MINERAL RESOURCES TASMANIA

REMEDIATION INVESTIGATIONS & PILOT WORKS IN THE ZEEHAN MINERAL FIELD

prepared
by

EARTH SYSTEMS PTY. LTD.

in association with

THOMPSON & BRETT PTY. LTD.,
MILLIN ENVIRONMENTAL MANAGEMENT SERVICES
&
TECHNICAL ADVICE ON WATER

September 1999

Plate 1: View of part of the Zeehan Mineral Field, looking north from Queen Hill. Pea Soup Wetland is in the foreground. The brown colouring in the middle foreground is the ferric hydroxide terraces developed from drainage discharging from the Oonah South workings. The ground behind the terraces rises to Oonah Hill.

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EXECUTIVE SUMMARY

Mineral Resources Tasmania (MRT) commissioned a study to identify prime remediation targets in the Zeehan Mineral Field, and key technologies for effectively adding alkalinity to acidified waterways. This report details the results of investigations and pilot trials undertaken to determine rehabilitation and remediation strategies.

The Zeehan Mineral Field was world renowned for its high grade Silver-Lead-Zinc lodes around the turn of the 20th century. Present day Zeehan is still rich in the history of those mining days, with numerous vestiges of its mining heritage on display. Like many orphan sites, extensive mining activity in the field has resulted in the development of widespread acid and metal pollution in local waterways.

A series of student-based research projects has provided a good information base on environmental issues and potential remedial strategies in the area. Existing water quality data and previous research was insufficient to accurately define the areas contributing to major pollutant loads, or provide a comprehensive baseline dataset for the mineral field.

A water sampling and gauging program confirmed the area draining into the Pea Soup Wetland as the main source of acid and metals in the region, and quantified the inputs. In particular, the survey highlighted the waste materials and workings in Oonah Creek as specifically contributing a substantial proportion of the total load of metals and acid in Pea Soup Creek above Nike. Key metal contaminants from the Zeehan Mineral Field, particularly with regard to the protection of aquatic ecosystems, appear to be zinc, lead, aluminium, cadmium and iron.

Alkalinity addition was identified by the MRT as a crucial factor in improving water quality at Zeehan. A range of alkalinity addition options were canvassed and assessed. Pilot trials tested a new concept in the application of mineral carbonates to acid drainage remediation: a water powered mill, known as a Hydro-Active Limestone Treatment (HALT) System. This was developed and then tested in the Pea Soup Wetland at Zeehan. The HALT trials demonstrated that subaqueous autogenous / attritional grinding mills are a viable method for cost effectively dosing acidified waterways with a very fine grained, highly soluble carbonate slurry. The pilot scale system was routinely dispensing 5.5 g $CaCO_3$ / second (equivalent to neutralising 100 litres/second flow with a “Total Acidity” of at least 55 mg/l $CaCO_3$).

An appropriately modified, full scale HALT System providing a maximum output of approximately 10 g $CaCO_3$ / s is expected to be sufficient for optimum alkalinity addition at Zeehan.

Pilot scale limestone and magnesite drains were also installed to assess their application in passive alkalinity addition. No significant results are available at this stage.

Alkalinity addition represents one component of a comprehensive approach to improving water quality at Zeehan. Other key components identified include:

- Subaqueous disposal of selected polluting waste materials.
- Alkalinity storage dams.
- Shallow flow wetlands.
- Settling basins / wetlands.
- Water diversion works.
- Capping and revegetation.

In order to provide the maximum reduction in metals and acid within the Zeehan Rivulet and the Little Henty River, the following staged remediation options are proposed. These recommendations are expected to provide a sustained improvement in water quality in the Zeehan Rivulet (50 - 90% reduction in key metals, zinc, lead, cadmium, aluminium and iron) and a 50% reduction in acidity measured in the Zeehan Rivulet above the Little Henty River.

RECOMMENDATIONS

RECOMMENDATION 1:

Conduct detailed costings of the following six proposed phases of remediation at Zeehan.

PHASE 1 Modification, Construction and Installation of a HALT System

Design and build a full scale, improved HALT system and locate it in the Oonah Creek catchment (using grid electricity as a power source).

PHASE 2 Wetland / Sulphidic Material Disposal

Dispose of key areas of waste rock and tailings material located in the Oonah Creek catchment (and possibly elsewhere) by constructing a disposal terrace over the existing Pea Soup Wetland. Install a shallow flow wetland on top of this terrace.

PHASE 3 Rehabilitation of the Queen Hill Lode Bench

Conduct rehabilitation and revegetation of the bench excavated over the Queen Hill Lode by Aberfoyle Exploration.

PHASE 4 Alkalinity Storage Dam 1

Install an alkalinity storage pond downstream of the HALT System in Oonah Creek, but upstream of the Pea Soup Wetland.

PHASE 5 Alkalinity Storage Dam 2

Install a second alkalinity storage dam downstream of the disposal terrace / shallow flow wetland, but within the Pea Soup Wetland.

PHASE 6 Clean Water Diversion

Conduct earthworks to isolate the relatively clean water of upper Silver-Lead Creek from the Pea Soup Wetland.

RECOMMENDATION 2:

Install the proposed remediation measures.

RECOMMENDATION 3:

Monitor the results of the remedial strategy.

RECOMMENDATION 4:

Evaluate the monitoring results and determine the likely water quality benefits of progressing to the next phases of work, involving:

PHASE 7 Settling Basin / Wetland

A settling basin / wetland on the eastern margin of Zeehan to act as a final filter for any metalliferous precipitates not immobilised in the Pea Soup Wetland area.

PHASE 8 Combined Shallow and Deep Flow Wetland

A variable depth wetland at the western edge of the Zeehan township.

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1.0 Introduction

A consortium comprising Earth Systems Pty Ltd, Thompson & Brett, Millin Environmental Management Services (MEMS) and Technical Advice on Water (TAW) was engaged by Mineral Resources Tasmania to assess and trial alkalinity addition options and provide a comprehensive rehabilitation and remediation strategy for the Zeehan Mineral Field.

Over 50 mines were active in the Zeehan Mineral Field, an area covering some 65 km2, over the period from the 1880's to 1960. In total the field produced some 200,000 tons of lead, 27 million oz of silver, 2,700 tons of zinc and minor copper, tin and cadmium with production peaking in the years between 1897 and 1913 (Both & Williams, 1968). The largest mines were the Zeehan Montana, Spray, Zeehan Western, Zeehan Queen, Oonah and Oceana Mines. Many of the old mines of the Zeehan Mineral Field are within a radius of two kilometres of the Zeehan township and fall within the catchment of the Zeehan Rivulet (refer Plan Zhn 01).

The widespread occurrence of iron sulphides throughout this field has led to the development of acid and metal polluted waterways in the Zeehan area. Acid water (pH 2.5-4) enriched in iron, manganese, lead, zinc, aluminium, cadmium, copper and sulphate discharges from many mine workings. Several key regions of contamination have been identified including Queen Hill on the eastern side of Pea Soup Creek and the Oonah workings on the western side. Relatively recently developed wetlands occurring along Pea Soup Creek ("Pea Soup Wetland") have been identified as providing some natural remediation of acid waters flowing from these source areas to the downstream Little Henty River.

Other contamination sources of lesser significance include the Old Spray Mine, the Zeehan Western workings and the site of the Tasmanian Smelter.

1.1 Aim & Objectives

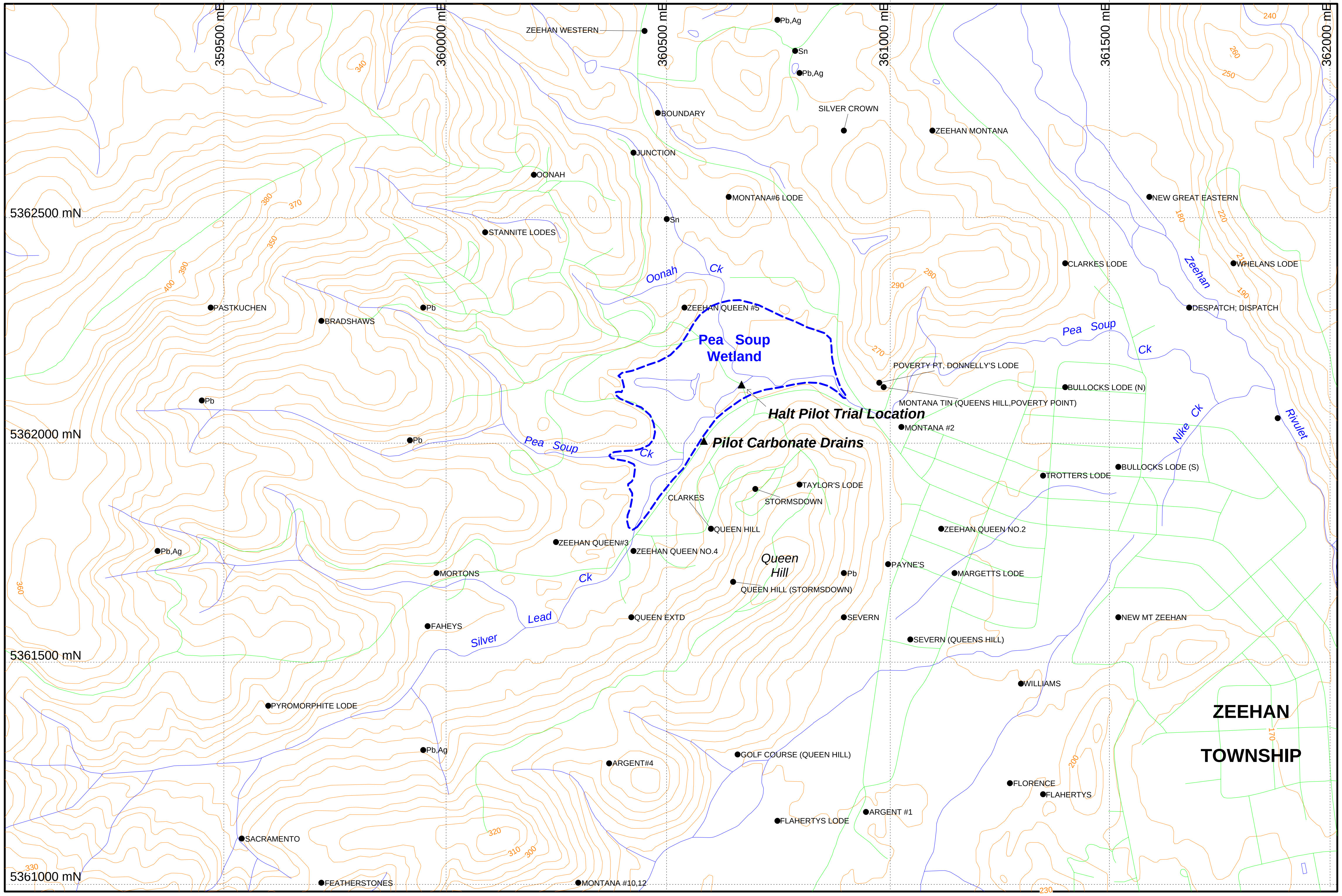
The aim of this study is to determine the most appropriate strategies for the remediation of The Zeehan Mineral Field.

Key objectives include:

- Identify major sources of acidity and metals to the Zeehan Rivulet and Little Henty River From the Zeehan Mineral Field.
- Assess a range of appropriate alkalinity options and conduct focussed trials to establish the efficacy of specific methods for improving water quality at Zeehan.
- Identify the most cost effective remediation options for improving water quality in the Zeehan Rivulet and the Little Henty River.

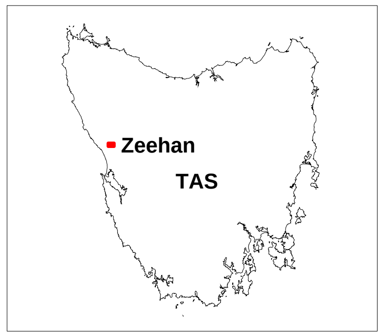
1.2 Previous Studies and Work Programs

A number of student research projects have been undertaken on various environmental aspects of the Zeehan Mineral Field. A 1995 study evaluated the effect of the Pea Soup wetland on heavy metal concentration in Pea Soup Creek (Ladiges, 1995). Parr (1997) assessed water quality in the Zeehan District, and attempted to quantify the sources of acid mine drainage. He also proposed a range of remediation options for selected mining areas. Oosting (1998) analysed environmental impacts caused by historical mining activity in the Zeehan area and identified various strategies for rehabilitation.



LEGEND

● OONAH Old Mine Site



LOCATION DIAGRAM

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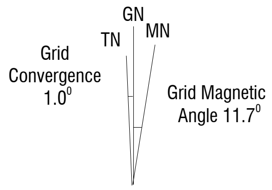
Length in Metres



Projection : AMG Zone 55 (AGD 84)

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Zeehan Project
Location of Old Mine Sites
and Pilot Trials

Author: N.Murphy	Ref: Pieman 7914 1:100K
Drawn: C.Pike	Filed as: Zhn_01.wor
Date: 9-7-99	Report No.:
Scale: 1 : 10000	Plan No.: Zhn01

Based on his research studies, Parr was commissioned by Mineral Resources Tasmania to identify recommendations for an acid drainage remediation program in the Zeehan District (Parr, 1998). This report identified the key area of concern as the Queen Hill region. Four main recommendations were made as detailed below:

- recontouring of waste piles on Queen Hill;
- capping of the larger waste dumps at Zeehan Queen No. 4;
- construction of Successive Alkalinity Producing Systems (SAPS) and flow diversion works from contaminated sources; and
- enhancing the Pea Soup Wetland

An assessment of existing water quality data and Parrs' recommendations are made in Section 2.1 and other parts of this report.

1.3 Geographic and Geological Setting

The Zeehan Mineral Field is located in hilly terrain on the west coast of Tasmania near the township of Zeehan (Refer Plans Zhn 01 and 02).

The field lies largely in the catchment of the Little Henty River which drains south and east from Zeehan to the west coast of Tasmania. A small part of the field drains to the north into the Pieman River catchment.

Understorey vegetation is now often dense and vigorous across most of the field even though most of the vegetation was cleared at the time of mining and many areas burnt out during recent bushfires (eg. 1981). Some mining affected areas are still struggling to revegetate.

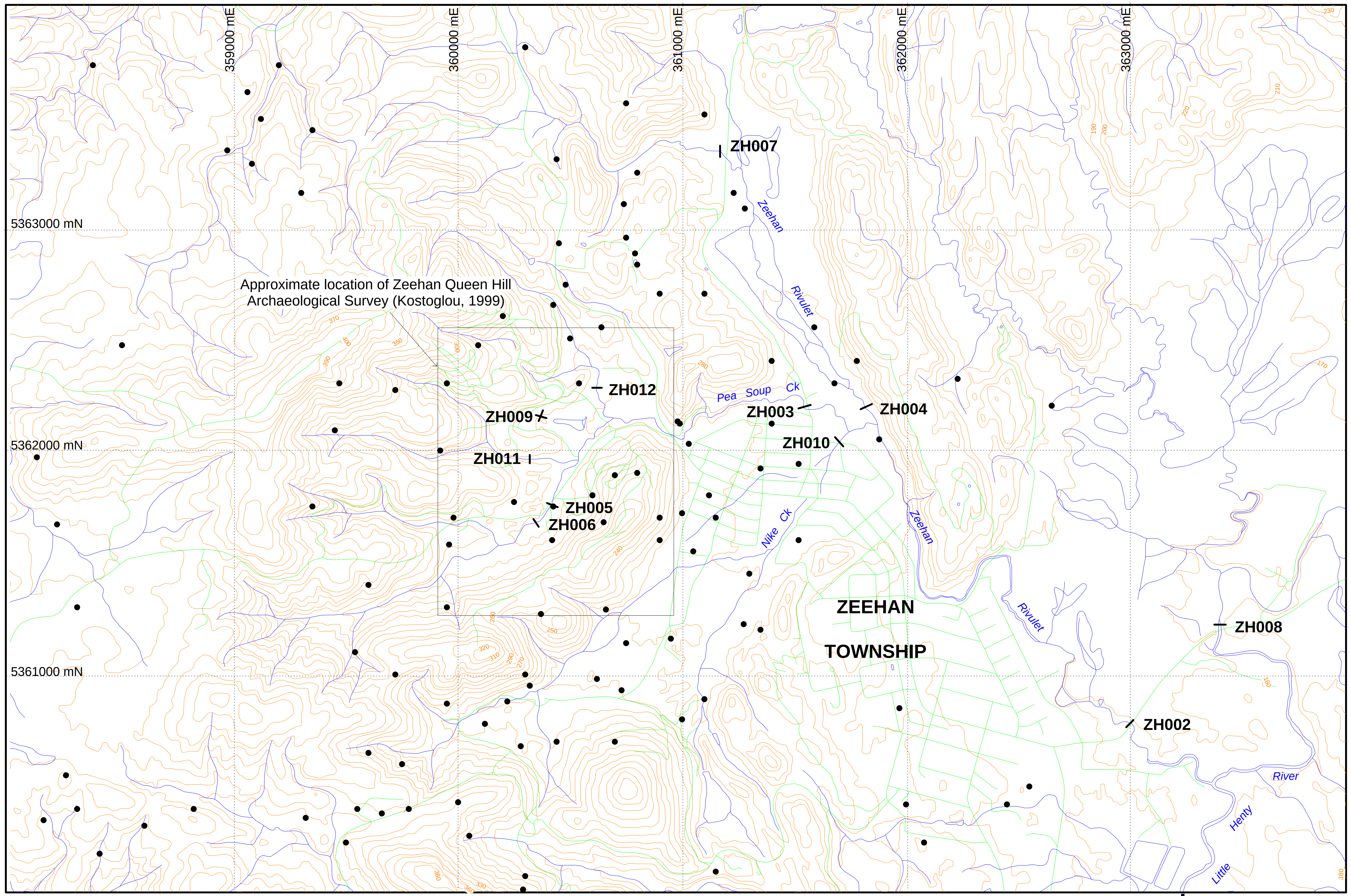
The geology of the field consists of tightly folded and faulted quartzite, siltstone, shale, slate and rare mafic volcanics and dolomitic sediments of Upper Proterozoic and Lower Cambrian age. Mineralisation commonly consists of galena and sphalerite, and more rarely chalcopyrite, cassiterite and stannite. Gangue mineralogy is generally dominated by either iron sulphide or iron carbonate with lesser quartz and calcite.

The Zeehan area has a wet and temperate climate. The township of Zeehan receives an average annual rainfall of approximately 2408 mm with peak precipitation between April and October. Monthly rainfall is lowest in February with an average value of approximately 110 mm. Annual evaporation is thought to be low, approximately 600 mm / year. February is the warmest month with an average temperature of 14^{o}C, whilst July is the coldest with an average temperature of 7^{o}C.

1.4 Historic Setting

The historic significance of the Zeehan Queen Hill workings have recently been assessed in a study commissioned by Mineral Resources Tasmania (Kostoglou, 1999):

"The Zeehan mining field is of undoubted national significance in regard to the mining history of this country. As a Silver - Lead deposit, it is rivalled chronologically and technologically only by the Broken Hill mineral field in New South Wales, which was discovered shortly after the Zeehan field. In a Tasmanian context, this mineral field is all the more outstanding, given that between 1887 and 1915, it was all but pre eminent in the mineral economy of the state. That this field gave birth to a major regional township which survived the demise of its parent mines creates a substantial social as well as historical legacy." Kostoglou, 1999.



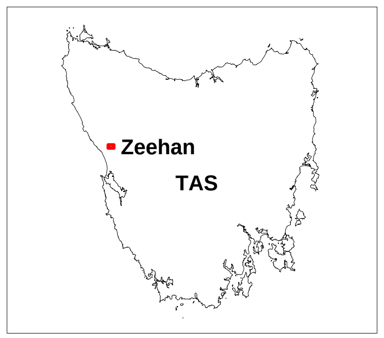
LEGEND

● Old Mine Site

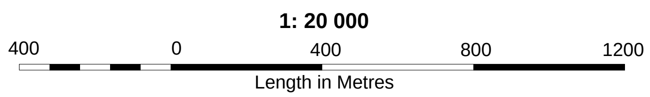
ZH002 Water Sampling Site

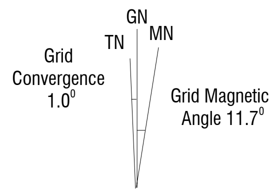
↓ Downstream ~ 6km ZH001

Projection : AMG Zone 55 (AGD 84)



LOCATION DIAGRAM





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Zeehan Project
Water Sampling Site
Location Plan

Author:	N.Murphy	Ref:	Pieman 7914 1:100K
Drawn:	C.Pike	Filed as:	Zhn_02.wor
Date:	9-7-99	Report No.:	
Scale:	1 : 20000	Plan No.:	Zhn02

The report by Kostoglou (1999) recommends that a number of sites be protected. Remediation options need to be developed with these recommendations in mind.

1.5 Background to Acid Generation and Metal Mobilisation

1.5.1 Acid Drainage

Acid drainage is a low pH, iron and sulphate-bearing water usually formed when rocks containing sulphide minerals (eg. pyrite, pyrrhotite, marcasite) are exposed to the atmosphere or an oxidising environment, and subsequently leached by water. Acid drainage is a major issue affecting the metal mining and coal industry throughout the world, including Australia. Many old mining sites, including the Zeehan Mineral Field, have a legacy of acid drainage long after the completion of mining. The major sources of acid drainage at mine sites and the associated minimisation, control and treatment techniques are summarised in Figure 1.

The production of acid via iron sulphide (eg pyrite) oxidation can be represented by the following reaction:

$FeS_2 + 3.75\ O_2 + 3.5\ H_2O = Fe(OH)_3$ (Orange Precipitate) $+ 2\ SO_4^{2-} + 4\ H^+$ **(1)**

(Iron sulphide + Oxygen + Water = Ferric Hydroxide + Aqueous sulphuric acid)

The following more detailed reactions demonstrate the key steps in the acid forming process, and highlight the importance of ferric hydroxide ($Fe(OH)_3$) precipitation in the production of acidity:

$FeS_2 + 3.5\ O_2 + H_2O = Fe^{2+} + 2\ SO_4^{2-} + 2\ H^+$ **(2)**

Pyrite is exposed to air and decomposes into water soluble components; acid is produced.

$Fe^{2+} + 0.25\ O_2 + H^+ = Fe^{3+} + 0.5\ H_2O$ **(3)**

The relatively reduced water soluble components are further oxidised; acid is consumed.

$Fe^{3+} + 3\ H_2O = Fe(OH)_3$ (Orange Precipitate) $+ 3\ H^+$ **(4)**

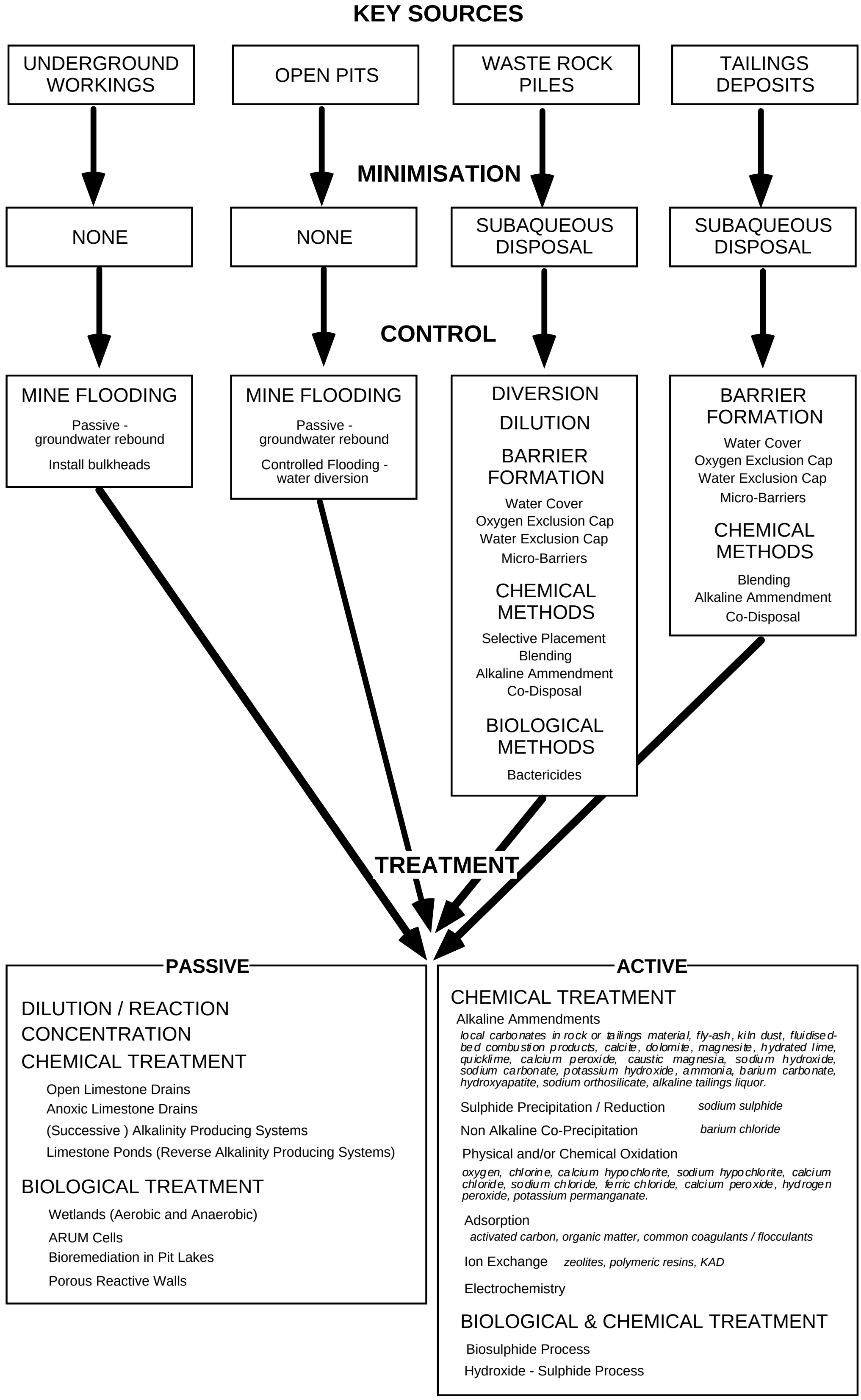
The formation of ferric iron in water results in the precipitation of ferric hydroxide precipitate; acid is produced.

Ferric hydroxide will only precipitate from water (above pH 3.3) after it has been sufficiently aerated / oxidised to facilitate the conversion of soluble ferrous iron to soluble ferric iron. As can be seen from reaction (4), this process is a key acid producing stage. Once sulphides have been oxidised, it is extremely difficult to avoid ferric hydroxide precipitation.

When the formation of soluble ferric iron (Fe^{3+}) can occur on site and in the presence of fresh iron sulphide, further sulphide oxidation can occur, as represented in the following reaction:

$FeS_2 + 14\ Fe^{3+} + 8\ H_2O = 15\ Fe^{2+} + 2\ SO_4^{2-} + 16\ H^+$ **(5)**

Figure 1: Acid Mine Drainage Management Strategies



Iron sulphides in geologic materials that are located below the water table will remain largely stable, since the potential for oxidation is limited[1]. However, where sulphidic materials are exposed to oxidising conditions (air), which can occur due to mining or other disturbances, the iron sulphides will react and water can move the reaction products (eg. iron and sulphate) into surface water and groundwater. As the acid water migrates, it further reacts with other minerals and dissolves a broader range of metals.

Whilst pH is a measure of hydrogen ion concentration (H^+ in reactions (2) to (5)), “acidity” is a measure of both hydrogen ion concentration and mineral (or latent) acidity. Mineral or latent acidity includes the concentration of hydrogen ions that could potentially be generated by the precipitation of various metal hydroxides from any given solution when titrated to a specific pH (eg. such as for ferric hydroxide as shown in reaction (4) above). In common acid drainage solutions, such metals include iron, aluminium, manganese, copper, lead, zinc, cadmium and other metals). Total Acidity (ie. existing + latent) is measured in a laboratory by thoroughly oxidising a water sample, and titrating it to a specific pH (eg. commonly 8.3). Provided in units of mg/l $CaCO_3$, this measurement quantifies the ideal neutralisation requirements of the water sample to the specified pH.

One thousand tonnes of material containing 0.5% sulphur as pyrite which completely oxidises will require approximately 16 tonnes of $CaCO_3$ (used efficiently) to neutralise the sulphuric acid generated.

1.5.2 What Problems are Created by Acid Drainage?

Acid drainage can have extreme impacts on the ecology of streams, effecting the beneficial use of waterways downstream of mining operations. Acid conditions can:

- mobilise (bring into solution) metals to levels injurious to aquatic ecosystems, riparian communities and possibly human health (eg. zinc, cadmium, aluminium, copper);
- limit the downstream beneficial uses of the receiving water (eg. stock, recreation, fishing, aquaculture, irrigation);
- alter important life supporting balances in water chemistry (eg. bicarbonate buffering system);
- lead to the development of chemical precipitates (eg. ferric hydroxide, aluminium hydroxide...etc) that can smother aquatic habitat and reduce light penetration;
- impact on groundwater quality;
- lead to the installation of expensive control, treatment and rehabilitation programs;
- create long term environmental liabilities, and
- limit the reuse of mine site water and exacerbate the corrosion of site infrastructure and equipment.

Acid drainage can also lead to revegetation and rehabilitation difficulties. Acidity in soils can lead to significant excesses and deficiencies of key elements for plant growth and difficulties in stabilising mine wastes. Acid conditions in soils are at best a significant limitation on the

[1] The concentration of dissolved oxygen in natural waters is approximately 25,000 times lower than found in the atmosphere.

vegetation types that can be used for rehabilitation and at worst the reason for a failed rehabilitation program.

Experience has shown that acid drainage, if not properly managed has the potential to be a long term liability. A recent study assessing acid mine drainage in Australia (Harries, 1997) conservatively estimated that over 15 years, the total cost of managing potentially acid generating mine wastes from current mines is $900 million.

1.5.3 Acid Drainage Influencing Factors

The following factors can affect the production of acid drainage:

- the ready availability of oxygen;
- the ready availability of water for oxidation and transport;
- physical characteristics of geologic materials which encourage rapid oxidation (ie. high surface area / small grainsize iron sulphides);
- water with a low pH;
- elevated water temperatures;
- high soluble Fe^{3+}/Fe^{2+} ratios;
- the presence of micro-organisms (bacteria, eg. *Thiobacillus thiooxidans and T. ferrooxidans)* which can act as a catalyst by utilising iron sulphide as an energy source, thereby oxidising the sulphide mineral;
- the absence of neutralising materials (eg. calcium carbonate); and
- climate.

1.5.4 Management Strategies

Key strategies for managing and controlling acid drainage include:

- selective placement of acid generating wastes to minimise sulphide oxidation or avoid interaction with water (eg. subaqueous disposal, deep placement in waste rock piles with clay covers ..etc);
- pro actively predicting the likely extent, severity and timing of ARD by materials characterisation (static tests to determine acid-base accounting and kinetic tests to estimate the likely timing and duration of acid formation);
- controlled blending of acid producing wastes with highly reducing, oxygen consuming or acid neutralising materials that will promote sulphide re-precipitation, oxygen exclusion and in-situ treatment of drainage;
- physical (collection, containment and evaporation), chemical (neutralising ± oxidising reagents) and biological (bactericides, wetlands, SRB) treatment of acid drainage prior to discharge.

2.0 Identifying Acid & Metal Sources

2.1 Background

To confirm and clarify the results of previous investigations (Parr, 1997,1998 and Oosting, 1998) a detailed assessment of all existing water quality and flow data was made. The full details of this assessment are attached in Appendix 1.

The objectives of this assessment were:

1. To identify the major sources of metal inputs from the Zeehan Mineral Field to the Zeehan Rivulet;

2. To determine whether the Zeehan Mineral Field is a significant source of metal pollution to the Little Henty River.

3. To identify whether sufficient water quality and flow data has been collected to adequately define a pre-remediation baseline (ie to enable assessment of the effectiveness of future remediation works); and

4. If data are insufficient, propose a cost effective water quality / flow data collection program that will satisfy Objectives 1 to 3.

