

**RECOMMENDATIONS FOR
AN ACID DRAINAGE
REMEDICATION PROGRAM
IN THE ZEEHAN DISTRICT**

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Executive Summary

This report is based on a research thesis that was conducted in 1997 as part of an Environmental Geology course at the University of Tasmania. The research thesis identified that the streams passing through the township of Zeehan contained trace metal concentrations and acidity well above environmental guidelines. The main source of the contamination in the streams and creeks through the township was from a highly mineralized zone to the northwest of the town. The old mine workings in this region allow the exposure of large quantities of sulphide rich minerals to oxygenated water and it was concluded that this produces the majority of the contamination found in the streams of the township (Parr, 1997).

This report discusses ways to reduce the contamination in the streams passing through Zeehan.

A field study was conducted in January 1998 to look at the sources of the water contamination in the area northwest of Zeehan. Eight major water sources were identified of which five are the major sources of contamination.

The research thesis had identified two areas of natural remediation. It was concluded that the Zeehan Rivulet to the north of the township was having its contamination remediated by extensive wetlands. Wetlands are known as a remediation technique for this type of contamination (Jones & Chapman, 1992). A previous research thesis had been conducted into the wetland to the northwest of the township known as Svens Swamp in this report, after the student who conducted the study in 1995. Sven had found that the native vegetation in the swamp had adapted to the acid conditions and high trace metal contents of the waters. Currently this wetland is unable to cope with the high contamination in this area but as wetland forms an integral part of several remediation strategies, Svens swamp should significantly reduce the cost of setting up a wetland filter system. Therefore any remediation strategy for Zeehan should make use of the current naturally occurring remediation which is already happening in this wetland.

Various remediation techniques were then investigated and discussed with reference to the fieldwork previously mentioned. Using the Mount Lyell Remediation Reports as a

guide, each remediation technique's initial cost, maintenance costs and area required for implementation was assessed.

A selection of remediation techniques was then chosen for the Zeehan area from those discussed. The recommended strategies involves:

- Recontouring of the waste dumps and old workings to reduce the flow of oxygenated waters through the old workings.
- Removal of iron hydroxides and small waste piles in Svens swamp to assist the wetland in remediating the waters.
- The implementation of an alkalinity addition system known as SAPS to reduce the acidity of the waters, from the five contamination sources identified. Settling ponds for the precipitation of trace metals and the reduction of water flow through Svens swamp would be part of this.
- Capping of the larger waste piles including any contamination materials dredged out of the wetland using a clay cap or three layer capillary break capping system if the materials can be found.
- A large settling pond could be constructed at the old Montana No. 2 minesite at the end of the wetland and just before the township to allow the final settling out of any trace metals. This would also provide a water cover to the old waste piles here, preventing them oxidizing further and producing more contamination.

Before implementation of this strategy, monitoring of the water sources in this area needs to be undertaken to confirm that the right water sources have been chosen for the SAPS treatment. A pilot study would also be required to prove that the recommended remediation strategies would purify these waters. Any further work on remediation in this area would need to be combined with an acceptable water-monitoring program to show any problems or successes in remediating this old mining area.

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Background

During 1997 a thesis entitled Acid Mine Drainage in the Zeehan area was produced by myself, referred to here after as the research thesis. This involved several field trips to Zeehan and extensive water sampling and analysis of pH, Eh, conductivity, temperature, alkalinity, sulphate content and concentration of seventeen elements (Ag, Al, As, Cl, Cd, Co, Cu, Fe, K, Na, Ni, Mn, Mo, Pb, Sn, V & Zn). Many of the results used in this report are based on the research thesis and onsite pH tests carried out in early January 1998.

The results showed that pH of water is a good indicator of the amount of contamination from acid mine drainage (AMD) present in the waters. This enabled the use of pH data in this report to define the contamination from various AMD sources where no other data was available.

Visual indicators of contamination due to high build-up of iron hydroxides and the presence of manganese reducing bacteria were also used in determining AMD contamination sites and potential areas requiring remediation. Where possible adits were checked and waste piles were measured to determine volume of materials.

The research results indicated that the highest contamination levels would be reached after the first heavy autumn rains in April. Rainfall data from the area was used to extrapolate what stream flows and contamination levels would be during this period of maximum contamination.

Remediation strategies used in this report come from the 1996 MEND conference proceedings and the Mount Lyell Remediation Report 108, Remediation options to reduce acid drainage from historical mining operations at Mount Lyell, Western Tasmania. While the locations of Mt Lyell and Zeehan are only 15kms apart the Zeehan mineral field has a different style of mineralization and therefore major modification of the Mt Lyell techniques maybe required. Extensive laboratory testing or an onsite pilot study, neither of which are included here due to constraints on the report preparation, can only find out these differences.

Defining the problem

Acid Mine Drainage from old mine workings in the Zeehan area is contaminating the creeks flowing through the township of Zeehan. One of the results from the research thesis was a contamination map showing the areas of worst AMD contamination around Zeehan. The large Yellow section in figure 1 starts at Queen hill and moves northwest identifying this area as the origin of the worst of the AMD contamination effecting the township of Zeehan.

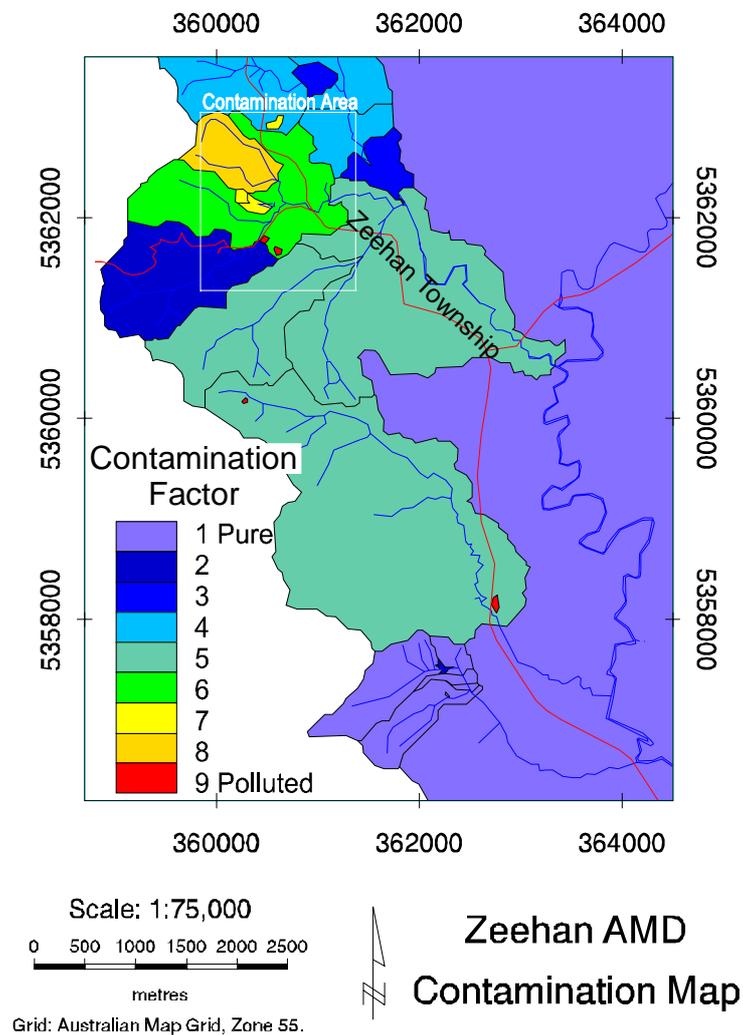


Figure 1: Hazard map of the AMD contamination around Zeehan (Parr, 1997).

This map shows that the majority of the AMD pollution was coming from the old mines down the northwestern side and across the valley from Queen Hill. This conforms to the model of geological controls on drainage waters proposed in the

research thesis. These highly contaminated waters are originating from an area of high pyrite mineralization formed by the fluids from the Heemskirk granite, which lies close under the surface. The results of the research thesis found that the waters passing through the township of Zeehan were contaminated when compared to the Australian National Water Quality Guidelines for Aquatic Ecosystems and the results are shown in Table 1.

Table 1: Contamination levels for Silver Lead Creek entering and the stream leaving the township of Zeehan and the Australian National Water Quality Guidelines for Aquatic Ecosystems (1992).

