In the words of a Strahan resident upon hearing the range of remediation options 'if I had $100, I would spend $98 on fixing the lease site...and the other $2 on a party to celebrate it being fixed' (D Gerrity, pers com).

6 MLRRDP findings: Remediation options for the lease site

6.1 Overview and criteria for evaluating remediation options

An extensive review of remediation options applicable to the Mount Lyell lease site was completed as an MLRRDP project (Miedecke 1996).

The *ultimate* goal of remediation is to achieve the downstream EQOs, and the MLRRDP must define a path to reach this goal. However, this path must take account of economic and technical realities. Therefore, interim measures which will partially achieve the EQOs or at least be a 'step in the right direction' have also been given serious consideration. It cannot be strongly enough expressed, however, that based on the findings of the MLRRDP, virtually *all* of the acid drainage presently exiting the lease site must be eliminated for the EQOs to be achieved.

This view holds for both the rivers and harbour, because although toxicity results suggest that reducing the copper concentrations by one-half in the harbour will reduce the risk to acceptable levels in saline waters, the harbour is subject to freshwater King River plumes. In effect, the King River 'flows' over the surface of the Harbour, creating the same toxicological threat as exists in the river, in the harbour. Historically, these plumes have been implicated in fish kills in the harbour, and because of this, the harbour cannot be considered 'safe' until the incoming King River water is no longer toxic to organisms.

This approach is reflected in the criteria which have been chosen by the MLRRDP for evaluating possible remediation options for the Mount Lyell lease site, rivers and harbour.

- The *effectiveness* of the option is of primary importance and has been evaluated in terms of its ability to promote the downstream EQOs in both the short and long-term time scales.
- The *feasibility* of potential remediation options has been considered, including issues associated with using 'new' technologies. Mount Lyell presents some unique problems because of the scale and magnitude of the acid drainage problem, and it is often difficult to determine whether a technology which has successfully been employed on a much smaller scale will be effective at Mount Lyell.
- The *cost* of each remediation technique has been evaluated, including costs associated with the initial establishment or installation of the remediation technique, and ongoing running and maintenance costs over the life of the technique.
- Remediation strategies have also been considered with respect to *social acceptability*. The views of the community need to be reflected in a remediation plan, as does waste reduction, waste minimisation and 'best practice environmental management' policies as currently adopted by both State and Commonwealth Governments.
- Other issues considered by the MLRRDP are the *flexibility* of the remediation option to take advantage of new technologies or respond to radically changed conditions (such as reduced flow of acid drainage or variation in composition), and the *impact of mine closure/development* on the option.

These criteria are discussed in relation to each of the available techniques for reducing major acid drainage sources in this chapter, with a comparative discussion included in Chapter 7 'Recommended remediation options'. The same criteria are not fully discussed for the available techniques for reducing minor acid drainage options, because the effectiveness, cost, flexibility, etc. would be highly dependent on the scale and siting of the option.

Remediation options are presented in a downstream order, with most emphasis placed on the lease site due to it being the source of the problem. Lease site options are divided into 'Available techniques for reducing major acid drainage discharges' and 'Available techniques for reducing minor or diffuse acid drainage sources'.

6.2 Mount Lyell lease site

6.2.1 Available techniques for reducing major acid drainage discharges

Several different approaches are technically feasible to bring about a significant reduction in the amount of acid drainages leaving the lease site and impacting the downstream environment. They include prevention of acid drainage formation through water management; neutralisation by mixing some acid drainage with alkaline tailings (the 'do nothing' option), neutralisation of *all* the acid drainage; and diversion of the water flow.

Water management

Preventing the formation of acid drainage is the optimal solution for the Mount Lyell lease site. Theoretically this could be accomplished through the diversion of all surface water and rain water away from the lease site before it comes in contact with acid drainage generating rock. This solution would not eliminate the creation of acidity and release of metals on the lease site, but would prevent the transport of these pollutants into the downstream environment. Passive diversion works which are low maintenance and rely on gravity rather than pumping to divert water away from Mount Lyell would be an effective component of mine close out plans.

Practically, water diversion is a very complicated engineering problem because of the large area of the lease site, high volumes of rainfall, 'flashy' nature of rain storm events, fractured underlying bedrock, and complicated hydrology of the waste rock dumps and underground workings. Because water management is an integral part of the overall mine management, and is primarily an engineering issue, it is best progressed as an integrated part of present and future mine management and development. It must be recognised that as the mining operation evolves, the quantity and quality of acid drainage produced on the lease site will change, and additional remediation efforts must be flexible enough to respond to tomorrow's development in a cost effective manner.

Neutralisation of acid drainage

The direct addition of alkalinity to acid drainage and retention of resultant precipitation products is a proven technique which is widely used in the mining industry, and has been adopted as the 'Best Available Technology Economically Achievable' in the USA and Canada (Miedecke 1996). Miedecke (1996) summarised the steps of conventional neutralisation and metal precipitation technology as follows:

- 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 coagulation/flocculant addition

The general method involves the collection and neutralisation of acid drainage using lime, limestone, or other neutralisation agent which results in the precipitation of metals from the water. The reaction usually takes place in a recycling thickener or settling pond with the precipitation solids retained and stored in a high pH environment, and the clear clean water discharged. The method is very effective as a means of improving water quality, although the storage and final disposal of the metal-rich sludge presents separate issues. Because it is a labor and capital intensive means of improving water quality, it is generally not considered as a long-term 'walk away' option for mining operations.

(a) Neutralisation with tailings only—'Do nothing' option (base line condition)

Feasibility

As a baseline, the MLRRDP considered what would occur environmentally if no additional remediation work was completed on the Mount Lyell lease site aside from that committed to by CMT for the life of the mine. Best Practice Environmental Management, as adopted by CMT and approved by the State Government, includes the utilisation of tailings produced during the milling process to neutralise some of the acid drainage emanating from the underground workings. Therefore, the 'do nothing' option is a limited neutralisation scenario where tailings are used to neutralise part of the acid drainage.

Presently, about 12% of acid drainage pumped from underground, which is equivalent to about 8% of the lease site acid drainage, is neutralised using tailings. The solid precipitation products (primarily metal hydroxides) are pumped to, and retained in, the tailings pond. The remaining 90% of the copper load under 'normal' flow conditions, and *all* high flows continue to enter the Queen River directly. Figure 6.1 is a schematic flow diagram representing the present pathways of acid drainage on the lease site. Presently not all of the neutralisation capacity of the tailings is utilised due to infrastructure limitations.

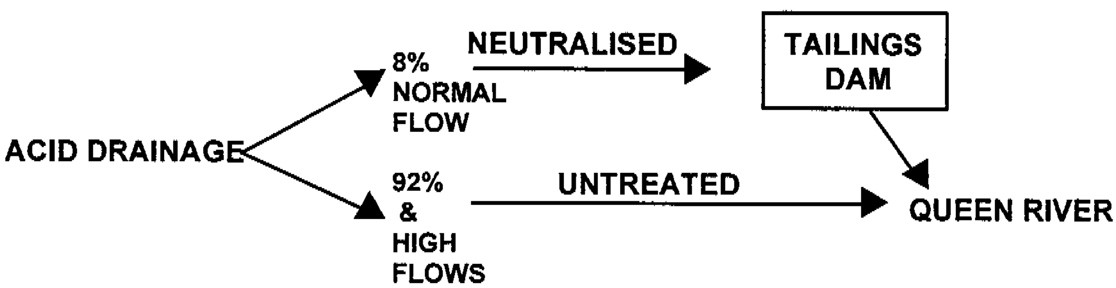

Figure 6.1 Schematic diagram of present situation on Mount Lyell lease site. CMT neutralises approximately 8% of the acid drainage on the lease site, and pumps the resultant water and sludge to the tailings pond

Under full production (3.5 million tonnes per annum, approximately 30% increase over present production), which is expected to be achieved within the next few years and continue for the life of the mine, the percentage of acid drainage which could be neutralised with tailings will increase to 70% of the acid drainage pumped from underground (about 45% of the total), if the full neutralisation capacity of the tailings is used. The remaining 55% will continue to directly enter the river system (figure 6.2).[1]

As proposed by Imtech (1997), the contact between tailings and acid drainage will occur in a pipe reactor, with the additional mixing and precipitation of sludge taking place in a thickener. The 'clean' overflow will be discharged directly into the Queen River, and the precipitated sludge will be pumped to the tailings pond.