The following reports and data were reviewed:

- Recommendations for an Acid Drainage Remediation Program in the Zeehan District, 1998 by Tim Parr.
- Acid Mine Drainage in the Zeehan District, 1997 by Tim Parr.
- Environmental Geology of the Dundas Drainage Basin, 1996 by Jeremy S. Lawrence.
- Rehabilitation of Abandoned Mine Sites in the Zeehan Area, 1998 by Naomi Oosting.
- Heavy Metal Levels in Stream Waters, Vegetation, Soil and Soil Solutions in an evolving Wetland, Zeehan, Tasmania, 1995 by Sven Ladiges.
- Unpublished HEC water quality and flow data for the Little Henty River.

2.2 Evaluation of Existing Data

Analysis of existing water quality data did not provide sufficient confidence to unambiguously identify priorities for remediation work. Significant questions that remained partly or fully unanswered include:

- Is zinc the major metal of environmental concern in the catchment?

- What metals are in excess of ANZECC water quality guidelines in the Little Henty River? Are metals in soluble or particulate form?

- What is the water quality of the catchment during low summer flow and during the Easter flush?

- How significant will be the benefit of remediation of the Zeehan Rivulet / Pea Soup Creek on downstream water quality in the Little Henty River?

- Is the Pea Soup Wetland contributing significantly to the remediation of acid drainage from Queen Hill and the Oonah Workings.

- Have all significant sources of acid drainage been identified in Pea Soup Creek / Zeehan Rivulet? (There appears to be some discrepancy between the source levels of metals and sulphates from Oonah and Queen Hill workings and downstream readings in Pea Soup Creek).

In conclusion, existing water quality and flow data from the Zeehan Mineral Field does identify some, if not most, of the major sources of acid drainage. However, the quality and spatial distribution of this data is insufficient to:

(I) prioritise remediation works to maximise the benefit to catchment water quality; and

(ii) provide a water quality baseline from which the effectiveness of future remediation works can be judged.

In view of the above conclusion, a recommendation for further water quality sampling was made. This work programme was accepted and the results of this work are detailed below.

2.3 Further Sampling and Flow Data Collection

Additional sampling of water quality and flow was conducted to meet the following objectives.

- To provide sufficient water quality and flow data to enable remediation priorities for the Zeehan Mineral Field to be firmly established.

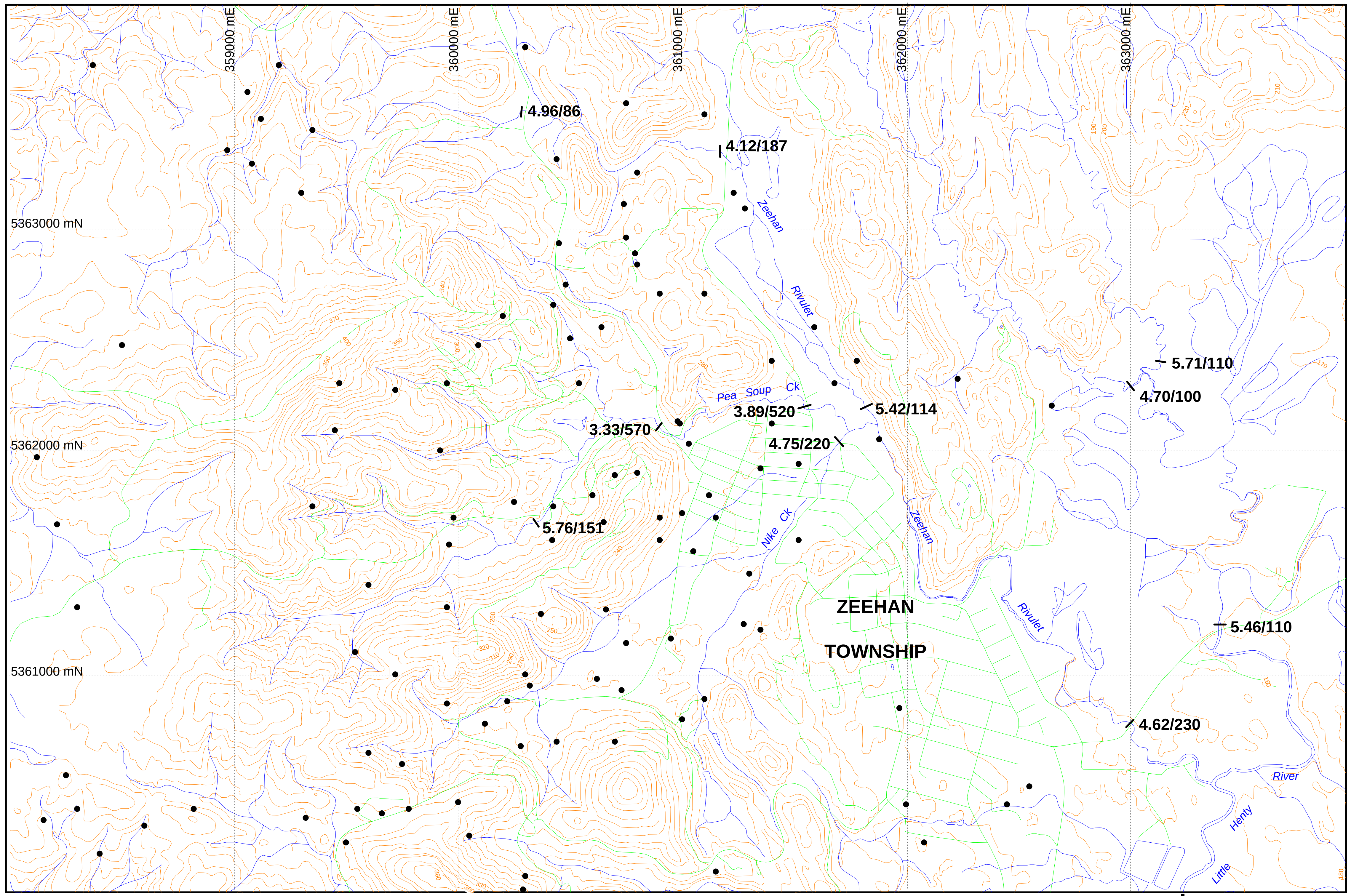
- To establish a water quality baseline that will enable quantification of water quality benefit derived from remediation undertaken at the Zeehan Mineral Field.

2.3.1 Methods

Field pH, conductivity, dissolved oxygen, turbidity and temperature measurements were collected in-situ using a Horiba u10 multi-function meter and at twelve locations water samples were collected for detailed chemical analysis by DELM in Hobart (Refer to Plans Zhn 02-04 and Plates 2-5).

Laboratory analysis was conducted for pH, conductivity, alkalinity, acidity Ca, Mg, Na, K, Cl, SO_4, DOC. In addition an extensive suite of metals (Al, As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Se, Zn) were analysed at detection limits of usually 1μg/l (refer Appendix 2).

Flow data and samples were collected at various sites on three separate occasions as detailed in Table 2.1. Flow data were collected by the Water Resources Department of the Hydro-Electric Corporation using a current meter to construct flow velocity profiles.



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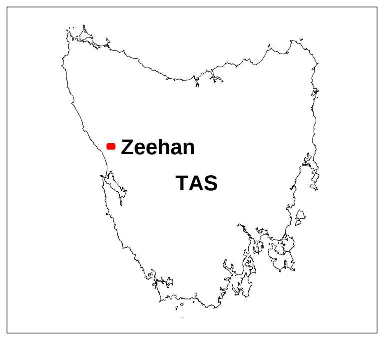

LOCATION DIAGRAM

1: 20 000

400 0 400 800 1200

Length in Metres

Grid Convergence 1.0°

TN GN MN

Grid Magnetic Angle 11.7°

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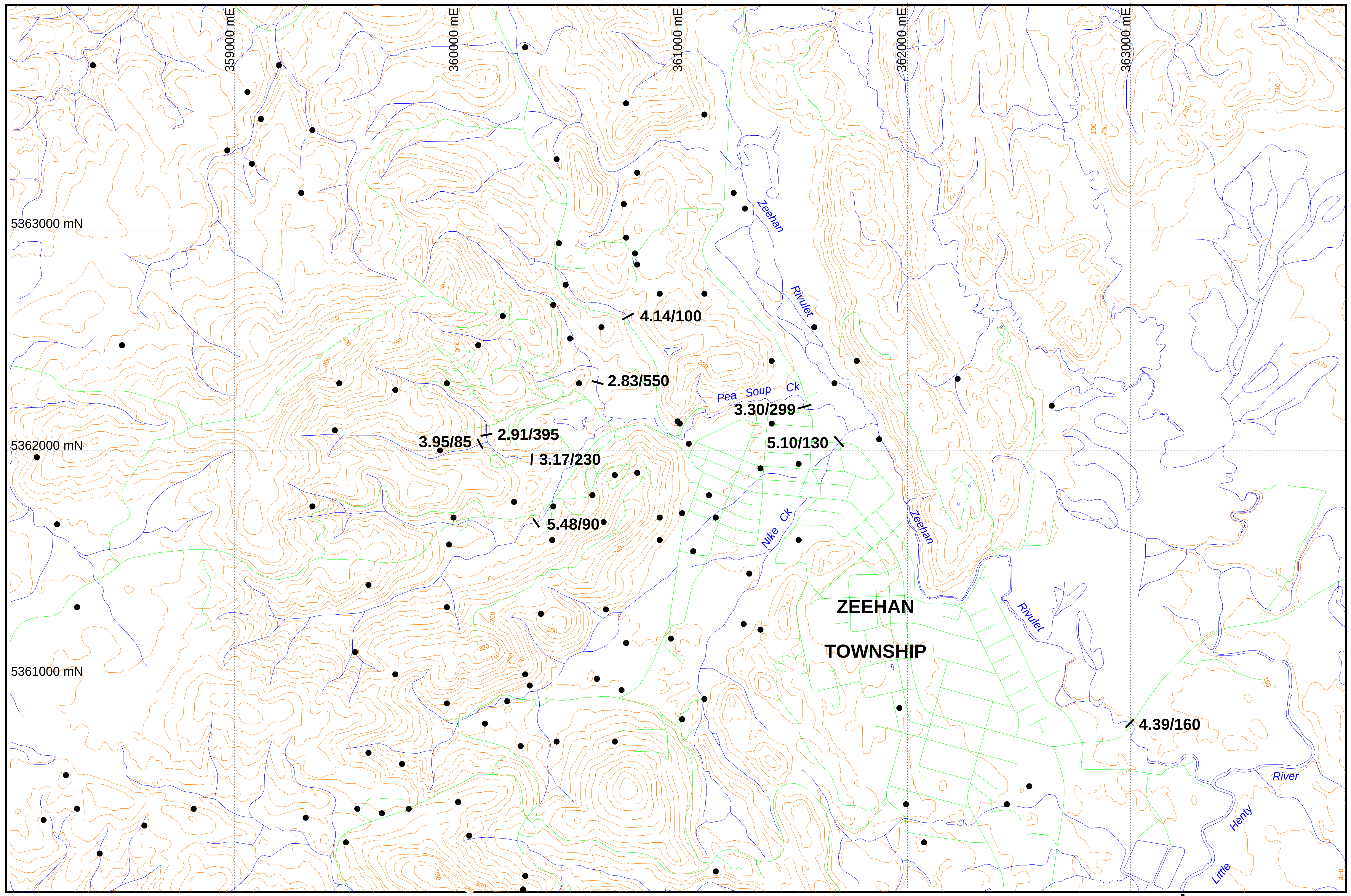
Zeehan Project
Field Measurements
pH/Electrical Conductivity
19 & 20th February 1999

Author:	N.Murphy	Ref: Pieman 7914 1:100K	
Drawn:	C.Pike	Filed as:	Zhn_03.wor
Date:	9-7-99	Report No.:	
Scale:	1 : 20000	Plan No.:	Zhn03



Strahan Rd Bridge 5.69/70

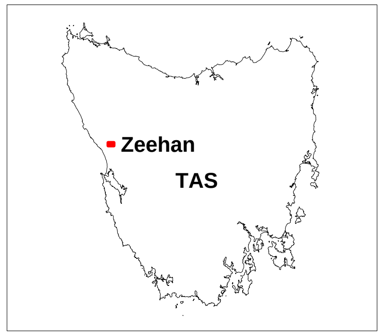
Projection : AMG Zone 55 (AGD 84)

LEGEND

● Old Mine Site

4.39/160

pH — EC (μS/cm)



LOCATION DIAGRAM

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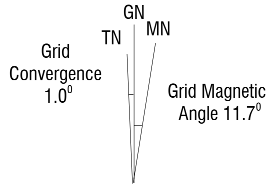
Length in Metres



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Zeehan Project
Field Measurements
pH/Electrical Conductivity
17 & 18th May 1999

Author:	N.Murphy	Ref:	Pieman 7914 1:100K
Drawn:	C.Pike	Filed as:	Zhn_04.wor
Date:	9-7-99	Report No.:	
Scale:	1 : 20000	Plan No.:	Zhn04

Plate 2: A program of in-situ water quality monitoring was conducted across the Zeehan Mineral Field in conjunction with flow gauging and laboratory analysis of water samples.

Plate 3: Gauging of the Zeehan Rivulet at the bridge on the Zeehan Highway, at the eastern end of the Zeehan township.

Plate 4: Gauging of the Little Henty River at the bridge on the Strahan Highway, south of the Zeehan township.

Plate 5: An inspection was made of numerous historical workings during the field water quality monitoring survey. This is a waste rock pile at the Oonah workings showing the results of a previous attempt at revegetation.

Sample No.	Location	Grid Reference	Sampled 19/2/99	Sampled 11/03/99	Sampled 18/5/99
ZH001	Little Henty River at Strahan Road Bridge	(GR 645 547)	✓	✓	✓
ZH002	Zeehan Rivulet at Zeehan Hwy	(GR 630 609)	✓	✓	✓
ZH003	Pea Soup Creek above Zeehan Rivulet	(GR 616 622)	✓	✓	✓
ZH004	Zeehan Rivulet above Pea Soup Creek	(GR 618 622)	✓	✓	✓
ZH005	Queen No. 4 Shaft	(GR 604 618)	✓	✗	✗
ZH006	Silver Lead Creek above Queen No. 4 Shaft	(GR 603 617)	✓	✓	✗
ZH007	Zeehan Rivulet at Parting Creek Road	(GR 612 633)	✓	✓	✗
ZH008	Little Henty River at Zeehan Hwy	(GR 634 612)	✓	✗	✗
ZH009	Oonah South Workings	(GR 604 622)	✓	✗	✗
ZH010	Nike Creek above Pea Soup Creek	(GR 617 620)	✗	✗	✓
ZH011	Pea Soup Creek above wetland	(GR 603 620)	✗	✗	✓
ZH012	Oonah Creek above wetland	(GR 606 623)	✗	✗	✓

Table: 2.1 *Location of Water Sampling Sites and dates on which they were sampled.*

2.3.2 Major Pollutants

Water quality derived from derelict mining sites in the Zeehan Mineral Field is usually of a poor quality and frequently does not meet ANZECC water quality guidelines for aquatic ecosystems (Table 2.2).

The key indicators of acid drainage at Zeehan are pH, iron, zinc, aluminium, cadmium, sulphate and manganese.

Pea Soup Creek was sampled near the Zeehan Caravan Park (ZH003). This creek drains through the northern part of the Zeehan Township and is severely affected by acid drainage. Its water quality significantly does not meet ANZECC water quality guidelines for aquatic ecosystems in zinc, aluminium, arsenic, cadmium, copper, pH, lead and iron.

The Zeehan Rivulet at the Zeehan Highway does not meet ANZECC water quality guidelines for aquatic ecosystems in zinc, aluminium, cadmium, copper, pH, lead and on occasion iron. (The water quality at this site is comparable to the quality of water running through the main part of the township of Zeehan).

The Little Henty River at the Strahan Highway Bridge exceeds ANZECC Water Quality Guidelines for aquatic ecosystems for zinc, lead and on occasion aluminium copper and pH.

Key metal contaminants from the Zeehan Mineral Field, particularly with regard to the protection of aquatic ecosystems, appear to be zinc, lead, aluminium and cadmium.

It is worth noting that a revised Draft of the ANZECC Water Quality Guidelines is currently available for public comment. Recommended guidelines for the protection of aquatic ecosystems for a number of the key metals are significantly lower (especially in low alkalinity water) than current guidelines (eg. cadmium, copper).

Sites where water quality was at its worst included small quantities of flow from the Queen No. 4 Shaft, Oonah South workings and a more significant flow in Oonah Creek. From these sources pollutants reached maximum values of 14,000 μg/l Zn, 5,620 μg/l Al, 600 μg/l Pb, 302 μg/l Cu, 56 μg/l Cd, 507 mg/l acidity and a pH low of 2.5. All these sources are in the Pea Soup Creek catchment.

Location	pH	Al	As	Cd	Cu	Fe	Hg	Pb	Se	Zn
Pea Soup Creek at Caravan Park	3.1-3.4	928-1850	20	12-13	90-91	10400-11000	<0.05-0.05	343-575	<1	3410-4450
Zeehan Rivulet at Zeehan Highway Bridge	4.0-4.6	261-557	4	6-7	26-37	844-3670	<0.05-0.05	146-237	<1	1390-2350
Little Henty River at Strahan Road Bridge	5.7-7.0	<50-285	<1-2	<1	5-6	630-756	0.05	9-30	<1	179-204
Av Abund.			2		7		0.007	3	0.2	20
Drinking[1]	6.5-8.5		50	5	1000	300	1	50	10	5000
Aquatic (ANZECC, 1992)[1]	6.5-9.0	5[3]	50	0.2-2.0	2.0-5.0	1000	0.1	1.0-5.0	5.0	5-50
Aquatic (ANZECC, 1999)[4]		1.2	1.6	0.01	0.33		0.013	1.2	1.4	2.4
Irrigation[2]	4.5-9.0	5000	100	10	200	5000		200		2000

1 Based on ANZECC Water Quality Guidelines (ANZECC, 1992), values listed are maximum recommended
2 FAO recommended maximum concentrations of trace elements in irrigation water from Table 6-48 in The Water Encyclopaedia, Leeden et al., 1990.
3 This guideline is based on a pH <=6.5. For a pH > 6.5 the aluminium guideline is less than 100 μg/l.
4 Based on Draft ANZECC Water Quality Guidelines (ANZECC, 1999) released for public comment at a water hardness of less than 60 mg/l.

Table 2.2 *Analytical results for selected metals from water samples draining the Zeehan Mineral Field, with comparison to various guidelines. Note samples are total samples, that is they were not filtered before analysis. Refer Appendix 2 for full analytical results and Plan Zhn02 for sample locations (all analytical values measured in μg/l).*

2.3.3 Pollutant Loads

Identifying remediation options for improving downstream water quality requires the identification of the major sources of pollutants. Tables 2.3 to 2.5 provide calculated pollutant load data for zinc, iron and acidity using collected flow and analytical data. (Refer also to Plan Zhn 05).

A comparison between the contribution of pollutant load from the Zeehan Rivulet relative to the Little Henty River at the Strahan Road Bridge indicates that at moderate to high flow the Zeehan Rivulet provides only a small contribution of acidity and iron loads. The Zeehan Rivulet's contribution to zinc and lead loads in the Little Henty is far more substantial ranging in the vicinity of 30% to 60%.

Load data indicates that Pea Soup Creek above the Zeehan Rivulet (ie. Pea Soup Creek at the Zeehan Caravan Park) accounts for the vast majority of zinc, iron and acidity loads in the Zeehan Rivulet at the Little Henty River junction. Other significant pollutants show a similar trend (eg. cadmium, copper). Whilst Pea Soup Creek accounts for less than 50% of the flow it accounts for upwards of 80% of the major pollutants.

Within Pea Soup Creek, sufficient analytical and flow data has been collected to enable some key pollutant sources to be identified. The catchment of Pea Soup Creek can be broken up into five areas as detailed below:

- Silver Lead Creek above Pea Soup Wetland
- Pea Soup Creek above Pea Soup Wetland
- Oonah Creek
- Pea Soup Wetland / northern part of Queen Hill
- Pea Soup Creek below Pea Soup Wetland

The water quality within Silver Lead Creek above Pea Soup Wetland is relatively good, with this catchment a small contributor of load.

Pea Soup Creek above Pea Soup Wetland provides a more significant contribution to load particularly with regard to iron and acidity. The contribution to zinc load is low.

Water quality data from Oonah Creek indicates that this is a major source of pollutants. Acidity, iron, zinc, cadmium and lead loads are high, particularly if catchment size is used to estimate flow. Flow was difficult to determine from Oonah Creek because the creek bed is filled with mining wastes, probably resulting in substantial sub-surface flow.

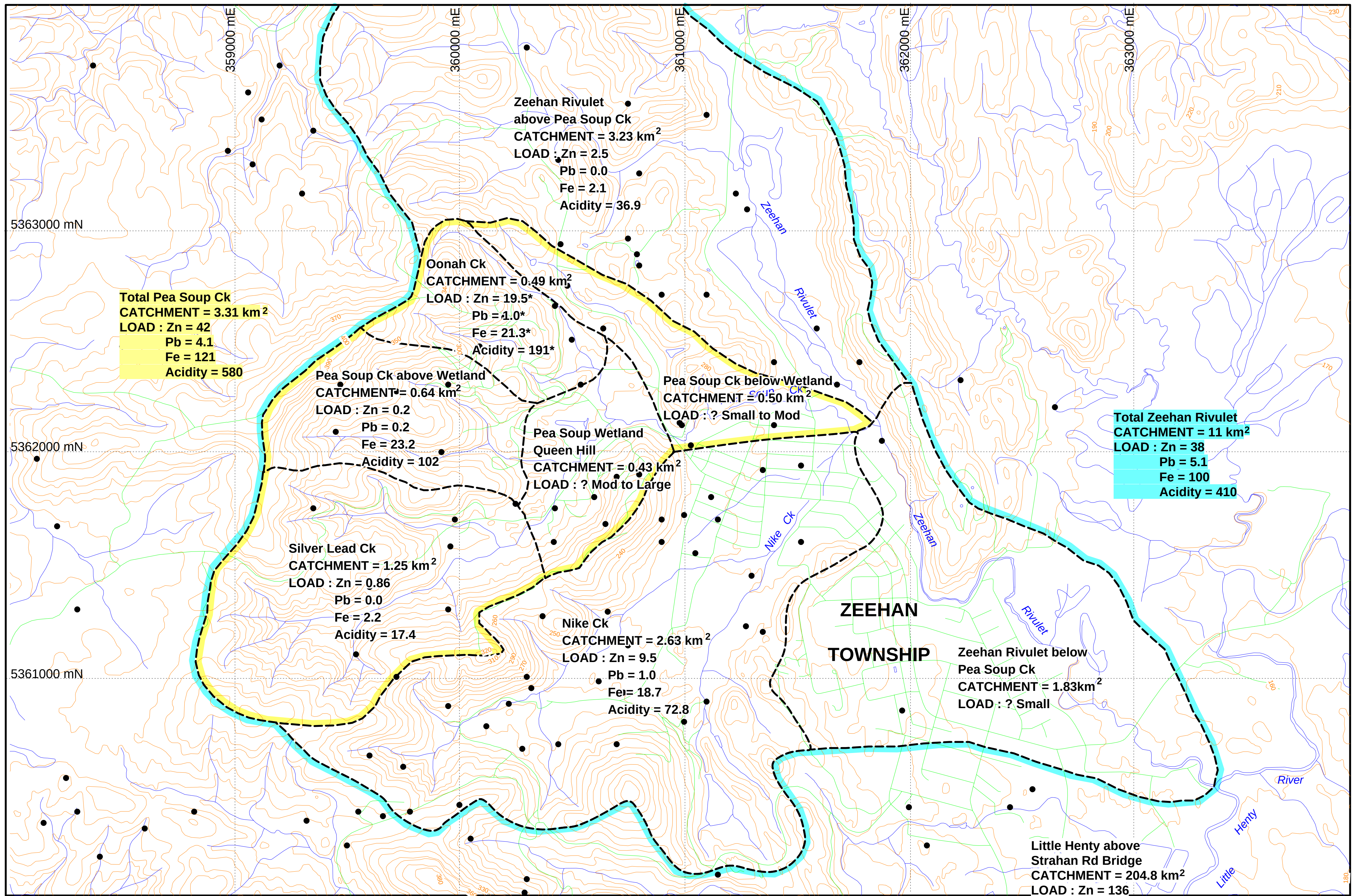
The contribution of Pea Soup Wetland and the northern part of Queen Hill to pollutant load is difficult to quantify due to the number of diffuse pollutant sources within the wetland. Two of these sources were sampled (Queen No. 4 Shaft, Oonah South) and the results were indicative of severe acid drainage. Whilst Pea Soup Wetland is undoubtedly effective to some degree in acid drainage remediation (eg. trapping iron hydroxides, placing some sulphidic materials in an aqueous environment), there is a cumulative contribution from a number of sources in and around this wetland that probably contributes significantly to load. After Oonah Creek the area draining into the wetland is probably the second most significant source of pollutants to Pea Soup Creek.

Pea Soup Creek downstream of Pea Soup Wetland is thought to supply some pollutants to the catchment (eg. from sources such as Poverty Point, Donnelly's Lode) although its contribution like its catchment area is thought to be small. This is supported by field water quality sampling which indicates similar pH and conductivity values in Pea Soup Creek below Pea Soup Wetland with those at the Caravan Park.

Sample No.	Location	Total Zn kg/day 19/2/99	Total Zn kg/day 11/03/99	Total Zn kg/day 18/5/99
ZH001	Little Henty River at Strahan Road Bridge	132.2*	23.0	136.5
ZH002	Zeehan Rivulet at Zeehan Hwy	83.9	14.3	38.0
ZH003	Pea Soup Creek above Zeehan Rivulet	47.2	13.6	42.1
ZH004	Zeehan Rivulet above Pea Soup Creek	7.6	0.5	2.5
ZH005	Queen No. 4 Shaft	1.2*	✗	✗
ZH006	Silver Lead Ck above Queen No. 4 Shaft	0.9	0.3	0.86
ZH007	Zeehan Rivulet at Parting Creek Road	5.6	1.5	✗
ZH008	Little Henty River at Zeehan Hwy	3.6*	✗	✗
ZH009	Oonah South Workings	1.1*	✗	✗
ZH010	Nike Creek above Pea Soup Creek	✗	✗	9.5
ZH011	Pea Soup Creek above wetland	✗	✗	0.22
ZH012	Oonah Creek above wetland	✗	✗	9.9*(19.5)#

* At these sites flow is estimated in calculating load. # Oonah Creek load where flow is based on catchment size.

Table 2.3 *Calculated zinc loads from the Zeehan Mineral Field for three different time periods. Refer Appendix 2 for full analytical results and hydrological data.*

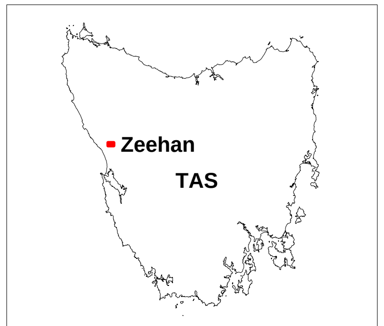


Note : * Calculated flow estimated from catchment size
All load values are in kg / day

LEGEND

● Old Mine Site

Projection : AMG Zone 55 (AGD 84)



LOCATION DIAGRAM

1: 20 000

400 0 400 800 1200

Length in Metres

GN TN MN

Grid Convergence 1.0°

Grid Magnetic Angle 11.7°

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EARTH SYSTEMS PTY LTD

Zeehan Project
Catchment Pollutant Loads
18th May 1999

Author:	N.Murphy	Ref:	Pieman 7914 1:100K
Drawn:	C.Pike	Filed as:	Zhn_05.wor
Date:	9-7-99	Report No.:	
Scale:	1 : 20000	Plan No.:	Zhn05

Sample No.	Location	Total Fe kg/day 19/2/99	Total Fe kg/day 11/03/99	Total Fe kg/day 18/5/99
ZH001	Little Henty River at Strahan Road Bridge	489.9*	95.8	452.6
ZH002	Zeehan Rivulet at Zeehan Hwy	128.6	5.1	100.2
ZH003	Pea Soup Creek above Zeehan Rivulet	152.3	31.9	120.6
ZH004	Zeehan Rivulet above Pea Soup Creek	7.5	0.2	2.1
ZH005	Queen No. 4 Shaft	16.2*	✗	✗
ZH006	Silver Lead Ck above Queen No. 4 Shaft	2.4	1.4	2.2
ZH007	Zeehan Rivulet at Parting Creek Road	6.2	3.2	✗
ZH008	Little Henty River at Zeehan Hwy	120.8*	✗	✗
ZH009	Oonah South Workings	6.3*	✗	✗
ZH010	Nike Creek above Pea Soup Creek	✗	✗	18.7
ZH011	Pea Soup Creek above wetland	✗	✗	23.2
ZH012	Oonah Creek above wetland	✗	✗	10.8*(21.3)#

* At these sites flow is estimated in calculating load. # Oonah Creek load where flow is based on catchment size.

Table 2.4 *Calculated iron loads from the Zeehan Mineral Field from three different time periods. Refer Appendix 2 for full analytical results and hydrological data.*

Sample No.	Location	Total Acidity kg/day 19/2/99	Total Acidity kg/day 11/03/99	Total Acidity kg/day 18/5/99
ZH001	Little Henty River at Strahan Road Bridge	6480.0*	12.8	3591.6
ZH002	Zeehan Rivulet at Zeehan Hwy	703.4	12.2	409.6
ZH003	Pea Soup Creek above Zeehan Rivulet	678.2	24.5	579.6
ZH004	Zeehan Rivulet above Pea Soup Creek	131.1	0.1	36.9
ZH005	Queen No. 4 Shaft	43.8*	✗	✗
ZH006	Silver Lead Creek above Queen No. 4 Shaft	13.3	0.1	17.4
ZH007	Zeehan Rivulet at Parting Creek Road	87.7	1.3	✗
ZH008	Little Henty River at Zeehan Hwy	1244.2*	✗	✗
ZH009	Oonah South Workings	27.3*	✗	✗
ZH010	Nike Creek above Pea Soup Creek	✗	✗	72.8
ZH011	Pea Soup Creek above wetland	✗	✗	101.5
ZH012	Oonah Creek above wetland	✗	✗	96.8*(191.2)#

* At these sites flow is estimated in calculating load. # Oonah Creek load where flow is based on catchment size.

Table 2.5 *Calculated acidity loads from the Zeehan Mineral Field from three different time periods. Refer Appendix 2 for full analytical results and hydrological data.*

2.4 Relating Water Quality to Past Mining Activity

In summary, water quality data indicates that the main pollutant loads from the Zeehan Mineral Field appear to be derived from the wastes and workings in Oonah Creek and a number of workings in and around Pea Soup wetland. Pea Soup Creek above Pea Soup Wetland also appears to be a significant, although lesser, source of acid and iron. These areas are identified as the key areas for remediation within the Zeehan Mineral Field to achieve a significant reduction in pollutants within Pea Soup Creek and the Zeehan Rivulet.

These results and conclusions regarding significant pollutant sources in the Zeehan Mineral Field differ from those of Parr (1998). Parr identified remediation priorities around Pea Soup Wetland / Queen Hill. Our data indicates that Oonah Creek and Pea Soup Creek above Pea Soup Wetland are also priorities, with remediation of mine waste within Oonah Creek probably the highest priority in achieving a benefit to downstream water quality.

2.5 Significant Findings

In identifying acid and metal sources within the Zeehan Mineral Field, the most significant findings are:

- Confirmation that the major pollutant loads in the Zeehan Rivulet are sourced from the area of the Zeehan Mineral Field draining into Pea Soup Creek (consistent with Parrs' conclusions).

- The major pollutant loads in Pea Soup Creek are derived from Oonah Creek, diffuse sources around Pea Soup Wetland (eg. Queen No. 4, Queen No. 5) and Pea Soup Creek.

- Zinc lead, cadmium and aluminium are the contaminants most likely to be of ecological concern derived from the Zeehan Mineral Field.

- The Zeehan Rivulet at the Zeehan Highway does not meet ANZECC water quality guidelines for aquatic ecosystems in pH, zinc, aluminium, cadmium, copper, lead and on occasion iron. (The water quality at this site is comparable to the quality of water running through the township of Zeehan).

- Pollutant loads appear to be significantly greater when associated with flushing events (ie heavy rainfall after a dry period).

- The Little Henty River at the Strahan Highway Bridge exceeds ANZECC Water Quality Guidelines for zinc, lead and on occasion copper, aluminium and pH.