Contaminant measured	Silver Lead Creek Before Township	Stream leaving the Township	Guideline
pH in field	3.8	4.5	>6.5
Al (ppm)	1.45	0.36	0.01
As (ppm)	0.01	0.00	0.05
Cu (ppm)	0.05	0.02	0.00
Fe (ppm)	10.32	1.96	1.00
Ni (ppm)	0.04	0.02	0.02
Pb (ppm)	0.31	0.18	0.001
Sn (ppm)	0.22	0.06	<0.001
Zn (ppm)	3.68	2.13	0.005
Cd (ppm)	0.01	0.01	<0.001

Location of Acid Mine Drainage point sources

The mines in the main contamination area (Queen Hill and to the northwest of Queen Hill), are all rich in pyrite which is found in veins throughout the old workings and can make up to 10% of the minerals in the waste rock piles in the area. This area is noted geologically as the Pyrite zone of mineralization and is referred to as the Contamination Zone forthwith (Both & Williams, 1968). The oxidation of all the sulphides in the contamination zone will take hundreds of years. The main minesites in this zone are the Zeehan Queen No. 4, Stormdowne open cut, Oonah and Junction mines (Fig 2).

There are eight major sources of water entering this area, indicated in figure 2, five of these sources contain high levels of contamination that require remediation.

Zeehan Queen No. 4 shaft

Location: H (fig 2)

Discharge Rate: 1.88 L/sec

This is the old shaft from the main workings of the Zeehan Queen No. 4 mine. The water flows up out of the shaft and overflows into Silver Lead Creek. The contamination here is extreme and marks the start of the contamination in Silver Lead Creek. The source of the AMD here is groundwater soaking through the old underground workings. Blissett in his report from 1962 says that the main ore body mined here was Clarkes Lode. Clarkes Lode is a pyritic ore body striking northeast and containing irregular bands of Galena and Stannite, with traces of Chalcopyrite and Sphalerite. This was first mined from adits into Queen Hill and then accessed from the shaft here and at Zeehan Queen No. 3. This history indicates that the shaft is connected to many of the old workings both above on Queen Hill and further northeast. Blissett indicates that the main mining stopped in 1905 with only minor scratchings by prospectors since.

The underground workings could cover several hundred metres and even if the various adits and shafts are not physically connected, groundwater can still pass from one to the other through the faults and porous rocks. The flow rate here indicated some pressure of water and I suspect that the old workings are flooded above the height of this shaft, making this the lowest point open to the surface in the underground workings.

The source of AMD contamination here is oxygenated water flowing through the sulphide mineralization. Below the water table only dissolved oxygen is able to react with the sulphides. In stagnant flooded workings the oxygen is used up and the sulphides cannot react. Only flooded workings with free flowing water as observed here produce AMD contamination (Sengupta, 1993).

Zeehan Queen No. 4 surface runoff

Location: G (fig 2)

Discharge Rate: 0.67 L/sec

The surface runoff from the waste piles at Zeehan Queen No. 4 and about half of the northwest side of Queen Hill run through the drain here by the side of the Trail Harbour road. This is due to the topography of Queen Hill where the drainage centers on the Zeehan Queen No. 4 minesite.

The source of the contamination here would be from water soaking through the waste dumps covering Queen Hill. Many of these waste piles have water catchments formed behind them forcing the surface run off from rain to pool behind the waste rock dumps and drain by soaking through to the front of the waste pile. This soaking leaches out the AMD contaminants as oxygenated waters come into contact with the sulphides in the waste piles (Sengupta, 1993).

Adit on Trial Harbour Road

Location: F (fig 2)

Discharge Rate: 0.58 L/sec

Here by the side of Trial Harbour road a small adit enters Queen Hill. The adit is flooded and a small trickle of water flows out of it and into the drain at the side of the road. The water probably originates from groundwater leaching into the side of Queen Hill.

Pipe from under Trial Harbour road

Location: E (fig 2)

Discharge Rate: 1.21 L/sec

The pipe here corresponds with an adit from the old workings as seen in figure 3. The adit is the lowest opening of at least two adits that run into Queen Hill and probably drains ground water from such areas on Queen Hill as Stormdowne open cut. The build up of iron hydroxides in the pipe is considerable, therefore indicating high levels of contamination.

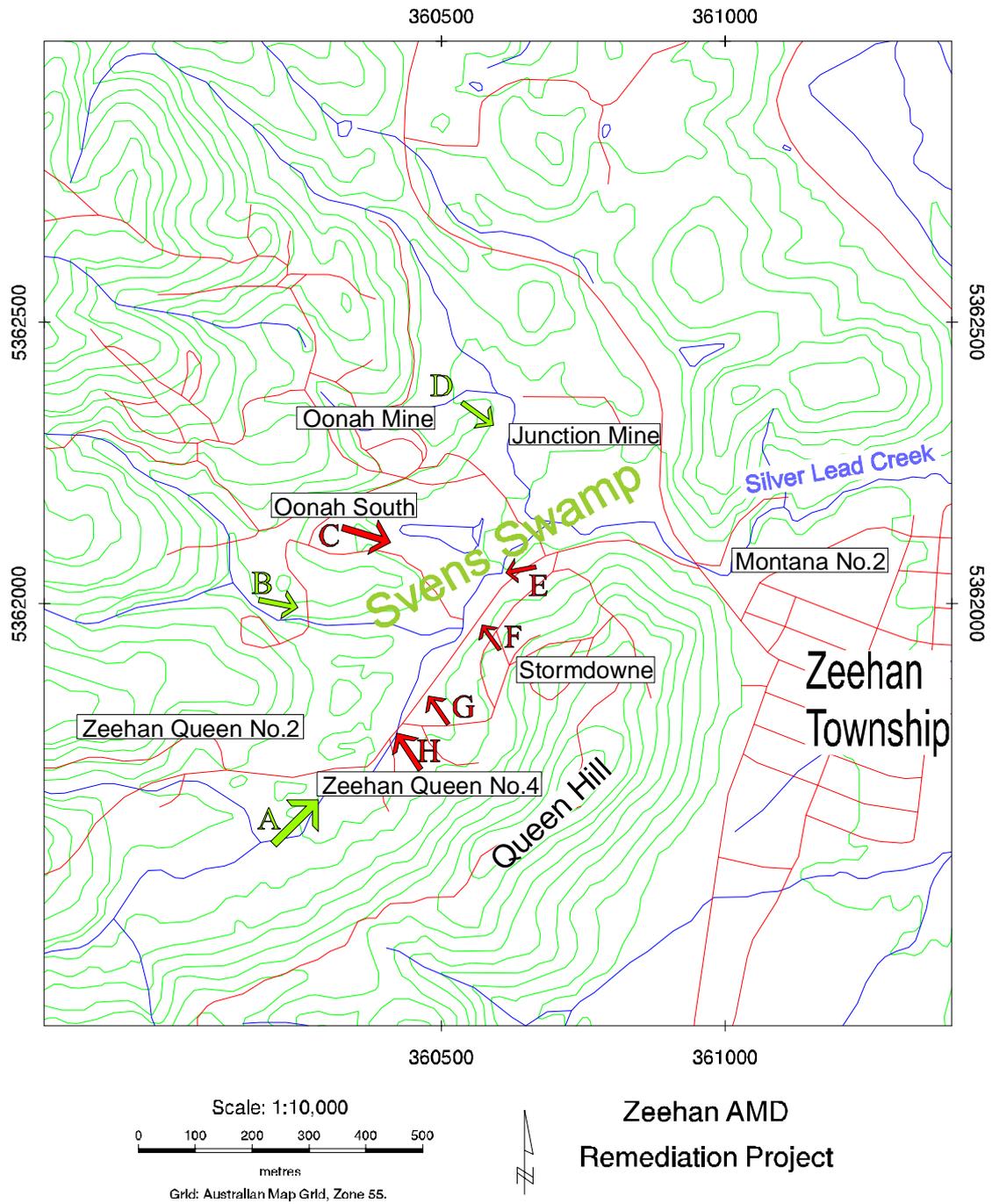


Figure 2: The Contamination Zone (Queen Hill and areas to the northwest of Queen Hill) is the source of the main contamination from AMD. Water enters the drainage of this area from eight major point sources as indicated. Red arrows indicate the contaminated sources, green arrows the less contaminated sources.

Collapsed Adit at the minor Oonah Mine site

Location: C (fig 2)

Discharge Rate: 0.68 L/sec

The water here is the second worst AMD contamination in the Pyrite zone after Zeehan Queen No. 4 shaft. This appears as a large pond with clear water. Stirring the water exposes the iron hydroxides that line the pond and releases methane gas bubbles from the pond indicating sulphur-consuming processors are probably active here (Sengupta, 1993). This drainage precipitates the largest volume of hydroxides in the area. The hydroxides cover an area 15m wide by 124 m long in Svens swamp and are over a metre deep in parts, giving a volume of 1860m³.