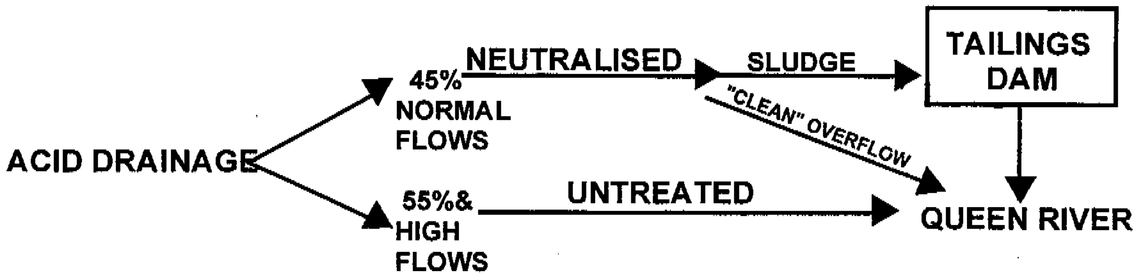

Figure 6.2 Schematic diagram of full production neutralisation scenario utilising only tailings to neutralise acid drainage

This scenario would provide greater protection for Princess Creek—the receiving environment for discharges from the tailings dam—because compounds which are not removed in the neutralisation process, would not report to the tailings pond but be discharged directly into the Queen River. A disadvantage of this scenario is that because only a portion of the acid drainage will be neutralised, any metal hydroxide precipitates which escape from the thickener would be redissolved in the acidic Queen River, and the associated metals would be released back into solution.

An important consequence of the 'do nothing' scenario is that the remaining untreated acid drainage flows and all high flows enter the Queen River untreated. Based on the geochemical modelling (Klessa et al 1997) and freshwater toxicity work by Humphrey et al (1997), this would have very serious toxicological impact on the lower King River. As fully discussed in section 5.5, the MLRRDP studies have found that releasing even a small percentage of acid drainage from the lease site would have severe toxicological implications in the Queen and King Rivers.

Effectiveness

The downstream implications of the 'do nothing' option are that copper and other metal loadings will be reduced by up to 45% under 'typical' river flows for the life of the mine, which is likely to be between 10 and 65 years. However, 55% of acid drainage and all high flows will continue to enter the river systems. This would not be sufficient for the recovery of the riverine aquatic ecosystems, and although copper concentrations in Macquarie Harbour would be decreased most of the time, there would still be conditions under which toxic plumes could spread across the harbour.

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[1] Under full production, only about 20–25% of the acidity load will be treated. The discrepancy between the figures is because the underground water contains high copper concentrations and relatively low acidity, while the acid drainage from the waste rock dumps contains high acidity and relatively low copper concentrations.

Costs

The costs associated with the 'do nothing' option are nil to the State, though there are costs incurred by CMT to treat the 45% of acid drainage. These costs are have been estimated by CMT to be approximately $1–$1.5 million for infrastructure and $320 000 per year for operating costs.

Social acceptability

Although using a waste product (tailings) as a resource (neutralisation agent) is a socially acceptable concept consistent with Best Practice Environmental Management and waste reduction/minimisation strategies, the resultant downstream environmental outcome would not be acceptable to society, nor reflect Tasmania's Sustainable Development Advisory Council position that at a minimum all mine water should be treated (SDAC 1995).

Flexibility/mine closure

At mine closure, assuming the underground workings will be flooded, an unquantified reduction of up to 65% or more of the copper loadings will occur. The remaining acid drainage, derived primarily from the waste rock dumps, will continue to flow into the Queen for centuries to come (ANSTO 1994a, 1994b). Based on the modelling of Klessa et al (1997) and Humphrey et al (1997), this scenario will not result in water quality suitable for ecological recovery in the Queen or King Rivers. Copper loadings and copper concentrations under median flow conditions to the harbour will be reduced, but large flushes which can result in toxic plumes in the harbour will not be significantly reduced.

Summary

The 'do nothing' option will not achieve or promote the downstream EQOs in the short or long term. In spite of this, the neutralisation of acid drainage with tailings alone is a 'step in the right direction' and could serve as the start of a large scale neutralisation system. Establishing the infrastructure for neutralisation, such as a secondary thickener, would be required in the longer term for a larger scale system, and therefore should be pursued.

(b) Neutralisation of all acid drainage on the lease site

Feasibility

The obvious 'next-step-up' scenario for lease site remediation would be the use of additional neutralisation reagents and water management strategies such that *all* acid drainage on the lease site could be neutralised, with the retention of all precipitation products. The implementation of such a strategy would require the use of limestone and lime in addition to the alkaline tailings.

Though many engineering and financial issues would need to be resolved, water treatment using lime is technically feasible if a suitable retention pond and disposal site for sludges can be identified. As for any remediation strategy, the recovery of the downstream environment will be dependent on the collection of all acid drainage sources and the efficiency of the technique. If all acid drainage can be collected and treated, and all precipitation products can be retained and safely stored in a disposal site (most likely the tailings dam), then the strategy would be highly successful.

As envisaged by the MLRRDP, the strategy would require a large holding pond where all acid drainage sources would be collected prior to neutralisation. The endpoint of the neutralisation reaction would be pH 6.5, and would be achieved through reaction with tailings, limestone and lime. The reaction would occur in large thickeners on the lease site, and the 'clean' overflow would be discharged directly to the Queen River.

Several variations on the neutralisation scenario have been investigated by Imtech (1997) for CMT, including the neutralisation of a smaller percentage of the total flow, or neutralisation to a pH lower than 6.5. Geochemical modelling and toxicological testing show, however, that any deviation from the treatment of all flows to a pH of 6.5 has serious downstream consequences, and will not achieve the target EQOs. Table 6.1 shows the expected copper concentrations in the lower King River under different neutralisation scenarios. The percentages listed under 'total AD neutralised' represent treatment of the Conveyor Tunnel (65%), the Conveyor, North Lyell and West Lyell Tunnels (80%), and the West Lyell waste rock dumps, in addition to all of the tunnels (99%). Though partial neutralisation of flows or neutralisation to a pH somewhat less than 6.5 would appear to be environmentally beneficial, the ultimate target must be the treatment of all flows to pH 6.5 if the EQOs are to be met via this approach.

Table 6.1 Model soluble copper concentrations (µg/L) in the lower King River under median flow conditions and power station off (Klessa et al 1997)

	Total acid drainage neutralised		
pH endpoint	65%	80%	99%
6.5	1120	657	73
5.5	1708	1383	971

Effectiveness

The effectiveness of the technique is very good, and it is estimated that the total copper, aluminium, zinc and iron loads in the effluent would be reduced by at least 98%, with a lesser reduction in manganese and sulphate (Miedecke 1996). If all acid drainage streams were treated, this level of reduction should be sufficient to promote the environmental quality objectives in the King River and Macquarie Harbour

Costs

The costs associated with a water treatment plant are substantial: Estimates range from $2.8 million for a 225 L/s plant (Miedecke 1996) to $7 million for a 450 L/s plant (Imtech 1997). Additional costs for water management and construction of a holding pond are estimated at $1 million to $2 million. Operating costs are also considerable primarily due to the high cost of lime, and for a system capable of neutralising all flows (450 L/s), are estimated at approximately $2 million per annum.

Social acceptability

The implementation of a water treatment plant would be socially acceptable. However, there would be substantial community concern if treatment were discontinued when mining ceased and there was a decrease in downstream water quality.

