	$10 000
Materials and supplies	$12 000
Labour/ construction	$10 000
Monitoring (12 mths)	$25 000
Evaluation/recommendations	$22 000
Contingency	$ 6 000
Total	$85 000

6.4.3 ALD trial in Linda Creek catchment

(i) Description

This would consist of a 200 tonne constructed ALD in the upper Linda or Idaho Creek catchment to see what levels of alkalinity can be generated. It would provide for the treatment of 1 L/s.

The performance would be monitored by initially weekly and then monthly water sampling of inflow and outflow.

After a 6 month period, an initial report and evaluation would be made, with a full evaluation and recommendations for extension to full scale treatment made after 12 months.

(ii) Costs

Engineering design (Hedin, JMP)	$2 000
Materials and supplies (limestone)	$7 000
Labour/ construction	$4 000
Monitoring (12 mths)	$5 000
Evaluation/recommendations	$4 000
Contingency	$2 000
Total	$24 000

6.4.4 Limestone addition in Linda Creek and Idaho Creek catchments

(i) Description

This would consist of an initial addition of 200 tonnes of limestone sand and 100 tonnes of crushed rock at either Cooleys Creek and/or Idaho Creek (access is required).

The performance would be monitored by initially weekly and then monthly water sampling of above and below the limestone. Flow gauging would be required.

After a 6 month period, an initial report and evaluation would be made, with a full evaluation and recommendations for extension to full scale treatment made after 12 months.

(ii) Costs

Engineering design (Hedin, JMP)	$2 000
Materials and supplies (limestone)	$10 500
Labour/ construction	$2 000
Flow weir	$2 000
Monitoring (12 mths)	$7 500
Evaluation/recommendations	$4 000
Contingency	$2 000
Total	$ 30 000

6.4.5 SAPS at Cape Horn

(i) Description

This would consist of a simplified one or two component SAP system which would raise the pH and add alkalinity to drainage water for downstream precipitation. It would test a cheap and simple method of adding alkalinity to a contaminated drainage.

The performance would be monitored by initially weekly and then monthly water sampling of above and below the system. Flow gauging would be required.

After a 6 month period, an initial report and evaluation would be made, with a full evaluation and recommendations for extension to full scale treatment made after 12 months.

(ii) Costs

Engineering design (Damariscotta, JMP)	$5 000
Materials and supplies (limestone, pipe)	$7 000
Labour/construction	$10 000
Flow weir	$2 000
Monitoring (12 mths)	$12 000
Evaluation/recommendations	$5 000
Contingency	$3 000
Total	$44 000

6.5 Mine closure planning

The ongoing operations of CMT have resulted in a marked improvement to the environment of the lease site and provided the impetus for ongoing remediation works. It is important that any ongoing site remediation works and future mining activities should consider the long-term planning for mine closure and site rehabilitation, otherwise at some time in the future the Tasmanian Government may again be facing an expensive solution to an ongoing long-term environmental problem.

This should include the preparation of a mine closure strategy plan which would be designed to remediate AD and minimise ongoing remediation and provide the focus for both CMT planning and any further MLRRDP involvement. It is appropriate that worldwide expertise should be engaged in this planning.

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