Maps of the old workings indicate that the source pond could be the collapsed end of an adit that leads back up to the main Oonah mine. Certainly the Main Oonah mine contains large waste piles with 10-15% sulphide minerals. The mine also sits in what should be a large catchment area and yet little drainage comes from the main Oonah mine site during the dry summer months. I suggest the groundwater soaking through the waste dumps at the main Oonah mine is draining underground and out through the adit here, making this the lowest point in the underground workings from the Oonah minesite.

Waste rock piles

There are approximately thirty piles of waste rock or muloch in the contamination zone and four areas of Hydroxide precipitation. An estimate of the volume and area covered by these is indicated in Table 2. There is 12368 m³ of muloch occupying some 13830 m², while there are 6532 m³ of hydroxide precipitates covering 7354 m². These waste piles can be grouped into four locations: the Zeehan Queen No. 4 mine site, Oonah mine site, Svens swamp and the other Queen Hill sites (Figure 3).

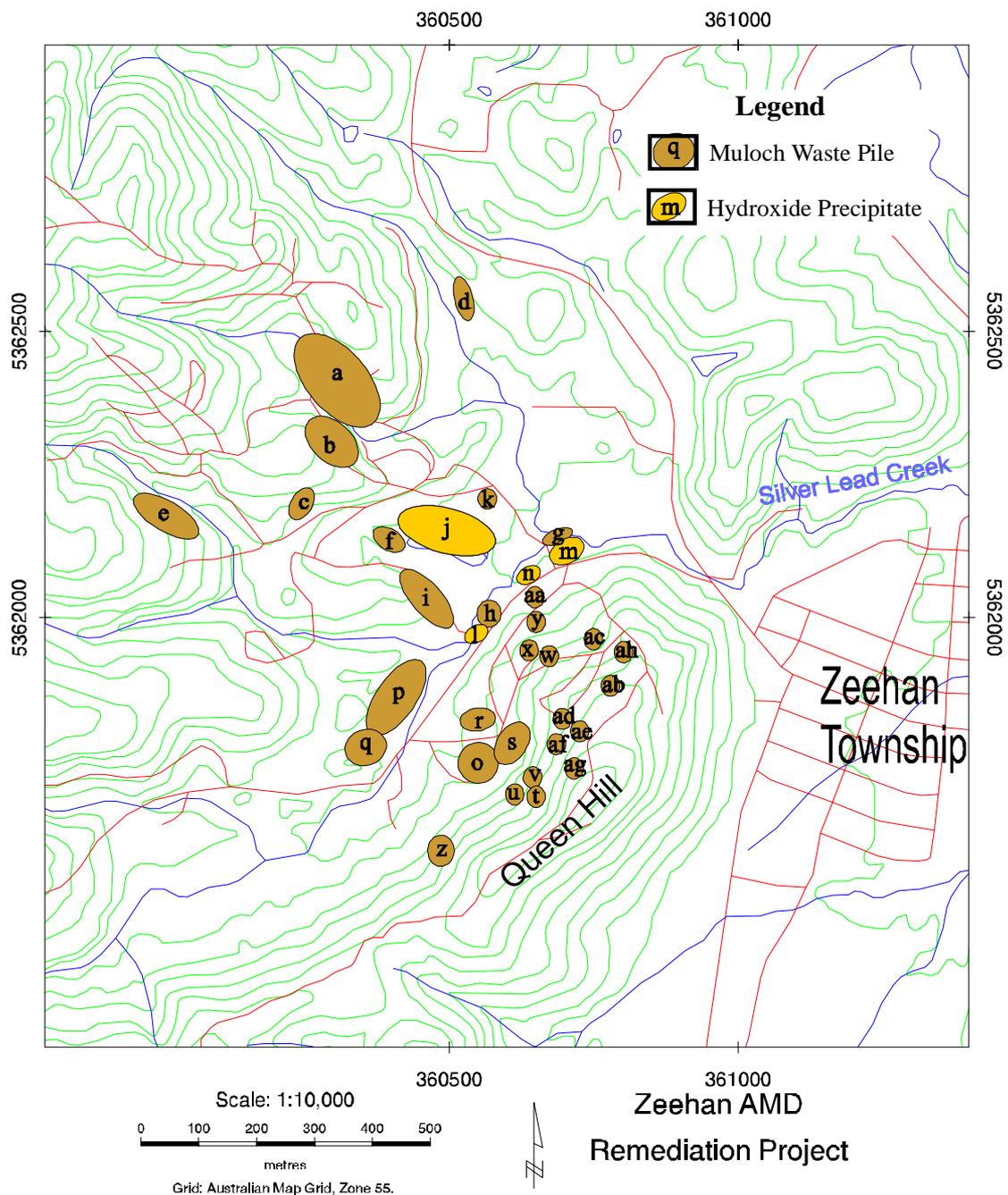


Figure 3: Location of waste piles from Table 2.

Table 2: Estimates of the volume and areas of the Waste piles of Muloch (M) and Hydroxide precipitation (H) in the contamination zone.

Waste Piles

Title	Code	M or H	Volume (m ³)	Area (m ²)
Oonah Mine				
Eastern	a	M	1135	512.5
Southern	b	M	344	709.5
Small Southern	c	M	677	646.8
Junction mine	d	M	78	112
Oonah West	e	M	1529	1575
Oonah in swamp	f	M	588	672
Sven's Swamp				
Dyke by SL	g	M	23	23.7
Adit Muloch	h	M	108	66
Course Way Dyke	i	M	46	44.5
Precipitate (Yellow Boy)	j	H	6440	6468
Small pile	k	M	4	10.8
Hardpan by Course way	l	H	2	15.3
Hardpan by Dyke Trial Harbour Rd	m	H	85	858
Hardpan by pipe	n	H	5	12.84
Queen Hill Zeehan Queen No. 4				
Large Pile	o	M	349	345
Car Park	p	M	4144	3751.8
Next to carpark	q	M	752	960
Small Disturbed area	r	M	1054	1071
Large Disturbed area	s	M	880	910
Top Adit Central	t	M	17	68.8
Top Adit southern	u	M	33	55.5
Top Adit northern	v	M	7	93
Queen Hill others				
Stormdowne 1	w	M	38	160
Stormdowne 2	x	M	44	230
Road below SD	y	M	29	126
Southwest of ZQ4	z	M	14	27
Above pipe on Trail Harbour road	aa	M	112	126
Waste pile near top of road	ab	M	83	120
Adit East of Stormdowne	ac	M	80	86.4
Above ZQ4 workings & SD	ad	M	38	91
Above ad pile	ae	M	34	55
Just above ZQ4	af	M	118	494
Highest pile on Queen Hill	ag	M	5	12
3 waste piles on hill above pile ac	ah	M	7	675

Queen Hill Zeehan Queen No. 4

Estimates show that over half the volume of waste rock is located at the Zeehan Queen No. 4 mine site. The largest muloch pile is spread out across the Trial Harbour road from the minesite. This area could be used for tertiary remediation treatment with the

muloch relocated and then removed from the sulphide oxidation cycle. These piles are only loosely compacted and easily allow the inflow of water.

Queen Hill other sites

The other waste piles on Queen Hill are significantly smaller than the waste piles at Zeehan Queen No. 4. These piles mostly divert the surface run off into the old workings. Many of these piles trap water behind them forcing the water to flow through the uncompacted muloch contaminating the water.

Svens swamp

The causeway muloch pile through the swamp along with another deep in the swamp are covered in vegetation and are no longer considered a contamination source. This maybe because these piles show signs of being compacted. The other muloch piles in the swamp are less compacted and are probably adding contamination were it is least needed in the naturally remediating wetland. These piles would be less than 200 m³ and could be relocated away from the swamp and removed from the sulphide oxidation cycle.

Oonah Mines

The large muloch piles at the Oonah mine contain materials rich in sulphides suggesting high levels of contamination. The site is located at the base of a large water catchment suggesting high water flows through the waste piles and lots of contamination. Contrary to these observations the flow of contaminated water from this site is low. The waste piles have had some revegetation work carried out several years ago; this is starting to take off. As the revegetation is progressing and contaminated water flow is minimal this site could be left the way it is.

Naturally Remediating Systems

The swamp, which stretches from the old Zeehan Queen No. 4 workings to the Trial Harbour road intersection, is a naturally remediating system in the area. Research from Sven Ladiges in 1995 has shown that wetlands are generating conditions for sulphur reduction and heavy metal precipitation from the solutions. To get the most from these natural processes, the contaminated waters should have a good acid buffering potential before entering the wetlands to counteract the acid generation from sulphate reduction.