Flexibility/mine closure

A large scale neutralisation system could be highly flexible which is an advantage on a lease site where flow regimes and acid drainage composition may change in the future. Mine closure would significantly affect this option because the supply of alkaline tailings would cease, but so would the volume of acid drainage requiring treatment.

Ocean discharge of acid drainage

Feasibility

The engineering feasibility and costs associated with constructing a pipeline that would divert acid drainage from the lease site away from the rivers and Macquarie Harbour and discharge directly into the sea were investigated by the MLRRDP. Advantages of a pipeline include the long-term, low maintenance elimination of acid drainage from the Queen and King Rivers and Macquarie Harbour regardless of future mining operations. Engineering investigations have not identified any major impediments to the establishment of a pipeline.

Effectiveness

Removing acid drainage from the King River catchment would be a very effective way of promoting the downstream environmental quality objectives. The efficiency of the system would be limited by the capability of collecting all acid drainage affected water on the lease site, and the capacity of the pipeline. For this remediation strategy to succeed, a pipeline would need to be constructed which could receive a minimum of 450 L/sec of low pH acid drainage. To eliminate the threat to the Queen and King Rivers from high-flow storm events, a holding pond or ponds would need to be constructed and maintained. Additionally, if pumping of effluent is required, a holding pond would be required to remove suspended solids from the acid drainage to minimise damage to pumps.

The installation of a pipeline would alter the flow regime of the Queen River by removing the 15% of flow contributed by Haulage Creek under median flow conditions. This would have a minor impact in the lower reaches of the King River where Haulage Creek contributes less than 5% of the flow based on median flow rates, and the flow is already highly regulated. Significantly, based on modelling results and toxicological testing, the complete (99% or greater) removal of acid drainage from the King River is the only way of ensuring recovery of the aquatic ecosystem.

Other environmental impacts

The environmental impacts associated with such a remediation strategy, or how a pipeline might be integrated with other remediation techniques (such as partial neutralisation) have not been fully investigated. However, one possible scenario would be the establishment of a copper recovery system at the front end of a pipeline which would minimise the amount of copper transported to the ocean (more fully discussed in section 6.3.4). The low copper acid drainage would then be piped to the ocean where the remaining metals would rapidly precipitate.

Costs

Miedecke (1996) estimated that a suitable pipeline could be constructed along the alignment of the Abt railway for about $7 million. The pipeline would be approximately 40 km long and have a fall of about 200 m, and have a capacity of 240 L/s. It was suggested that there would be minimal costs associated with maintenance and operation. No costings were provided for holding or settling ponds.

More detailed estimates of costs associated with the construction and operation of pipelines of varying capacities were obtained from HECEC Australia Pty Ltd (1997). Three pipeline routes and various piping materials were investigated, with the most cost effective option being a topographic route over Misery Flats. However, as this route passes through undisturbed lands, the alternative routes which followed the HEC transmission line and the old Abt Railway route may be preferred based on social or environmental criteria. The range of costings for a pipeline with a capacity of 450 L/s is presented in table 6.2, and figure 6.3 is a map showing the investigated routes.

Table 6.2 Summary of cost estimates for different pipeline options (AUS$)

Option	Polyethylene (MDPE)	Fibreglass (FRP)
Abt Railway Line	$27m	$50m
Transmission Line	$31m	$45m
Topographic Route	$23m	$34m

These costings include expenditures for a retention basin ($840 000), a settlement basin ($120 000), and pumps ($120 000–$160 000 depending on route). An operating cost of $1.5 to $2 million per annum has been estimated to cover energy and maintenance costs over a 30 year period, assumed to be the life of the pipeline. These costings do not include land acquisition costs or costs associated with the required environmental impact studies. Obviously, many environmental and social acceptability issues would need to be resolved before such a strategy could be implemented, such as the marine impacts associated with the ocean discharge of acid drainage.

Social acceptability

The establishment of a pipeline to discharge untreated or partly treated effluent is inconsistent with best practice environmental management, and waste reduction/minimisation strategies. As such it would probably not be endorsed at the Commonwealth, State or local level of government, unless no other remediation option was able to achieve the downstream environmental quality objectives.

Flexibility/mine closure

A pipeline is not a flexible option, because it must be designed and constructed to accommodate maximum flows. Additionally, it is not suitable for step-wise implementation, because no environmental benefit is realised until the entire structure is complete and operating. Once constructed, a pipeline would be a long-term ‘solution’ which would not be greatly affected by mine closure, assuming operating costs continue to be met.

6.2.2 Extraction of copper from acid drainage

Prior to the closure of The Mount Lyell Mining and Railway Company, the high concentrations of copper in the acid drainage streams on the lease site had attracted the attention of commercial operators interested in trying to economically extract the dissolved copper using solvent extraction/electro winning (SX/EW) technology. SX/EW is a water treatment plant which, through a series of chemical and electro-chemical reactions, is able to extract high purity copper from the waste water.

The main advantage of employing such a technology is that a major pollutant is removed from the waste water streams which provides a revenue stream. Additional investigations by CMT have confirmed the suitability of SX/EW technology for some acid drainage streams.

Disadvantages to employing the technology include the fact that the resultant waste water, or raffinate, still contains all other pollutants in the acid drainage (metals, acidity), and in addition, contains up to 15 ppm organic solvents (kerosene). Because the technology is not 100% efficient, under most flow conditions, at least 15 ppm copper would also remain in the raffinate.