- Alkalinity addition of approximately 8g/s $CaCO_3$ is theoretically required to neutralise the acidity generated by the Zeehan Mineral Field (as measured at ZH002). In practice, 6-8g/s $CaCO_3$ slurry from a HALT System should be capable of removing all of the heavy metals contributing acidity except manganese.

3.0 Alkalinity Addition Trials

3.1 Background

Water quality data indicates that lowering acid, zinc, lead and cadmium loads in the Zeehan Mineral Field will substantially improve water quality in the Zeehan Rivulet and Little Henty River. The identification of multiple, diffuse source emissions of acid and metals from the Queen Hill / Oonah Hill / Montana Hill area limits options for effective remediation.

Whilst discrete sources of excavated materials releasing significant pollutants can be handled to lower metal and acid loads (eg. subaqueous disposal), options for addressing broad scale emissions from multiple underground workings and widespread sulphidic surface outcrops are more limited.

The most cost effective option for addressing diffuse-source water pollution at Zeehan is likely to be alkalinity addition.

The concentration of zinc, lead and cadmium in water is strongly dependent on pH, with low levels being associated with high pH. Figure 2 displays the positive correlation between soluble zinc concentrations and pH. To lower zinc to harmless concentrations by pH control alone, it is necessary to adjust pH to a value between 8 and 9. Since background water conditions are naturally acid (pH≈5-6), and the mining legacy has locally exacerbated the release of mineral acids, effective lowering of zinc will not occur naturally.

Another process that is expected to be effective for lowering zinc and other soluble metal concentrations is adsorption onto solid ferric hydroxide. The acid waters around Zeehan are strongly iron enriched due to past mining activity, and the iron precipitates out of solution readily due to aeration, dilution and pH increases. The solid iron precipitate is an effective adsorbent for a variety of other metals, including zinc, removing them from solution at pH levels approaching neutral (ie. 5-7) if settling occurs. Iron precipitation is far more sensitive to pH changes around 3-4 than zinc, and therefore alkalinity addition to precipitate ferric hydroxide is likely to be effective at collateral zinc and other metal reduction.

Continuous treatment of local waterways in the Zeehan Mineral Field with a conventional chemical dosing plant will not be economically attractive. However, passive alkalinity addition to select polluted water sources using low cost, naturally occurring carbonates could be more economically attractive. Such a system could raise the pH sufficiently to facilitate substantial ferric hydroxide precipitation and subsequently lower zinc by adsorption onto the floc.

The development of a technically viable and economically sustainable passive alkalinity addition has therefore been regarded as a fundamental component of remediation for the Zeehan Mineral Field.

Alkalinity addition systems suitable for the passive treatment of acid drainage routinely utilise commonly occurring (and therefore low cost) mineral carbonates such as limestone and dolomite. The key issue for most cost effective passive alkalinity addition systems is to facilitate the sustainable dissolution of carbonate minerals whilst minimising the need for human intervention.

The problem faced by most systems used for mining remediation in the past is that they are static and as a consequence promote neutralisation reactions which are inherently self limiting. Neutralisation reactions generate precipitates which coat and armour carbonate minerals.

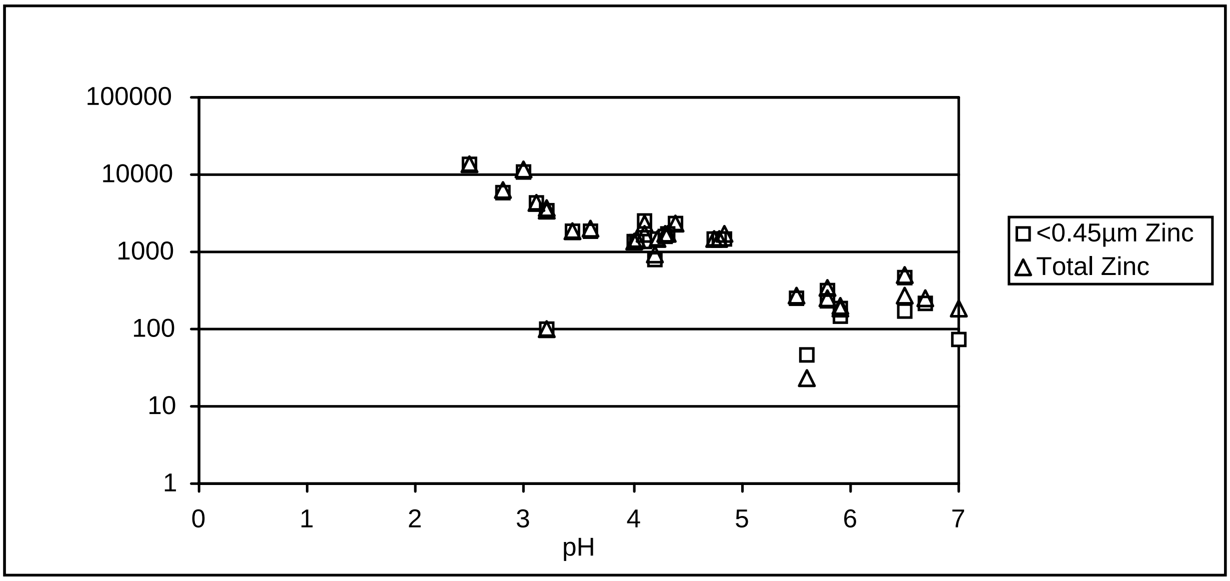


Figure 2: Graph showing the relationship between zinc concentrations and pH.

Whilst static systems lend themselves to "set and forget" strategies, in practice their effectiveness over time is limited. Routine maintenance can overcome some of these issues, but the systems can no longer be considered "passive". In addition, if only a small proportion of the carbonate employed in passive systems is actually utilised for neutralisation, such systems can not be regarded as particularly cost effective relative to more conventional chemical treatment.

The most appropriate alkalinity options for a pilot trial should be based on both technical suitability and cost effectiveness, but none are expected to provide a total solution to elevated zinc concentrations if used in isolation. Successful alkalinity addition strategies are expected to comprise one component of a total package of water treatment / remediation measures for the Zeehan Mineral Field.

3.2 Choice of Alkalinity Addition Options

The discussion paper in Appendix 3 outlined five potentially suitable options for alkalinity addition to key streams in the Zeehan Mineral Field. These options were:

(i) Successive Alkalinity Producing System - SAPS;
(ii) Anoxic Carbonate Drain - ACD (Limestone or Magnesite);
(iii) Open Carbonate Drain - OCD (Limestone or Magnesite) in either a polluted or an unpolluted catchment;
(iv) Water Powered Autogenous Limestone Mill (ie. Hydro-Active Limestone Treatment - HALT);
(v) Reverse Alkalinity Producing Systems - RAPS.

Based on the Zeehan setting, geochemical considerations, and current Best Practice, the following preliminary recommendations were made to Mineral Resources Tasmania regarding pilot trials in the Zeehan Mineral Field:

(i) Design and build a pilot scale water powered limestone mill or slurry system (HALT; Hydro-Active Limestone Treatment) and quantify its ability to control the pH and metal concentration of acid drainage in the Zeehan Rivulet.
(ii) Examine and quantify the efficacy of carbonate drains employing either limestone or magnesite for the treatment of concentrated acid drainage.
(iii) Collate and assess all available geochemical data on the performance of SAPS (Successive Alkalinity Producing System) trials in Tasmania, or elsewhere at metal mines. Use this data to make recommendations about the benefits of SAPS for sustainable and cost effective treatment of acid drainage.
(iv) Install a RAPS (Reverse Alkalinity Producing System) in a suitable shaft in the Zeehan area and assess its effect on drainage water quality.

Two key factors determined the choice of alkalinity addition pilot trials. These were:

(i) to test an alkalinity addition methodology that was likely to prove viable for permanent adoption at Zeehan, and ;

(ii) to implement pilot trials within budget constraints.

Only two alkalinity addition options were specifically excluded from consideration at Zeehan. These included open carbonate drains in either polluted or unpolluted catchments, and rapid flush carbonate drains.

Open carbonate drains located in unpolluted catchments require the provision of very large quantities of limestone to achieve the same degree of alkalinity addition as those in acidic catchments. While this approach may be suitable for some acid drainage issues in some areas (eg. Storeys Creek), budget estimates indicate that it is not a cost-effective option at Zeehan. In addition to this, only the upper reaches of Silver Lead Creek would qualify as largely unpolluted, and little suitable ground is available in this area.

Open carbonate drains in polluted sections of waterway were regarded as unlikely to be effective for extended periods due to the high concentrations of soluble iron and aluminium in the water. To even be effective in the short to medium term, open carbonate drains need to be substantially larger than there anoxic equivalents to cater for the relatively low limestone usage which results from the coating of limestone aggregates with metal precipitates. Greater limestone usage could be achieved from open drains if mechanical methods were used to routinely disrupt the drain (eg. deep ripping), but this introduces additional ongoing expense and limits design specifications. Anoxic carbonate drains were regarded as more likely to be effective than open drains at Zeehan.

Rapid flush carbonate drains (anoxic) were proposed as a conceptual method for avoiding the build-up of precipitates in the pore spaces of limestone aggregates drains. No such drains are known to have been proposed or trialed elsewhere. Given budget limitations, it was not considered appropriate to conduct pilot trials on such a conceptual and potentially expensive system.

3.2.1 Water Powered Limestone Treatment (HALT)

Of all the alkalinity addition options examined, only the HALT system was innovative and untested. The HALT approach offered one key benefit over all existing alkalinity addition options; continuous removal of metal precipitates from carbonate aggregates and dissolution of effectively all of the carbonate used.

General arrangement drawings and specifications for the prototype, pilot-scale water powered limestone dosing system are provided in Appendix 4. The mill chamber and holding vessel were constructed in Victoria (Dandenong) and transported to Exeter in north-east Tasmania where a water turbine and belt reduction system was added. After tests in Exeter, the HALT system was transported by trailer to Zeehan. Photographs of the constructed system operating in Zeehan are provided in Plates 6-8. The system is based on Earth Systems' patented Neutra-Mill water treatment technology, with modifications permitting a combination of attritional and autogenous grinding, and a water turbine power source. The HALT mill was designed to provide a low-cost method of adding highly soluble carbonate slurry to acidic waterways, by using conventionally quarried and crushed carbonate aggregate. The provision of a water powered system provides an additional degree of freedom to locate the HALT mill at sites where the supply of electrical power may be prohibitively expensive.

A Francis-type water turbine was mounted above the cylindrical mill, with its draft tube feeding spent turbine water into the vessel housing the mill. The turbine was employed to enable the HALT mill to operate in a remote location without the need for electrical power. It was rated as providing an effective maximum output of approximately 800 watts at an optimum rotation speed of 975 rpm, given hydraulic inputs with the equivalent of a 7.0 m head and 15 l/s flow rate. Constraints on the power rating of the turbine were controlled by optimum hydraulic parameters based on realistic figures obtained from Pea Soup Creek upstream of the Pea Soup Wetland.

A two-belt/pulley reduction system was designed to provide a final mill rotation speed of close to 50 rpm. The cylindrical mill measured 0.7 m diameter and 1.0 m long and was open ended to facilitate carbonate inputs and outputs. The mill was housed in a vessel to ensure that it could be routinely partially submerged, thereby minimising power requirements by capitalising on the buoyancy effect of water.

Plate 6: The pilot scale HALT (Hydro Active Limestone Treatment) system in operation in Pea Soup Creek, within the Peak Soup Wetland at Zeehan. The feed chute, mill and water turbine are all evident in this picture.

Plate 7: The HALT system operating in Pea Soup Creek. For the purposes of the trial, the water turbine on the HALT system was powered by a petrol pump, using the polluted water directly from Pea Soup Creek.

Plate 8: The grey colouration of the water in the foreground is a result of the limestone slurry being dispensed into Pea Soup Creek from the HALT system, just out of the picture.

Plate 9: Pilot limestone drains under construction at the Highway adit on the Trial Harbour road, a few hundred metres west of the edge of the Zeehan township. The two central PVC pipes (ie. drains) contain magnesite (magnesium carbonate) and the two outer pipes contain limestone (calcium carbonate).

The principal grinding mechanism was considered likely to be autogenous. In order to enhance carbonate output, a thin-walled (0.9 mm) perforated steel sheet was welded to the internal surface of the mill to assist with attritional grinding of carbonate aggregate around the circumference of the mill.

A 90° V-notch weir was installed above the outlet valve of the vessel. This enabled accurate assessment of the flow rate from the turbine under different operating conditions, and permitted calculation of the energy requirements of the HALT mill.

To reduce the cost of the trials, the water turbine was driven by an 11 horsepower petrol pump, rather than installing the pipework, roads and weirs required for water powered systems. The pilot scale HALT mill was transported via trailer to Zeehan and installed on the bank of Pea Soup Creek in the Pea Soup Wetland (refer to Plan Zhn01). The pump was set up to draw highly acid water from Pea Soup Creek, feed it through the turbine and direct the spent water into the holding vessel for mixing with the carbonate slurry. The carbonate slurry was then released into the waterway from the base of the vessel via a valve (refer to Plate x).

Trials with the pilot scale system were conducted over 12 days to:

- become familiar with the operational characteristics of the prototype mill;
- identify the optimum settings for maximum carbonate slurry output;
- quantify the performance of alkalinity addition for improving water quality;
- identify the size of a full-scale HALT mill suitable for ongoing treatment of water in the Zeehan Rivulet;
- document necessary design modifications / improvements and additional components for a full scale system to operate effectively;
- clarify the power output of the pilot-scale mill / turbine steep under different conditions, and predict the power requirements of a full-scale mill;
- assess the relative merits of limestone and magnesite for pH control.

3.2.2 Carbonate Drains

General arrangement drawings for a series of anoxic carbonate drain pilot trials are provided in Appendix 4 and photos of the drains under construction are provided in Plate 9. These trials were designed to test:

(i) the relative rate of alkalinity addition to acid drainage between limestone and magnesite in passive drains;
(ii) the benefit of employing organic matter to maintain reducing conditions in acid drainage prior to its introduction to carbonate material; and
(iii) the relative rate of porosity reduction within a limestone drain and a magnesite drain due to interaction with acid drainage.

The carbonate drains are located outside of the Road Tunnel Adit (Refer to Plan Zhn 01), and are treating drainage which is discharging from these workings. They are being maintained water saturated. The trials were monitored initially after installation, and will be checked periodically over the next few months. Leaking end seals prevented the immediate use of a large vessel containing organic matter that was to be used to enhance reducing conditions and potentially add biogenic bicarbonate to the adit drainage for one set of carbonate drains (Refer to Appendix 4). This vessel will be brought on line during the next site visit. A full report will be provided on the effectiveness of the carbonate drains when more data becomes available.

If the results of these drains are encouraging, it may be appropriate to employ such systems in key adits on Queen Hill to lower the load of pollutants entering Pea Soup Wetland. Such systems are not expected to be able to replace the alkalinity addition provided by a HALT System, but could provide an important low cost, albeit inefficient alkalinity adjunct for the myriad of diffuse ARD sources from Queen Hill.

It is highly unlikely that anoxic drains will be effective for medium or long term treatment of the drainage in Oonah Creek, a key pollutant source. With elevated iron, aluminium and zinc, most static alkalinity addition systems will not be capable of sustained alkalinity addition. Other alkalinity addition systems (eg. HALT) will be required to address these kinds of acid drainage problems.

3.2.3 Successive Alkalinity Producing Systems

The key issue for successful application of SAP systems at metal mines would appear to be the careful choice of sites with negligible soluble ferric iron, and the control of aluminium hydroxide precipitates. It is not clear that these issues can be successfully addressed, particularly at a site such as Zeehan. The size, cost and likely ongoing maintenance requirements of a SAP System at Zeehan are also likely to be considerable.

Miedecke (1999) provides good data on the performance of the SAP system at Mount Lyell, but data on other Successive Alkalinity Producing Systems is currently being sought (ie. ABM at Port Latta and SEMF in NE Tasmania). All available data will be collated and evaluated over the next 3-6 months. It was concluded that as much information as possible would need to be gained from past experience and current test cases before further SAPS trials or a full scale system would be considered for Zeehan.

Some preliminary conclusions regarding the SAP systems can be drawn from the Miedecke (1999) report. Initial results from the pilot scale HALT trials (provided here) clearly demonstrate that such systems are capable of significantly greater alkalinity addition per unit time than the similarly scaled pilot SAP system at Mount Lyell:

Zeehan HALT System Output:	5,500 mg $CaCO_3$ / second (average)
Mount Lyell SAP System Output:	150 mg $CaCO_3$ / second (maximum)

A simple comparison of the pilot operations can also be made to provide indicative relative costs of full scale alkalinity addition systems:

Pilot HALT System (Zeehan)

Capital and Installation Cost:	$ 24,000
Estimated Cost of Automated Feed System:	$ 15,000
2 Week Operating Cost (ie. limestone):	$ 120
Total Output from Continuous 2 Week Operation (Assuming 5.5 g $CaCO_3$ / sec):	6,653 kg $CaCO_3$
Cost per kilogram of Alkalinity over 2 weeks:	$ 5.90

Pilot SAP System (Mount Lyell)

Capital and Installation Cost:	≈ $ 40,000
2 Week Operating Cost:	$ 0
Total Output from Continuous 2 Week Operation (Assuming 6 L/min and 1,500 mg/L $CaCO_3$):	182 kg $CaCO_3$
Cost per kilogram of Alkalinity over 2 weeks:	$ 220

For a full scale alkalinity addition system, the HALT approach is thought to be capable of delivering a tonne of alkalinity at one and possibly two orders-of-magnitude lower cost than a similarly scaled SAP system.

3.2.4 Reverse Alkalinity Producing Systems

Deployment of a combination of organic matter and carbonate material down a shaft was proposed for the Zeehan area. Similar approaches in water impoundments have been referred to as reverse alkalinity producing systems (ie. RAPS). In such systems, groundwater discharge into an impoundment is maintained in a highly reduced state by the organic matter and forced through a large store of carbonate for neutralisation; metal precipitation normally occurs in another pond. The substantial focussing of highly reduced groundwater discharge from Queen Hill out of the Queen No. 4 shaft (and others in the area) suggested that the RAPS approach down a shaft may be very effective.

The Queen No. 4 shaft has been backfilled with waste rock and is therefore not readily accessible for the purposes of a pilot trial. Several other shafts in the area were also examined, but no suitable sites were located in the Zeehan area. Most readily accessible shafts in the Zeehan area have been backfilled for safety or waste disposal purposes.

No RAPS pilot trials were conducted during this phase of work due to the lack of suitable sites. Despite this, it is recommended that the technique be tested if a suitable shaft can be located in the future, and the results of the carbonate drains are encouraging.

3.3 Results

3.3.1 Water Powered Limestone Treatment (HALT)

Daily logs, operating parameters and summary results of the trials are provided in Appendix 5. Typical operating conditions included:

Carbonate Aggregate: -38 mm limestone aggregate was obtained from the Halls Creek quarry at Lynchford, south of Queenstown. 10 tonne of this material cost $18/tonne delivered to Zeehan. Refer to chemical data on the limestone in Appendix 6. Approximately 10-15 wt.% of this aggregate limestone batch occurred as a readily elutriable component (approx. <0.5 mm). -40mm + 25mm magnesite was sourced from the Savage River iron ore mine at Savage River. 5 tonne of this aggregate cost $130/tonne delivered to site. No chemical data is available for this material, but substantial proportions (approx. 5-10%) were from non-carbonate sources. This material was characterised by trace to 1% concentrations of pyrite.

Mill Capacity: The operating load of the mill was varied between 80 and 160 kg, but was generally in the range 80-100 kg. This load was either carbonate aggregate only or a combination of carbonate and abrasive material such as quartz sand or quartz pebbles.

Abrasive Agent: Abrasive agents were not always used, but included quartz pebbles (1-10 cm) and quartz sand (0.5-5 mm). Various ratios of abrasive agent to carbonate were tested.

Mill Rotation Speed: The speed of the mill was controlled by the throttle on the pump, but was maintained between 20 and 90 rpm, and was most commonly maintained around 35-45 rpm. The role of different mill rotation speeds on grinding effectiveness was tested.

Power Requirements:

The power output of the pump, and therefore the power requirement of the HALT mill was measured by recording water pressure at the turbine inlet and water flow over a v-notch weir built into the outlet end of the vessel:

Water Pressure (kPa) /10 = Water Head (m)
Water Head (m) x Flow Rate (l/s) x Gravity (m/s^2) = Power Output of the Turbine
for example, upper Pea Soup Creek has the potential to provide;
7 m x 15 l/s x 9.8 = 1,030 watts
Given a typical turbine efficiency of 80%, this is equivalent to:
1,030 x 0.8 = 820 watts effective energy output.

Power requirements determined for loaded and unloaded runs varied between 140 and 846 watts. Carbonate loaded runs displayed power requirements between 140 and 450 watts. Refer to water pressures, v-notch weir water levels, calculated flow rates and power outputs detailed in Appendix 5.

Carbonate Output:

Quantifying the output of carbonate from the HALT system under various operating conditions involved weighing all inputs to the mill over a specified time period, and weighing the residue at the completion of a run. Outputs were calculated in grams $CaCO_3$ / second, and varied from 3-7.5 g/s. Average outputs were approximately 5.5 g/s, with between 10 and 15 wt.% of the (<0.5 mm) slurry being supplied directly from the raw feed material.

pH Adjustment:

The pH of Pea Soup Creek upstream of the HALT system ranged between 3.1 and 4.5, depending on climatic conditions. For an initial pH of 3.1, post limestone treatment pH values immediately downstream of the mill were 5.6 to 5.8. When a sample was left to stand for 10 minutes, the pH of the treated water rose to 6.2. When left to stand over night, the pH settled at 6.8. Such samples were saturated with respect to limestone. Similar results were obtained with water sampled directly from the HALT vessel, and a veneer of ferric hydroxide was routinely precipitated from treated water contained in the HALT vessel over night.

Monitoring:

Some trials were conducted to identify operating parameters for providing the maximum carbonate slurry output, and others were designed to examine the effect of alkalinity addition on downstream water quality. The key monitoring point for quantifying water quality improvements was the Zeehan Rivulet at the Zeehan Highway (ZH002) at the eastern end of town (refer to Plan Zhn 01). ZH002 was sampled in the morning prior to the commencement of treatment effectiveness runs, and again at the end of a day's treatment. Field pH was also recorded during sampling. Samples were refrigerated at Zeehan and normally dispatched to the laboratory within 2 days of collection. They were subjected to analysis for pH, mineral acidity, total zinc and soluble zinc. Analytical data is summarised in Table 3.1. A significant discrepancy was noted between field and laboratory pH values (see below for discussion). Field trials were conducted on water from ZH002, ZH003 and upstream of the HALT system to clarify the rate of pH change. The results from this study are included in Table 3.2.

Sample	Date	Time	Field pH	Lab pH	Total Zn (mg/l)	Soluble Zn (mg/l)	Acidity mg/l $CaCO_3$	Acidity % Decrease
Baseline	8/6/99	15:15	4.40	4.33	1.77	1.77	18	-
Baseline	10/6/99	08:20	4.34	4.23	1.45	1.45	17	-
Pre Treat	12/6/99	11:45	4.61	3.44	1.90	1.90	42	-
Post Treat	12/6/99	17:20	5.20	3.60	1.96	1.79	30	29%
Pre Treat	19/6/99	08:45	4.70	4.03	1.46	1.36	16	-
Post Treat	19/6/99	18:30	5.50	4.74	1.46	1.44	9	44%
Pre Treat	20/6/99	08:30	4.65	4.30	1.65	1.60	16	-
Post Treat	20/6/99	19:10	6.02	4.83	1.72	1.49	10	38%

Table 3.1: *Analytical data from HALT field trials.*

Alkalinity Plume: Negligible neutralisation is actually conducted in the vessel, since the majority of the carbonate is released as a very fine grained slurry into the waterway for reaction. This slurry forms a visible plume for several hundred metres downstream. The persistence of a visible plume depends on the background water turbidity. Field monitoring of the alkalinity plume during operation of the HALT mill indicated that it tended to migrate significantly slower than the average water velocity. Travel time for the plume from the location of the HALT system to monitoring point ZH002 was approximately 3.0 to 3.5 hours. The prime reason for this appeared to be the significant acid water storage at various locations along Pea Soup Creek. These storages were natural pools at different locations that had sufficient stored acid water to retard the migration of the plume by consuming alkalinity. It is considered likely that 2-3 days (or more) of continuous alkalinity addition would be necessary for the full effect of alkalinity addition to be recorded at monitoring point ZH002.

Design Variations: The prototype HALT system provided for a series of on-site design modifications to examine the effect of variables on the nature and quantity of solids output. Variables included:

(i) variable chamber rotation speed by pump throttle and variable pulley diameter;

(ii) 0.5 mm and 1.0 mm removable screens over the outlet end of the mill;

(iii) two mill-door designs - one solid and the other perforated and fitted with 0.5 mm and 1.0 mm removable screens;

(iv) attachments for 5 mm thick steel chain to emulate the role of lifters and additional abrasive surfaces within the mill.

SAMPLE NUMBER	ZHOO2	ZH003	ZH012
DATE / TIME			
22/6/99			
9:00 AM	5.42		
9:17 AM		4.12	
9:30 AM			4.18
9:50 AM	5.22		
9:55 AM		4.15	
9:58 AM			4.20
10:09 AM	5.18		
12:34 PM	4.98		
12:37 PM		4.02	
12:40 PM			4.10
3:17 PM	4.99		
3:23 PM		4.03	
3:30 PM			4.14
23/6/99			
7:30 AM	4.91		
7:40 AM		4.00	
7:45 AM			4.09

Table 3.2: *Field pH data over time for selected water samples.*

3.4 Discussion

The prototype HALT mill operated above design specifications throughout the trials. It effectively produced carbonate slurries over a broad range of operating parameters and conditions, and provided clear proof of the effectiveness of alkalinity addition by this method.

If treatment were conducted over several days rather than 2-7 hour runs, the post treatment chemical results could be expected to be significantly improved. This is largely due to the progressively increasing alkalinity storage / build-up in the waterway.

The average output of the pilot scale HALT system (5.5 g $CaCO_3$ /s) could be substantially improved by:

(i) increasing the screen size on the output end of the mill chamber to allow a larger grainsize of ground material to be released;
(ii) modifications to the internal chamber design to improve grinding rates, and;
(iii) an increase in the size of the chamber to accommodate more carbonate per unit time.

Aspects of all of these items are expected to be included in the final HALT design for Zeehan.

3.4.1 Design Modifications & Additions

The trials identified key design features that a final HALT treatment system will require:

- The vessel needs a base and side walls that focus slurry flow through the outlet valve, and provide no hang-up points for any solids. A more steeply pitched floor and angled side walls should suffice.

- The feed chute needs to be sealed around the inlet end of the mill chamber to prevent any solids escape from filling the base of the vessel. A rubber flange connected to the inlet end of the chamber should be sufficient.

- A 10 tonne feed hopper is required above the vessel.

- A water powered (or at least activated) feed system for delivering carbonate to the feed chute needs to be designed, built and tested.

- Rather than a shaft drive system, the mill chamber should be driven around its circumference by a waterproof belt system in the same way as the conventional portable Neutra-Mill is at present. This will reduce stress on the shaft and provide a simpler method of rpm reduction from a turbine.

- The inside surface of the service door of the mill needs to be continuous with the inside surface of the remainder of the chamber.

Only 20-50% of the energy theoretically available to drive a turbine-powered HALT system in upper Pea Soup Creek was actually used during the course of carbonate-bearing trials. This means that additional energy is available for grinding. One of the few ways in which this energy could be efficiently utilised is to increase the size of mill chamber. Based on the likely need for greater carbonate slurry output, a larger mill chamber is proposed for a full scale HALT system. A minimum increase to 1.0 m diameter and 1.5 m long is proposed.

The impact of a conventional rubber liner on the internal surface of the mill chamber on a) maintenance costs, and b) carbonate slurry output rates needs to be assessed by field tests. Such trials should be conducted on the pilot scale system.

Further assessment for maximising attritional and autogenous “grinding” needs to be made to assist with improvements to the internal structure of the mill chamber.

3.4.2 Chemical Effectiveness

Prior to the HALT trials, acidity measurements recorded in the Zeehan Rivulet at monitoring point ZH002 indicated maximum alkalinity addition requirements (to a pH of 8.3) of 8,140 mg $CaCO_3$/s (obtained from the total acidity load data in table 2.3). Data collected during the HALT trials indicated loads up to three times as high for brief periods (<1-2 days). Short term fluctuations in acidity loads were found to be very common during the 3 weeks of trials, and were also partly reflected in variable in-stream pH values. The identification of these short term fluctuations has significant implications for alkalinity addition and overall water quality improvement at Zeehan. For example:

(i) the maximum acidity load in the Zeehan Rivulet is still poorly understood, and therefore the minimum scale of an alkalinity addition system is difficult to calculate; and

(ii) any effective alkalinity addition system needs to be able to routinely deal with these spikes in acid load;

The residence time of the carbonate slurry plume in the water appeared to be an important factor for effective neutralisation. The change in pH value over time for treated water samples demonstrated the benefit of extended reaction times between the coarser carbonate particles and acid water.

Given a maximum desirable pH in treated water at Zeehan of 6.0 to 6.5 (prior to entering the Little Henty), it will not be possible to completely neutralise all of the acidity using carbonate. Manganese, for example, will remain in solution until at least a pH >9.0. Hence, based on the chemical data in Appendix 2, the best likely outcome from carbonate alkalinity addition would be an approximately 50% reduction in mineral acidity. This would account for precipitation of Al, Fe, Pb and some Zn and Cd, as well as metal removal related to adsorption. Ideally, only manganese and its associated acidity would remain in water entering the Little Henty river from the Zeehan Rivulet.

Alkalinity addition at Zeehan during the HALT pilot trials routinely provided a 30% reduction in mineral acidity (refer to Table 3.1). Based on the available Zn and pH data, this appeared to be sufficient to account for the Al and Fe precipitation, and a small proportion of additional free H+ ions. Negligible Zn was precipitated or adsorbed as a result of the alkalinity addition. This was largely attributed to the fact that post treatment pH values plunged after ferric hydroxide precipitated from the water. Not only is more alkalinity required, but more effective oxidation and floc formation is needed (see below). Although difficult to determine, probably only marginally larger amounts of sustained alkalinity addition are required for full time treatment at Zeehan.

Trials were not extensive enough to quantify the relative merits of limestone versus magnesite. Both carbonates produced substantial pH increases in acid water, but a detailed comparison was hindered by substantial daily variations in water flow rates and total acidity loads. Given the local availability of limestone and its relatively low cost, it is recommended that priority be given to calcium carbonate for full scale alkalinity addition at Zeehan.

The difference in pH values between in-stream water and samples that had been stored for a period of time highlight two key features of the chemistry of alkalinity addition at Zeehan:

(i) Little of the soluble iron leaving the Pea Soup Wetland is precipitated as ferric hydroxide during its journey through Zeehan, even after substantial alkalinity addition raises its pH up to 6.0. In this case, the pH drop associated with ferric hydroxide flocculation does not substantially occur until after the Zeehan Rivulet meets the Little Henty. This suggests that factors could be at work (eg. possibly physical or kinetic) which retard flocculation.

(ii) Left to sit undisturbed (in a sample bottle), acid production associated with ferric hydroxide flocculation was found to be essentially complete within one hour, even in untreated water (refer to Table 3.2). This suggests that low turbulence and high surface area oxidation processes are likely to assist with relatively rapid floc formation and associated acid production. Such conditions need to be encouraged in order that ferric hydroxide precipitation, Zn adsorption, complete neutralisation and floc settling can be routinely achieved as high up the Zeehan Rivulet - Pea Soup Creek catchment as possible.

3.4.3 Regulating Output

The HALT system is designed to provide the maximum possible slurry output for a given load of limestone in the mill. Output rates will often need to be varied in response to changes in acidity loads. The best method of varying slurry output appears to be changing the feed rate, which will change the mass of limestone in the mill.

The limestone feed system should therefore be metered by water flow rates. In the event of low flow but relatively high loads, the system should be permitted to achieve quasi-saturation with respect to limestone downstream of the HALT in an alkalinity storage facility.

Flushing events are likely to periodically consume part or all of the stored excess alkalinity, and a quasi-saturated pH of 6.0-6.5 will be environmentally benign.

In effect, the HALT systems will be responding to variations in flow rather than directly pH or acidity loads, but will still deal simply and effectively with neutralisation by employing downstream alkalinity storages.