These wetlands form natural wetland filtering systems. Wetland filter systems are complex assemblages of aerobic and anaerobic bacteria, floating plants; abiotic chemical processes emergent rooted plants epiphytes on surface plants and algae all co-existing. These complex saturated environments are able to remove trace metals from water and can raise pH levels, making them ideal for the remediation of AMD. The processes that reduce metal concentrations in a wetland are shown along with their controls in table 3 (Jones & Chapman, 1992).

Under oxidizing conditions Fe and Al will precipitate out of solution and as the pH increases maximum precipitation will occur above pH 6. These precipitated hydroxides will scavenge Cd, Cu, Ni, Pb and Zn with great efficiency above pH 6. Trace metals are also removed from solution by adsorption onto biofilms, algae or epiphytes. The removal of sulphate from the waters will require reducing conditions. These can occur in the substrate especially when it is carbon rich. This process can be increased by sulphate reducing bacteria (Jones & Chapman, 1992).

The key factor then in a wetland filtration system is an initial pH above 6 and the presence or absence of oxygen. Water flow rate and the amount of plant material in the flow channels also effect remediation. The metals precipitated in a wetland can be easily reactivated by flood events. So the flow of water through the wetland needs to remain constant for optimum storage of metals. The locking up of metals in a wetland is a finite process, but no research into the limitations on the metal storage potential in a wetland has been done (Sengupta, 1993).

Table 3: Processes in wetlands that reduce metal concentration and acidity
(Jones & Chapman, 1992)

Process	Nature	Controlling Variables
Dilution	Physical	Volume of Water
Dispersion	Physical	Flow velocity, channel geometry and roughness
Oxidation	Chemical Microbiological	Concentrations of oxygen and organic carbon
Precipitation/ co-precipitation	chemical	Concentration of components, pH, redox potential
Adsorption on precipitates	Chemical	Amount of precipitation, concentrations of major cations and anion, pH
Adsorption/ion exchange on suspended and bed sediments	Physical Chemical	Concentration of suspend sediment, particle size and mineralogy, pH, concentrations of major cations and anions
Sulphate reduction	Microbiological	pH, organic carbon, concentrations of oxygen and sulphate
Uptake by biofilms, algae and aquatic macrophytes	Chemical Biological	Density of plants, temperature, light intensity, availability of nutrients

Due to the several decades since mining has finished here a natural wetland filter system has developed with many of the processes required for remediating the AMD. The wetland could be assisted by raising the pH of drainage waters entering the natural wetlands to near neutral. This would greatly increase the precipitation of trace metals out of Silver Lead Creek by the wetland.

Reducing the flow of water throughout the wetland by adding a couple of large settling ponds would aid metal precipitation. One could be on the other side of the Trial Harbour intersection where a barren empty mine dump currently stands. These ponds would act as the main storage for the precipitating trace metals and this would need dredging to remove large accumulations of this material every few decades. The time span for dredging would need to be assessed by further studies, as would the placement of settling ponds (fig 10).

Remediation Strategies

AMD contamination can be remediated by removing the sulphides from an oxidizing environment or by treating the waters formed to neutralise the contamination.

Remediation strategies can be divided into three categories (Sengupta, 1993):

1. Primary remediation is used before sulphide oxidation begins and involves the control of acid producing bacteria, exclusion of oxygen, exclusion of water, control of temperature, sulphide isolation and controlling the pH to prevent oxidation starting.
2. Secondary remediation strategies center on the isolation of the source from the oxidizing environment. This involves covering waste piles and plugging adits and shafts.
3. Tertiary strategies involve the remediation of drainage waters away from the source using passive system, limestone drains and wetland filter systems. More active tertiary strategies include chemical extraction and treatment plants that filter the waters, however these require high and ongoing maintenance.

Primary Treatments

As sulphide oxidation and AMD contamination are already occurring at Zeehan primary remediation techniques won't work.

Secondary Treatments

Secondary AMD treatment is based around isolation of sulphides from air or water. Entombment or encapsulation of waste rock, tailings and slag piles are the way this isolation is achieved.

This form of remediation requires careful planning to reduce long-term maintenance and receive the best possible remediation with the resources available. The various stages in design are:

- Site allocation involves looking at the background environment of the disposal site, the weather conditions experienced, natural drainage porosity and stability of the surface rocks which will all impact on any disposal method constructed.

Knowledge of the groundwater movement is required to prevent the contamination moving into the ground water system and poisoning other areas.

- Design philosophy and performance criteria for a containment area determines the standards the disposal site needs to obtain in water quality and aesthetics. The tolerance of the receiving environment from any breakouts of the containment needs to be considered.
- Solution design involves the modeling of various engineering solutions to determine which best fits the site conditions and meets the criteria established in the philosophy and performance criteria. Key considerations at this stage would include seepage generation, stability of the solution and quality of water from the site.
- Economic evaluation considers the funding available to construct and maintain the containment area.
- Ongoing responsibility of the disposal site once construction has finished needs to be undertaken to allow further monitoring of the disposal site to gauge whether predicted performance criteria is achieved. On-going maintenance needs to be undertaken to ensure continued performance.

The four main containment options are encapsulation, in-pit disposal, mixing and co-disposal and micro-encapsulation (Watson, 1992)

Tertiary treatments

Tertiary treatments involve remediating the AMD waters once they leave the waste pile or adit. Treatments are designed to raise pH, which involve using an acid buffering agent like limestone to raise pH and a filtering system to remove the trace metals. Limestone can be added using a lime doser which involves oxygenating the waters by cascading them over falls prior to the addition of lime or magnesia.

Alternatively anoxic limestone drains can be used to remediate pH. Mechanical water filtering systems usually need the pH to be as high as pH 10 to completely remove the metals, these systems are expensive to run and maintain. A natural wetland filter system requires an initial pH above 6 to facilitate metal removal. Construction costs of a wetland filtration system maybe high but once established its maintenance is minimal. The preferred treatments of AMD at minesites are the use of anoxic limestone drains to neutralise pH and follow this with a wetland filtration system to remove trace metals.

Remediation options should ideally bring the water quality back to the natural levels before mining started in the area.

As the contamination sites are not producing revenue the ideal secondary and tertiary remediation techniques for the Zeehan area would be low maintenance cost strategies. This means secondary treatment strategies that reduce the oxidation of sulphides using natural processors and tertiary treatments that complement the existing wetland filter systems for treating contaminated waters

Several of these remediation strategies such as Electro Wining and Lime Dosing are not considered as they involve high long-term costs. A variety of other treatments are available for consideration and these range from preventing formation of AMD to remediation processing of the AMD downstream from the source. A summary of the estimated cost of each treatment is found in table 4 (Miedecke, 1996). The treatments discussed here are:

- Recontouring surface workings for flow direction
- Capping of waste piles (Encapsulation)
- Flooding of old workings by plugging adits
- Prealkalinity saturation of receiving waters
- Porous reactive walls for neutralisation of AMD contamination
- Anoxic limestone drains for neutralising AMD contamination
- Successive alkalinity producing systems (SAPS) for neutralising AMD contamination
- Wetlands for removal of heavy metal contamination

Recontouring surface workings for flow direction

Recontouring of the old waste mounds to facilitate the surface runoff flowing over the waste mounds and redirecting surface flow away from the old workings will reduce the water penetration to the sulphides. This would involve filling in old workings to prevent water pouring off the hanging wall and entering the broken up ground or old workings directly below the hanging wall. Reshaping of waste piles to remove the areas where water ponds behind waste piles to reduce water from soaking through the waste rocks (Fig 3).

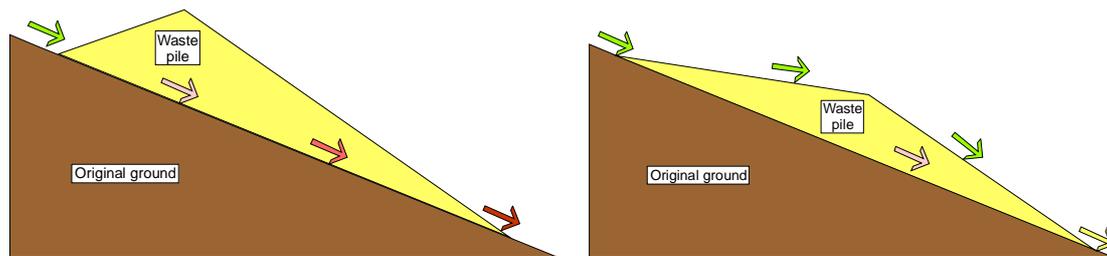


Figure 4: Recontouring and compaction of waste piles should reduce the flow of contaminated water through the piles. As indicated by the arrows in the diagram, the red arrows indicate contaminated water while green is pure water.