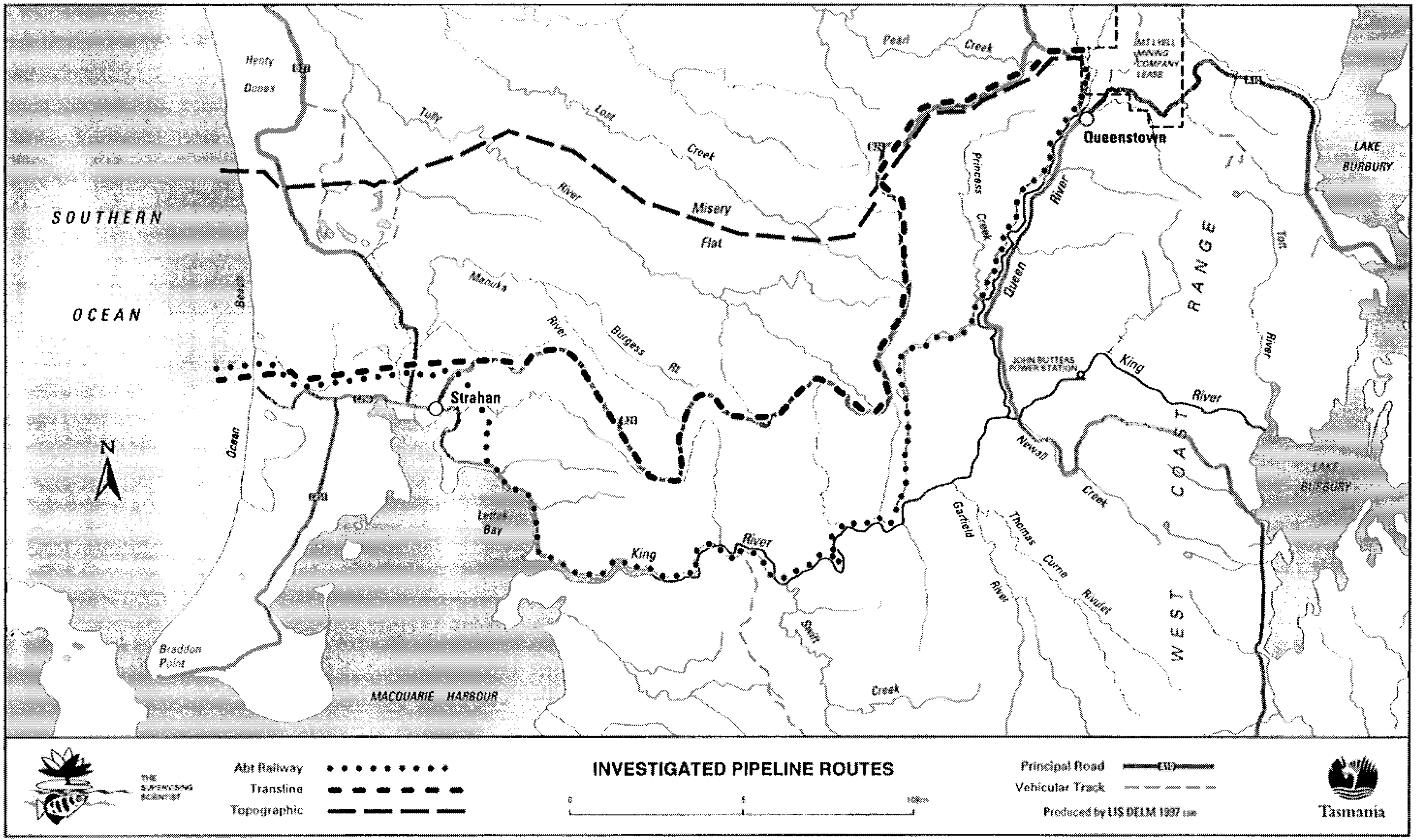

Figure 6.3 Investigated pipeline routes

Based on available information, it is strongly recommended that copper recovery technology be incorporated as part of the remediation effort. Presently SX/EW appears to be suitable, although there are other emergent technologies, such as osmotic membranes, which might enhance the performance of SX/EW and require evaluation.

It is essential that a copper recovery system be developed recognising the possibility of reduced copper loads associated with successful diversion works. The incorporation of SX/EW technology in both the neutralisation and pipeline scenario, based on the present flow regime and water quality of the lease site, is discussed below.

Incorporation of solvent extraction/electro winning technology in neutralisation scenario

Klessa et al (1996) used a chemical model and median flow conditions to predict copper concentrations in the Queen and King Rivers under different neutralisation and SX/EW scenarios with the following findings:

- 99% of the acid drainage presently leaving the lease site would have to be neutralised to a pH of 6.5 and have the precipitation products removed prior to discharge to the Queen River before concentrations of copper in the lower King River are sufficiently low to allow ecological recovery. This represents neutralisation of all three of the major acid drainage waste water streams (Conveyor Tunnel, North and West Lyell Tunnels, West Lyell waste rock dumps).
- The use of SX/EW technology will not promote downstream recovery unless all raffinate is neutralised to at least a pH of 6.5. Neutralisation to a pH of 5.5 is not sufficient.

These findings are substantiated by table 6.1 which shows the expected dissolved copper concentrations in the lower King River under different treatment scenarios. The percentages listed under 'Total AD neutralised', and the first two entries are the same as table 6.1.

Table 6.3 Model soluble copper concentrations (µg/L) in the lower King River under median flow conditions and power station off (Klessa et al 1996)

	Total acid drainage neutralised		
pH endpoint	65%	80%	99%
6.5	1120	657	73
5.5	1708	1383	971
6.5 + SX/EW	1120	657	73
5.5 + SX/EW	1387	987	482

From table 6.3 it is evident that 99% of the acid drainage must be neutralised to a pH of 6.5, with or without the inclusion of SX/EW, to meet downstream water quality targets. Neutralisation to the lower pH endpoint of 5.5 (with or without SX/EW) does not sufficiently reduce downstream copper concentrations.

Variations of neutralisation—SX/EW scenario

Although neutralisation of all acid drainage sources is required for downstream recovery, there are a number of variations on the 'neutralisation—SX/EW' scenario which need to be considered. While not achieving the desirable outcome in the Queen and King Rivers, they would significantly reduce copper fluxes and concentrations entering Macquarie Harbour, and could also provide a revenue stream for undertaking additional remediation options.

Figure 6.4 shows one possible SX/EW scenario, with the neutralisation capacity of the tailings being used to neutralise about 45% of the raffinate, with the remaining 55% entering the Queen River without treatment. This scenario is generally equivalent to the 'Do nothing—full production scenario' with the differences being the profitable recovery of copper from the waste streams, and an additional reduction in copper concentrations exiting the lease site (from 104 mg/L to about 15–30 mg/L). Because the plant would most likely have a capacity to handle median flow conditions, high flows and associated acid drainage 'pulses' would bypass the SX/EW circuit and continue to enter the Queen River without copper removal.

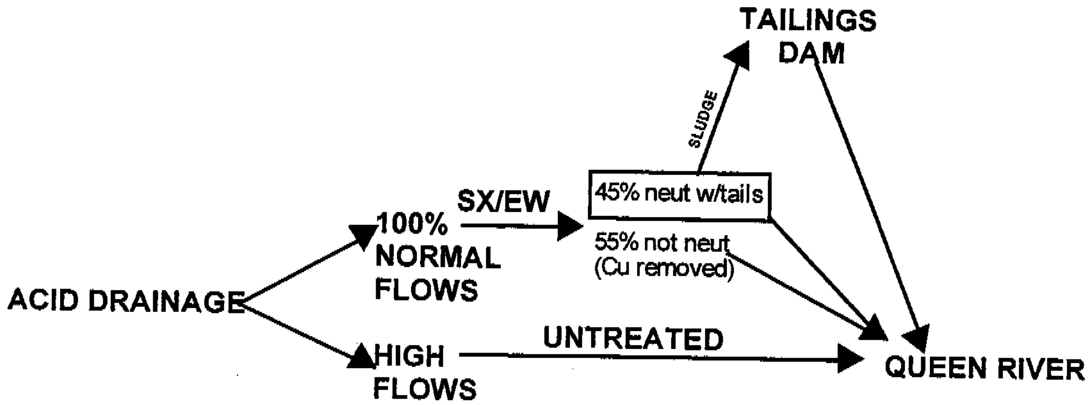

Figure 6.4 Schematic of possible SX/EW scenario utilising neutralisation capacity in tailings to treat 45% of raffinate

A second possible SX/EW scenario, and one that would begin to approach the conditions required for the recovery of the lower King River is presented in figure 6.5. This is similar to the first SX/EW scenario presented with the only difference being that 100% of the raffinate is neutralised; 45% by the tailings and the remainder through the addition of lime and limestone.

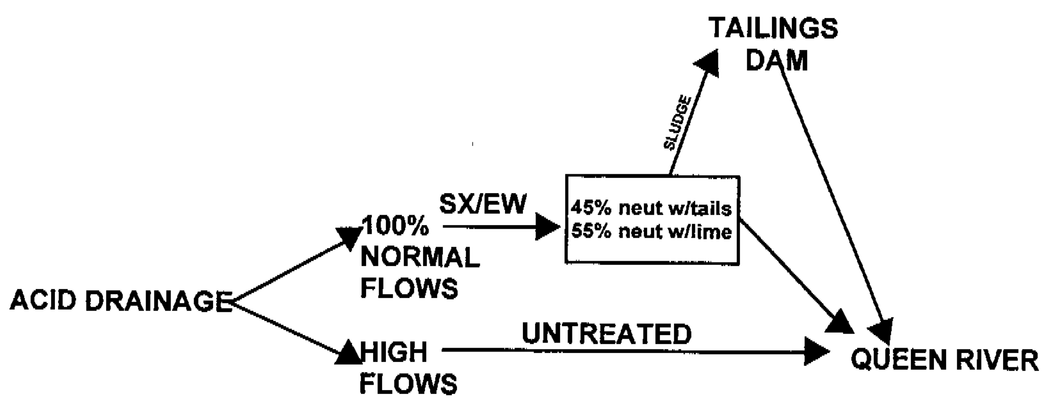

Figure 6.5 SX/EW scenario including treatment of all sources under median flow conditions and the neutralisation of all raffinate

There are significant additional costs associated with this scenario, in that substantial quantities of lime and limestone are required, as is a greater volume in a tailings dam for the deposition of neutralisation precipitation products.