3.5 Significant Findings

The following findings from the alkalinity addition trials have a significant bearing on future remediation of the Zeehan Mineral Field.

The HALT approach involves the production of a highly reactive carbonate slurry which requires a downstream reaction and precipitate settling system. This method appears to address many of the reagent inefficiency problems associated with other alkalinity addition systems, but unlike some techniques will require ongoing reagent addition and some routine maintenance.

An appropriately modified, single HALT system used in conjunction with other techniques for manipulating water chemistry is expected to be effective in achieving significant water quality improvements in both the Zeehan Rivulet and downstream in the Little Henty.

Based on the chemical (± physical) responses of the Zeehan waterways to alkalinity addition, the following approaches are considered to comprise the key components to fulfil water quality objectives.

A: Subaqueous disposal of key polluting waste rock materials.

B: The successful performance of the pilot scale trials and the lack of technically and economically appropriate alternatives suggests that alkalinity addition work focus on developing a full scale HALT System. Such a system should employ limestone and provide an enhanced carbonate slurry output relative to the pilot scale system. A routine maximum output of approximately 10g $CaCO_3$/s will probably be sufficient if the recommendations outlined in Section 4 are adopted. Carbonate slurry output rates from a full scale HALT system should be controlled by using water flow rates to vary the mass of limestone held within the mill.

C: A dam or dams to store alkalinity as a buffer for sporadic peaks in acidity loads, and to provide enhanced residence time for acid water with limestone particles. Such storages will simplify the response mechanisms needed for alkalinity addition mills dealing with variable flow rates and acidity loads (refer to Section 4).

D: One or more areas are required to provide shallow, slow-flow, large surface area, oxidation / flocculation ponds / wetlands for removing and storing ferric hydroxide precipitates after alkalinity addition. Such wetlands may also have the benefit of increasing the interaction between limestone particles and acidic water.

E: Water diversion works to segregate relatively clean water from highly acid flows in order to minimise the scale and improve the performance of the dams and wetlands.

A comprehensive remedial strategy for the Zeehan Mineral Field, including a detailed rationale and costing for key components is provided in the following section.

4.0 Remediation Options

4.1 Introduction

This study has identified the two key sources of major pollutants (ie. acid, zinc, lead, aluminium, cadmium and iron) to be:

a) the Oonah catchment and workings, and
b) diffuse sources from multiple workings on Queen Hill, draining into the Pea Soup Wetland.

Silver Lead Creek above the Queen No. 4 Shaft is relatively unpolluted, and upper Pea Soup Creek is contributing substantial iron and acid but little else.

Primarily, remediation should be focussed on permanently minimising sulphide oxidation by subaqueous disposal of key wastes. At Zeehan, the proportion of sulphidic waste that can be disposed of subaqueously is relatively small. Hence, removing unavoidable toxic metal components from the water is essential.

4.2 Background to Metal Removal by pH Adjustment

Metal removal from acid drainage is often achieved through pH control using lime based compounds (eg. calcium oxide, calcium hydroxide or calcium carbonate / limestone). As the pH of acid solutions is raised, soluble metal sulphate species are converted to insoluble metal hydroxide species and the sulphate is precipitated as calcium sulphate (gypsum). In situations where it is not economically viable to use refined calcium-based chemicals, limestone is a preferred treatment reagent. Limestone is ideal for neutralising highly acid water, but in most situations it can only be expected to raise drainage pH to between 5 and 7. Under these slightly acid to neutral conditions, iron(III), aluminium and lead will have precipitated as metal hydroxides from waters in equilibrium with the air. There will be some resistance / delay to precipitating iron under these circumstances only if the drainage is not in equilibrium with air (ie. sufficiently oxidised), and possibly if physical conditions do not favour floc formation. Oxidation of soluble iron(II) to iron(III) and subsequent precipitation of iron(III) hydroxide (or ferric hydroxide) is relatively rapid above pH 5 in typically oxygenated surface waters (Jones and Chapman 1995).

4.2.1 Zinc and Cadmium Removal by Adsorption

Numerous studies demonstrate that neither zinc nor cadmium can be expected to substantially precipitate as metal hydroxides at pH levels between 5 and 7. Several laboratory studies show, however, that removal of zinc and cadmium from near neutral to slightly acid mine drainage solutions can be achieved through adsorption onto ferric hydroxide precipitates (Webster et al., 1998; Jones and Chapman, 1995; Johnson, 1986; Chapman et al., 1983; Benjamin and Leckie, 1980; Gadde and Laitnen, 1974). Since most acid drainage waters, including those at Zeehan, are relatively iron-rich, it is possible to promote the precipitation of ferric hydroxide and thereby encourage zinc and cadmium removal via adsorption.

Studies by Webster et al., (1998), Jones and Chapman (1995) Johnson (1986), Benjamin and Leckie (1980) and Gadde and Laitnen (1974) show that adsorption of zinc and cadmium is primarily dependent on pH, with high pH being associated with greater adsorption. Webster et al., (1998) provide data indicating that at pH 6.5, between 50-95% of zinc and 50% of cadmium can be removed from an acid drainage solution by adsorption onto natural ferric hydroxide precipitates. Jones and Chapman (1995) state that the pH of AMD should be raised to at least 6 prior to oxidation of Fe(II) to Fe(III) in order to make the best use of the metal absorbing capacity of ferric hydroxide precipitates. Their data suggests that the pH at which a metal ion concentration can be lowered by 50% through adsorption is 5.5 for zinc and 6.0 for cadmium (ie. pH_{50}). These pH_{50} levels are for low initial metal concentrations (20 µg/L), and will be higher for higher initial metal concentrations. In a laboratory based study, Benjamin and Leckie (1980) report a pH_{50} for zinc of 6.1 to 6.7 and for cadmium of 5.9 to 7.3 depending on the initial concentration of the metal, but at similar concentrations to those encountered at Zeehan. Gadde and Laitnen (1974) conducted laboratory tests using very high concentrations of zinc and cadmium, and only demonstrated a ≈10% removal of zinc and cadmium with ferric hydroxide.

It is clear from some research (Webster et al., 1998; Benjamin and Leckie, 1980; Gadde and Laitnen, 1974) that factors other than just pH also contribute to the metal adsorption capacity of natural systems in typical acid drainage scenarios. Such factors include:

- The initial metal ion concentration: higher initial metal ion concentrations displace the pH_{50} to higher values.

- The adsorbent / adsorbate ratio: the relative amount of adsorbent to soluble metal affects the number of sites available for metal adsorption. The higher the adsorbent / adsorbate ratio, the more effective the metal removal.

- The nature of the adsorbent: most typical acid drainage solutions have the capacity to develop a number of precipitates, each with a different capacity to adsorb metal ions. These include iron, aluminium and manganese hydroxides, and in combination they may be expected to provide better metal adsorption than any one in isolation.

- The crystallinity and origin of the metal hydroxide adsorbent: Webster et al., (1998) documented substantial differences in the adsorption capacity of synthetic and natural hydrous iron precipitates, and concluded that natural (?bacterially mediated) ferric hydroxide bearing precipitates were significantly more effective at zinc and copper adsorption than their synthetic equivalents.

- Presence of adsorbed sulphate: Webster et al., (1998) identified the importance of ternary complexes between the oxide surface, a zinc (or copper) ion and adsorbed sulphate ions, re-emphasising the enhanced performance of natural systems relative to laboratory experiments.

- Biological adsorbent's: Additional adsorbent surface provided by bacterial, algal or simple aquatic plant activity is expected to enhance zinc and cadmium removal from acid drainage.

Laboratory based studies tend to underestimate the capacity of natural systems to remove metals by adsorption because they cannot account for the combined effects of adsorption from iron, aluminium and manganese hydroxide, sulphate ions, as well as other biological surfaces. The recent study of a SAPS system by Miedecke (1999) may be a good example. Monitoring data in Appendix B, Table 1 from Miedecke (1999) shows that a passive, limestone-based system has the ability to lower initial soluble zinc concentrations from 37.6 mg/L at pH 2.88 to 5.43 mg/L at a pH of 6.13 (85% reduction) in a natural acid drainage solution from the Mount Lyell minesite. The same solution demonstrated a change in soluble cadmium from 0.11 mg/L at pH 2.88 to 0.02 mg/L at pH 6.13. It is likely that adsorption of both zinc and cadmium onto a range of materials (iron, aluminium and manganese hydroxides and organic matter) was responsible for these substantial metal reductions at the modest pH level recorded. These selected results provide the best available evidence of the capacity of a limestone-based system at Zeehan to adequately lower zinc and cadmium concentrations by adsorption. While the SAP system at Mount Lyell was not able to maintain this result, this may be attributed to a reduced capacity to sustainably add alkalinity to the mine drainage stream.

4.3 Effective Water Treatment at Zeehan

It can be concluded from the aforementioned range of studies that metal adsorption is a complex issue that cannot be readily resolved with laboratory testwork alone. The behaviour of a particular acid drainage solution is expected to be a function of site specific factors and conditions. However, it can be inferred from these studies that under appropriate physical and chemical conditions (specified below) that 50-90% of the zinc and 50-80% of the cadmium in drainage waters at Zeehan could be removed by adsorption onto metal hydroxide precipitates and biological surfaces. Indeed, as surface flow wetlands become more established, we could expect to see greater metal removal from drainage by adsorption on the surfaces of biofilms, algae and aquatic plants.

Based on fundamental geochemical considerations outlined above, effective water treatment at Zeehan needs to accomplish the following:

(i) Alkalinity addition sufficient to initially raise the drainage pH to at least 5. The pilot scale HALT trials demonstrated that this approach to alkalinity addition has the capacity to deliver all of the neutralising capacity required for the considerable acid and metal loads in Zeehan waterways.

(ii) Sufficient residence time in a holding pond at elevated pH to promote thorough oxidation of soluble iron(II) precipitation of metal hydroxides. An impoundment providing a high surface area interaction with the atmosphere for at least several hours, and much larger if possible, would be important. Tests conducted during the alkalinity addition pilot trials indicated that little ferric hydroxide precipitation was promoted by aeration of water travelling down the Zeehan Rivulet. Despite an appropriate pH regime during the trials, most ferric hydroxide precipitation was clearly still occurring somewhere in the Little Henty River. This observation indicated that effective removal of zinc and cadmium via adsorption onto ferric hydroxide would need to occur as high up the Zeehan Rivulet catchment as possible.

(iii) Sufficient excess or stored alkalinity to neutralise the additional acid produced by ferric hydroxide precipitation, and maintain the pH as high as possible (eg. pH 5-7).

(iv) An impoundment capable of ensuring low energy flow conditions suitable for promoting ferric hydroxide floc formation and settling, and consequent metal removal from the water column.

(v) Sufficient stored alkalinity to cope with short term flushing events caused by typical rain events and interspersed dry days. Stream acidities can vary by a factor of at least 3-4, and pH can vary by at least 1.5 log units on successive days during median flow events. Alkalinity storages need to scaled to overcome the acidity in both median and peak flows to provide effective and sustained water quality and environmental benefit.

4.4 Remediation Objectives

The key objectives for comprehensive remediation of the Zeehan Mineral Field need to be:

(A) Lower acid and metal concentrations (soluble and solid) draining from mine workings and through mine wastes in the Queen and Oonah Hill areas, in order to improve the water quality passing through the township of Zeehan, and;

(B) Lower zinc, lead, cadmium, aluminium and iron loads into the Little Henty so that concentrations are more compatible with ANZECC water quality guidelines for aquatic ecosystems.

Results of water quality investigations and pilot trials conducted in the Zeehan Mineral Field indicate that these objectives will require the following methodologies:

(i) Subaqueous disposal facility for sulphidic waste to provide a long term strategy for minimising sulphide oxidation associated with currently identified and future reserves of polluting material (eg. Tasmanian Smelter tailings).

(ii) Cost effective and sustainable alkalinity addition system.

(iii) Storage facilities for the safe, long term disposal of treatment precipitates.

(iv) Alkalinity storage dams to provide a low cost mechanism for managing / buffering the impacts of short and long term acidity flushing events.

(v) Low cost methods / facilities for enhancing the oxidation of water and promoting ferric hydroxide floc formation and settling, which minimise the likelihood of remobilisation during subsequent high flow events.

(vii) Earthworks and revegetation programs which substantially improve the visual amenity of the area without impacting on the mining heritage.

4.5 Key Remediation Components

Based on recent water quality data and the results of the alkalinity addition trials, the following methods form key facets of a total remediation strategy at Zeehan.

Subaqueous Disposal

Subaqueous disposal of the worst acid and metal producing material, in an appropriate location is a fundamental strategy for long term avoidance and minimisation of acid drainage. Disposing sulphidic waste materials (ie. waste rock and tailings) under water is the most effective method for retarding oxidation and minimising acid drainage formation. Subaqueous disposal can be achieved at Zeehan by a) constructing a raised terrace of sulphidic waste material over a portion of the existing Pea Soup Wetland and saturating this layer to form an elevated wetland, or b) reshaping valley floors in the Oonah catchment to accommodate nearby sulphidic wastes that can form water saturated terraces / cascading wetlands. In both situations, the wastes would be dammed to ensure saturation and shallow flow wetlands (see below) would be established on the surface to reduce water velocity, facilitate oxidation and enhance residence time to promote carbonate reaction, floc formation, settling and sedimentation.

Alkalinity Addition

Diffuse acid drainage sources from workings Queen Hill and Oonah will continue in spite of subaqueous disposal of key waste sources. At present, only alkalinity addition has the potential to address these sources of pollution. Based on the success of the pilot scale trials and the lack of well defined and effective alternatives, quasi-passive, low-cost alkalinity addition using a single HALT system will form an important aspect of successful remediation at Zeehan.

Alkalinity Storage

Alkalinity storage dams are simply water impoundments located downstream of alkalinity inputs that are designed to accumulate treated water. These storage dams have been devised as a vital component of acid drainage treatment at Zeehan in order to address a) short and long term acidic flushing events, and b) to increase the interaction time between sparingly soluble carbonates and acid water. The dams will have the additional benefit of facilitating oxidation and ferric hydroxide settling and storage.

Shallow Flow Wetland

Shallow oxidation / flocculation ponds or “Shallow Flow Wetlands” are primarily designed for maximising ferric hydroxide floc formation (ie. oxidation) and settling. Such wetlands provide for optimum interaction between water and the atmosphere, and enhanced water residence times. A shallow flow wetland can be the primary repository for treatment precipitates, and can be located above a sulphidic waste disposal terrace. In order to be effective and sustainable, shallow flow wetlands should be located downstream of alkalinity addition. Once fully established with vegetation, wetlands also have the potential to improve water quality through filtering, cation exchange, biogenic neutralisation reactions and complex microbiological processes (eg. biosorption).

A wetland has developed in Pea Soup Creek above the township of Zeehan. Aerial photographic evidence indicates that this wetland, which has become known as Pea Soup Wetland has developed substantially since 1984, and was virtually nonexistent in 1947. Pea Soup Wetland now covers approximately 10 hectares (0.1 km^2) approaching its natural size limit based on topographic constraints. Due to the diffuse nature of the acid drainage additions around the wetland it is difficult to quantify its impact on water quality. However it does appear to contribute to improvements in downstream water quality by a) assisting precipitation and settling of fine grained sediments (eg. iron hydroxides) and b) covering some sulphidic waste materials with water.

Clean Water Diversion

Clean water diversion facilities optimise the performance of alkalinity storage dams and wetlands by enhancing water residence times.

Settling Basin / Wetland

Deep settling / flocculation basins or wetland systems could be important as a final filter and medium to long term storage facility for metalliferous precipitates.

Revegetation

The final component of remediation will involve selective revegetation to stabilise waste materials, introduce organic and potentially neutralising material into the substrate, and improve the visual amenity of the area.

4.6 Proposed Remediation Options

A broad range of permutations and combinations of the above remediation components was assessed against the water quality objectives. The options proposed below represent a balance between the degree of realistic benefit obtainable and other factors such as cost, risk, climate, terrain, local natural resources and site logistics.

The remediation approach proposed for Zeehan involves several phases. A Timeline for the conduct of this work is provided in Figure 3. All remediation options take into account the importance of the mining heritage of the Zeehan area, and the need to preserve key sites of archaeological significance (Kostoglou, 1999).

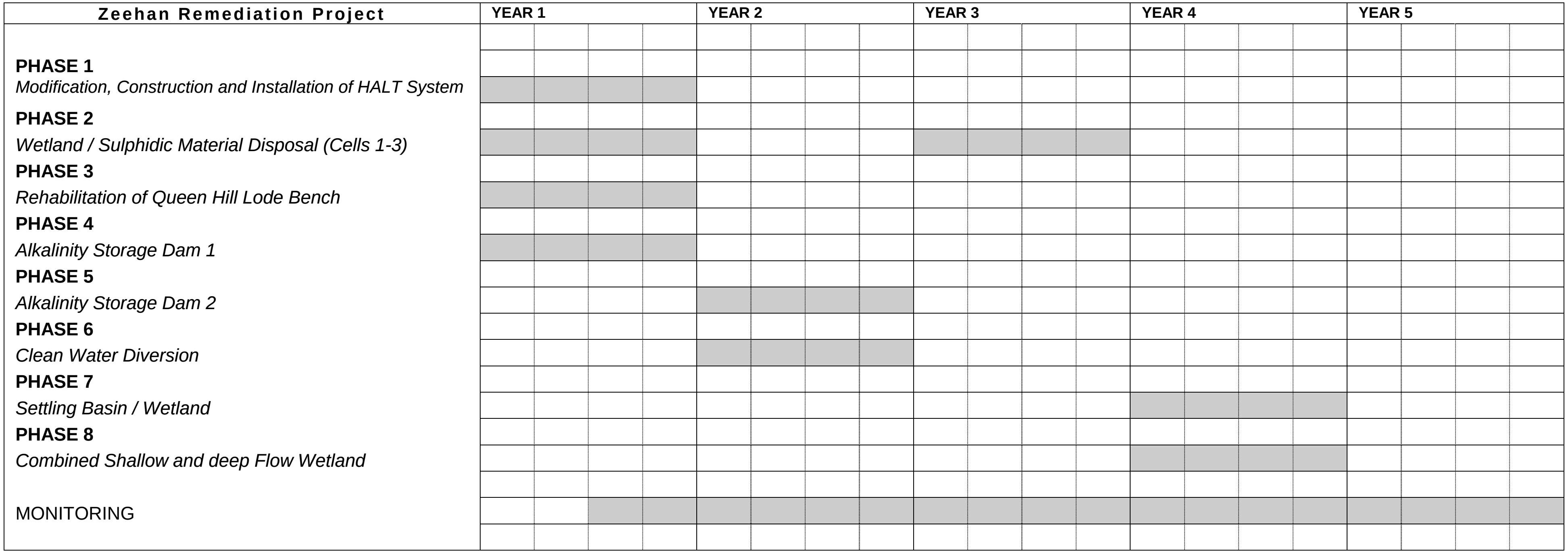
The budget estimates provided below for civil works related to development of waste storage cells, alkalinity dams, diversion channels and wetlands can only be considered as "first pass" estimates. They are based on estimated quantities derived from broad scale mapping with very limited investigation of site subsoil conditions and waste material properties. The approach to costing has been conservative on several issues, including:

- material quantities believed to be rounded upwards;
- all waste materials have been assumed to be polluting;
- the proposed alkalinity storage dams are based on practical sizing related to natural land formation and are possibly excess to minimum requirements;
- 20% contingencies have been allowed.

Consideration of quantities for waste materials and for earthworks has been highly influenced by the lack of good survey information. All work to date has been based on 5 m contours from Land Information Bureau Orthophoto data. Given that most waste rock dumps or proposed embankments are lower than the contour interval, there has been considerable interpretation necessary to derive the quantities used.

It is possible that the cost of various phases of work could be reduced when a more detailed assessment is conducted (refer to recommendations).

Figure 3: Proposed project timeline for staged remediation of the Zeehan Mineral Field



4.6.1 PHASE 1 Modification, Construction and Installation of a HALT System

Improve the performance of the pilot scale alkalinity addition HALT system. This will involve:

- Installing a rubber liner in the HALT mill and test its effect on mill life and carbonate slurry output.
- Improving the grinding rate of the mill by refining the internal design.
- Design, build and test a water powered carbonate feed system.
- Design and build a full scale, improved HALT system, as per the modifications recommended above.
- Design and build a 10 tonne hopper for the HALT system.
- Test the performance of the carbonate storage, feed and grinding equipment.
- Transport the equipment to Zeehan and set up to operate during the disruptive earthwork phase.

A HALT System could be located in a range of places. There are at least two good locations for a HALT System in the vicinity of the Pea Soup Wetland.

Option A An electrically powered HALT System could be located in the upper Oonah Creek catchment (refer to Figure 4), and;

Option B A water powered HALT System could be located in upper Pea Soup Creek (refer to Figure 4).

The choice of these options is not expected to affect the carbonate slurry output, but may influence capital cost, maintenance requirements and ongoing costs.

As an identifiable discrete source, Oonah Creek contributes the largest Zn load in the district (≈50% of the total load in Pea Soup Creek). It is therefore appropriate to consider alkalinity directly into this catchment to lower Zn levels as rapidly and effectively as possible. This would require the installation of electrical power lines (see below and Figure 4.).

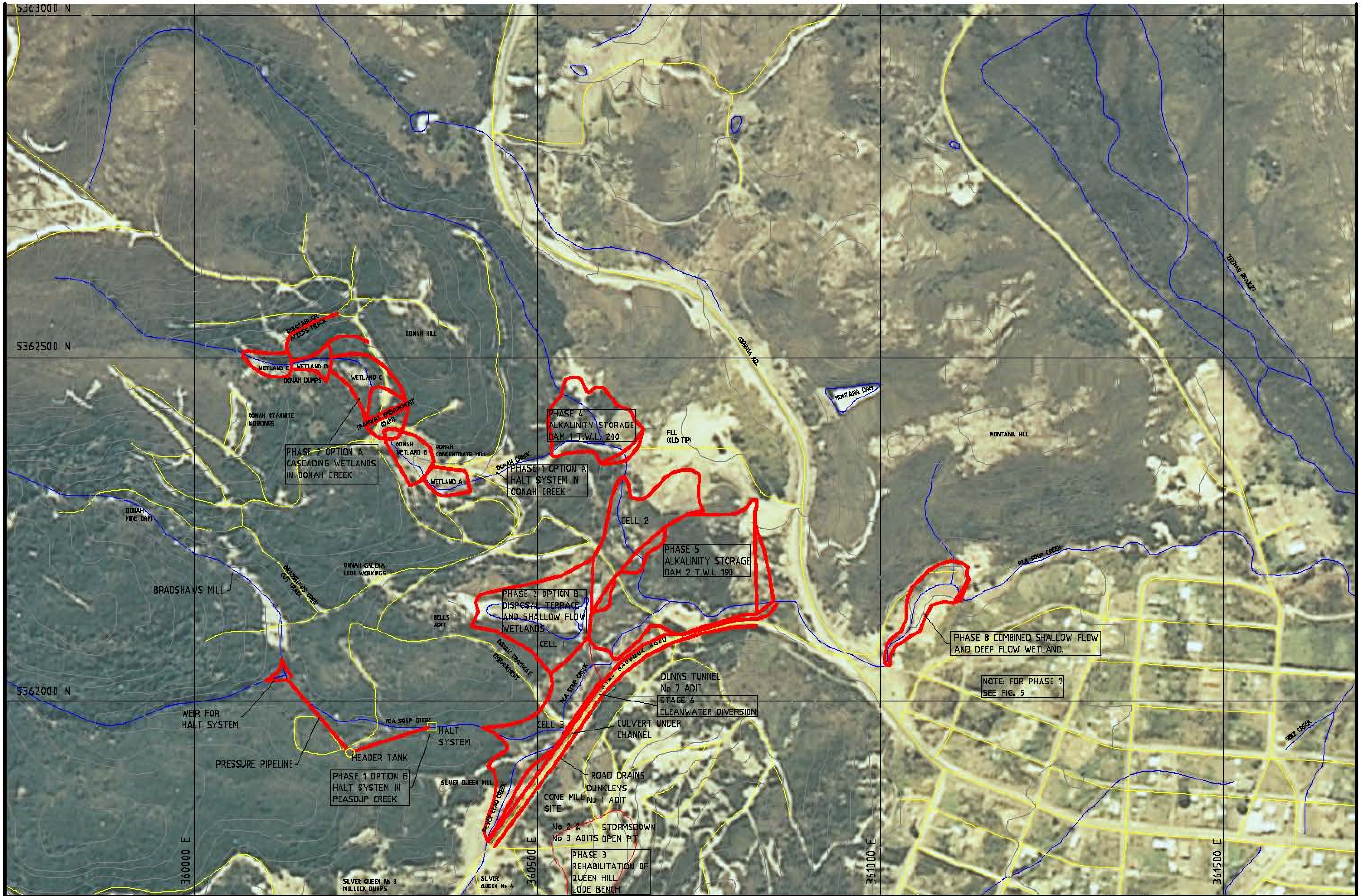
The upper Pea Soup catchment is the only location currently identified that is capable of providing the head and flow characteristics suitable for the operation of a water turbine with adequate power to operate an appropriately scaled HALT System. The water powered HALT, Option B is designed around this limitation, rather than being a site selected for optimum treatment. Option A is preferred for optimum treatment results (see below).

PRELIMINARY BUDGET

System Refinement & Optimisation:	$ 5,000
Full Scale HALT System Design & Construction:	$ 27,500
Design, Construct & Test Feed System:	$ 17,000
Construct 10 Tonne Storage System:	$ 8,000
Transport to Zeehan:	$ 2,900
Zeehan Installation:	$ 8,000-18,000*
Commissioning of System:	$ 3,000
Expected Costs:	**$72,000-82,000**

Limestone Reagent - 1 year supply (200 tonnes):	$3,600
Alkalinity Addition Monitoring & Assessment:	$7,500 / yr

* The lower figure is for the electrically powered HALT system in Oonah Creek (Option A), the higher figure is for the water powered system in Pea Soup Creek (Option B).



Revisions: REV. No / Date / Description	Thompson & Brett Pty. Ltd. Consulting Engineers 8 Bayfield Street, Rosny Park. 7018 Phone (03) 6244 6855 Fax (03) 6244 6331 E-mail : tb@trump.net.au	Design D.M.B Date JUL. 1999 Drawn M.R.H Date JUL. 1999 Design Check Drawing Check	Scale 1 : 2500 A1 File MINES - 10 Controlled Document Yes No Approved	Client & Project MINERAL RESOURCES TASMANIA ZEEHAN REHABILITATION PROJECT	Drawing Title REHABILITATION OPTIONS PEA SOUP WETLAND AREA Drawing No. FIGURE 4

4.6.2 PHASE 2 Sulphidic Waste Disposal / Wetland

Disposal Terrace and Shallow Flow Wetland

This option allows for the establishment of a large, shallow pond area below which waste rock can be effectively submerged to provide a high level of security against continued oxidation. Various locations were assessed, and the two most suitable options are costed and evaluated below.

One location would involve constructing an earthen dam embankment within the Pea Soup Wetland area to allow a pond level of around RL 194 as shown on Figure 4. A total storage of around 60,000 m^3 can be provided in this area in a series of cells. Cell 1 would be constructed by raising an existing tramway to the south of Oonah workings. Sulphidic waste from the Oonah dumps (≈25,000 m^3) would be placed and compacted in layers in the floor of Cell 1 prior to flooding. Sufficient storage would be available in future cells to accommodate other highly polluting waste sources (eg. waste rock from Queen Hill and tailings from the Tasmania Smelter site). The area should also permit >20 years storage of water treatment precipitates from the Oonah workings, and maintain a shallow water cover over the wastes at all times. The surface of the area is to be designed as a "shallow flow wetland". Water from the Oonah South workings will flow directly into this shallow flow wetland.

The wetland on the surface of disposal cells will provide for varying water depths and would feature exposed surface shapes to increase diversity of physical features for plant establishment. This may include shaping to provide islands and alternating deep and shallow areas to allow colonisation by varying aquatic macrophyte plants. It should also provide channel ways within the wetland to reduce the velocity of peak flow events and minimise disruption to settled sediments and precipitate.

The impounded wetland should provide for the capture of all direct drainage from Oonah Creek by open channel, Oonah South workings and surface runoff from exposed areas around the existing wetland area.

DIMENSIONS

Ultimate Length of Wall:	330 m
Cell 1 Wall length	180 m
Width of Wall:	34 m base to 4 m top
Height of Wall:	5 m
Total Surface area:	35,000 m^2
Average Depth of Fill:	1.8 m
Average Depth of Standing Water:	10-20 cm
Total Solids Storage Capacity	60,000 m3
Initial Volume of Fill:	25,000 m^3
Excess Solids Storage Capacity:	35,000 m^3

PRELIMINARY BUDGET

Cell 1 Dam Embankment 10,000 m^3 at $4	$ 40,000
Spillway	$ 10,000
Upgrade Haul roads	$ 10,000
Cart, place and Compact Waste, 25,000 m^3 at $4	$ 100,000
Establish wetland and land plants: 10,000 m^2 @ $3	$ 30,000
Contingencies and Engineering, 30%	$ 57,000
Estimated Cost Cell 1	**$247,000**
(Possible Future Dam Embankment 30,000 m^3 at $4	*$120,000)*

There will be some cost savings if the two disposal cells are constructed simultaneously, as a dividing wall between the cells will not be necessary.

As Oonah Creek drainage is highly acidic with high metal loads, it is critical that prior treatment is provided to neutralise the drainage to about pH 6-6.5. This is required to ensure that acidity from precipitation of ferric hydroxide is adequately buffered in the wetland and that ferric hydroxide precipitates settle or attach to plant and other surfaces in the wetland. It is hoped that these precipitates will provide binding sites for the immobilisation of other metals such as zinc.

The available volume for the proposed surface flow wetland on top of the disposal cell is comparable with similar wetland systems built elsewhere (ie. up to 3.5 ha for a median flow of 1000 m^3 per day from Oonah Creek). For example, a 4.2 ha wetland at the Hilton Mine (Jones and Chapman, 1995) is used to lower iron, zinc and manganese concentrations in a 3000 m^3 per day flow, once the pH has been raised to 8. In Tennessee, design relationships between iron loads and water surface area requirements indicate about 0.75 m^2 per mg iron per minute, where pH of inflow is above pH 5.5 (Jones and Chapman, 1995). With an indicative iron load in Oonah Creek of about 21 kg/day, the required surface area of wetland would be approximately 11,000 m^2. The final available area proposed above is about 35,000 m^2 (ie. cells 1 and 2). Ryan and Hosking (1992) reported US and Canadian workers (uncited) basing area requirements of between 10 to 60 m^2 of wetland per m^3 of flow per day. Under median flows for Oonah Creek (10.5 l/s), this equates to a wetland surface area of between 9-55,000 m^2. Wildeman et al., (1991) reported in Ryan and Hosking (1992) required at least 1000 square feet per gallon per minute for high removal rates of iron, zinc copper and pH buffering. This equates to 28 m^2 per litre per minute or an area of 17,640 m^2.

A shallow flow wetland will not be effective or sustainable unless upstream alkalinity is added. Hence, this location relies to some extent on the installation of an alkalinity addition system in Oonah Creek.

Alternative Option Assessed - Cascading Wetland in Upper Oonah Creek

This option allows for the stabilisation of waste rock dumps in the Oonah Creek area with the minimum earthworks and disturbance. The concept is to construct five, water saturated in-situ terraces or cascading wetlands from waste rock and tailings material upstream of the Oonah Concentrate Mill area. The terraces would incorporate the maximum extent of wetland area to facilitate subaqueous encapsulation of the sulphidic wastes. The location of these features is shown on Figure 4.

The estimated volumes of waste material in the Oonah catchment are:

Below Tramway Wall	17500 m^3
Tramway Wall	5000 m^3
Upstream Waste Dump 1	5000 m^3
Upstream Waste Dump 2	3000 m^3

The lower two Wetlands A and B, would be prepared by reshaping material downstream of the existing tramway embankment. This work would be designed to minimise any disturbance to archaeological sites in the area. reshaping would provide stable batters and spillways lined with selected non reactive rock. Wetland C would utilise the existing earthen wall provided by the tramway, which would be infilled with wastes excavated from upstream dumps.

Wetland D and E would be constructed upstream of the tramway bund to suit the location of waste material. Each wetland would feature a downstream wall constructed from clay and soil material excavated from off site. Any exposed waste would be capped with clay. Spillways lined with stable rock would link the wetlands.