Table 4: Costs and land requirements of various AMD remediation treatments
(Modified from Miedecke, 1996)

Remediation treatments	Total cost for the main contamination sites in dollars	Area required or size of structures	Notes
Successive Alkalinity Producing System (SAPS)	215 000- 480 000	3ha	A wetland filter system is included in these estimates. As a natural wetland is already present, costs should be reduced.
Anoxic Limestone Drains (ALD)	250 000	7 500 tonnes	This treatment is used in conjunction with a wetland filter system. As a naturally occurring wetland exists, few further costs are required.
Prealkalinity	500 000	15 000 tonnes	The waters are really too neutral before the contamination to gain much alkalinity from limestone.
Capping Encapsulation	300 000		This estimate is for a simple clay cover. A capillary break cover would be almost double the cost.
Recontouring	50 000	NA	
Plugging	100 000	Minimal	Plugging would mean that the workings would flood up to the next surface opening.
Porous Walls	100 000	Minimal	Fitting a porous plug of compost to leaking adits and shafts. A nice idea but a new technology.
Wetland Filter	Naturally occurring here		Naturally existing wetland could be made use of and enhanced greatly reducing the cost of a wetland filtration system.

Capping of waste piles (Encapsulation)

Encapsulating waste piles involves isolating the rocks in the waste piles away from the normal environment this involves covering piles of sulphide rich rock with benign material to prevent the intrusion of air and water to reduce oxidation rates. For this to be effective the pile needs to be compacted and sculpted to assist surface runoff, preventing erosion and allowing access to the slopes by machinery (Watson, 1992).

Waste piles can be covered with a variety of materials from large synthetic liners that seal out everything but are easily pierced to more natural covers using combinations of soils, clays and vegetation (Watson, 1992)

Synthetic covers can be polymer coatings that can be sprayed on the waste piles. These can be applied to uncompacted piles but are very prone to subsidence unless support structures are included. The polymer coatings available are alkyd, asphalt, concrete, polyester, polysulfide, polyurethane, silicone, synthetic rubber, thermoplastic molten sulphur and vinyl. Polymer covers are easy to install and repair as they can be sprayed onto the waste piles (Sengupta, 1993)

Advantages

- Flexibility to conform and sufficient strength to support vehicles applying the coverage.
- Good weatherability and long wearing.
- Non-reactive with the waste stored.
- Immune to biological attacks.
- Easy of placement with minimal defects.
- Easy to repair.

Disadvantages

- Difficult to regulate coverage thickness.
- High cost of materials used.
- Specialised equipment to apply coatings.

Synthetic covers also come as membranes or liners, which provide barriers to air and water penetration of waste piles. These materials can be used on steep slopes but are easily damaged by subsidence. The general types of materials are Polyethylene, high-density polyethylene, chlorinated polyethylene, chlorosulfonated polyethylene, PVC,

ethylene propylene diene monomer and butyl rubber. These are usually draped over waste piles usually after a cover of sand has been applied and the edges and joints are sealed using specialised sealing equipment. They can be covered by soils but care needs to be taken not to damage the membrane and the slopes must be less than 3 to 1 or the cover will slide off (Sengupta, 1993).

Advantages

- Very low permeabilities typically below 0.1 cm/sec.
- Resistant to chemicals and bacteria.
- Readily installed as used in a variety of applications.
- Economic to install and maintain.

Disadvantages

- Vulnerable to attack from ozone and UV light.
- Limited ability to resist traffic.
- Susceptible to laceration, abrasion and puncture
- Weakening due to temperature extremes.
- Difficulties with making seams.

Natural covers can vary from a single layer of clay to several layers including a synthetic liner. These need to be designed for the area they are to be constructed in. To be effective natural covers need to be compacted and this involves resculpting the waste pile so no slope exceeds a 3 in 1 incline. The sculpting needs to prevent the forming of erosional channels that will remove or damage the cover. The best natural covers use a layer of silty material over a coarser sandy layer to create a capillary break (Figure 5). A capillary break creates a saturated layer of silt over the waste preventing air penetration. Capillary action will cause water to move from a material with large pore spaces to a material with small pore spaces keeping the silty material saturated and the sandy layer dry. To prevent the inflow of water shallow rooted vegetation can be planted in the silty layer or in a more porous layer above that to aid in increased transpiration. Vegetation will also assist erosion prevention. Water penetration of the inner sandy layer is also controlled by the thickness of the silty layer and in very wet areas an extra sand layer can be added to drain away excess water. The idea is to keep the silty layer saturated but balance the vegetation and thickness of the outer two

layers to prevent over saturation of the silt so that it allows penetration of water to the sand layer and the waste rock. Similarly the cover must prevent the silty layer from drying out and letting air penetrate to the waste material.

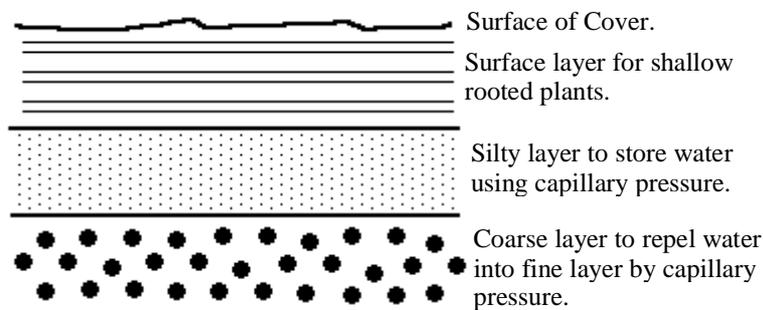


Figure 5: The three layers of an effective natural cover design.

Natural covers are far cheaper to build and maintain than synthetic covers as the materials are usually near at hand and with careful design the cover will stabilize and last indefinitely (Wilson per com, 1997).

As these covers need to last for thousands of years, design and maintenance are very important factors to consider.

Flooding of old workings

Flooding of the old workings by plugging of the egress points will allow back flooding of the old workings. This will trap the sulphides in the flooded areas in an anoxic environment preventing further oxidation of these sulphides. Flooding old mine workings is a good preventative treatment of AMD producing minesites.

Adits can be a point source of AMD contamination. Where the hydrology is known these can be plugged and work done to minimise further access of oxygenated water to the workings. If the hydrology and mine are not known the plugging of one adit can lead to the contaminated water seeping out elsewhere. The only recommendation in these cases is to keep plugging as this will increase the height of the watertable and reduce the oxidizing environment available for AMD production. The best plugging materials is one rich in acid buffering potential to assist in neutralising any leakage, making concrete ideal (Sengupta, 1992)

Ideally the Zeehan Queen No. 4 shaft could be plugged and this would back fill the old workings with stagnant water and stop the production of AMD. In reality there are no

really detailed maps of the old workings and the plugging of one shaft or adit could lead to other problems as the water flow is diverted to another area.

Currently we know the outflows from the old workings and these flows are treatable with tertiary remediation techniques. While plugging the known shafts and adits may drastically reduce the problem, it could also just move the problem further along.

Therefore plugging is not seen at this time as a viable solution to the Zeehan AMD problem.

Prealkalinity saturation of receiving waters

If a stream's alkalinity can be enhanced before it reaches the contamination the acidity can be buffered by the stream, leaving the existing wetland to filter out the trace metals (Miedecke, 1996).

No known examples of this technique can be found. Chemically the near-neutral natural waters will be slow to take up the alkalinity from the limestone. This would require limestone drains at least twice as large as those used on the contaminated waters. In the event of armouring from iron and aluminium the drains would need to be anoxic. So this technique appears to be twice as expensive as more traditional tested tertiary treatments and is not recommended here.

Anoxic Limestone Drains for neutralising AMD contamination

Limestone is a known buffering agent that will reduce the acidity of AMD contaminated waters. Under oxidizing conditions limestone will become coated by ferric hydroxide precipitate, reducing the contact surface area and the acid buffering potential of the limestone. In an anoxic environment the lack of oxidation of Fe^{2+} and Fe^{3+} stops the formation of the ferric hydroxide coating. Anoxic Limestone Drains (ALD) are usually constructed as a ditch filled with highly pure limestone that is flooded to remove the air and then sealed using a cover to prevent oxygen penetration. A sump at either end of the ditch excludes the air from the inflow and outflow. Inclusion of organic material initially helps to create the anaerobic conditions by feeding bacteria, which will rapidly consume any oxygen. The effectiveness of this remediation treatment depends on several factors. The water contact area with the limestone, rate of water flow through the drain, pH of the water initially and the

amount of dissolved Al^{3+} in the waters. At near neutral pH, the Al^{3+} will precipitate forming a gelatinous mass that can clog the drain (Jones & Chapman, 1992).

ALD will neutralise the acidity of the waters but these need to be combined with a treatment to remove the trace metals from the waters. Combining the ALD with a wetland filter system can do this (Miedecke, 1996).