Under this scenario, downstream water quality targets would only be met under median flow conditions, with flows in excess of median continuing to enter the river system untreated. Based on the chemical modelling of the King River (Klessa et al 1997) and toxicological testing results (Humphrey et al 1997), this scenario would not provide sufficient protection for the lower King River for significant biological recovery to take place. In order for the 'SX/EW scenario' to result in a suitable improvement in the lower King River, *all* (>99%) of the acid drainage would need to pass through a water treatment plant *all* of the time.

Incorporation of solvent extraction electro winning technology in the pipeline scenario

A copper recovery system at the 'front end' of a pipeline would provide a significant environmental benefit because of the reduced copper flux entering the ocean as compared with the present situation of raw acid drainage entering Macquarie Harbour. It has been found that while iron and presumably aluminium precipitate out of solution as King River water is mixed with more saline harbour water, only about 15% of the dissolved copper entering the harbour is retained in the harbour's sediments. The vast majority of copper is maintained in the water column and ultimately exits the harbour. Therefore, the copper recovery – pipeline scenario would result in a net increase in iron and aluminium entering the ocean, but a net decrease in copper.

6.2.3 Available techniques for reducing minor or diffuse acid drainage sources

Diversion drains

Diversion drains have been successfully used in the mining industry for reducing the amount of acid drainage by directing 'clean' storm water away from acid generating areas. On the Mount Lyell lease site, diversion drains have already been successfully used as part of the HEC remediation works aimed at minimising copper inputs into Lake Burbury. Some scope still exists for establishing additional diversion drains to direct storm waters away from acid generating regions of the lease site, such as waste rock dumps. CMT is presently working towards establishing a reliable water balance for the lease site which will aid in the determination of areas suitable for diversion drains. Another advantage of diversion works is that the remaining acid drainage will be more concentrated, and will be more economically viable for the application of SX/EW technology. The feasibility, cost, and effectiveness of diversion drains will not be known until a greater understanding of the lease site hydrology is available.

Anoxic limestone drains (ALD), wetlands and successive alkalinity producing system (SAPS)

Smaller scale treatment options for minor acid drainage sources have been identified as being feasible by Miedecke (1996). These include anoxic limestone drains (ALD), wetlands, and successive alkalinity producing systems (SAPS). All are passive treatment systems which, when used in appropriate combinations, impart alkalinity to acidic waters and remove metals.

Because the flows that can be treated by these options are small in comparison with the ≈100 L/s present in the principal waste water streams on the lease site, these treatment options are only applicable to small adits or other acid drainage sources which are not easily re-directed to the main acid drainage discharge points for alternative treatment.

In an ALD, alkalinity is produced when the acidic water contacts limestone in an anoxic, closed environment (Miedecke 1996). Typically, the alkaline water is then passed through an oxic wetland where precipitation of metal hydroxides occurs. This combination has been successfully used in the treatment of waste waters which contain low concentrations of iron and aluminium and dissolved oxygen. The presence of these components results in the precipitation of metal hydroxides within the limestone drain, coating the surface of the limestone and reducing the effectiveness of the system.

Anaerobic wetlands have also been used to impart alkalinity to waste waters through a combination of bacterial activity and limestone dissolution. However, they require the conversion of large plots of land for successful implementation.

SAPS combine ALD systems with anaerobic wetland-style sulphate reduction mechanisms to greatly increase the amount of alkalinity available to the acidic waters. SAPS consists of a vertical flow of acidic waters through a series of organic substrates and limestone beds prior to discharge. SAPS have been found to require significantly less area than anaerobic compost wetlands due to using a combination of alkalinity producing processes, and probably offer the most potential for treatment of the small, discrete and dispersed acid drainage sources at Mount Lyell (Miedecke 1996).

SAPS is being trialed as part of the MLRRDP on a portion of the Tharsis Adit drainage, and preliminary designs have been prepared for the full scale treatment of Tharsis and Comstock drainages (figure 5.1). Figure 6.6 and plate 1 show a schematic diagram of the prototype SAPS system and a photo of the unit which is being trialed, respectively. Detailed monitoring of the raw waste water and clean discharge during the first few months of operation has indicated that the system is working effectively. Physical blockages of the connecting pipes, primarily caused by large amounts of iron precipitating out of the acid drainage, have been the only hindrances to the system's performance, and would require modification if the system were to be expanded.

Table 6.4 contains monitoring results from the first three months of operation of the SAPS, and shows that the system is effective, though variable. The first monitoring was completed very soon after installation, and the lower removal rates and lack of acidity removal may indicate the biological reactions upon which the SAPS is based were not operating at full capacity.

Table 6.4 Monitoring results from trial SAPS system. All concentrations in mg/L except pH. Alkalinity and acidity expressed as mg/L $CaCO_3$

	18 December 1996		31 January 1997		26 February 1997	
Parameter	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
pH	2.91	5.96	2.88	7.3	2.77	5.96
Aluminium	56.7	3.8	89.1	<0.05	95.5	0.3
Cadmium	0.06	0.06	0.11	<0.01	0.12	0.05
Copper	25.2	6.6	34.3	0.16	35.8	2.26
Iron	19.5	<0.02	49.9	2.47	73.2	0.03
Manganese	52.0	77.4	119	71.5	126	122
Lead	0.28	0.01	0.20	0.02	0.26	<0.01
Zinc	19.3	21.3	39.0	18.2	38.2	26.5
Alkalinity	<1	11	<1	150	<1	22
Acidity	620	523	963	<1	1040	<1
Sulphate	588	953	1370	1170	1500	1130

The second set of monitoring results shows an excellent removal of metals and acidity, and generation of alkalinity. Between the second and third samplings, some clogging of connector pipes was observed, and the results once again indicate a diminished performance. As expected, manganese, zinc and sulphate concentrations are not greatly altered by the SAPS.