PRELIMINARY BUDGET

Re-establish Access Roads on old road alignments	$10,000
Excavation and Spreading of waste	
(allow ≈30% of total 25,000 m^3) 8000 m^3 at $4	$32,000
Spillways 600 m^2 at $30	$18,000
Dam walls and capping clay: 5,000 m^3 at $10	$50,000
Establish wetland and land plants: 16,000 m^2 @ $3	$48,000
Contingencies and Engineering 30%	$47,000
Estimated Costs:	**$205,000**

These costs could be incurred incrementally if the five wetlands were installed in stages.

NOTE: *One of the concerns / risks with this option is the potential for underground workings to drain water from the terraces, thereby leaving the waste subject to oxidation. Current drainage from the Oonah South workings highlights these concerns. This option also does not provide for the disposal of sulphidic wastes from other locations in the mineral field. It is not the recommended approach.*

4.6.3 PHASE 3 Rehabilitation of the Queen Hill Lode Bench

Funding for rehabilitation and revegetation of the bench excavated over the Queen Hill Lode by Aberfoyle Exploration has already been allocated. This work will include water diversion, disposal of key waste rock materials (eg. to disposal cell), identification and excavation of a clay borrow pit, recontouring of surface features and revegetation. The removal and subaqueous disposal of highly sulphidic wastes from this bench will be a important component of this phase.

This phase is not expected to provide a significant improvement in water quality in the Zeehan Rivulet.

PRELIMINARY BUDGET

Work Program

- Water Diversion Works
- Sulphidic Waste to be Disposed
- Acquisition of Suitable Fill / Cover Material
- Recontouring
- Revegetation

Estimated Cost: **$ 50,000**

4.6.4 PHASE 4 Alkalinity Storage Dam

Option A - Alkalinity Storage Dam 1

If the HALT System is electrically powered and located proximal to the main Oonah workings, a downstream alkalinity storage impoundment is recommended to buffer acidity surges and ensure optimum alkalinity addition. An alkalinity storage dam could be constructed on Oonah Creek, topographically above the proposed location of the disposal terrace / shallow flow wetland. A reasonably attractive site is indicated by the contours shown in Figure 4.

The dam should have the capacity for storing at least 2-3 days of water under median flow conditions (ie. approximately 2-3 ML), but a significantly larger capacity would be more desirable to cater for peak flow events. The proposed dam is located in a broad valley, and will accumulate significant amounts of suspended sediment, limestone and treatment precipitates. Excess storage capacity is factored to account for >20 years storage of such solid materials. Alkaline water overflowing from the dam will overflow into the shallow flow wetland lying above the proposed disposal terrace outlined in Phase 2 / Option B. If only cell 1 is available, an open channel will be required from the storage dam 1 to the upper part of cell 1.

DIMENSIONS

Length of Dam Wall:	90 m
Height of Dam Wall:	4 m
Width of Wall:	28 m base to 4 m top
Surface area:	10,800 m^2
Average Depth of Standing Water:	1.5 m
Water Storage Capacity:	16,000 m^3
Storage Duration under Median Flow:	16 days
Storage Duration under Peak Flow:	2.5 hours

PRELIMINARY BUDGET

Clear and Strip site	$10,000
Dam Embankment 4,000 m^3 at $5	$20,000
Spillway	$ 5,000
Topsoil Spreading and Vegetation 1 ha at $20,000	$20,000
Contingencies and Engineering, 30%	$14,000
Estimated Cost:	**$69,000**

The dam could be constructed in staged lifts in order to lower construction costs and determine the optimum size the dam by performance monitoring.

If the HALT System is located in upper Pea Soup Creek, rather than Oonah Creek, then the Alkalinity Storage Dam No. 1 will not be necessary, but Alkalinity Storage Dam No. 2 outlined in Phase 5 below will need to be as large as possible.

4.6.5 PHASE 5 Alkalinity Storage Dam 2

A second alkalinity storage and settling dam is recommended downstream of the disposal terrace / shallow flow wetland and upstream of the junction between the Trial Harbour and Granville Harbour roads (refer Figure 4). This dam will be used to treat and oxidise all of the drainage from Queen Hill and upper Pea Soup Creek. It will be particularly important as the primary alkalinity storage impoundment if the HALT System is located in upper Pea Soup Creek, rather than in the Oonah catchment. This dam should have the capacity to store at least 24 hours of water under median flow conditions, not including contributions from the relatively clean upper Silver-Lead Creek (ie. 3.5-4.0 ML). The capacity of this dam to store alkalinity will be adversely affected if Silver-Lead Creek is not diverted past the Pea Soup Wetland. An allowance for the storage of solids (suspended sediments and treatment precipitates) is also required. This dam will be the primary treatment zone for water draining Queen Hill and upper Pea Soup Creek (ie. Bradshaw's workings). The larger and more effective this dam is, the lower the requirement will be for large-scale downstream settling basins / wetlands.

DIMENSIONS

Length of Dam Wall:	120 m
Height of Dam Wall:	5 m
Width of Wall:	35 m base to 5 m top
Surface area:	26,000 m^2
Average Depth of Standing Water:	2.0 m
Water Storage Capacity:	52,000 m^3
Storage Duration under Median Flow:	15 days
Storage Duration under Peak Flow:	2.25 hours

PRELIMINARY BUDGET

Clear and Strip site	$15,000
Dam Embankment 8,000 m^3 at $5	$40,000
Spillway	$35,000
Topsoil Spreading and Vegetation 2 ha at $20,000	$40,000
Contingencies and Engineering	$39,000
Estimated Cost:	**$169,000**

This dam could also be constructed in staged lifts in order to lower construction costs and to permit an assessment of the minimum size for required water quality improvements.

4.6.6 PHASE 6 Clean Water Diversion

The low quality drainage from Queen Hill and associated workings needs to be isolated from the relatively good quality drainage in upper Silver-Lead Creek. It is proposed that Silver-Lead Creek be diverted via a constructed channel along the southern margin of the Pea Soup Wetland, parallel and adjacent to the Trial Harbour road (refer to Figure 4). This clean water diversion will optimise the performance of alkalinity storage dam 2.

In addition, drainage from the Queen No. 4 Shaft and road drains along the base of Queen Hill will need to be directed across the Silver-Lead Creek channel and into what remains of the Pea Soup Wetland or directly into alkalinity storage dam No. 2. The diverted Silver-Lead Creek water should be recombined with overflow from the dam downstream of the Pea Soup Wetland (or alkalinity storage 2). Refer to Figure 4. The remaining portions of the Pea Soup Wetland will therefore receive a substantial metal and acidity load and drain into the proposed alkalinity storage dam 2 for treatment and flocculation.

PRELIMINARY BUDGET

Channel Length 800 m	
Cut to fill earthworks, 5000 m^3 at $5	$25,000
Rock Lining, 2000 m^2 at $30	$60,000
Road Drains, 800 m at $5	$ 4,000
Channel Crossing Culverts, 6 no. at $2,500	$15,000
Topsoil Spreading and Vegetation 1 ha at $20,000	$20,000
Contingencies and Engineering	$37,000
Estimated Cost:	**$161,000**

4.6.7 PHASE 7 Settling Basin / Wetland

Water quality monitoring after the installation of phases 1-6 will identify the need for phases 7 and 8. Even if deemed necessary, the size and cost of the settling basin proposed below could be revised depending on the outcome of ongoing water quality monitoring.

A settling basin / wetland may be required on the eastern edge of the township of Zeehan to remove any precipitates that were not deposited in the modified Pea Soup Wetland - alkalinity storage system (refer to Figure 5). Since an excess of alkalinity is expected to leave dam No. 2, and additional metal and acidity sources are subsequently encountered (eg. Nike Creek and Upper Zeehan Rivulet), some additional precipitation is expected to occur. This basin needs to provide a few hours of water storage during high flow events (ie. 5-10 ML). The only viable site for this storage is to the east of the Zeehan aerodrome. A diversion channel would collect water from the Zeehan Rivulet and direct it to the storage. The storage would be designed to take a first flush during a flood event with subsequent flow remaining in the Zeehan Rivulet.

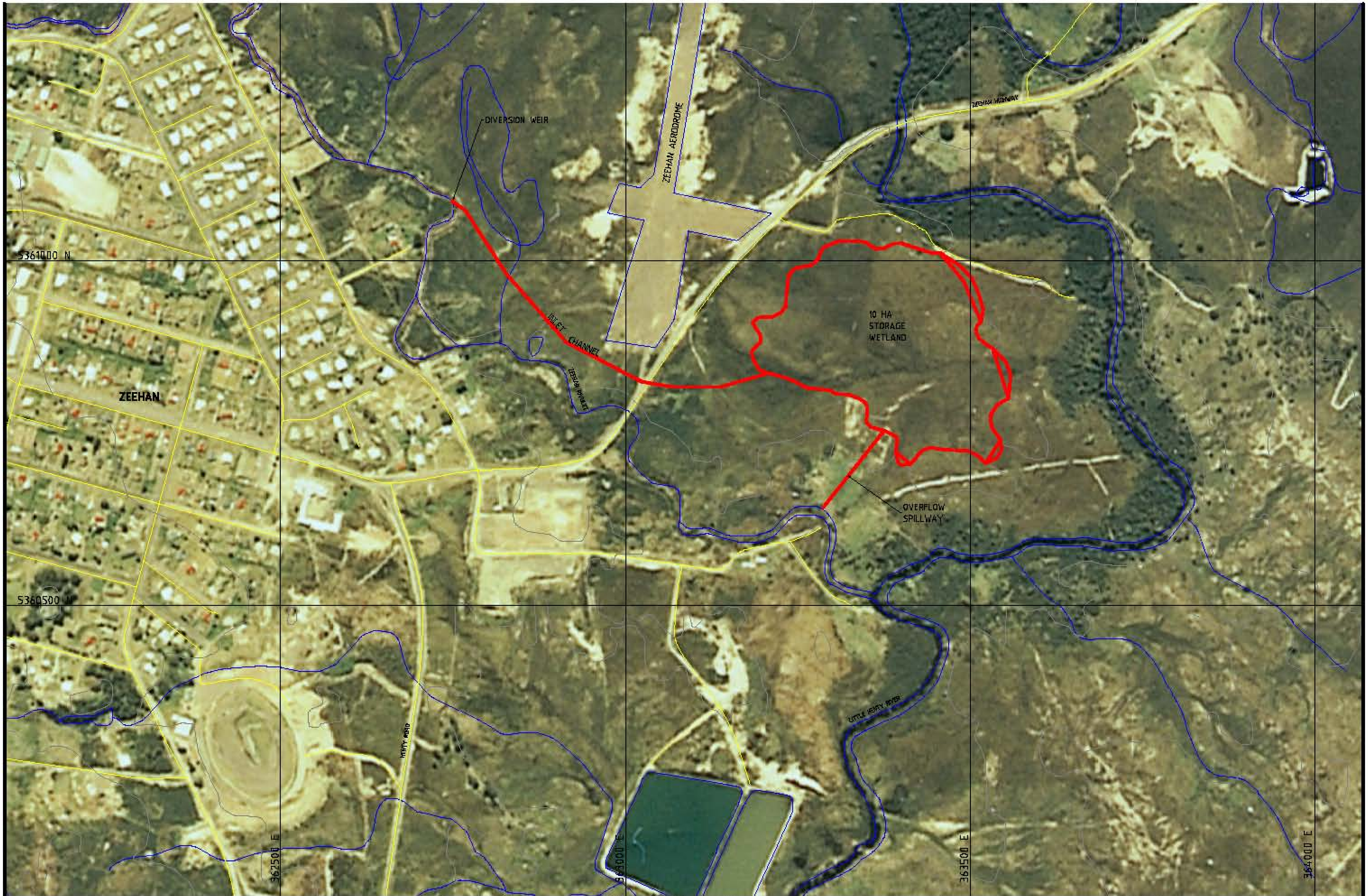
Prior to construction, the environmental benefit of this settling basin needs to be assessed by monitoring and evaluation of the upstream remediation measures.

DIMENSIONS

Length of Dam Wall:	600 m
Height of Dam Wall:	3 m
Width of Wall:	21 m base to 5 m top
Surface area:	100,000 m^2
Average Depth of Standing Water:	1.2 m
Water Storage Capacity:	120,000 m^3
Storage Duration under Median Flow:	5 days
Storage Duration under Peak Flow:	>3 hours depending on diversion design

PRELIMINARY BUDGET

Clear and Strip site	$ 30,000
Dam Embankment 20,000 m^3 at $5	$100,000
Diversion Channel, 600 m at $100	$ 60,000
Spillway, 150 m at $100	$ 15,000
Topsoil Spreading and Vegetation 3 ha at $20,000	$ 60,000
Contingencies and Engineering, 30%	$ 80,000
Estimated Cost:	**$345,000**



Revisions		
REV. No	Date	Description

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ZEEHAN REHABILITATION PROJECT

Drawing Title
EAST ZEEHAN
STORAGE POND AND WETLAND

Drawing No. FIGURE 5

4.6.8 PHASE 8 Combined Shallow and Deep Flow Wetland

A combined shallow and deep wetland system may be beneficial at the western edge of the Zeehan township, depending on the effectiveness of other strategies proposed. The highly degraded area immediately downstream of the bridge over Pea Soup Creek (near the junction between the Trial and Granville Harbour roads) comprises highly sulphidic waste rock and tailings. Submerging this would provide the dual benefit of preventing further oxidation of this sulphidic material and providing additional oxidation, floc settling and precipitate storage capacity.

The likely environmental benefit of this wetland needs to be revisited after the performance of the earlier phases has been evaluated.

DIMENSIONS

Length of Dam Wall:	65 m
Height of Dam Wall:	3.5 m
Width of Wall:	25 m base to 5 m top
Surface area:	7,200 m^2
Average Depth of Standing Water:	2.0 m
Water Storage Capacity:	15,000 m^3
Flood Storage Capacity:	20,000 m^3
Storage Duration under Median Flow:	3.5 days
Storage Duration under Peak Flow:	0.75 hours

PRELIMINARY BUDGET

Clear and Strip site	$ 5,000
Dam Embankment 4,000 m^3 at $5	$20,000
Spillway	$ 5,000
Topsoil Spreading and Vegetation 1 ha at $20,000	$20,000
Contingencies and Engineering	$15,000
Estimated Cost:	**$65,000**

The final dimensions of this wetland can be refined after the impact of previous remedial measures is quantified.

4.7 Summary

4.7.1 Preferred options

Based on evaluation of technical, economic and risk factors, the following strategy is proposed for the Zeehan Mineral Field:

(i) Modification, construction and installation of a HALT system in Oonah Creek.
(ii) Construction of a shallow flow wetland above a disposal terrace on part of the existing Pea Soup Creek.
(iii) Rehabilitation of the Queen Hill Lode bench.
(iv) Construction of alkalinity storage dam 1 upstream of the disposal cell in Oonah Creek.

(v) Construction of alkalinity storage dam 2 downstream of the disposal cell in the Pea Soup Wetland.
(vi) Divert Silver-Lead Creek around the Pea Soup Wetland.

After the performance of these strategies has been defined, an evaluation is required of the benefit to water quality of progressing to the next phases of work, involving:

(vii) A settling basin / wetland to the east of the airfield at the eastern end of Zeehan.
(viii) A shallow and deep flow wetland at the western end of town, downstream of the Pea Soup Wetland.

It is proposed that the alkalinity addition system be installed prior to the onset of earthworks in order to control construction impacts.

4.7.2 Expected Outcomes

Sustained improvement in water quality in the Zeehan Rivulet (50 - 80% reduction in key metals (zinc, lead, aluminium, cadmium and iron), and also a 50% reduction in acidity measured in the Zeehan Rivulet above the Little Henty. Given the 30-60% contribution of the Zeehan Rivulet to zinc loads in the Little Henty, a substantial improvement in water quality can also be expected downstream.

GLOSSARY

Acid Mine Drainage	High acidity / low pH water often characterised by high levels of metal pollutants draining from mine sites or mine wastes. Acid mine drainage is mostly derived from the oxidation of iron sulphide producing sulphuric acid and ferrous iron.
Adsorption	The taking up of one substance at the surface of another.
Alkalinity	Acid neutralising capacity (pH) buffering) of water. Alkalinity is usually due to the presence of inorganic anions.
Aquifer	A permeable body of rock capable of yielding groundwater.
Baseline data	Data obtained from studies undertaken to establish the condition of the study area prior to any disturbance by mining or other activities.
Bioaccumulation	The process by which specific chemicals are taken up by organisms leading to a concentration of that substance in certain tissues and body organs.
Bioavailability	That portion of a chemical compound or element that can be taken up readily by living organisms.
Diffusion	Process by which dissolved ionic and molecular species move from areas of higher concentration to areas of lower concentration.
Drawdown	Lowering of a water table from an unconfined aquifer or the potentiometric surface of a confined aquifer caused by pumping or release of groundwater from wells.
Ecotoxicology	The study of the fate and effects of pollutants in natural ecosystems.
Groundwater	Water that sinks into the soil and is stored in often slowly flowing and slowly renewed underground reservoirs called aquifers.
Heavy metals	Metallic elements with relatively high atomic weights (over 5.0 specific gravity), such as lead, cadmium and mercury. Frequently toxic in relatively low concentrations to plant and animal life.
pH	A measure of acidity or alkalinity on a scale of 0 to 14 with pH 7 being neutral.
Piezometer	Cased bore used for groundwater level measurements.

Porosity Ratio of the volume of void spaces in a rock or sediment to the total volume of the rock or sediment.

Potable water Water suitable, on the basis of both health and aesthetic considerations, for drinking or culinary purposes.

Recharge area Any area of land allowing water to pass through it and into an aquifer.

Toxicity The inherent potential or capacity of a material to cause adverse effects in a living organism.

Uptake A process by which materials are absorbed and incorporated into a living organism.

Water table Upper surface of the zone of saturation in which all available pores in the soil and rock in the earth's crust are filled with water.

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APPENDIX 1 - ASSESSMENT OF EXISTING WATER QUALITY DATA FOR THE ZEEHAN MINERAL FIELD

ASSESSMENT OF EXISTING WATER QUALITY DATA FOR THE ZEEHAN MINERAL FIELD

by

EARTH SYSTEMS PTY. LTD.

and

TECHNICAL ADVICE ON WATER

for the

Mineral Resources Tasmania
Zeehan Acid Drainage Remediation Project

December 1998

1.0 INTRODUCTION

1.1 Background

As part of the Zeehan Acid Drainage Remediation project an assessment was made of existing water quality and flow data for the Zeehan Mineral Field. The primary aim of this work was to identify areas that should form the focus of remediation efforts, in order to maximise ecological benefits to the Little Henty catchment.

1.2 Objectives

The objectives of this data assessment are:

1. To identify the major metal loads from the Zeehan Mineral Field;
2. To identify whether there are sufficient water quality and flow data to define a pre-remediation baseline (with which to identify the effectiveness, from a catchment water quality perspective, of future remediation works); and
3. If data are insufficient, propose a cost effective water quality / flow data collection programme that will satisfy Objectives 1 & 2.

1.3 Scope of Work

The following reports and data were reviewed:

- *Recommendations for an Acid Drainage Remediation Program in the Zeehan District, 1998* by Tim Parr
- *Acid Mine Drainage in the Zeehan District, 1997* by Tim Parr
- *Environmental Geology of the Dundas Drainage Basin, 1996* by Jeremy S. Lawrence
- *Rehabilitation of Abandoned Mine Sites in the Zeehan Area, 1998* by Naomi Oosting
- *Heavy Metal Levels in Stream Waters, Vegetation, Soil and Soil Solutions in an evolving Wetland, Zeehan, Tasmania, 1995* by Sven Ladiges
- *Unpublished HEC water quality and flow data for the Little Henty River.*

2.0 PREVIOUS WORK

2.1 Tim Parr's Work

Tim Parr completed a BSc Honours Thesis on acid mine drainage in the Zeehan District which was submitted at the end of 1997. In this work he identified the Silver Lead Creek (Queen Hill / Oonah workings) as the priority focus for remediation largely based on an arbitrary ratio of trace metals to pH in water analyses (Contamination = trace metals/pH).

In 1998, he followed this up with a report recommending remediation options predominantly for the Queen Hill / Oonah workings. This report is titled *Recommendations for an Acid Drainage Remediation Program in the Zeehan District*.

These works by Parr provide information on the design of a remediation program in the Zeehan District and the majority of existing water quality data relevant to this project.

Parr's thesis work involved the collection of water samples at a number of sites on four occasions (17-22 sites on the 30 July, 18 August, 8 September and 2nd October 1997). Some limited initial water sampling was also conducted during the period 2 March to 1 April.

Whilst these data are useful in determining the major sources of acid drainage / metal pollutants in the Zeehan Mineral Field, they are subject to significant limitations. The most important of these are:

I. Detection Limits are routinely very high. They appear to be approximately 0.1 ppm (100 μg/l) for a number of metals. This detection limit is significantly higher than the ANZECC aquatic ecosystem guidelines for virtually all metals except iron.

II. There are only limited regional water quality analyses (background or baseline), so the current influence of acid drainage from the Zeehan Mineral Field on the Little Henty River catchment is impossible to clearly establish.

III. Water quality analyses were collected during high flow winter conditions. There are no summer or first flush (Easter) water quality data.

IV. Water flow data are very limited. Collection methods used are crude and there appears to be substantial inconsistencies with the data (eg relative flow between H1 and H4, ZW and Z above SL). It is not clear whether flow data were collected on the same day.

Other aspects to note are that the samples collected are filtered samples and that there are no analyses for chromium, selenium and mercury.

Aspects of Parr's data interpretation are also questionable. His use of a contamination index (trace metals/pH) to identify priority remediation sites only takes into account absolute concentrations, which, while important for acute toxicological impact, provide no information as to pollutant loads.

2.2 Naomi Oosting's Work

Naomi Oosting completed a BSc Honours Thesis titled *Rehabilitation of Abandoned Mine Sites in the Zeehan Area* in early 1998 and followed this up in July 1998 with a short report on the same topic. Although this work is a valuable technical source for the remediation of the Zeehan area, it provides no further water quality data.

2.3 Sven Ladige's Thesis

In 1995 Sven Ladige completed a BAgSc Honours Thesis titled *Heavy Metal Levels in Stream Waters, Vegetation, Soil and Soil Solutions in an Evolving Wetland Zeehan, Tasmania.*

Ladige's thesis focussed on a small, developing wetland along Silver Lead Creek near Zeehan. Water quality data that was collected is limited and only relevant to this drainage.

This work identified the developing wetland in Silver Lead Creek as a sink for transported metals but did not quantify the remedial effect of this wetland on water quality.

2.4 Jeremy Lawrence's Thesis

Jeremy Lawrence completed an Honours Thesis titled the Environmental Geology of the Dundas Drainage Basin in May 1996. This work examined water quality in drainages around the Dundas mining district. This mining district is proximal to the Zeehan Mining Field and also drains into the Little Henty River.

Although water quality sampling in this study is over a relatively small area and flow data are limited, it does indicate that the Dundas mining district (Dundas River) is probably a major contributor of metal enriched waters to the Little Henty River.

Samples analysed in this study were not filtered prior to analysis and hence include particulate metals. This makes direct comparison with Parr's dataset difficult.

2.5 HEC Data

Limited water quality and flow data is available from the HEC for the Little Henty River. The data consists of single samples collected in 1971 from Pea Soup Creek and the Little Henty River at the Zeehan Highway and 30 samples collected from 1975 to 1978 from the Little Henty River at the road to Strahan.

The data from Pea Soup Creek and the Little Henty at the Zeehan Road contain limited metal analyses and therefore have limited worth.

The samples collected from the Little Henty at the road to Strahan are of more value, and include total (ie particulate and soluble) metal analyses for copper, zinc, lead and cadmium. The metal of most ecological significance from these results appears to be zinc with values ranging from 0.21 to 0.51 mg/l, apart from one questionable value of 0.056 mg/l. Lead values are about an order of magnitude less, copper values are approximately two orders of magnitude less, and cadmium lower again. Zinc values are high irrespective of stream flow which varies from 0.142 cumecs to 34 cumecs. Of particular note, is one of the highest zinc values (0.51 mg/l) which occurred in March at a time of very high stream flow, possibly indicating a first flush after the summer.

These data are old and the analytical and sampling methodology is unknown. Some of the detection limits appear unusually low for the seventies, but the internal consistency of the dataset provides some confidence about its accuracy.

3.0 DISCUSSION

3.1 Metal Loads Calculated by Parr

Parr calculated estimated metal loads based on his collected water analyses and flow data. As a result of data limitations discussed above, meaningful relative loads can only be calculated for Zn.

River / Stream	No. of Samples	Av Zn (kg/day)	Comments
Zeehan Rivulet (Z1)	4	13.95	At Little Henty
Zeehan Western	4	31.2	Mine workings
SL Dougs	4	3.7	Silver Lead Creek
Nike	4	1.5	
Old Spray	4	14.2	Mine Workings
Austral Creek	4	5.6	Downstream of Old Spray
Little Henty (H4)	1	10.3	Upstream of Zeehan Rivulet
Little Henty at Strahan Hwy*	29	206	Min. 3.5 kg/day, Max. 1247 kg/day, Median 76 kg/day

Table 1 Average zinc loads based on flow and concentration data mostly derived from Parr 1997. *The data for the Little Henty at Strahan is from the HEC.

The above table indicates that Zeehan Western and Old Spray are likely to provide the major zinc loads from the Zeehan Mineral Field to the Little Henty River. Note also the high input from the Little Henty River upstream of the Zeehan Rivulet. The sum of Parr's zinc load, about 80 kg/day is consistent with median zinc loads from the HEC.

Parr's work also indicates that the Zeehan Western, Old Spray and workings feeding into Silver Lead Creek are the major sources of sulphate addition to the Little Henty River.

Flow and water quality data from one sample site, "Z above SL", is difficult to reconcile with other data and has not been used in the above figures. It was postulated by Parr that wetland remediation / neutralisation by the Gordon Limestone may be causes of this discrepancy. This however does not account for the anomalously low flow data at "Z above SL" relative to data further up the catchment.

3.2 Regional Scale - Recalculation of Metal Loads Using Catchment Area

As a result of the limitations and apparent inconsistencies identified in Parr's flow data, loads have been recalculated using zinc concentrations and catchment size as a measure of flow. All water quality data are from Parr 1997 except data for the Dundas River catchment and Little Henty at the Strahan Road derived from Lawrence, 1996 and HEC data respectively.

This is predicted to be more accurate on a regional scale than using the limited flow data.

River / Stream	No. of Samples	Av Zn mg/l	Catchment Area km^2	Load (Av. Zn x Catchment Area; Relative Units)	Comments
Zeehan Rivulet	4	1.75	12.3	21.5	Filtered samples / Parr
Pyramid Creek	4	0.1	4.6	0.46	Filtered samples/ Parr
Austral Creek	4	1.8	6.9	12.4	Filtered samples/ Parr
Little Henty (H4)	1	0.3	64.2	19.3	Filtered samples/ Parr
Dundas River at Murchison Hwy	5	0.67	27.2	18.2	Unfiltered samples / Lawrence
[2]Little Henty above H1	1	<0.1	141.2	-	Filtered sample/ Parr
Little Henty at Strahan Road Bridge	29	0.3	204.8	61.4	Unfiltered samples / HEC

Table 2 Estimated zinc loads based on averaged concentration and catchment areas.

These values compare with the guideline maximum value for Zn for protection of aquatic ecosystems of 5 to 50 μg/l depending on hardness. Due to the very 'soft' nature of the Tasmanian West Coast waters, the guideline value should be considered to be towards the lower end of this range. However, toxicitiy testing using water from the nearby Pieman River catchment and trout, demonstrated that up to 60 μg/L total zinc was an acceptable concentration if trout were the primary organism of concern. This result is in stark contrast to the published ANZECC guideline, and even more surprising because recent work by a PhD student in the Pieman catchment has demonstrated that *all* zinc in the ambient waters is in a dissolved form, and would be expected to be biologically available. Table 2 indicates that with the exception of the Little Henty above H1, the average value of all samples greatly exceeds even the 60 μg/L 'local guideline', and would be expected to have serious toxicological impacts in the environment.

The zinc load data in Table 2 indicates that although the Zeehan Rivulet has the highest contribution of zinc to the catchment, the Little Henty upstream of the Zeehan Rivulet, Dundas River and Austral Creek are also major sources of zinc to the catchment.

The HEC data, although old, indicates zinc is at very high levels as far down the Little Henty River as the Strahan Road bridge.

3.3 Summary

Analysis of existing water quality data raises several questions and does not provide sufficient confidence to unambiguously identify priorities for remediation work. Significant questions that remain partly or fully unanswered include:

- Is zinc the major metal of environmental concern in the catchment?
- What metals are in excess of ANZECC water quality guidelines in the Little Henty River? Are metals in soluble or particulate form?
- Why is flow at sample site Z1 so low and water quality much improved from the upstream sample sites (ZW and ZW var)?

[2] Parr collected one sample in the Little Henty downstream of the Dundas River (Site H1) and this failed to detect Zn. However, the detection limit was very high at 100 μg/l and the samples were filtered (as opposed to the unfiltered samples collected by the HEC).

- What is the water quality of the catchment during low summer flow and during the Easter flush?

- How significant will be the benefit of remediation of the Zeehan Rivulet / Silver Lead Creek on downstream water quality in the Little Henty River?

- Is the current wetland in Silver Lead Creek contributing significantly to the remediation of acid drainage from Queen Hill and Oonah?

- Have all significant sources of acid drainage been identified in Silver-Lead Creek / Zeehan Rivulet? (There appears to be some discrepancy between the source levels of metals and sulphates from Oonah and Queen Hill workings and downstream readings in Silver-Lead Creek).

4.0 CONCLUSIONS AND RECOMMENDATIONS

The results of this assessment indicate that available water quality and flow data from the Zeehan Mineral Field has identified some, if not most, of the major sources of acid drainage. However, the quality and spatial distribution of this data is insufficient to:

(i) enable prioritisation of remediation works to maximise benefit to catchment water quality; and
(ii) provide a water quality baseline from which the effectiveness of future remediation works can be judged.

In view of the above conclusion, it is recommended that a water quality sampling programme involving the collection of approximately fifty samples be initiated immediately as described in Attachment 1. Some water flow measurements and modelling will also be required as part of this programme.

This work should be conducted concurrently with the design and construction of suitable alkalinity addition systems. These should be established in Silver Lead Creek or the Zeehan Rivulet for logistical purposes but will be designed to be capable of deployment in the most appropriate catchment or catchments as identified by the recommended water quality sampling programme.

Attachment 1 - Scope of Works

Water Quality Assessment Zeehan Mineral Field / Little Henty River Catchment

Objectives

(i) To provide sufficient water quality and flow data to facilitate the scoping of remediation activities in the Zeehan Mineral Field. Specifically this includes two sub-catchments; a) Silver Lead Creek and b) the Zeehan Rivulet above Silver Lead Creek.

(ii) To establish a water quality baseline that will enable quantification of water quality benefit derived from remediation undertaken at the Zeehan Mineral Field.

Scope of Work

(i) Collect total water samples for laboratory analysis at the following locations on three occasions under different flow regimes (Low Flow during summer conditions, during the First Flush after summer, and during average flow within a month or so of the First Flush).

Site A *Little Henty River at Strahan Road Bridge (GR 645 547)*
Site B *Zeehan Rivulet above Little Henty River junction (GR 631 609)*
Site C *Silver Lead Creek above Zeehan Rivulet (GR 613 622)*
Site D *Silver Lead Creek above Queen 4 Shaft (GR 602 616)*
Site E *Zeehan Rivulet above Silver Lead Creek (GR 617 623)*
Site F *Zeehan Rivulet above Zeehan Western (GR 607 633)*

(ii) Use in situ methods to measure T°C, pH, EC and ORP at all sites during the initial and final collection of water samples. Collect field measurements from other sites as appropriate.

(iii) Analyse water quality at the following 3 sites during the First Flush after summer.

Site G *Queen 4 Shaft*
Site H *Oonah Workings (feeding Pea Soup Wetland)*
Site I *Zeehan Western Workings*

(iv) Determine flow at sites C to F at the time of water sampling (HEC have small, portable v-knotches that can be used at most of the sites).

(v) Analyse total samples for pH, TDS, Ca, Mg, Na, K, Cl, HCO_3, SO_4, acidity, DOC. Analyse both total and acidified / filtered samples by ICP for Hg, Al, As, Cd, Sb, Se, Cu, Zn, Pb, Co, Mn, Fe, Ni, Cr using μg/l detection limits (DOC and some metals eg. Hg will not require analysis at certain sites).