Successive Alkalinity Producing Systems

A Successive Alkalinity Producing System (SAPS) is really a redesigned ALD with a combined wetland filtering system. SAPS starts with an alkalinity pond that works like an ALD to decrease the acidity of the water. A wetland filter and settling pond are the next part of the SAPS system; these allow the precipitation of any metals in the waters. This process of neutralizing acidity and settling out trace metals can be repeated several times until the water reaches natural purity levels (fig 6, Miedecke et al. 1997).

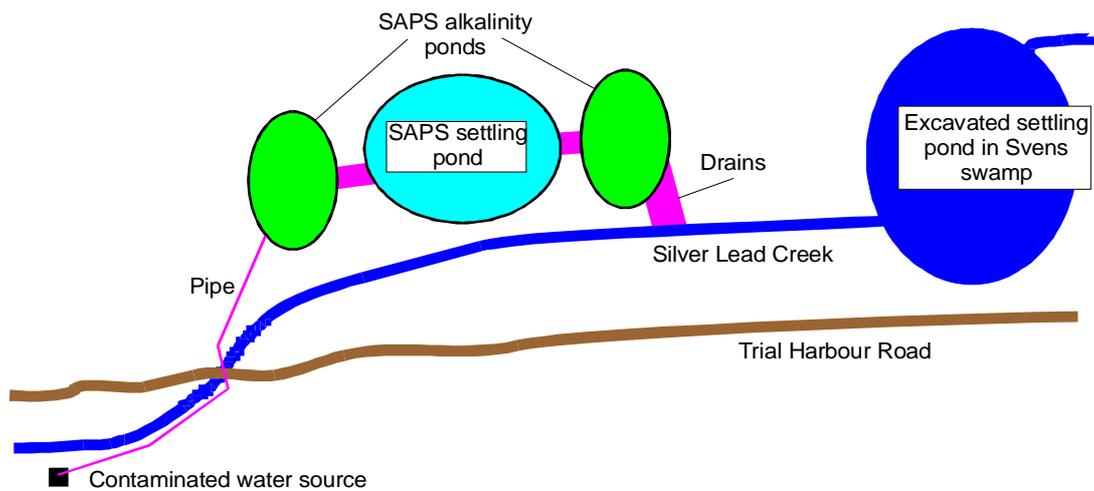


Figure 6: A typical SAPS system with two cycle repeats for a contaminated water source.

The alkalinity pond uses a compost filter to remove any precipitated iron and aluminium hydroxides from the waters before they come in contact with the limestone (Fig 7). The compost forms a rich organic layer that also removes the oxygen from the water keeping the limestone in an anoxic environment to prevent the formation of iron or aluminium oxide coatings on the limestone (Miedecke et al. 1997).

The water leaving the alkalinity pond would trickle through a small wetland area and then collect in a settling pond. The wetland would reoxygenate the water to assist in the removal of trace metals. The iron and aluminium will precipitate and settle out in

the settling pond or get caught up around the roots of the wetland vegetation. Other trace metals are mostly adsorbed by the hydroxides.

Supplying a cover over the alkalinity ponds would seem reasonable to prevent the public tampering with the alkalinity ponds and to stop them filling with rain water during periods of heavy rain.

Alkalinity pond design would depend on the seepage rate of water through the compost. If a layer of compost 0.5m thick has a hydraulic conductivity of 3m/day and the discharge from the water source is 1 L/sec the compost area would need to cover 34.6m². So a SAPS with two alkalinity ponds and a settling pond would cover 1 hectare for a 1L/sec discharge.

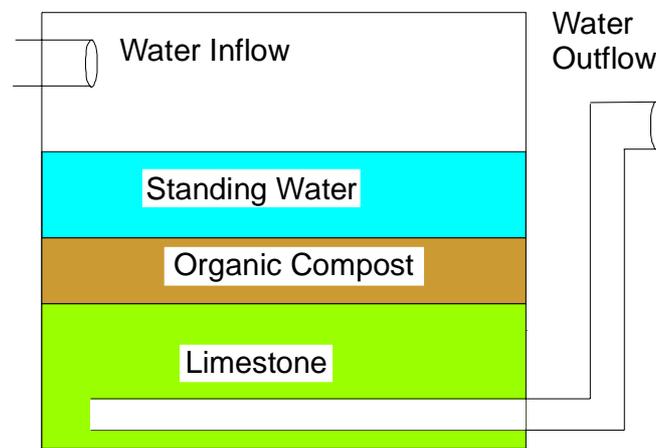


Figure 7: A section through the alkalinity pond in a SAPS system (Miedecke, 1996)

Wetlands for removal of heavy metal

Large wetlands are already in place in Silver Lead Creek, neutralisation of the pH of waters coming into the wetlands should improve the efficiency of these wetlands in scavenging metal contaminants. As chemical remediation processes in a wetland are acid producing alkalinity is required to buffer these processes (Table 3). If the waters contain alkalinity that can buffer the acidity that these process create the wetland is at its most efficient. However if the waters are already acidic the wetland needs to buffer the waters reducing the efficiency of the wetland to scavenge trace metals.

Creating large settling ponds for the metals to accumulate in can help the wetland scavenge the trace metals by slowing the flow of water and letting particulate matter

drop out of the solution. These settling ponds may require dredging every 50 - 100 years to remove the build up of waste metal particularly Fe hydroxides.

The old minesite at Montana No. 2 could also be made into a settling pond at little extra cost as this area is low lying and most of the old tailings have being removed. The remaining tailings are a source of contamination and flooding these by creating a settling pond will prevent them contributing any further contamination. The pond created will also act, as a final settling pond for any material not trapped in the wetland.

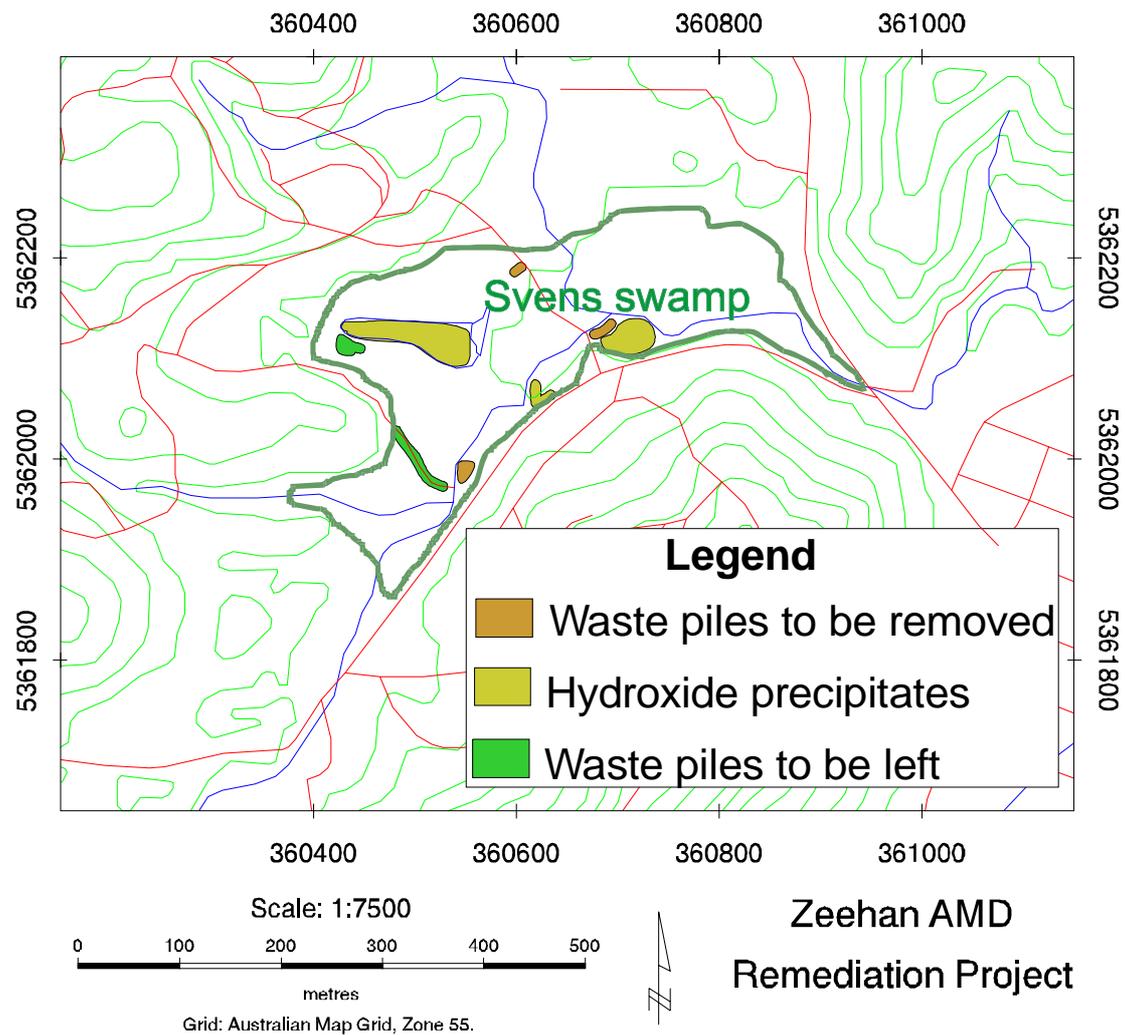


Figure 8: Waste piles located within Svens swamp

Several waste piles within the wetland, particularly those with little revegetation on them, could be contributing to the contamination. As these waste piles have a combined volume less than 200m³ they could be removed to a safe storage location (Fig 8).