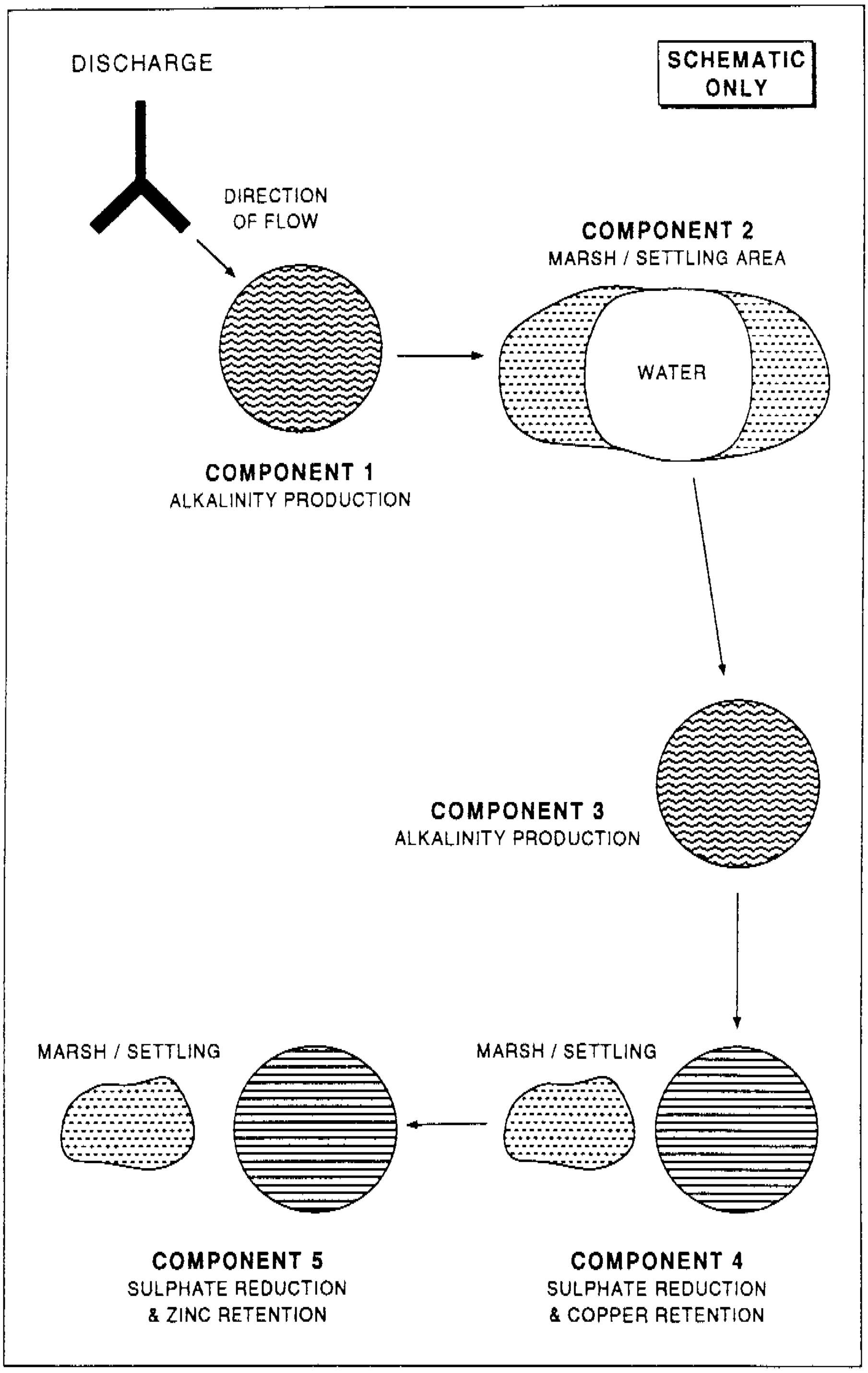

Figure 6.6 Schematic diagram of SAPS installed on Mount Lyell lease site

In a large scale SAPS, the level of treatment observed in this trial would be expected to continue for up to 20 years before large scale maintenance was required, and therefore represents a long-term solution for low-flow sources (Miedecke 1996).

Establishment costs will vary depending on the volume of acid drainage to be treated and diversion costs for acid drainage streams if available land areas are not sufficient. A SAPS at the Tharsis Adit is estimated to cost $80 000–$160 000.

Plate 1 SAPS. Large black tanks are 'components' and smaller green tanks are 'marsh/settling' areas. Refer to schematic in figure 6.6.

Covering of waste rock dumps

Impermeable covers on waste rock dumps have been demonstrated to be an effective way of decreasing the discharge of pollutants from dumps. Covers need to eliminate the ingress of oxygen into the dump to reduce the rate of oxidation (ANSTO 1994a, 1994b). Reducing the influx of water into the dump reduces the volume of water exiting the dump and entering river systems. Covers tend to be costly due to transport of clay and other capping materials, and the labour intensive process of reshaping and compressing the cover material to acceptable standards.

As part of the MLRRDP, a small waste rock dump, Magazine Creek, has been capped in an attempt to reduce the acid drainage emitted and entering one of the major acid drainage streams. The dump was capped over a one year period, and will now be monitored by the MLRRDP and CMT to evaluate its success. Monitoring will include both determining the acid drainage exiting the toe of the dump, and obtaining oxygen and temperature profiles from within the dump.

The capping of the larger waste rock dumps on the Mount Lyell lease site, such as the large West Lyell waste rock dumps, is not feasible for a number of reasons. Costs associated with implementing this technique would be in the many millions of dollars, and in the long term mining development it is possible that the waste rock dumps might be re-treated if a large open pit were developed on the lease site. This would result in the re-milling of the waste rock, recovery of the extractable copper and gold, and deposition of the residue in a tailings pond. Investing large amounts of capital into the covering of dumps which may be reprocessed in the next few decades would not be the most efficient use of remediation funds.

Revegetation of hillsides

The acid drainage produced through the oxidation of exposed sulphidic minerals on the hills surrounding Queenstown is a very minor component (<1%) of the total acid drainage produced on the lease site. However, revegetation of the hills would decrease this contribution by limiting the ingress of water and oxygen into the hills, and drawing water out of the hills via evapotranspiration.

Revegetation has been the focus of social impact studies associated with the closing of The Mount Lyell Mining and Railway Company, and the community has expressed a desire to not proceed with major revegetation works. In light of the minor contribution of pollutants from the hillsides, community desires, and slow but progressive natural revegetation (mostly in the valleys and gullies) the MLRRDP does not consider the revegetation of the hillsides to be a high priority issue for the recovery of the rivers and harbour.

6.3 Remediation options for rivers

6.3.1 Do nothing

Similar to the approach used for evaluating remediation strategies for the lease site, the 'do nothing' strategy was evaluated for the rivers as a means of establishing base line conditions.

Based on the findings of Taylor et al (1996), the river banks are a very minor source of acid drainage compared with the lease site. As discussed in section 5.3.2, the exception to this may be under certain, limited conditions, when the resident tailings and slag in the King River release considerable quantities of metals during power station operation or rain events. As a 'worst case scenario', inputs from the banks and river beds were estimated to be as high as a couple of hundred kg/day dissolved copper, which would represent about 10% of the present copper load derived from the lease site.

However, it is highly likely that these instances are limited and reflect past conditions. Since the cessation of tailings discharge, there has been a considerable reduction in the volume of unoxidised sediments present on the river banks due to erosion. Most of the newly exposed banks are well oxised, and chemical testing has shown that the sandy, orange bank material has lower concentrations of metals.

Therefore, for the purpose of developing an overall remediation strategy, it is assumed that the river-derived sources of pollution are negligible compared with the lease-site derived 'upstream' sources of pollution. Under these conditions the 'do nothing' option would probably achieve the water quality objective required to re-establish a modified ecosystem in the Queen and King Rivers *if all upstream acid drainage sources were eliminated.* If all lease site sources were eliminated, the pH of the river would increase which would reduce the leaching of metals from the river banks and beds, leading to a reduction of 'new' soluble metal in the system. Riverine pollutant contributions would be controlled by equilibria reactions with the clean river water, and after an initial re-adjustment period, would be very likely to decrease from present values.

Under the 'do nothing' scenario, revegetation of the banks would be a long process, and the visual pollution resulting from the tailings deposits would not be remedied.

6.3.2 Removal of tailings banks

The removal of the major tailings banks in the King River would eliminate the tailings as a source of pollution to the river, and enhance the visual amenity of the river. Removing the banks might also promote more rapid revegetation once the 'natural' banks were re-exposed. However, Locher (in prep) has found that copper and other metals have migrated out of the tailings and are present in the 'natural' banks in concentrations equivalent to those found in the tailings material. These metals may retard the re-establishment of vegetation even if all tailings were removed.

Because the flow regime of the King River has been very significantly altered by the establishment and operation of the King Power Scheme, and the larger tailings banks were all deposited under the old flow regime, it is highly unlikely that the tailings will be removed by a natural flood event, and complete erosion of these storages, if it occurred, would be on a time scale of decades to centuries (Locher 1997). More likely is that channel widening caused by bank erosion will be limited by hydraulic factors (Locher, pers comm)

Removal of bank material would involve the movement of tailings into the river, where the natural flow would transport the material downstream. The most appropriate method would need to be determined by trials, and would probably result in a combination of methods involving a long reach excavator, small bulldozers and/or a barge-mounted pump and monitors for sluicing material into the river (Giudici et al 1996). The volume of tailings material resident in the river has been estimated by Locher (1997), to be 1.2 million m^3, or roughly equivalent to 1 years worth of tailings discharge from the Mount Lyell mine in the early 1990s. The cost of removing this material has been estimated to be about $2 per cubic metre, with an estimated $3.4 million dollars required to remove all subaerial river deposits.

If material were shifted from banks directly into the river (eg. with a bulldozer), it could result in greatly increased turbidity in the King River and 'plumes' of lower pH and copper-laden water entering Macquarie Harbour. The rate of tailings removal would be important, because if the material were rapidly mobilised there would be the possibility of creating much larger plumes than were common when tailings were discharged into the river system. Prior to tailings removal, additional information about the composition of the tailings and how the material would respond chemically during transport would need to be reviewed. Trials and modelling would need to be undertaken to determine the most favourable flow and wind conditions (to promote mixing in the harbour) for tailings removal.