(vi) Document methodology and results and provide collected data in GIS format.

Sampling and Analytical Techniques

Sample collection and preservation of water samples will be conducted using standard APHA methods.

Cost Estimate

Sampling / Flow Data Collection + Vehicle: 3 days		
	HEC Person located at Tullah	2,250
Analytical:	21 water samples @ av $180 per sample	3,780
Supervision	2 days at $600 per day	1,200
Data interpretation and reporting		
	1.5 days at $600 per day	900
GIS / Map compilation		500
Field Equipment / Consumables / Accommodation		900
	Total	**$ 9,530**

APPENDIX 2 – WATER QUALITY & GAUGING DATA

Sample Number	Site Description	Date Sampled	Time Sampled	Flow Data L/sec	Field T°C	Field pH	Lab pH	Dissolved Oxyg (mg/l)	Field EC µS/cm	Lab EC µS/cm	Alkal. HCO3 mg/L CaCO3	Acidity mg/L CaCO3	Chloride mg/L	Sulphate mg/L	Al (Soluble) µg/L	Al (Total) µg/L
ZH 001	Little Henty @ Strahan Hwy	19/2/99		7500 *	12.2	5.84	5.9	10.3	105	70	2	10	11	5.8	212	277
ZH 002	Zeehan Rivulet @ Zeehan Hwy	19/2/99		581.5	12.8	4.62	4.1	10.3	230	161	<1	14	11	34	261	254
ZH 003	Pea Soup above Zeehan Rivulet	19/2/99		160.2	12.4	3.39	3.2	10.2	520	404	<1	49	12	72	928	974
ZH 004	Zeehan Rivulet above Pea Soup	19/2/99		252.9	14	5.42	5.8	8.42	114	77	2	6	16	13	58	142
ZH 005	Queen No. 4 Shaft	19/2/99		1 *	11.8	2.85	2.5	0.15	1430	1560	<1	507	63	1800	5220	5620
ZH 006	Silver Lead above Queen No. 4	19/2/99		38.6	12.6	5.76	6.5	9.3	151	100	9	4	14	32	<50	<50
ZH 007	Zeehan Rivulet @ Parting Creek Rd	19/2/99		72.5	12.8	4.12	4.2	9.4	187	124	<1	14	11	28	315	350
ZH 008	Little Henty @ Zeehan Hwy	19/2/99		1800 *	9.1	5.46	5.6	9.1	110	73	2	8	11	21	156	322
ZH 009	Oonah South Workings	19/2/99		2 *	11.1	3.3	2.8	0.13	986	910	<1	158	13	200	2790	2850
ZH001	Little Henty @ Strahan Hwy	11/3/99	12:30 PM	1486.3	14.8	6.68	7	9.01	105	116	18	<1	13	7	<50	102
ZH002	Zeehan Rivulet @ Zeehan Hwy	11/3/99	8:00 AM	70.6	12.4	4.47	4.1	10.69	267	296	<1	2	16	84	557	546
ZH003	Pea Soup above Zeehan Rivulet	11/3/99	10:00 AM	35.5	13.3	3.62	3.1	10.37	499	590	<1	8	17	240	1850	2000
ZH004	Zeehan Rivulet above Pea Soup	11/3/99	10:45 AM	10.6	13.2	6.37	6.5	7.88	95	105	14	<1	14	11	78	173
ZH006	Silver Lead above Queen No. 4	11/3/99	11:30 AM	11.9	13.5	6.55	6.7	8.16	127	137	23	<1	16	7	<50	<50
ZH007	Zeehan Rivulet @ Parting Creek Rd	11/3/99	9:10 AM	7.47	11.6	5.35	4.4	9.42	199	227	<1	2	15	70	404	508
ZH001	Little Henty @ Strahan Hwy	18/5/99	4:15 PM	8314.2			5.9			79	6	5	12	5.9	86	285
ZH002	Zeehan Rivulet @ Zeehan Hwy	18/5/99	5:15 PM	316.03			4			193	<1	15	16	61	311	515
ZH003	Pea Soup above Zeehan Rivulet	18/5/99	9:30 AM	134.16	9.5	3.64	3.2	12.38	354	421	<1	50	14	100	1010	1280
ZH004	Zeehan Rivulet above Pea Soup	18/5/99	2:15 PM	106.71	9.7	5.48	5.5	9.77	88	89	3	4	14	10	<50	117
ZH006	Silver Lead above Queen No. 4	18/5/99	12:30 PM	40.33	10	5.96	5.8	10.65	106	106	11	5	20	15	<50	65
ZH010	Nike above Pea Soup Creek	18/5/99	10:25 AM	76.63	9.8	5.36	4.8	9.95	158	158	<1	11	17	39	<50	301
ZH011	Upper Pea Soup Creek	18/5/99	11:00 AM	25.53	9.3	3.65	3.2	12.72	300	336	<1	46	16	110	1280	1500
ZH012	Oonah Creek	18/5/99	1:10 PM	3.92	10.4	3.31	3	11.45	629	648	<1	112	15	420	3700	4180

* Flow data estimated.

Sample Number	Site Description	Date Sampled	Cd (Soluble) µg/L	Cd (Total) µg/L	Co (Soluble) µg/L	Co (Total) µg/L	Cr (Soluble) µg/L	Cr (Total) µg/L	Cu (Soluble) µg/L	Cu (Total) µg/L	Fe (Soluble) µg/L	Fe (Total) µg/L	Mn (Soluble) µg/L	Mn (Total) µg/L
ZH 001	Little Henty @ Strahan Hwy	19/2/99	<1	<1	<1	<1	<1	1	6	9	488	756	55	77
ZH 002	Zeehan Rivulet @ Zeehan Hwy	19/2/99	6	6	3	4	<1	<1	25	26	75	2560	1060	1100
ZH 003	Pea Soup above Zeehan Rivulet	19/2/99	13	13	10	10	<1	2	82	91	1170	11000	2610	2560
ZH 004	Zeehan Rivulet above Pea Soup	19/2/99	1	2	<1	<1	<1	1	4	5	231	341	42	95
ZH 005	Queen No. 4 Shaft	19/2/99	33	30	37	36	5	6	260	263	87900	188000	11400	11900
ZH 006	Silver Lead above Queen No. 4	19/2/99	<1	<1	<1	<1	<1	<1	<1	3	253	729	595	693
ZH 007	Zeehan Rivulet @ Parting Creek Rd	19/2/99	5	4	10	9	<1	1	6	6	395	982	1080	1070
ZH 008	Little Henty @ Zeehan Hwy	19/2/99	<1	<1	<1	<1	1	2	8	8	412	777	5	11
ZH 009	Oonah South Workings	19/2/99	20	20	38	40	<1	2	234	244	9020	36400	4330	4300
ZH001	Little Henty @ Strahan Hwy	11/3/99	<1	<1	<1	<1	<1	<1	5	6	224	746	56	96
ZH002	Zeehan Rivulet @ Zeehan Hwy	11/3/99	7	7	12	11	<1	<1	38	37	<20	844	3290	3330
ZH003	Pea Soup above Zeehan Rivulet	11/3/99	11	12	18	19	<1	1	93	90	4700	10400	4910	5140
ZH004	Zeehan Rivulet above Pea Soup	11/3/99	2	2	<1	<1	<1	<1	<1	1	73	187	424	437
ZH006	Silver Lead above Queen No. 4	11/3/99	<1	<1	2	2	<1	<1	<1	<1	279	1380	1690	1790
ZH007	Zeehan Rivulet @ Parting Creek Rd	11/3/99	5	5	22	23	<1	1	3	3	2960	4930	4010	4390
ZH001	Little Henty @ Strahan Hwy	18/5/99	<1	<1	<1	<1	<1	<1	<1	<1	245	630	8	99
ZH002	Zeehan Rivulet @ Zeehan Hwy	18/5/99	6	6	6	6	<1	<1	15	15	81	3670	1390	1500
ZH003	Pea Soup above Zeehan Rivulet	18/5/99	10	11	12	12	<1	<1	66	62	2760	10400	2240	2270
ZH004	Zeehan Rivulet above Pea Soup	18/5/99	<1	<1	<1	<1	<1	<1	<1	<1	114	230	<5	78
ZH006	Silver Lead above Queen No. 4	18/5/99	<1	<1	<1	<1	<1	<1	<1	<1	85	622	405	529
ZH010	Nike above Pea Soup Creek	18/5/99	2	6	9	9	<1	<1	<1	<1	<20	2810	1580	1670
ZH011	Upper Pea Soup Creek	18/5/99	<1	<1	5	5	<1	<1	199	202	2840	10500	12	100
ZH012	Oonah Creek	18/5/99	53	54	25	25	4	5	293	302	8180	12500	2870	2870

* Flow data estimated.

Sample Number	Site Description	Date Sampled	Ni (Soluble) µg/L	Ni (Total) µg/L	Pb (Soluble) µg/L	Pb (Total) µg/L	Sb (Soluble) µg/L	Sb (Total) µg/L	Zn (Soluble) µg/L	Zn (Total) µg/L	Ca (Total) mg/L	K (Total) mg/L	Mg (Total) mg/L	Na (Total) mg/L
ZH 001	Little Henty @ Strahan Hwy	19/2/99	3	4	14	30	<1	<1	148	204	2.37	0.31	1.58	7.32
ZH 002	Zeehan Rivulet @ Zeehan Hwy	19/2/99	13	13	170	199	<1	<1	1360	1670	6.28	0.62	4	9.46
ZH 003	Pea Soup above Zeehan Rivulet	19/2/99	25	26	536	554	<1	<1	3380	3410	6.51	0.64	5.86	8.89
ZH 004	Zeehan Rivulet above Pea Soup	19/2/99	9	9	2	11	<1	<1	313	349	2.65	0.3	2.09	7.66
ZH 005	Queen No. 4 Shaft	19/2/99	90	91	524	523	<1	<1	14000	13900	22.6	1.47	19	10.5
ZH 006	Silver Lead above Queen No. 4	19/2/99	6	7	<1	7	<1	<1	166	266	3.06	0.46	2.79	9.26
ZH 007	Zeehan Rivulet @ Parting Creek Rd	19/2/99	15	17	192	212	<1	<1	802	900	2.36	0.39	3.26	7.66
ZH 008	Little Henty @ Zeehan Hwy	19/2/99	4	4	<1	2	<1	<1	47	23	1.61	0.3	1.71	8.3
ZH 009	Oonah South Workings	19/2/99	115	112	430	457	<1	<1	5930	6190	12.4	0.67	18.1	8.47
ZH001	Little Henty @ Strahan Hwy	11/3/99	2	3	1	12	<1	<1	71	179	6.09	0.38	2.92	8
ZH002	Zeehan Rivulet @ Zeehan Hwy	11/3/99	67	26	229	237	<1	<1	2570	2350	11.6	0.64	7.18	11.4
ZH003	Pea Soup above Zeehan Rivulet	11/3/99	55	56	577	575	<1	<1	4170	4450	10.1	0.68	10.2	9.04
ZH004	Zeehan Rivulet above Pea Soup	11/3/99	15	15	3	5	<1	<1	474	497	3.53	0.25	2.56	8.22
ZH006	Silver Lead above Queen No. 4	11/3/99	9	10	2	5	<1	<1	217	249	4.23	0.54	4.08	9.62
ZH007	Zeehan Rivulet @ Parting Creek Rd	11/3/99	47	42	344	410	<1	<1	2270	2310	4.98	0.48	7.1	8.24
ZH001	Little Henty @ Strahan Hwy	18/5/99	3	3	9	13	N/A	N/A	187	190	2.7	0.28	1.88	8.35
ZH002	Zeehan Rivulet @ Zeehan Hwy	18/5/99	17	16	146	188	N/A	N/A	1360	1390	6.33	0.65	4.52	9.46
ZH003	Pea Soup above Zeehan Rivulet	18/5/99	26	33	343	356	N/A	N/A	3530	3630	5.88	0.64	6.02	8.64
ZH004	Zeehan Rivulet above Pea Soup	18/5/99	6	6	<1	2	N/A	N/A	259	273	2.12	0.45	2.19	8.23
ZH006	Silver Lead above Queen No. 4	18/5/99	5	5	<1	5	N/A	N/A	225	246	2.9	0.46	2.9	9.47
ZH010	Nike above Pea Soup Creek	18/5/99	15	19	79	232	N/A	N/A	1440	1440	5.89	0.63	4.57	9.98
ZH011	Upper Pea Soup Creek	18/5/99	9	9	23	23	N/A	N/A	101	100	0.54	0.43	1.99	9.35
ZH012	Oonah Creek	18/5/99	79	75	600	601	N/A	N/A	10900	11500	6.58	0.59	8.46	8.19

* Flow data estimated.

Sample Number	Site Description	Date Sampled	Hg (Soluble) µg/L	Hg (Total) µg/L	As (Soluble) µg/L	As (Total) µg/L	Se (Soluble) µg/L	Se (Total) µg/L	DOC mg/L	Total Zn Load kg/day	Total Fe Load kg/day	Total Al Load kg/day	Total Acidity kg/day	Total Acidity mg/sec
ZH 001	Little Henty @ Strahan Hwy	19/2/99	<0.05	0.05	<1	<1	<1	<1	14	132.19	489.89	179496.00	6480.00	75000.00
ZH 002	Zeehan Rivulet @ Zeehan Hwy	19/2/99	<0.05	<0.05	<1	4	<1	<1	3.1	83.90	128.62	12761.37	703.38	8141.00
ZH 003	Pea Soup above Zeehan Rivulet	19/2/99	<0.05	0.05	<1	20	<1	<1	1.7	47.20	152.25	13481.41	678.22	7849.80
ZH 004	Zeehan Rivulet above Pea Soup	19/2/99	<0.05	0.05	<1	<1	<1	<1	6.7	7.63	7.45	3102.78	131.10	1517.40
ZH 005	Queen No. 4 Shaft	19/2/99	<0.05	0.05	<1	65	<1	<1	1.4	1.20	16.24	485.57	43.80	507.00
ZH 006	Silver Lead above Queen No. 4	19/2/99	<0.05	0.33	<1	<1	<1	<1	3.4	0.89	2.43		13.34	154.40
ZH 007	Zeehan Rivulet @ Parting Creek Rd	19/2/99	<0.05	0.19	<1	<1	<1	<1	7.8	5.64	6.15	2192.40	87.70	1015.00
ZH 008	Little Henty @ Zeehan Hwy	19/2/99	<0.05	<0.05	<1	<1	<1	<1	16	3.58	120.84	50077.44	1244.16	14400.00
ZH 009	Oonah South Workings	19/2/99	<0.05	0.47	<1	3	<1	<1	1.1	1.07	6.29	492.48	27.30	316.00
ZH001	Little Henty @ Strahan Hwy	11/3/99	<0.05	0.05	<1	2	<1	<1	7.3	22.99	95.80	13098.46		
ZH002	Zeehan Rivulet @ Zeehan Hwy	11/3/99	<0.05	0.05	<1	4	<1	<1	0.4	14.33	5.15	3330.51	12.20	141.20
ZH003	Pea Soup above Zeehan Rivulet	11/3/99	<0.05	<0.05	<1	20	<1	<1	0.5	13.65	31.90	6134.40	24.54	284.00
ZH004	Zeehan Rivulet above Pea Soup	11/3/99	<0.05	0.05	<1	<1	<1	<1	3.7	0.46	0.17	158.44		
ZH006	Silver Lead above Queen No. 4	11/3/99	<0.05	<0.05	<1	<1	<1	<1	2.5	0.26	1.42			
ZH007	Zeehan Rivulet @ Parting Creek Rd	11/3/99	0.06	<0.05	1	4	<1	<1	0.9	1.49	3.18	327.87	1.29	14.94
ZH001	Little Henty @ Strahan Hwy	18/5/99	N/A	N/A	N/A	N/A	N/A	N/A	12	136.49	452.56	204728.86	3591.73	41571.00
ZH002	Zeehan Rivulet @ Zeehan Hwy	18/5/99	N/A	N/A	N/A	N/A	N/A	N/A	1.8	37.95	100.21	14062.07	409.57	4740.45
ZH003	Pea Soup above Zeehan Rivulet	18/5/99	N/A	N/A	N/A	N/A	N/A	N/A	1.5	42.08	120.55	14837.02	579.57	6708.00
ZH004	Zeehan Rivulet above Pea Soup	18/5/99	N/A	N/A	N/A	N/A	N/A	N/A	5	2.52	2.12	1078.71	36.88	426.84
ZH006	Silver Lead above Queen No. 4	18/5/99	N/A	N/A	N/A	N/A	N/A	N/A	3.4	0.86	2.17	226.49	17.42	201.65
ZH010	Nike above Pea Soup Creek	18/5/99	N/A	N/A	N/A	N/A	N/A	N/A	1.2	9.53	18.60	1992.87	72.83	842.93
ZH011	Upper Pea Soup Creek	18/5/99	N/A	N/A	N/A	N/A	N/A	N/A	2.8	0.22	23.16	3308.69	101.47	1174.38
ZH012	Oonah Creek	18/5/99	N/A	N/A	N/A	N/A	N/A	N/A	2.3	3.89	4.23	1415.72	37.93	439.04

* Flow data estimated.

APPENDIX 3 - ALKALINITY ADDITION DISCUSSION PAPER

ZEEHAN REMEDIATION PROJECT

Preliminary Working Paper Outlining Some Possible Alkalinity Addition Systems for Pilot Scale Trials at Zeehan

February 1999

INTRODUCTION

The following paper presents a selection of key technically and economically viable options for an alkalinity addition system for acid drainage from the Zeehan Mineral Field. It outlines the benefits and problems associated with each approach. It is intended to provide background information to stimulate discussion about alkalinity addition systems, in order that the most suitable option can be identified and a pilot trial established at Zeehan. Some conventional options have not been included and others may not have been considered. This paper should be regarded as a working document for refining the Zeehan teams ideas regarding suitable alkalinity addition options.

Alkalinity addition systems suitable for the passive treatment of acid drainage routinely utilise commonly occurring (and therefore low cost) mineral carbonates such as limestone and dolomite. Magnesite is less abundant but also highly suited to the task, due its high solubility relative to other natural carbonates. The occurrence of significant magnesite resources in and around the Savage River mine may favour its use at Zeehan. Bacterially generated bicarbonate alkalinity associated with an anaerobic / compost wetland is also an option.

The key issue for most cost effective passive alkalinity addition systems is to facilitate the sustainable dissolution of carbonate minerals whilst minimising the need for human intervention. The problem faced by most systems devised to date is that they are static and as a consequence promote neutralisation reactions which are inherently self limiting. Neutralisation reactions generate precipitates which coat and armour carbonate minerals. While static systems lend themselves to “set and forget” strategies, in practice their effectiveness over time tends to be very limited. Routine maintenance can sometimes overcome these issues, but the systems can no longer be considered to be strictly “passively”. In addition, if only a small proportion of the carbonate employed in passive systems is actually utilised for neutralisation, such systems can not be regarded as particularly cost effective relative to more conventional chemical treatment.

The most desirable site for conducting alkalinity addition pilot trials is the Silver Lead Creek catchment, in the vicinity of the Queen No. 4 Shaft. If community consultation identifies this site as unsuitable, trials could also be established out of public view in the Zeehan Rivulet catchment in the vicinity of the Zeehan Western workings.

Based on available data, estimated flow rates of acid drainage from the Queen No. 4 Shaft, one of the key sources of metal-rich acid drainage from the Zeehan Mineral Field, will range from 2-10 litres / second. Mineral acidity values (calculated from Parr’s water quality data) for drainage from the Queen No. 4 Shaft range from 700-1,000 mg/l $CaCO_3$. This means that 700-1,000 mg of $CaCO_3$ is theoretically required to remove toxic metals (ie. Al, Fe, Zn, Pb, Cu, Mn) from 1.0 litre of acid drainage. At flows of 10 litres a second, for example, this means that approximately 600-800 kg of $CaCO_3$ (equivalent) would be required per day for total (toxic) metal removal (if that were possible). Since it is possible to dissolve in the vicinity of 100-300 kg of $CaCO_3$ / tonne of $CaCO_3$ / hour in acid water (in the laboratory), a passive alkalinity addition system based on carbonate dissolution (eg. limestone) has the potential to provide effective alkalinity addition to Silver Lead Creek. As with any carbonate based system, it will not be possible to raise the pH of the acid water much above a pH of 4.5-5.0, but this is expected to significantly lower soluble metal concentrations. Slightly better neutralisation kinetics and a slightly higher final pH could probably be achieved with magnesite (magnesium carbonate) relative to limestone (calcium carbonate), but there is a cost differential between these reagents.

The final choice of pilot trial(s) needs to take account of the role of alkalinity addition as only one component of the total treatment measures that will be required for effective metal removal from mine drainage in and around the Pea Soup Wetland. For example, full treatment is predicted to include;

(i) extensive aeration of concentrated acid flows to enhance acid production prior to carbonate dissolution;
(ii) partial neutralisation by passive alkalinity addition;
(iii) selective dilution of partially treated acid flows with unpolluted water by the controlled/engineered recombination of flows to facilitate further metal precipitation;
(iv) manipulation of drainage pathways in the Pea Soup Wetland to optimise residence time (ie. dilution, adsorption, floc settling...etc).

The most appropriate alkalinity option(s) for a pilot trial should be based on both technical suitability and cost effectiveness.

The most appropriate alkalinity addition options are considered to be:

(i) Successive Alkalinity Producing System - SAPS;
(ii) Anoxic Carbonate Drain - ACD (Limestone or Magnesite);
(iii) Open Carbonate Drain - OCD (Limestone or Magnesite) in either a polluted or an unpolluted catchment;
(iv) Water Powered Autogenous Limestone Mill (ie. Hydro-Active Limestone Treatment - HALT);
(v) Reverse Alkalinity Producing Systems - RAPS.

SUCCESSIVE ALKALINITY PRODUCING SYSTEMS (SAPS)

Description

SAP systems combine the benefits of two important passive treatment approaches into a single constructed alkalinity addition device. By utilising a series of treatment vessels containing a basal layer of limestone overlain by a band of anaerobic compost and then standing water, highly reducing conditions and alkalinity addition is achieved simultaneously. This combination of conditions is generally successful at preventing the precipitation of ferric hydroxide around the limestone aggregate. The head of water is maintained in each vessel to avoid plugging of the limestone pore spaces with metal precipitates. The size and number of vessels is scaled to meet the requirements of the flow rate and average acidity of the incoming acid drainage. Appropriately located settling ponds are installed to permit the oxidation and precipitation of iron compounds, as well as other precipitates.

Key Benefits

- SAP systems appear to operate well at coal mines where elevated iron concentrations are the key concern and the soluble aluminium concentrations are negligible.

- Low operating cost.

- Potential for considerable life expectancy based on contained limestone.

- Under ideal conditions, the need for maintenance is negligible.

- Relatively small area required to implement.

Key Drawbacks

- High capital cost.
- Effectiveness can be affected by precipitates plugging the limestone aggregate, particularly at metal mines with elevated aluminium in the drainage.
- Gypsum precipitates cannot be avoided.
- The proportion of carbonate consumed can be affected by the coating processes.
- Maintenance requirements are likely to be prohibitively high in those situations where the aluminium hydroxide plugging processes cannot be avoided.

ANOXIC CARBONATE DRAINS (ACD)

Description

Anoxic carbonate drains can employ either limestone, dolomite or magnesite. Generally coarse carbonate aggregate is layed in carefully constructed drainage lines along gently graded slopes. Care is taken to avoid the possibility of covering the carbonate with clays or organic matter during operation, and to ensure that negligible air can be entrained into the drain. Synthetic liners are often used to cover the aggregate filled channels to facilitate oxygen exclusion. Raw and highly acid drainage is delivered directly into the covered channels as close to the source as possible, to avoid significant oxidation of the water. Low oxygen conditions are maintained within the drain in order to avoid the precipitation of iron. Long residence times are encouraged to prolong the interaction between the acid and carbonate. The specific characteristics of ACD's vary, but the concept is to scale the drains to maximise the alkalinity addition for the flow rate and acidity of the drainage. Aerobic ponds at the outflow end of ACD's facilitate oxidation and precipitation of the iron and other metal precipitates.

Key Benefits

- Operating costs are nil.
- In some circumstances they can assist with a "walk away" solution (eg. coal mines).

Key Drawbacks

- Capital costs are relatively high.
- Iron precipitation in the post drain settling ponds is a significant acid forming process which cannot be addressed by the drain, and once oxidised cannot easily be put through another drain.
- Gypsum and aluminium hydroxide precipitation cannot be avoided within the drains, and blockages are very common, especially at metal mines.
- The life expectancy of the ACD's is very limited at most metal mines (eg. 1-3 years), and at this stage only a very small proportion of the carbonate has actually been consumed (eg. anecdotal 5-10%).

- ACD's cannot be maintained. Once constructed, they either operate or need to be replaced.

OPEN CARBONATE DRAINS (OCD)

Description

Open carbonate drains are essentially identical to ACD's but make no attempt to exclude oxygen or minimise precipitate formation. The concept here is to use say 10 times more carbonate than is indicated for ACD's to cater for the fact that reagent armouring will reduce the effectiveness of the carbonate by at least this amount.

There are two alternatives to this approach that may have application at Zeehan. If OCD's are employed to treat acid drainage, they could be established to permit periodic disruption with earth moving equipment (eg. a ripper every 6-12 months), which may facilitate regular re-exposure of new reagent surfaces.

Another possibility is to utilise relatively large volume OCD's in one or more unpolluted drainage's to add alkalinity directly to the water, which would then mix with acid drainage further downstream.

The solubility of $CaCO_3$ (calcite) is 0.014 g/L (mw: 100.1), and for $MgCO_3$ it is 0.106 g/L (mw: 84.3). If magnesite were used in preference to limestone, it appears that almost 10 times less material could achieve the same neutralisation. The relative solubility could have a significant on the cost effectiveness of both OCD's and ACD's, since the cost differential is not likely to be greater than a factor of 2-3.

Key Benefits

- Low construction costs and low operating costs.
- Reagent armouring effects may be avoided if used in unpolluted drainage's.

Key Drawbacks

- High initial reagent costs.
- Chemical effectiveness not certain.
- Duration of effectiveness uncertain.
- Proportion of carbonate consumption unknown.
- Relatively large areas of existing drainage systems would need to be used.

WATER POWERED AUTOGENOUS LIMESTONE MILL (HALT)

Description

A new technique has been devised by Earth Systems to overcome the shortcomings of existing passive treatment systems. It involves a water powered, autogenous mill that can use mineral carbonate aggregates of varying sizes, and is fed via a water activated carbonate delivery system. Referred to as a HALT (Hydro-active Limestone Treatment) system, this technique will use the power of flowing water to abrade the precipitate coatings from carbonate aggregates, thereby continually exposing fresh carbonate surfaces for reaction with acid waters. When no drainage is flowing, the system will not be activated.

The HALT system will comprise 3 key components:

(i) partially submerged, acid resistant autogenous mill (water powered) in tank;
(ii) carbonate storage system (open hopper);
(iii) water flow controlled carbonate delivery / metering system.

Based on the water quality conditions outlined above, it is expected that a 20 tonne carbonate hopper would need to be filled approximately once every two months.

Key Benefits

- Water powered / gravity fed system.

- The principal advantage of the HALT approach is that the vast majority of the carbonate fed into the system will be dissolved under optimum conditions. The HALT system uses water power to abrade the armouring precipitates.

- Assuming a 100% pure limestone reagent, it is estimated that at least 70-80% could be consumed in a HALT system. Higher dissolution rates may be achievable with magnesite. Since most natural carbonates contain 5-10% impurities, some insoluble residue can be expected.

- The size of the area required for such systems will be very small compared to essentially all other options.

- Capital expense is expected to relatively low.

- HALT systems are predicted to remain effective for as long as they are fed with carbonate reagents.

Key Drawbacks

- HALT systems are conceptual. No such system has been built.

- From a cost perspective, a HALT system is likely to require a different budgeting approach relative to other passive treatment systems. ACD's for example involve a one-off capital expenditure, which includes the cost of the reagent that is calculated to be adequate for 10 or more years. Depending on site specific circumstances, HALT systems are expected to require a lower up front capital expenditure for equipment and reagent, but will need an ongoing reagent budget.

- Operating expenses are higher than some approaches, and spread out over the life of the system.

- Being an engineered mechanical device, a HALT system will have some maintenance requirements. While design considerations can minimise these, any mechanical system operating under harsh chemical conditions will require periodic attention (eg. SAPS).

- Routine flushing of insoluble reagent residues from the HALT systems will need to be a functional and important design feature.

REVERSE ALKALINITY PRODUCING SYSTEMS (RAPS)

Description

RAP systems employ organic matter and carbonate in a pond or impoundment directly receiving reduced acid drainage, preferably through the base of the impoundment. The concept is similar to SAPS but in the basal portion of a water body, and without any construction costs. The organic matter acts as a food source and substrate for SRB activity, as well as a crude filter for metal adsorption, while the carbonate adds alkalinity under reducing conditions. The partially treated drainage is subsequently oxidised and metals are further lowered by precipitation.

It is possible that this approach could be utilised at Zeehan by using existing key shafts (eg. Queen No. 4) as the RAPS impoundments. The water chemistry already suggests that the dolomitic horizon that forms part of the key mineralised zone (ie. proximal to Clarke's Lode) may be having a beneficial effect on the metal concentrations. Installing a RAP system in appropriate shafts may have the effect of enhancing in-situ passive treatment even further.

The methane and ?carbon dioxide gases observed from the underground workings suggests that abundant old timbers are probably already maintaining highly reducing conditions in the base of many of these shafts by encouraging microbial degradation. The addition of more organic matter to shafts is more likely to reinforce existing chemical conditions that upset them.

Key Benefits

- Potentially low capital cost.
- Potentially very simple installation as long as shafts are accessible.
- No maintenance is required.
- Precipitates will be effectively impounded with during treatment.
- No expression of the remediation will be visible.

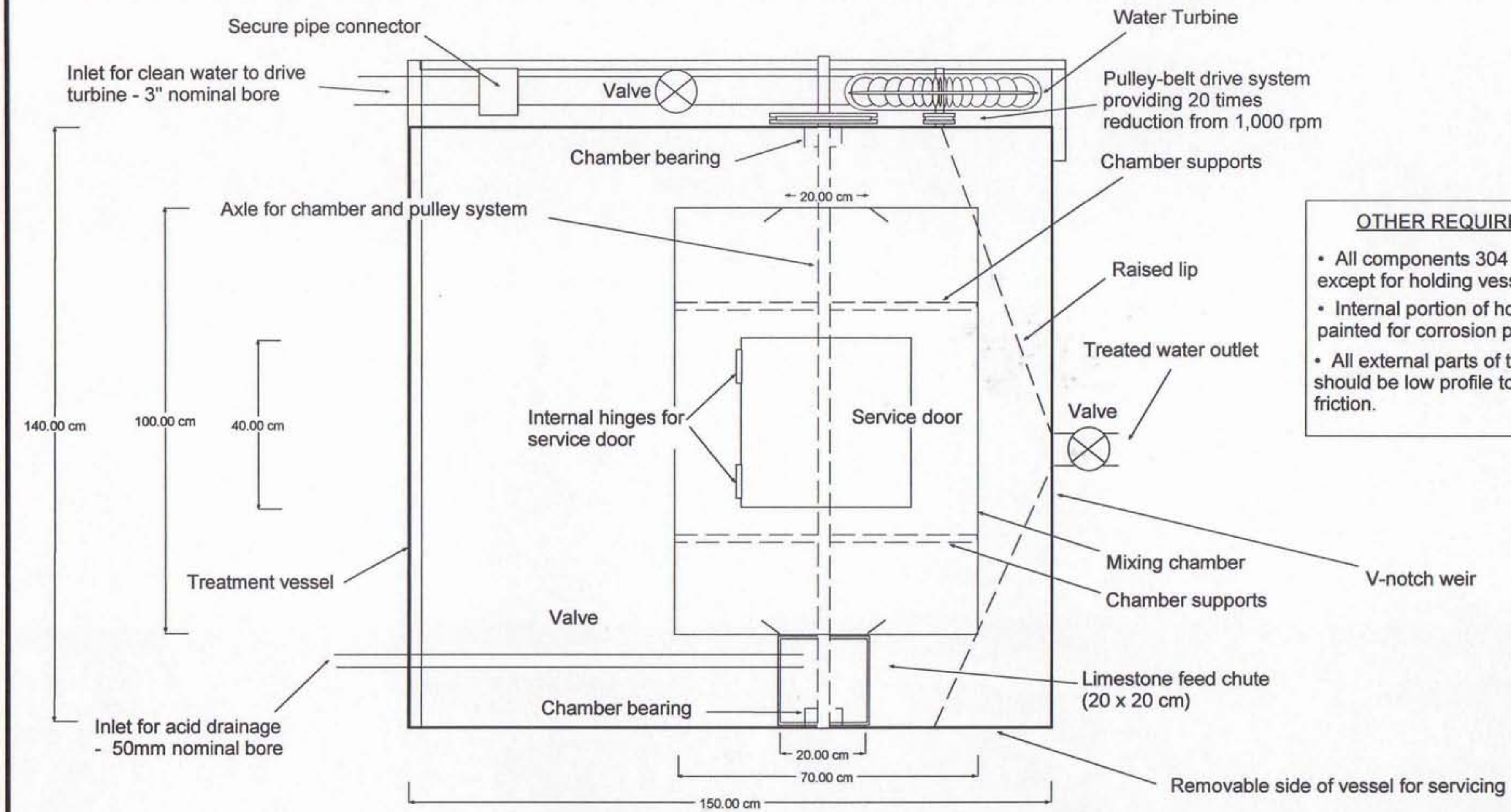
Key Drawbacks

- Access down key shafts is unknown.
- Placing significant tonnages of carbonates and organic matter into underground workings will make new mining ventures into these areas difficult.
- The duration of the neutralising effect is unknown.
- The proportion of carbonate likely to be consumed is unknown.