The Hydroxide precipitates currently in the wetland can be reactivated during flood events causing contamination. A wetland can only hold a finite amount of contaminant material. The wetland here has extensive areas of these hydroxides. Removal of some of this hydroxide material would not only make room for more contaminates to precipitate but would prevent reactivation of this material and help to make room for any SAPS pond required or a large settling pond.

Possible location sites for Remediation materials

The remediation materials required would need to be an acid buffering material, capping materials and compost.

Acid buffering

The best acid buffering material is limestone. Small pockets of Gordon limestone are located in the Zeehan area. Ocean Mine south of Zeehan is the only reasonable location to extract the limestone. The quality of this limestone would need to be assessed with respect to acid buffering. It may be cheaper to haul in good quality limestone for constructing SAPS or ALD tertiary treatments (Zeehan Sheet, 1994).

Capping

Clay is the primary capping material and is found in abundance 20km north of Zeehan in an area of weathered Jurassic Dolerite (Zeehan Sheet, 1994). Some clay can be scavenged from the ridges within a few kilometres of the area.

Tillite is located only 3km north of Zeehan at the Zeehan Montana minesite and can be used instead of clay although a thicker covering will be required (Zeehan Sheet, 1994).

Coarse sandstone, which is ideal for forming a capillary break in a waste pile cap, is available only 5km south, at the back of the Tasmania Smelter site.

Topsoil and a growing medium are rare on the West Coast for forming the top layer of a capillary break cover. The clay maybe suitable or the topsoil might be scavenged from the surrounding area.

Compost

The best source of compost would be from the Zeehan citizen's household vegetable waste. This could allow the citizens to contribute to the project. Alternatively the sewage ponds at Zeehan may have sludges in the bottom of them that need to be dredged out and can be used for compost.

Recommended Strategies

I would like to recommend the use of four of the previously mentioned remediation strategies to be considered for use in the Zeehan area. The reasons for choosing these four strategies are explained below and where appropriate the order in which the strategies should be carried out is discussed (Fig 9).

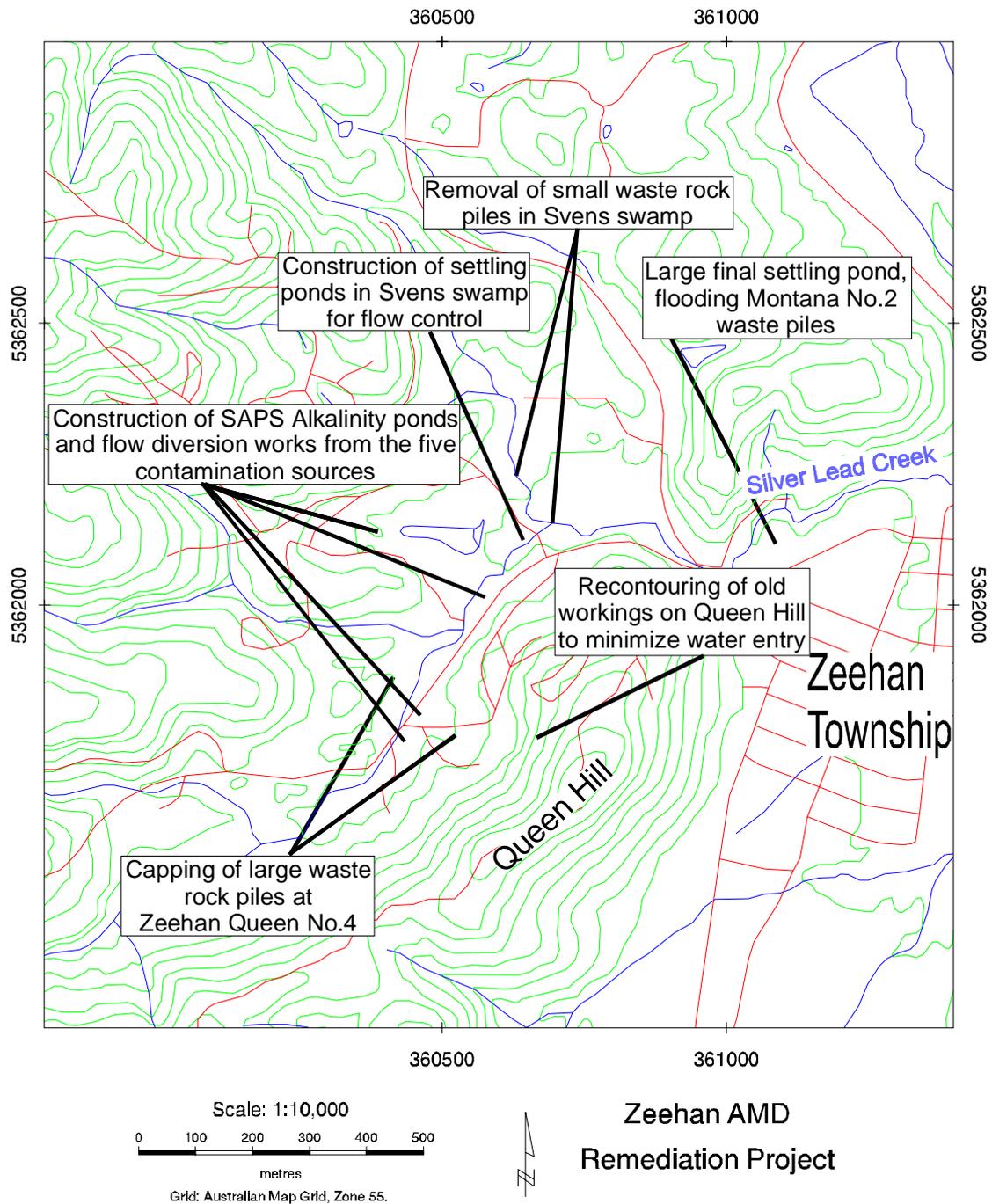


Figure 9: The recommended remediation strategies for the contamination zone.

Recontouring of waste piles on Queen Hill

Grading the old waste rock piles on Queen Hill to remove any ponding areas behind the waste piles and back filling of old workings. Compressing these graded waste rock piles to help minimise penetration of surface waters through the piles or down into the old workings. This should minimise the contamination of surface runoff from Queen Hill and may remove the need to treat any surface runoff altogether. Waters entering the old workings on Queen Hill are probably recharging the groundwater that is seeping out of adits and shafts at the base of Queen Hill. Recontouring would therefore reduce the flow of water out of these adits and shafts lessening the volume of water that needs treatment.

For these reasons after recontouring a period of monitoring should follow to detect changes in flow rates from adits and shafts at the base of Queen Hill and to see if the surface water runoff is reduced in AMD contamination.

Capping of the larger waste dumps at Zeehan Queen No. 4

Once the grading and compression of recontouring has been done on the waste rock piles on Queen Hill the larger waste piles at the Zeehan Queen No. 4 mine can be capped to further reduce through flow of water. These three piles were chosen as they contain large unconsolidated clasts of rock.

Waste rock and hydroxides removed from Svens swamp could be added to these piles prior to capping, to removing these materials too from the environment.

While a simple clay cap and diversion drains will make a difference in limiting water flow through these piles, a cap engineered with clay sandstone and vegetation coverage will be more efficient and better able to resist erosion. Cost and availability of materials will limit the cap being applied to these piles. If clay was readily available all the waste rock piles in the area should be capped.

Capping should be carried out after the final decision is made on which waste piles need to be removed as this material could be safely locked away under the caps covering the waste piles. This would make capping waste rock piles the last remediation strategy carried out in the area.