6.3.3 Revegetation of tailings banks

The revegetation of the tailings banks in the King River would improve the visual quality of the river, and has been found to be occurring naturally in some areas. The aim of any revegetation remediation would be to assist the natural process. An enhanced vegetation cover would screen and eventually obscure the bare banks and dead tree stumps that are currently visible (Giudici et al 1996). Revegetation trials completed by Giudici et al (1996), have found that while revegetation can be achieved, the great variation in the nature of the banks means that the same approach cannot be used every bank. Generally it has been found that:

- vegetation readily colonises on stable oxidised tailings material;
- colonisation is evident on permanently damp un-oxidised tailings;
- vegetation does not readily colonise transition zones between un-oxidised and oxidised tailings;
- wind erosion and consequent physical abrasion of established plants will limit revegetation success;
- build-up of wind blown tailings around the bases of established plants will ultimately suffocate and kill that plant;
- areas subject to flooding will be difficult to revegetate;
- fluctuating water levels may affect the survival of established plants;

A variety of methods have been suggested to achieve the revegetation of the river banks including:

- earthworks which result in the exposure of the underlying natural river bank or excavation to the water table, with the subsequent establishment of native species in the constructed wet and dry areas. The success of this approach is dependent on the composition and metal concentrations of the underlying bank material;
- excavation of underlying soil profile and burial of the tailings in the excavation, with the excavated materials used to cap surrounding tailings. Revegetation will involve the establishment of native species on the recovered soils. The success of this approach is also dependent on the composition of the excavated material;
- cap the tailings with soil removed from a pit or quarry followed by native species revegetation;
- direct revegetation of the tailings following remedial action such as lime and fertiliser application.

Plates 2 and 3 show a before and after sequence of one of the revegetation trial plots which included fertilisation and fencing to eliminate grazing by animals It is suggested by Giudici et al (1996), that the present revegetation trials be monitored for a minimum of 5 years to ascertain the success of each treatment. A monitoring period of this length is required because other revegetation sites have been observed to have very irregular growth rates, with plots that responded quickly, frequently showing very poor growth over longer periods, and conversely, plots which were slow to initially respond, later exhibiting excellent results.

The cost of revegetation will vary greatly depending on the type of treatment required. An estimate of $2000 to $7000 per ha has been given by Giudici et al (1996) for revegetating the banks of the river, with an estimate of $31 000 to $107 000 for the revegetation of all prominent banks. A simple technique such as placing slash and broadcasting fertiliser would be relatively inexpensive, whereas interventions requiring extensive earthworks would cost considerably more. The involvement of the local community in the revegetation strategy could potentially reduce labour costs which can be considerable in a revegetation program, and provide the community with the opportunity to be actively involved with remediation.

A progressive revegetation strategy has been recommended which would allow for an immediate improvement in the visual quality of some areas as well as allowing for the incorporation of monitoring information obtained from the established trials.

6.3.4 Dredging of the lower King River

The tailings resident in the bed of the King River are an impediment to navigation near the mouth of the river. Shallow shifting channels make entering the river difficult and dangerous, which has impacted tourist operators running boat trips up the river. Removal of metal-rich material might also result in an enhancement in the aquatic habitat of the lower river, and remove a source of contamination to the water column, though the contribution of bed material to the overall pollution in the King River is very small.

Giudici et al (1996), have investigated the dredging of the lower King River and have reported the following. In order to dredge a channel about 2 km long, 30 to 100m wide and 2m deep about 120 000 m^3 to 300 000 m^3 of material would need to be removed. Dredging would need to be carried out by a small barge-mounted dredge with the material being deposited at the edge of the delta or in a deep water area within the harbour.

Plate 2 Revegetation trial in the King River—'before'

Plate 3 Revegetation trial in the King River—'after'

The channel would be expected to silt up due to the deposition of material washed down from upstream and/or transported upstream from the delta, and long-term maintenance would be required.

Because the material being dredged would remain under water for the duration of the dredging operation, oxidation would not occur, and there should be only a limited release of acid and metals. However, disturbing tailings may release adsorbed metals regardless of the oxidation conditions, and trials would need to be conducted.

The costs associated with dredging the channel are considerable, ranging in the millions of dollars. Additionally, because the channel would repeatedly silt-up, a program of maintenance dredging would be required over many years at similarly high costs. Additional information about the estimated costs is provided under Section 6.4.2 'Dredging of tailings material from the delta'.

6.4 Remediation options for the delta

6.4.1 Do nothing

The large delta at the mouth of the King River has been identified as a generally minor contributor to water quality problems in the harbour, although high flow conditions may contribute 'flushes' of metals. The 'do nothing' option would result in the episodic continued release of metals and acidity from the delta, and provide a visual reminder of the past poor environmental management of tailings from the Mount Lyell lease site. The delta would also continue to be a source of dust under dry windy conditions.

Giudici et al (1996) suggest that there is some evidence that the underwater toe of the delta is unstable, and that subject to ongoing wave and tidal actions, the slope of the delta front will eventually gain an equilibrium slope of 1:40, as compared with the present slope of about 1:20 near the mouth. Such a re-adjustment may result in the inundation of some of the top 1.5 m of material which has been found to be the largest contributor of pollutants. There also may be plumes in Macquarie Harbour if the delta front failed catastrophically.

Under the 'do nothing' option revegetation of the delta would proceed at its natural pace, with colonisation progressing slowly from the landward end.

6.4.2 Dredging of tailings material from the delta

The aim of dredging the delta would be to inundate the top 1.5 m of presently unsaturated tailings so that it was covered with water during the lowest tide. This would eliminate the oxidation of the sulphidic tailings and subsequent release of metals. Given the area of the delta, approximately 250 ha, a volume of about 2.5 million cubic metres of material would need to be removed for each 1 metre depth of dredging. Maintenance dredging would be expected to be required because the movement of tailings by wave action will result in the formation of submarine dunes, and movement of tailings laterally into the dredged channel and onto foreshore beaches, where oxidation would occur (Giudici et al 1996).

A disposal site for the dredged material would need to be identified, with the most straightforward approach being the transport of tailings to a deep water site within the harbour. Under these conditions, the tailings would not be expected to release any more metals than the sediments already present on the harbour floor. A distinct advantage of this scenario is that a hydraulic dredge could be used which would minimise turbidity problems during transport, although some deterioration in water quality during the dredging operation would be expected from turbidity and from the release of metals in pore waters (Giudici et al 1996).

The costs associated with dredging the delta are very high. The removal of the top 1.5 m from the delta has been estimated to cost between $15 million to $25 million depending on the size of the dredges used and the distance to the disposal area. The operation would require two dredges working at full capacity for about 2.5 years to move this quantity of tailings.

A variation includes the removal of tailings material to a tailings dam rather than the bottom of the harbour. While this scenario would eliminate the disturbance of sediments in the bottom of Macquarie Harbour, other issues such as the identification of a large enough site for a suitable dam, the engineering problems associated with the construction and on-going maintenance of such a dam, and the additional expense of dam construction and transport costs would need to be considered. Giudici et al (1996) have identified a possibly suitable site about 1 to 2 km east of the township of Strahan, and have estimated that the construction of the dam would require 500 000 cubic metres of earthworks and cost between $5 million and $10 million.

6.4.3 Revegetation of the delta

Revegetation of the delta using dryland species is only possible in regions which are stable and not subject to inundation by salt water, or do not have acidic conditions in the substrate (Giudici et al 1996). Clearly, the delta in its present condition does not lend itself to direct revegetation. However, the treatment of at least a portion of the delta surface to provide an environment more conducive revegetation is feasible.