QUESTIONS

1. Could a rapid flush ACD or OCD be helpful?
2. Could CKD be used for alkalinity addition?
3. What are the possibilities for an anaerobic wetland?
4. What other possibilities have yet to be explored?

APPENDIX 4 - PROPOSED ALKALINITY ADDITION PILOT TRIALS FOR THE ZEEHAN MINERAL FIELD



OTHER REQUIREMENTS

- All components 304 Stainless except for holding vessel.
- Internal portion of holding vessel painted for corrosion protection.
- All external parts of the chamber should be low profile to minimise friction.

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Suite 209, 1 Princess Street, Kew, Melbourne, Australia, 3101.
Tel: (61-3) 9205 9515
Fax: (61-3) 9205 9519

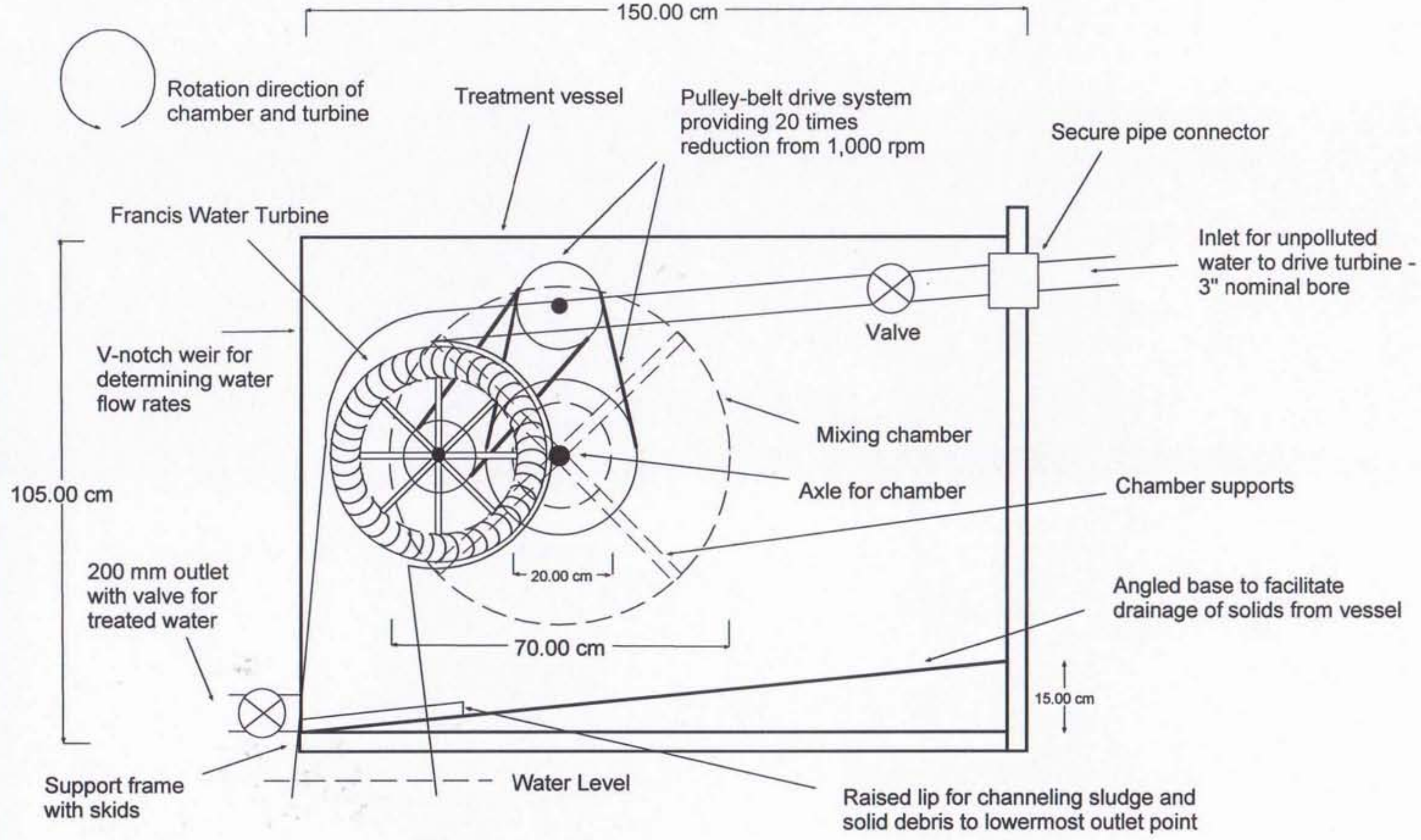
TITLE: **PLAN VIEW - WATER POWERED LIMESTONE DOSING SYSTEM**

CLIENT: MINERAL RESOURCES TASMANIA

SCALE: 1: 15	DATE: MARCH, 1999		PROJECT NO.: 98-29
DRAWN BY: JRT	APPROVED BY:	OFFICE: MELBOURNE	PLAN NO.: HALT-3

OTHER REQUIREMENTS

- Height adjustable legs on vessel for balancing the system.
- System for assisting with loading and unloading of vessel from trailer.
- Lifting hooks on vessel for mobilisation purposes.
- Attachment for stainless screens on outlet end of chamber.
- Ability to pin chamber in a fixed position for service purposes.
- Lockable safety grill for turbine and pulley system.
- System which permits adjustable tension on pulley belts.
- Turbine which enables dismantling for servicing (eg. blockages).
- Removable pulleys to permit change in chamber rotation speed or to replace belts.
- Filter over inflow end of turbine water pipe.
- Ability to lock door in an open position for self cleaning.
- Ensure that hinges for service door are on trailing edge to permit easy emptying.
- Avoid any lifters inside chamber.
- Maximise abrasion of limestone aggregate, but minimise comminution.



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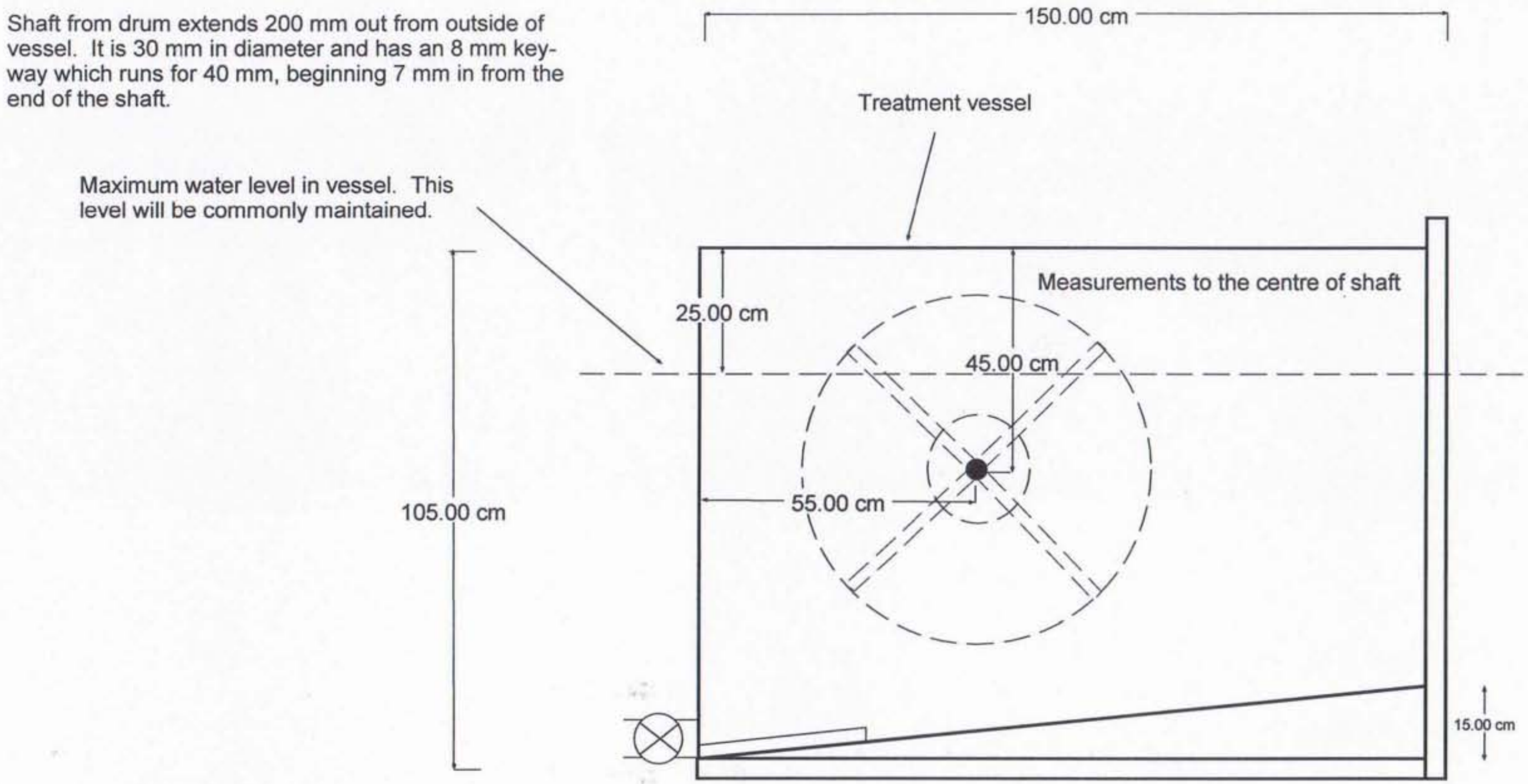
Fax: (61-3) 9205 9519

TITLE: **SIDE VIEW - SCHEMATIC OF WATER POWERED LIMESTONE DOSING SYSTEM**

CLIENT: MINERAL RESOURCES TASMANIA			
SCALE: 1: 15	DATE: MARCH, 1999	PROJECT NO.: 98-29	
DRAWN BY: JRT	APPROVED BY:	OFFICE: MELBOURNE	PLAN NO.: HALT-5



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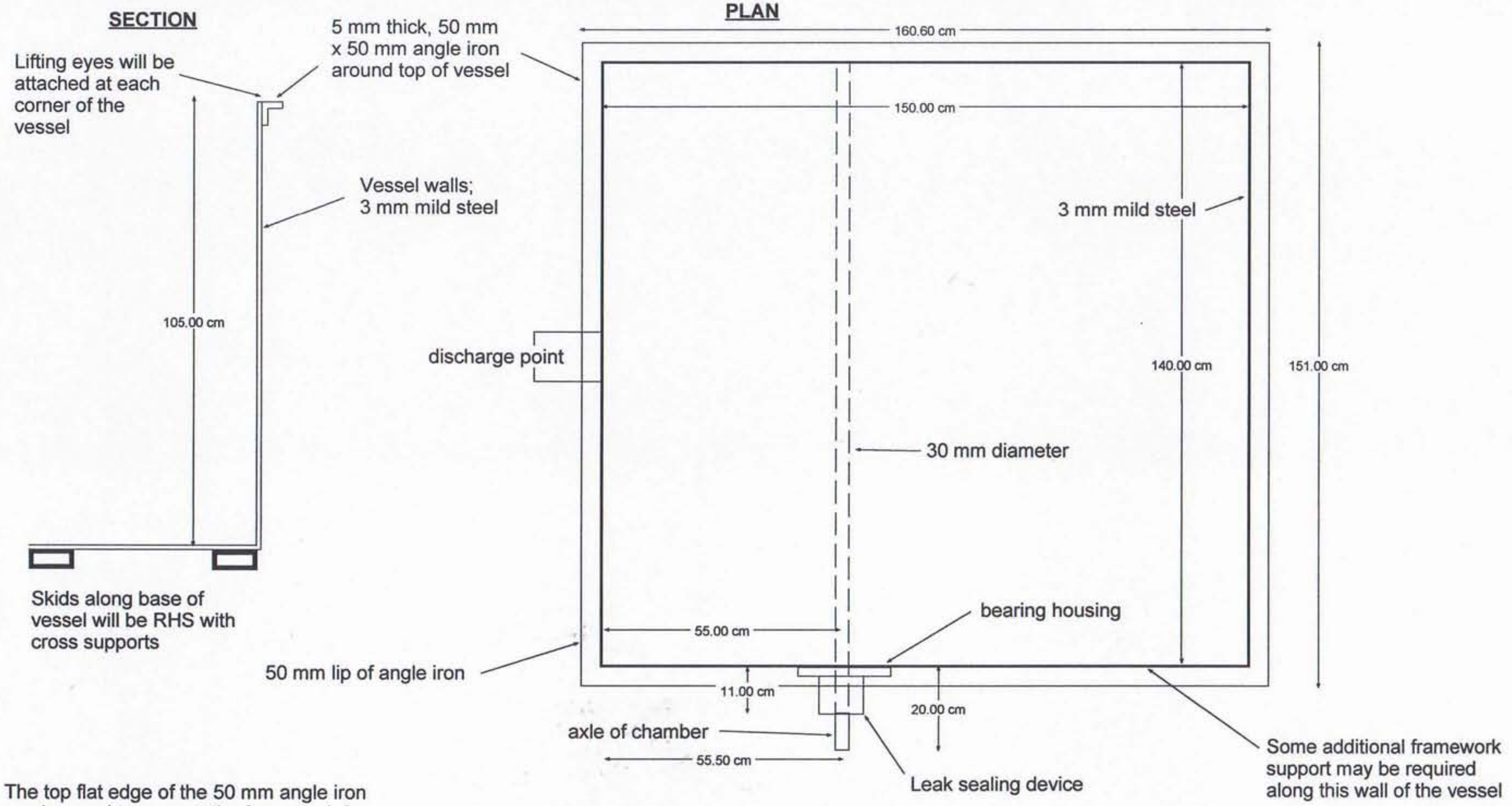
Fax: (61-3) 9205 9519

TITLE: **SIDE VIEW - SCHEMATIC OF WATER POWERED LIMESTONE DOSING SYSTEM**

CLIENT: MINERAL RESOURCES TASMANIA			
SCALE: 1: 15	DATE: MAY, 1999	PROJECT NO.: 98-29	
DRAWN BY: JRT	APPROVED BY:	OFFICE: MELBOURNE	PLAN NO.: HALT-14



The top flat edge of the 50 mm angle iron can be used to support the framework for the turbine and pulley assembly.

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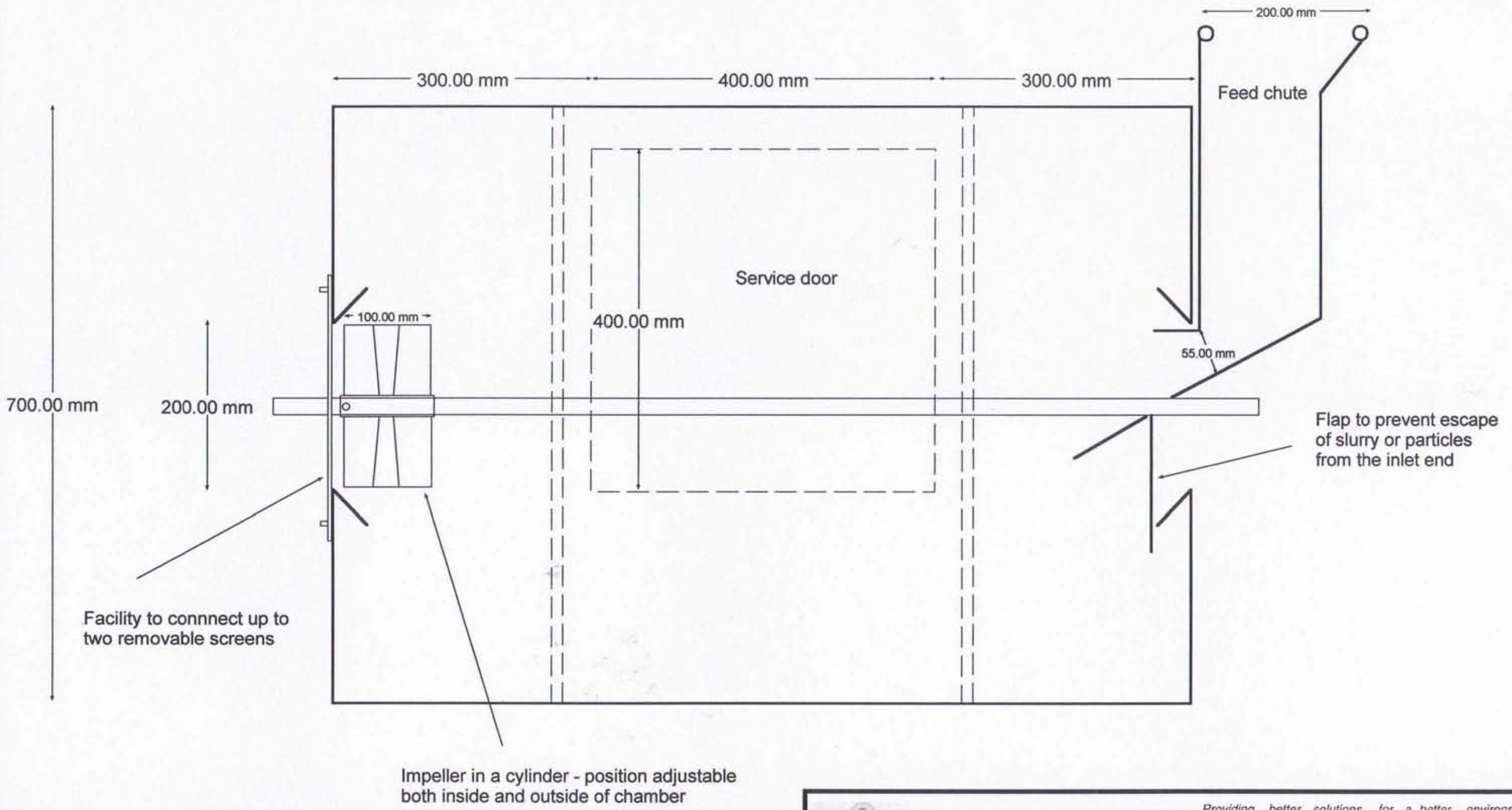
TITLE: **SCHEMATIC OF WATER POWERED LIMESTONE DOSING SYSTEM**

CLIENT: MINERAL RESOURCES TASMANIA			
SCALE: 1:15	DATE: MAY, 1999	PROJECT NO.: 98-29	
DRAWN BY: JRT	APPROVED BY:	OFFICE: MELBOURNE	PLAN NO.: HALT-15



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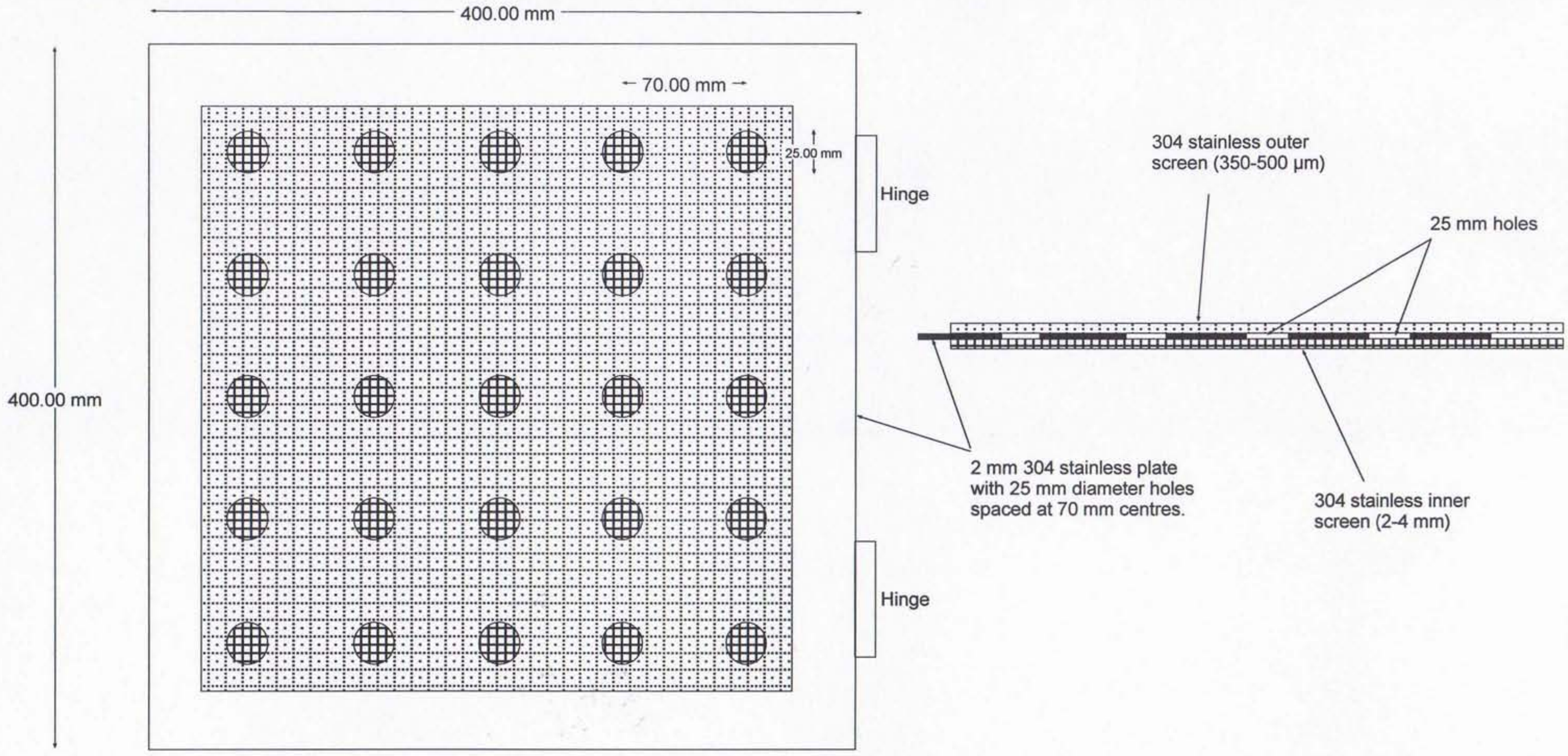
TITLE:	**DRUM AND IMPELLER DESIGN FOR HALT SYSTEM**		
CLIENT:	MINERAL RESOURCES TASMANIA	PLAN NO.:	HALT-10
SCALE: 1:7	DATE: APRIL 1999	PROJECT NO.:	98-29
DRAWN BY: JRT	APPROVED BY:	OFFICE:	MELBOURNE



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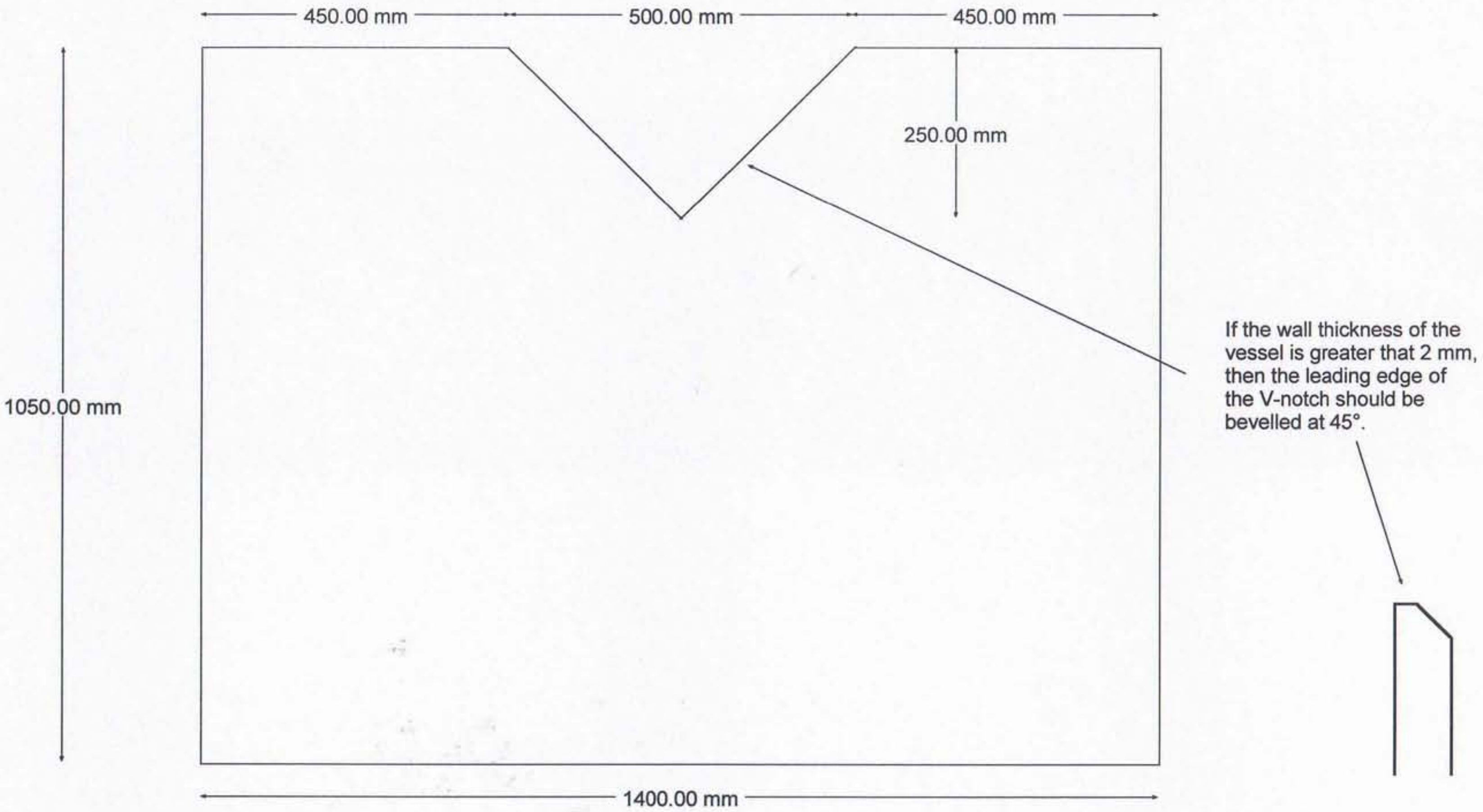
TITLE: **DESIGN OF SECOND DOOR FOR HALT SYSTEM**

CLIENT: MINERAL RESOURCES TASMANIA		PLAN NO.:	HALT-12
SCALE: 1:3.5	DATE: APRIL 1999	PROJECT NO.:	98-29
DRAWN BY: JRT	APPROVED BY:	OFFICE:	MELBOURNE



Support frame should be on outside of the vessel to avoid interruption of flow through V-notch weir

Ruler for measuring the height of the water column above the base of the V-notch should be at the back, inside end of the vessel.

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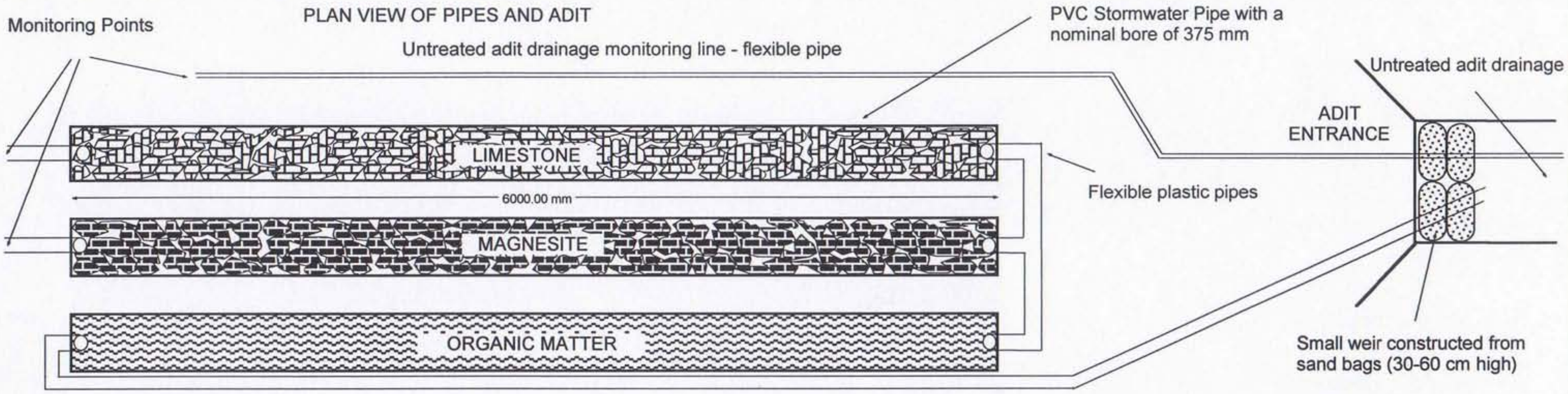
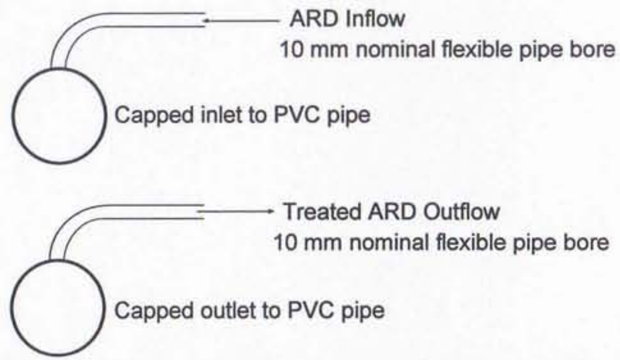
TITLE: V-NOTCH WEIR DESIGN FOR FRONT PANEL OF HALT VESSEL			
CLIENT: MINERAL RESOURCES TASMANIA		PLAN NO.:	HALT-13
SCALE: 1:10	DATE: APRIL 1999	PROJECT NO.:	98-29
DRAWN BY: JRT	APPROVED BY:	OFFICE:	MELBOURNE



OPERATING PARAMETERS

- Volume of Pipe = 0.663 cubic metres.
- Size of carbonate aggregates = 20 mm.
- Mass of carbonate = 830 kg $CaCO_3$ and 930 kg $MgCO_3$.
- Pore space water holding capacity of each drain = 330 litres.
- Flow rate = 0.1 litre / sec for each drain.
- Residence time for water ≈1 hour.
- Assuming average initial mineral acidity = 150 mg/l $CaCO_3$ and final mineral acidity = 25 mg/l $CaCO_3$
- Assuming total carbonate consumption, absolute minimum ideal lifetime of carbonate in drain = 770 days for 0.1 litres / sec or 385 days for 0.2 litres / sec.
- Air exclusion from drains is vital.