SAPS

SAPS are recommended over ALD and Prealkalinity as the tertiary remediation treatment. A SAP is better able to cope with high iron loads that can clog an ALD. No current implementation of prealkalinity treatment in AMD remediation can be found and the treatment would require acidic waters to get the most reaction from the limestone, whereas background waters are reasonably pure and so will barely react with the limestone to increase stream alkalinity.

SAPS would involve the construction of large ponds to catch water from each of the five main contamination sources. The ponds contain standing water over compost material, which covers the base of limestone pieces. Water drains down through the pond and out through the base increasing alkalinity (fig 7, Miedecke et al. 1997). Hydroxides are precipitated in the compost, which also forms anoxic conditions for the prevention of more hydroxide precipitates.

After flowing through the alkalinity pond the water is passed through a settling pond and then through another alkalinity pond before passing into Svens swamp. Where possible the second alkalinity pond could combine water from two of the sources. The size and number of these alkalinity and settling ponds is based on the discharge rates and acidity of the contamination sources. This step should be constructed after the recontouring to determine any change in discharge rate that may occur due to the recontouring.

The contaminated water from Zeehan Queen No. 4 would need to be redirected away from the stream. The crucial factor here is how high this water level can be raised before it flows out elsewhere?

Enhancing Svens swamp

The final part of the remediation strategy involves aiding the existing wetland to remove trace metals from the waters. To do this any contaminating muloch piles in the wetland can be removed along with some of the extensive hydroxide precipitates. This will remove the chances of these materials causing contamination within the wetland. A large settling pond can be dug in the middle of the swamp and a second one constructed at the Montana No. 2 minesite (Fig 10).

Diversion of the streams course through the wetland to help reduce the flow rate of the water and the setting up of small barriers to cascade the water aerating it will help the wetlands natural processes at minimal cost.

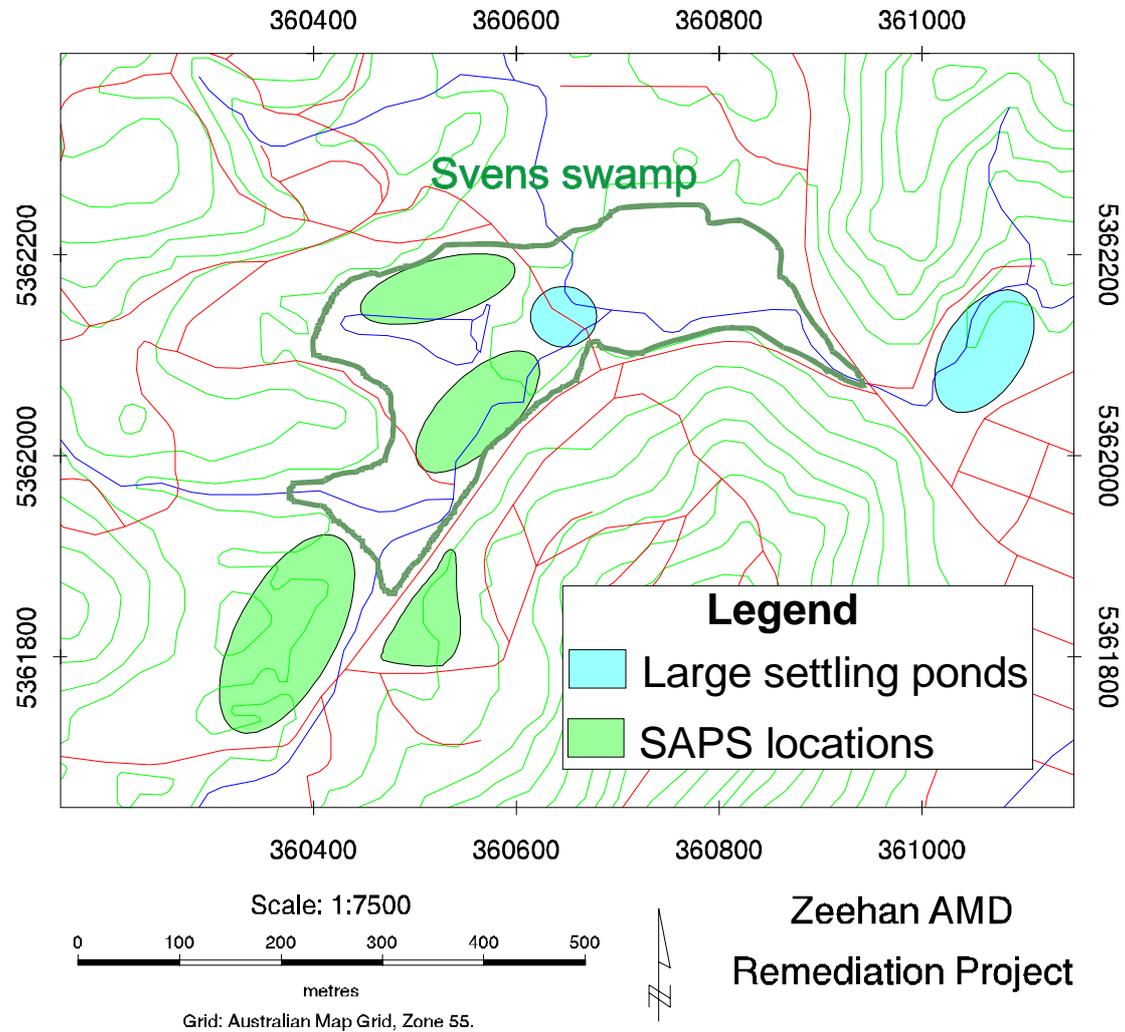


Figure 10: The impact of the recommended remediation strategies on the existing wetland, showing approximate locations of SAPS ponds and the two large settling ponds.

Further Work

Pilot Study

A pilot study would involve applying the preferred remediation techniques on a water source that contributes a significant part of the water contamination from this area.

Regular monitoring of the pilot study would determine how well the remediation techniques work. This monitoring would also show any areas for improvement in the remediation techniques being used.

The pilot study would need to be conducted in the contamination zone. This is to ensure that remediation techniques will work with the processes currently active in this region. The contamination zone is subject to variables unique to this area and these variables could have unforeseeable effects on the remediation processes.

The pilot study would be conducted on a water source that contributes about 10% of the daily discharge of trace metals and acidity out of Svens swamp and through the township of Zeehan. Initially an indepth analysis of the water sources around Svens swamp would need to be conducted to determine a suitable water source. Once the pilot source is chosen a SAPS remediation system would need to be designed to treat the contamination originating from this source.

Once construction and implementation of the SAPS system starts, a small selection of water samples needs to be taken to determine how the SAPS system is working.

These water sample sites would be located on several of the water sources and in the discharge area of Svens swamp. The other water sources need to be monitored, as any contamination variations from these sources will effect the pilot study. Water monitoring before, during and after the SAPS remediation pilot would show the effectiveness of this pilot program. These two monitoring programs would show the effect of SAPS in comparison to the rest of the water sources and can be used to determine if each of the stages of the SAPS system is working correctly. Initially these samples would be taken at monthly intervals and slowly phased out once proof of the success or failure of the pilot is confirmed.

The pilot system as it treats 10% of the contamination would be expected to cost about 10% of a full SAPS system, \$ 21 500 - 48 000 (Table 4).

Monitoring

Ongoing monitoring of the water contamination during any remediation exercise is vital, as it will:

- Confirm the sources of worst contamination requiring remediation.
- Determine the most appropriate place for a pilot study
- Determine the success of the remediation techniques.

Water sampling would involve taking in the field of pH and conductivity with later analysis for trace metals and acidity as these are the contaminants which need minimising.

Analysis of the major metals would increase the analyses costs but would provide more information on the chemical reactions occurring in the waters. A better understanding of these reactions taking place may identify ways to improve or shortcut the remediation process. It would also help identify reasons for any problems with the pilot study. For these reasons the extra cost of detailed water analysis is warranted.

The monitoring program would start with a snapshot analysis of the swamp this would involve ten to twenty water sample sites. A snapshot analysis would determine the sources of contamination requiring remediation and assist in choosing a pilot study area.

Further monitoring of the swamp using only five to ten sites on a monthly basis could look for any seasonal variations in the water contamination.

The pilot study would require its own monitoring program to determine the changes occurring as the waters pass through the remediation system this could involve several hundred samples over the time of the pilot study.

Implementation of the remediation strategy would require a water-monitoring program to show the success of the venture, this too could require several hundred samples over the first decade of the remediation strategy.

Costs of detailed chemical analysis of these water samples would be \$50 - \$100 each with possible extra costs for data interpretation. Over the first decade of the study \$25 - \$50 thousand dollars would need to be set aside just for water monitoring analysis. Further chemical interpretation of this data may incur additional costs.

To minimize costs of the water-monitoring phase much of this work and interpretation could be covered by student studies.

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