The revegetation of the delta will reduce metal loads to the harbour by stabilising the delta surface and providing some bioremediation through bacterial activity, though this improvement is thought to be fairly minor (Giudici et al 1996). The establishment of vegetation will also help reduce dust generation and enhance the visual aspect of the mouth of the river which is viewed by tourists both by water and land.

Giudici et al (1996) have suggested that wetland and dryland areas be created by excavation down to the water table and placement of the dug out material to create intervening 'dunes'. The shallow depressions would be flushed by fresh water directed from existing wetlands, with the design to encourage flushing in winter months. Each region would be planted with appropriate species (figure 6.7). A trial investigating the appropriateness of this technique has been initiated near the landward side of the delta as shown in plates 4 and 5.

6.4.4 Other remediation options for the delta

Other remediation options which were investigated and generally found to be not feasible for one or more reasons included: dredging the whole delta, re-processing the tailings, diverting the river mouth and 'High-tech' solutions such as electrical fusion (Giudici et al 1996).

Dredging the whole delta has been eliminated as a practical solution because of the great expense involved, the risk of releasing significant pollutant plumes during dredging, and the need to identify a very large volume, suitable site for disposal.

Reprocessing the tailings was found to not be an economic proposition, and even if it were, it has all of the disadvantages associated with the movement and ultimate deposition of the waste material.

Diverting the mouth of the King River through a low saddle south of the river mouth into Pine Cove would be an expensive exercise which would eliminate the direct contact of King River water with the delta and solve navigation problems in accessing the King.

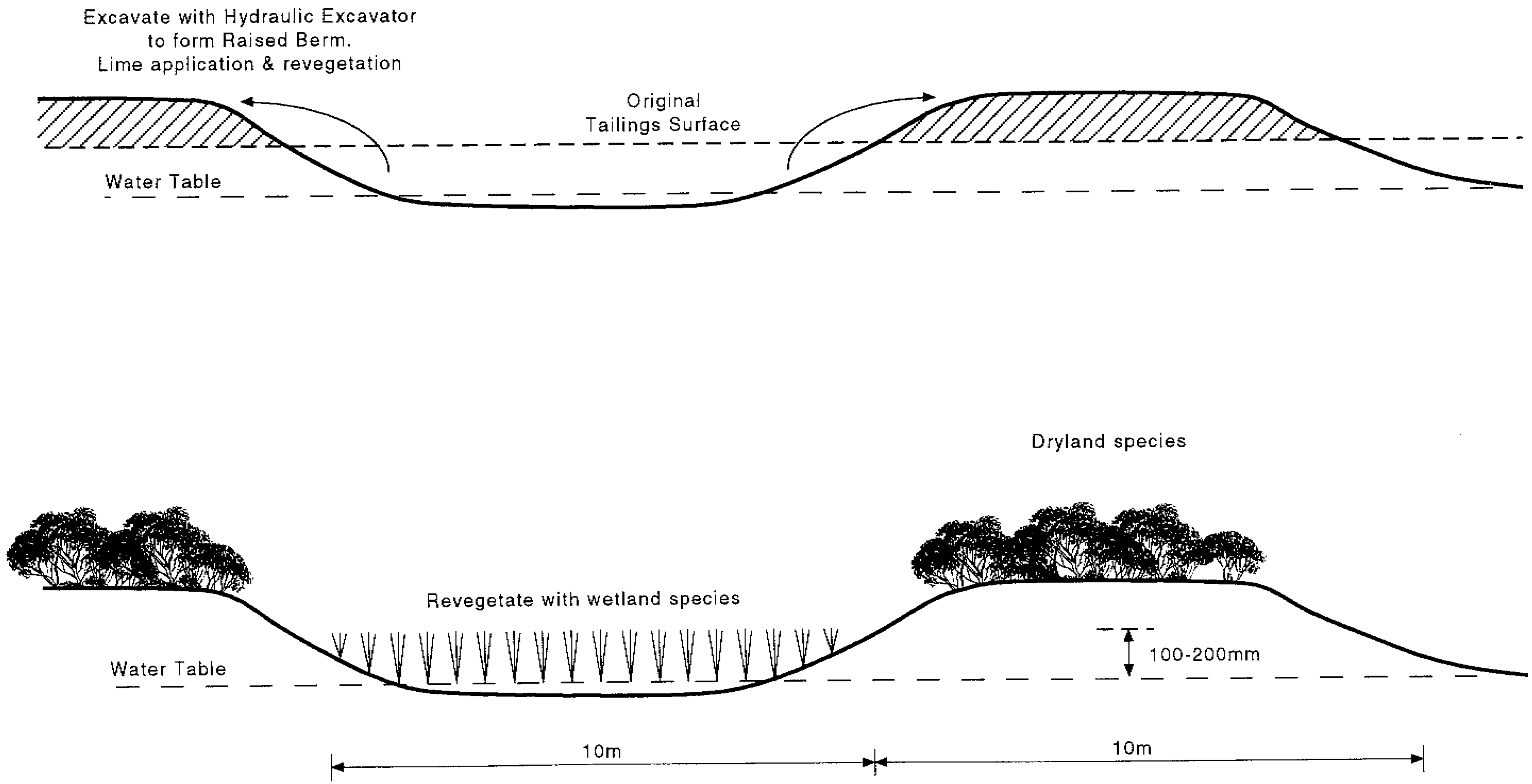

Figure 6.7 Proposed wetland/dryland revegetation strategy for King River delta

Plate 4 Construction and planting of wetland/dryland revegetation trial on the King River delta

Plate 5 Wetland/dryland revegetation trial during flooding of the King River delta

However, unless the delta were submerged or otherwise isolated from the atmosphere, oxidation would continue and metals and acidity would continue to enter the harbour. The visual pollution resulting from the presence of the delta would not be addressed by this approach either.

Unless the water quality coming off the lease site were first improved, diverting the river mouth would also divert toxic plumes into a different area of the harbour, with unknown consequences.

'High-tech' solutions, such as electrical fusion which would anneal the tailings into a more stable glass, are practical for small volume, highly dangerous wastes (such as nuclear wastes), but are economically prohibitive on a 'delta-sized' problem.

6.5 Remediation options for Macquarie Harbour

6.5.1 Do nothing

The 'do nothing' option for Macquarie Harbour will lead to an improvement in water quality if pollutant emissions from the lease site are substantially reduced. Water quality in the harbour rapidly reflects inputs from the King River (Koehnken 1996) so improving lease site emissions will improve the harbour. Similarly, since approximately 85% of the dissolved copper entering the harbour remains dissolved and ultimately exits the harbour, a reduction in lease site emissions will reduce copper inputs to coastal waters, and prevent further accumulation of copper in the harbour sediments.

If lease site emissions are not reduced, then no significant improvement in the water quality of Macquarie Harbour can be expected.

6.5.2 Dredge the most contaminated sediments

The sediments in the northern harbour have been identified as actively releasing metals to the water column. If this material were removed, presumably metal inputs to the water column would be reduced. However the great volume of sediments in the northern harbour (>100 Mm^3, Koehnken 1996) make this a highly expensive option, and one that would result in very little change in water quality unless all emissions from the lease site were eliminated. In addition to cost, the issue of a 'safe' disposal site and pollutant plumes associated with dredging operations would need to be resolved.

6.5.3 Capping contaminated sediments

Capping the most contaminated sediments in the harbour with a 'clean' layer of material such as clay, would reduce metal release to the water column without requiring the movement of the sediments. However, the costs associated with identifying, transporting and placing a suitable capping material have rendered this option not feasible (Guidici et al 1996).

7 Recommended remediation options

7.1 Objective of remediation strategy

The long-term objective of the remediation strategy is to ultimately achieve the environmental quality objectives set for the rivers and harbour (see section 5.7). Because the MLRRDP has overwhelmingly identified the lease site as the major source of contaminants, the remediation of the lease site to reduce the amount of acid drainage leaving it has been identified as the top priority of the remediation strategy. As summarised in this report, in order to achieve the downstream EQOs in the King River and Macquarie Harbour, approximately 99% of acid drainage emanating from the lease site must be eliminated. This is