VIEW OF PIPE ENDS



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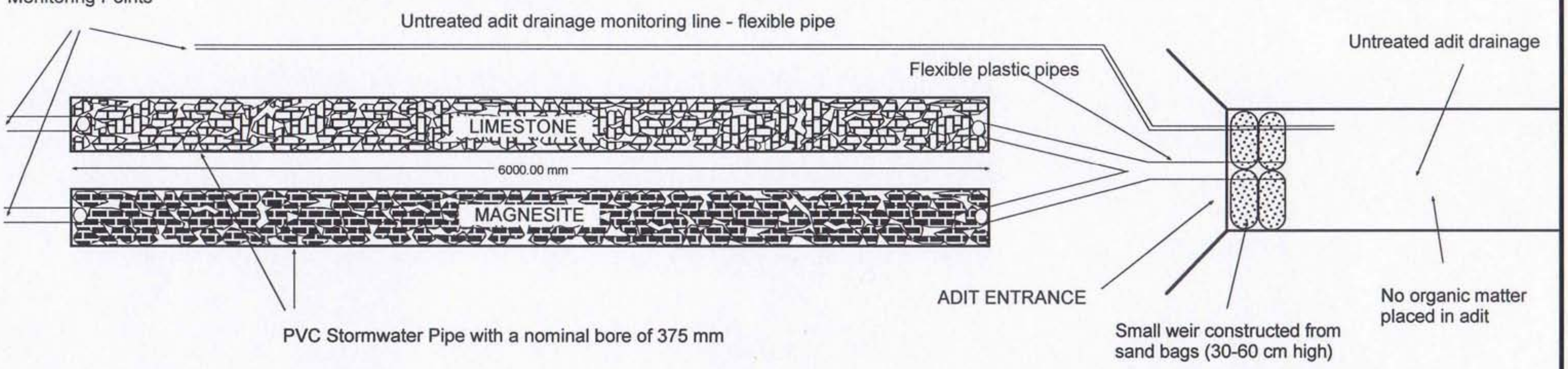
TITLE: **SCHEMATIC OF CARBONATE DRAINS WITH ORGANIC MATTER**

CLIENT:	MINERAL RESOURCES TASMANIA				
SCALE:	1: 40	DATE:	MARCH, 1999	PROJECT NO.:	98-29
DRAWN BY:	JRT	APPROVED BY:	OFFICE: MELBOURNE	PLAN NO.:	HALT-8

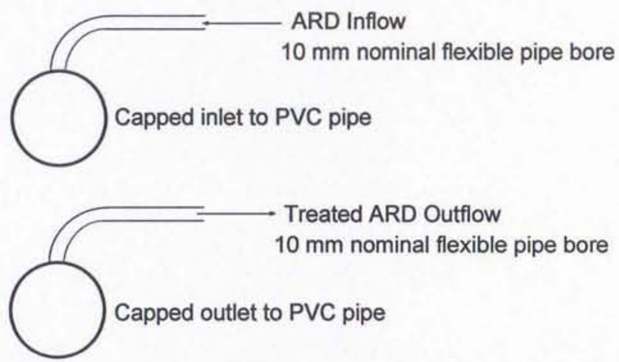
PLAN VIEW OF PIPES AND ADIT



OPERATING PARAMETERS

- Volume of Pipe = 0.663 cubic metres.
- Size of carbonate aggregates = 20 mm.
- Mass of carbonate = 830 kg $CaCO_3$ and 930 kg $MgCO_3$.
- Pore space water holding capacity of each drain = 330 litres.
- Flow rate = 0.1 litre / sec for each drain.
- Residence time for water ≈1 hour.
- Assuming average initial mineral acidity = 150 mg/l $CaCO_3$ and final mineral acidity = 25 mg/l $CaCO_3$
- Assuming total carbonate consumption, absolute minimum ideal lifetime of carbonate in drain = 770 days for 0.1 litres / sec or 385 days for 0.2 litres / sec.
- Air exclusion from drains is vital.

VIEW OF PIPE ENDS



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TITLE: **SCHEMATIC OF CARBONATE DRAINS WITHOUT ORGANIC MATTER**

CLIENT: MINERAL RESOURCES TASMANIA

SCALE: 1: 40	DATE: MARCH, 1999	PROJECT NO.: 98-29	
DRAWN BY: JRT	APPROVED BY:	OFFICE: MELBOURNE	PLAN NO.: HALT-9

APPENDIX 5 - DAILY LOGS AND RESULTS FROM THE HALT PILOT TRIALS

ZEEHAN REMEDIATION PROJECT
PILOT SCALE TRIALS OF THE HALT SYSTEM

RUN NUMBER: 1
DATE: 8/06/99
START TIME: 16:50
FINISH TIME: 18:00
MATERIAL TESTED: Unsorted -38 mm limestone
ABRASIVE AGENT: Nil
SYSTEM CONFIGURATION: Non perforated door, 1 mm screen only, outlets under water

Time	*Pressure (kPa)*	*Mass CaCO3 Added (kg)*	*RPM of Mill*	*Rel. Water Level (cm)*	*Level Over Weir (cm)*	*Operation Comments*
15:15						pH=4.4, Zn(sol)=1.77, Zn(tot)=1.77 at
16:50		22.0				HALT started.
16:55		23.0				
16:57		22.0				
17:08		17.5				
18:00						HALT stopped

COMMENTS:
RESIDUE (kg): 67.0
INPUT (kg): 84.5
DISPENSING TIME (hrs/min): 1:10
OUTPUT RATE (g/s): 4.17

RUN NUMBER: 2
DATE: 10/06/99
START TIME: 9:40
FINISH TIME: 11:57
MATERIAL TESTED: Unsorted -38 mm limestone
ABRASIVE AGENT: Nil
SYSTEM CONFIGURATION: Non perforated door, 1 mm screen only, both outlets under water

Time	*Pressure (kPa)*	*Mass CaCO3 Added (kg)*	*RPM of Mill*	*Rel. Water Level (cm)*	*Level Over Weir (cm)*	*Operation Comments*
8:20						pH=4.34, Zn(sol)=1.45, Zn(tot)=1.45 at ZH002.
9:40			90			HALT started.
		24.0	84			
		22.0	84			
9:49		22.5	81			
9:51		23.0	79			
10:19			78			
10:20		6.0	78			
10:43		5.0	78			
11:00		6.0	76			
11:15		8.0	80			
11:30		6.0	80			
11:45		5.0	80			
11:57						Stopped - out of fuel

COMMENTS:
RESIDUE (kg): 66
INPUT (kg): 127.5
DISPENSING TIME (hrs/min): 2:17
OUTPUT RATE (g/s): 7.48

RUN NUMBER: 3
DATE: 10/06/99
START TIME: 14:41
FINISH TIME: 17:20
MATERIAL TESTED: Unsorted -38 mm limestone
ABRASIVE AGENT: Nil
SYSTEM CONFIGURATION: Non perforated door, and 0.5 and 1 mm screens

Time	*Pressure (kPa)*	*Mass CaCO3 Added (kg)*	*RPM of Mill*	*Rel. Water Level (cm)*	*Level Over Weir (cm)*	*Operation Comments*
14:41			72	2		RPM started at 96 then adjusted down to 90 then to 72
14:44		20.5	72	2		
14:49		20.5		2		
14:55		24.5	66	2		
15:06		24.5	60	2		
15:30		5.0	64	2		
15:45		6.0	62	2		
16:00		8.0	62	2		
16:15		10.0	58	2		
16:30		5.0	62	2		
16:45		7.0	66	2		
17:00		9.0	62	2		
17:20				2		HALT stopped

COMMENTS:
RESIDUE (kg): 72
INPUT (kg): 140.0
DISPENSING TIME (hrs/min): 2:39
OUTPUT RATE (g/s): 7.13

RUN NUMBER: 4
DATE: 12/06/99
START TIME: 9:45
FINISH TIME: 17:30
MATERIAL TESTED: Unsorted -38 mm limestone initially then subsequent additions of -25 mm visually sorted limestone
ABRASIVE AGENT: Nil

SYSTEM CONFIGURATION: Non perforated door and 0.5 and 1 mm mesh

Time	*Pressure (kPa)*	*Mass CaCO3 Added (kg)*	*RPM of Mill*	*Rel. Water Level (cm)*	*Level Over Weir (cm)*	*Operation Comments*
9:45			66			HALT started.
9:46		24.0	63			
9:48		22.5	58			
9:52		24.0	54			
9:53		24.0	48			
9:58		24.5	43			Speed then adjusted to 30 RPM via the
10:05		24.5	24			
10:30		8.5	24			
10:45		7.0	22			
11:00			22			
11:16		6.5	19			
11:30			22			Adjusted to 22 RPM via pump
11:45		5.0	21			23 RPM prior to addition. pH=4.61, Zn(sol)=1.90, Zn(tot)=1.90, Acidity=42mg/L CaCO3 at ZH002
12:00			21			
12:15			22			
12:30		11.0	19			Mostly finer limestone -25mm added during remainder of run
12:45		6.5	26			
13:00		5.0	25			
13:15		8.5	24			
13:30			23			
13:45			24			
14:05						HALT stopped for refuelling
14:15		8.5	23			Restarted at 26 RPM
14:30		6.0	24			
14:45		5.5	21			Adjusted to 25 RPM via pump
15:00		6.0	24			
15:15		6.0	23			
15:30		6.0	23			
15:45		10.0	21			Adjusted to 26 RPM via pump
16:00		7.0	21			
16:15		7.0	22			
16:30		10.0	21			Adjusted to 26 RPM via pump
17:20						pH=5.2, Zn(sol)=1.79, Zn(tot)=1.96, Acidity=30mg/L CaCO3 at ZH002.
17:30						HALT shut down.

COMMENTS:
RESIDUE (kg): 165
INPUT (kg): 273.5
DISPENSING TIME (hrs/min): 7:34
OUTPUT RATE (g/s): 3.90

RUN NUMBER: 5
DATE: 15/06/99
START TIME: 9:55
FINISH TIME: 12:45
MATERIAL TESTED: "-38 mm" limestone visually sorted to -25 mm
ABRASIVE AGENT: Nil
SYSTEM CONFIGURATION: Non perforated door and 0.5 and 1 mm screens

Time	*Pressure (kPa)*	*Mass CaCO3 Added (kg)*	*RPM of Mill*	*Rel. Water Level (cm)*	*Level Over Weir (cm)*	*Operation Comments*
9:55	71		66			Chamber empty
10:00	55		74	1		Chamber empty
10:05	50	21.0	66	1		10.05 am - 10.23 am pressure measurements probably not correct as valve was shut
10:08	47	21.0	62	1		
10:14	44	20.0	57	0		
10:16	42	20.5	52	0		
10:23	36		36	1		
10:45	40	5.0	40	0.5		
11:04	39	6.5	39	1		
11:15	40	5.0	39	0		
11:30	40	5.0	39	1		
11:45	40	8.0	40	2		
12:00	39	6.5	38	1		
12:15	39	8.5	37	0.5		
12:45	39		38	0.5		HALT stopped

COMMENTS:
RESIDUE (kg): 78
INPUT (kg): 127.0
DISPENSING TIME (hrs/min): 2:50
OUTPUT RATE (g/s): 4.80

RUN NUMBER: 6
DATE: 15/06/99
START TIME: 14:45
FINISH TIME: 17:30
MATERIAL TESTED: Limestone -25 mm visually sorted
ABRASIVE AGENT: Nil
SYSTEM CONFIGURATION: Perforated door and 0.5 mm and 1 mm screens

Time	*Pressure (kPa)*	*Mass CaCO3 Added (kg)*	*RPM of Mill*	*Rel. Water Level (cm)*	*Level Over Weir (cm)*	*Operation Comments*
14:45						HALT Started
14:48	72	20.0	63	4		60-85 kPa averaged to 72 kPa due to flicking of needle
14:50	65	22.0	57	2		As above 50-80 kPa
14:55	55	19.5	54	0		As above 40-70 kPa

14:57	55	17.0	52	1		As above 45-65 kPa
15:00	42		46	0		Adjusted via pump
15:05			42			Adjusted via pump
15:40	39	9.0	40	2		
15:55	37	6.0	38	0		
16:10	37	7.5	37	2		
16:30	36	8.5	36	2		
16:45	33	9.0	32	0		
16:50	39		38			Adjusted via pump
17:00	38	7.0	37	0		
17:30	38		38	0		HALT Stopped

COMMENTS:
RESIDUE (kg): 77
INPUT (kg): 125.5
DISPENSING TIME (hrs/min): 2:45
OUTPUT RATE (g/s): 4.90

RUN NUMBER: 7
DATE: 16/06/99
START TIME: 11:58
FINISH TIME: 14:30
MATERIAL TESTED: Limestone -25 mm handsorted
ABRASIVE AGENT: Nil
SYSTEM CONFIGURATION: Non perforated door, 0.5 mm and 1 mm screens with 4 x 5 m internal chains to act as lifters

Time	*Pressure (kPa)*	*Mass CaCO3 Added (kg)*	*RPM of Mill*	*Rel. Water Level (cm)*	*Level Over Weir (cm)*	*Operation Comments*
11:58	47		51	1		
12:00	44	21.5	45	1		
12:02	37	22.0	42	1		
12:06	38	22.5	39	0		
12:08	39	13.5	39	1		
12:35	37	8.5	39	0		
12:50	37	6.0	38	0.5		
13:05	36	5.5	36	0		
13:15	35	9.5	36	0.5		
13:30	32	6.0	32	-0.5		
13:32	44		40			Adjusted by pump
13:45	42	5.5	39	2		
14:00	42	7.5	39	2		
14:30	41		39	2		Stopped operation - residue 81.5 kg

COMMENTS:
RESIDUE (kg): 81.5
INPUT (kg): 128.0
DISPENSING TIME (hrs/min): 2:32
OUTPUT RATE (g/s): 5.10

RUN NUMBER: 8
DATE: 17/06/99
START TIME: 8:32
FINISH TIME: 11:15
MATERIAL TESTED: Limestone -25 mm visually sorted
ABRASIVE AGENT: Nil
SYSTEM CONFIGURATION: Non perforated door with 0.5 mm and 1 mm screens and 2 x 3m chains to act as lifters

Time	*Pressure (kPa)*	*Mass CaCO3 Added (kg)*	*RPM of Mill*	*Rel. Water Level (cm)*	*Level Over Weir (cm)*	*Operation Comments*
8:32	60		57	2		2 x 3m chains in horizontal and vertical cross patterns to maximise disruption of body of reagent in between struts -chain 5 kg total, 5mm long link
8:37	52	24.5	50	2		
8:40	48	24.0	48	1		
8:44	42	20.5	42	1		
8:48	42	10.5	42	0.5		Shaft out side of vessel appeared to move ±5 mm whilst rotating
9:15	42	8.5	39	2		
9:34	36	5.5	36	0.5		
9:45	47	8.5	44	2		
10:00	44	8.0	42	0		
10:15	45	5.0	43	0.5		
10:30	45	5.0	42	0		
10:45	36	6.5	34	0		
11:15	45		43	1		stopped operation - residue 74.5 kg

COMMENTS:
RESIDUE (kg): 74.5
INPUT (kg): 126.5
DISPENSING TIME (hrs/min): 2:43
OUTPUT RATE (g/s): 5.32

RUN NUMBER: 9
DATE: 17/06/99
START TIME: 14:29
FINISH TIME: 16:10
MATERIAL TESTED: Unsorted limestone
ABRASIVE AGENT: Quartz pebbles
SYSTEM CONFIGURATION: Non perforated door and 0.5 mm and 1 mm screens

Time	*Pressure (kPa)*	*Mass CaCO3 Added (kg)*	*RPM of Mill*	*Rel. Water Level (cm)*	*Level Over Weir (cm)*	*Operation Comments*
14:29	43		50	0		
14:33	39	22.5	47	0-1		
14:38	35	23.5	42	0+1		

14:42	32	20.5	38	2		
14:48	28	15.0	32	0		
14:53	26		24	1		20kg quartz -50 mm to +10mm
14:55	40		40	2		Pump adjust
15:15	43		42	0		
15:17	40	14.0	38	2		Abundant suspension -300um particles
15:30	41	11.0	38	2		Shaft more stable during operation
15:45	39	14.0	36	2		
16:00	38	10.0	34	3		
16:10						Stopped operation as struts broke off shaft - 86 kg residue including 18 kg of quartz

COMMENTS:
RESIDUE (kg): 68
INPUT (kg): 130.5
DISPENSING TIME (hrs/min): 1:41
OUTPUT RATE (g/s): 6.47

RUN NUMBER: 10
DATE: 18/06/99
START TIME: 12:13
FINISH TIME: 14:15
MATERIAL TESTED: Recycled pre-ground limestone with no fines
ABRASIVE AGENT: Rounded limestone pebble material (no fines) mixed with quartz - 2:1 mix
SYSTEM CONFIGURATION: Non perforated door and 0.5 mm and 1 mm screens

Time	*Pressure (kPa)*	*Mass CaCO3 Added (kg)*	*RPM of Mill*	*Rel. Water Level (cm)*	*Level Over Weir (cm)*	*Operation Comments*
12:13	58		58	2		
12:17	52	24.5	54	2		
12:19	45	22.5	47	1		
12:22	45	14.0	45	2		
12:28	42		41	3		15kg quartz
12:34	38		36	0		15kg quartz
12:45	40	10.0	37	2		
13:00	41	8.0	38	1		
13:15	39	7.0	36	0		
13:30	39	7.0	35	0		
13:45	38	6.5	34	0.5		
13:50	44		37	2		Pump adjust
14:15	43		38	2		2.18 pm stopped operation

COMMENTS:
RESIDUE (kg): 79.5
INPUT (kg): 99.5
DISPENSING TIME (hrs/min): 2:02
OUTPUT RATE (g/s): 2.73

RUN NUMBER: 11
DATE: 19/06/99
START TIME: 9:55
FINISH TIME: 16:30
MATERIAL TESTED: Limestone -25 mm handsorted
ABRASIVE AGENT: +20mm Quartz
SYSTEM CONFIGURATION: Std door and 0.5 and 1 mm mesh

Time	*Pressure (kPa)*	*Mass CaCO3 Added (kg)*	*RPM of Mill*	*Rel. Water Level (cm)*	*Level Over Weir (cm)*	*Operation Comments*
8:45						pH=4.7, Zn(sol)=1.36, Zn(tot)=1.46, Acidity=16mg/L CaCO3 at ZH002.
9:55	48		60	2		HALT started.
10:05	44	23.0	48	1		
10:12	39	25.0	48	1		
10:18	33	24.0	42	1		
10:40	30		34	0		Further addition of limestone concentrated on -20mm fraction. 20kg of +20mm quartz
11:00	31	5.0	36	0.5		
11:15	32	5.0	34	1		
11:30	32	5.0	34	0.5		
11:34	40		40	0.5		Pump adjusted
11:45	42	5.5	42	2		
12:00	41	12.0	42	3		
12:20	41	7.0	40	3		
12:30	42	11.0	40	1		
12:45	40	9.0	39	1		
13:00	39	9.0	37	1		
13:15	39	5.0	36	1		
13:30	38	10.5	35	1		
13:45	38	5.0	34	2		
14:10	38		35	0	9	2.18 pm stopped for refuelling
14:38	46		40	2		Restarted pump
14:45	47	7.5	40	0		
15:05	50	8.0	42	3		
15:15	49	6.5	43	1		
15:20	50	8.5	43	3		
15:50	46	7.5	39	1		
16:00	46	8.0	37	3		
16:15	42	8.5	35	0		
16:30	40	7.0	31	2		
16:37	47		41	0		Pump adjusted; mill speed varies by ±5 RPM without adjustment
16:45	46	7.0	35	1		
17:00	42	7.5	35	2		
17:30	55		44	2	13.5	V notch 18-4.5=13.5cm @ 54 kPa. 128 kg residue including ≈18 kg quartz.
18:30						pH=5.5, Zn(sol)=1.44, Zn(tot)=1.46, Acidity=9mg/L CaCO3 at ZH002.

COMMENTS: More abrasion on outlet end of shaft and struts probably due to effects of coarse quartz particles
RESIDUE (kg): 110
INPUT (kg): 237.0
DISPENSING TIME (hrs/min): 7:35
OUTPUT RATE (g/s): 5.16

RUN NUMBER: Flow measurements
DATE: 20/06/99
START TIME: n/a
FINISH TIME: n/a
MATERIAL TESTED: n/a
ABRASIVE AGENT: n/a
SYSTEM CONFIGURATION: Barrel 98% submerged, probably partially floating due to trapped air.

Time	*Pressure (kPa)*	*Mass CaCO3 Added (kg)*	*RPM of Mill*	*Rel. Water Level (cm)*	*Level Over Weir (cm)*	*Operation Comments*
	80		66		12.5	
	58		55		11.75	
	50		52		11.5	
	37		44		11.25	
	97		72		12.75	

COMMENTS:
RESIDUE (kg): n/a
INPUT (kg): n/a
DISPENSING TIME (hrs/min): n/a
OUTPUT RATE (g/s): n/a

RUN NUMBER: 12
DATE: 20/06/99
START TIME: 10:05
FINISH TIME: 18:03
MATERIAL TESTED: Unsorted -38 mm limestone
ABRASIVE AGENT: Granitic quartz sand
SYSTEM CONFIGURATION: Non perforated door and 0.5 mm and 1 mm screens

Time	*Pressure (kPa)*	*Mass CaCO3 Added (kg)*	*RPM of Mill*	*Rel. Water Level (cm)*	*Level Over Weir (cm)*	*Operation Comments*
8:30						pH=4.65, Zn(sol)=1.60, Zn(tot)=1.65, Acidity=16mg/L CaCO3 at ZH002
10:05						20kg of fine sand added but little remained
10:15						20kg of coarser quartz sand was added. About 10 kg of sand remained in barrel.
10:38	45	23.5	49	2		Limestone being added is unsorted; creek level has fallen
10:42	38	24.5	43	2		
10:48	33	19.0	38	3		
10:53	31	12.0	34	2		
10:57	36		39	0		Pump adjusted
11:30	36	15.5	38	2		
11:40	36		38	3		Added 6.5 kg of coarse washed quartz sand
11:45	34	8.5	35	3		
12:00	34	8.0	35	2		
12:15	34	6.5	35	1		
12:30	35	8.5	33	1		
12:34	44		41	2		Pump adjusted
12:45	44	12.5	41	1		
13:00	42	9.0	38	1		
13:15	40	11.5	35	0		
13:30	37	12.5	34	1		
13:45	38	6.5	32	0		
13:50	37		26	1		Added 20kg granitic sand
13:55	47		40	2		Pump adjust
14:00	45	5.0	37	4		
14:28						Switched off to refuel
14:34	44		37	3		Restarted
15:00	48	6.5	39	0		
15:15	45	9.0	38	0		
15:30	47	6.5	37	0		
15:45	45	7.5	37	1		
16:00	45	11.0	34	1		
16:05	52		40	2		Pump adjusted
16:15	49	9.5	39	1		
16:30	49	12.0	37	0		
16:45	48	10.5	34	0		
16:50	55		39	2		Pump adjusted
17:15	52		38	0		Pump fluctuating
17:30	54		42	1		
17:45	60		48	2		
17:45	48		36	2		Pump adjusted
18:00					13.5	V notch measurement 18cm-4.5= 13.5cm @ 44 kPa
18:03						Out of fuel. 140.5 kg residue including 20 kg quartz.
19:10						pH=6.02, Zn(sol)=1.49, Zn(tot)=1.72, Acidity=10mg/L CaCO3 at ZH002.

COMMENTS:
RESIDUE (kg): 120
INPUT (kg): 255.5
DISPENSING TIME (hrs/min): 7:22
OUTPUT RATE (g/s): 5.25

APPENDIX 6 - CHEMICAL DATA ON LIMESTONE FROM THE HALLS CREEK QUARRY, LYNCHFORD, TASMANIA

Table 1

Halls Creek Limestone Quarry - Rock Chip Samples (%)

SAMPID	N	E	El	CaO	MgO	SiO2	Al2O3	CaCO3	MgCO3	Tot_CO3
H2251	5334774	377122	98	45.1	2.8	9.5	1.8	80.5	6.0	86.5
H2252	5334788	377104	102	45.8	3.0	8.4	1.6	81.8	6.4	88.2
H2253	5334796	377086	105	47.4	2.3	8.0	1.3	84.6	4.9	89.5
H2254	5334815	377190	91	46.2	0.5	12.1	2.0	82.5	1.0	83.5
H2255	5334843	377193	89	47.8	0.7	9.4	1.3	85.4	1.4	86.8
H2256	5334844	377209	90	43.4	1.0	15.1	2.1	77.5	3.2	80.7
H2257	5334813	377193	83	48.7	0.6	8.7	1.4	86.9	1.3	88.2
H2258	5334787	377209	84	30.7	14.2	9.4	2.1	54.8	29.9	84.7
H2259	5334734	377207	85	46.1	3.5	7.8	0.4	82.3	7.4	89.7
H2260	5334723	377192	84	44.5	3.8	8.8	1.9	79.5	8.0	87.5
H2261	5334698	377196	80	48.9	2.1	6.3	1.4	87.4	4.5	91.9
H2262	5334692	377208	80	50.4	2.7	3.1	0.6	89.9	5.6	95.5
H2263	5334618	377287	80	49.7	2.7	3.2	0.5	88.7	5.6	94.3
H2264	5334656	377247	79	49.0	2.6	4.2	0.9	87.6	5.4	93.0
H2265	5334677	377228	80	51.7	2.4	1.5	0.3	92.3	5.0	97.3
H2266	5334659	377216	80	50.8	2.1	3.0	0.8	90.8	4.5	95.3
H2267	5334625	377217	83	49.4	3.6	3.1	0.5	88.3	7.6	95.9
H2268	5334622	377211	83	51.0	1.9	3.5	0.7	91.1	4.0	95.1
H2269	5334624	377201	81	50.3	2.4	3.3	0.6	89.9	5.0	94.9
H2270	5334639	377204	84	47.8	4.9	1.0	0.4	85.4	10.2	95.6
H2271	5334631	377185	85	49.9	3.3	1.7	0.5	89.1	6.9	96.0
H2272	5334646	377178	85	48.0	2.6	5.4	1.5	85.8	5.4	91.2
H2273	5334640	377194	80	49.9	3.6	1.6	0.5	89.1	7.6	96.7
H2274	5334651	377205	79	51.3	2.5	1.9	0.3	91.6	5.3	96.9
H2275	5334649	377233	79	48.0	4.8	2.7	0.4	85.7	10.0	95.7
H2276	5334698	377192	79	49.8	2.1	4.1	0.7	88.9	4.5	83.4
H2277	5334711	377184	80	49.8	3.4	2.4	0.4	88.9	7.2	96.1
H2278	5334722	377182	80	50.7	3.0	2.2	0.4	90.5	6.2	96.7
H2279	5334735	377180	79	40.5	2.6	16.2	2.9	72.3	5.5	77.8
H2280	5334756	377183	79	51.3	1.2	4.4	0.9	91.6	2.5	94.1
H2281	5334794	377168	82	50.1	1.0	5.9	1.3	89.4	2.0	91.4
H2282	5334800	377176	82	40.6	5.1	10.4	2.8	72.4	10.7	83.1
H2283	5334789	377187	80	52.4	0.8	3.9	0.7	93.5	1.8	95.3
H2284	5334780	377192	81	52.7	1.1	2.6	0.5	94.2	2.4	96.6
H2285	5334772	377193	81	48.8	2.1	5.3	1.0	87.2	4.3	91.5
H2286	5334760	377195	82	50.7	1.4	4.5	0.8	90.5	2.9	93.4
H2287	5334732	377157	78	38.0	5.7	15.0	2.1	67.9	11.9	79.8
H2288	5334761	377146	80	51.1	1.7	3.5	0.6	91.2	3.6	94.8
H2289	5334755	377139	80	48.6	2.1	6.0	1.2	86.7	4.5	91.2
H2290	5334749	377130	82	50.3	1.4	5.1	1.0	89.8	3.0	92.8
H2291	5334736	377122	79	44.2	2.3	12.5	1.9	78.9	4.8	83.7
H2292	5334728	377115	81	48.6	1.7	7.7	1.0	86.8	3.5	90.3
H2293	5334716	377121	79	48.6	1.6	8.0	1.0	86.9	3.3	90.2
H2294	5334656	377180	81	48.2	1.7	6.6	1.7	86.1	3.6	89.7
H2295	5334666	377164	76	48.9	2.0	6.1	1.3	87.3	4.2	91.5
H2296	5334672	377156	77	51.4	1.8	2.8	0.5	91.8	3.7	95.5
H2297	5334672	377146	78	53.3	1.3	1.1	0.2	95.2	2.7	97.9
H2298	5334681	377137	78	50.4	2.1	3.0	0.6	90.0	4.4	94.4
H2299	5334690	377124	81	49.8	2.2	5.4	1.0	88.3	4.5	92.8
H2300	5334700	377110	82	48.9	2.5	5.0	0.8	87.3	5.3	92.6

Table 2
Halls Creek RC Percussion Drilling (September 1996) Summary Logs

96HCC-0001	
Coords	5,334,620 N
	377,178 E
RL 92.6m	
AZ 119 AMG	
Declin. 55°	
TD 39m	
0-1m soil, regolith	
1-39m fresh limestone	

96HCC-0002	
Coords	5,334,686 N
	377,083 E
RL 98.8m	
AZ 329 AMG	
Declin. 50°	
TD 39m	
0-4m soil, regolith	
4-5m weathered limestone	
5-13m fresh limestone	
13-20m cavity	
20-39m fresh limestone	

96HCC-0003	
Coords	5,334,773 N
	377,101 E
RL 99.8m	
AZ 044 AMG	
Declin. 50°	
TD 24m	
0-3m soil, clay	
3-24m clay, decomposed limestone, cavities	

96HCC-0004
Coords 5,334,771 N
377,100 E
RL 99.8m
AZ Vertical
Declin. 90°
TD 19m
0-1m soil
1-9m clay, decomposed limestone, cavities
9-19m fresh limestone

96HCC-0005
Coords 5,334,844 N
377,174 E
RL 92.0m
AZ 050 AMG
Declin. 50°
TD 30m
0-4m soil, weathered shale, limestone
4-10m weathered limestone, cavities
10-30m fresh limestone

96HCC-0006
Coords 5,344,839 N
377,228 E
RL 87.5m
AZ 135 AMG
Declin. 50°
TD 39m
0-2m soil, weathered limestone
2-5m weathered limestone, cavities
5-39m fresh limestone

96HCC-0007	
Coords	5,334,682 N
	377,182 E
RL 75.4m	
AZ Vertical	
Declin. 90°	
TD 22m	
0-22m fresh limestone	

Precollars of 5-6 metres were rotary air drilled with a 6 inch tricone and cased with uncemented PVC. A 4.75 inch TRC42 face sampling bit was used with the hammer drilling. Two holes were vertical and five were declined at -50° or -55° (Table 2). No significant ground water was encountered.

Cyclone samples were collected every metre into polyweave sacks and ~ 1.5 kg representative 2 metre composite splits were taken by hand into calico bags.

Sample preparation and assaying were carried out by Analabs. All samples were assayed by XRF for CaO and MgO (Table 3). Additional analyses for sulphur and acid reactivity tests were done by CMT at Queenstown (Table 4). Collar locations were surveyed by the mine survey section.

The summary logs (Table 2) show that weathering is restricted to a maximum depth of 9 vertical metres. 96 HCC-3 appears to have drilled parallel to topographic slope, through an apron of cavity-fill sediments which may indicate a fault position. Below the weathered zone, fresh limestone with minor cavities was encountered in all holes. The overall cavity content (by linear metres drilled) in the fresh limestone was 4.4%.

$CaCO_3$ content decreases from south to north (Figures 10-13) with the highest grade intersections occurring in holes 96 HCC-1 and 96 HCC-7. This trend correlates in general with the seismic data, which show a decrease in limestone velocity between lines A and C (Figures 4-6).

Reactivity trials with controlled concentrations of sulphuric acid consistently produced CaO values higher than the Analabs XRF assays from the equivalent samples, confirming that some of the dolomite is also reactive (Table 4). The reactivity results show that essentially the total $CaCO_3$ content plus some of the $MgCO_3$ is effectively neutralising sulphuric acid and so for resource definition and classification purposes the task is to combine relatively high grade limestone with relatively low stripping ratio.

TABLE 3 - DRILL HOLE ASSAY VALUES (%)

SAMPID	BHID	FROM	TO	CaCO3	MgCO3	Total CO3
H0829	96-HCC1	1.0	3.0	86.6	7.2	93.8
H0830	96-HCC1	3.0	5.0	82.0	13.6	95.6
H0831	96-HCC1	5.0	7.0	88.2	8.2	96.4
H0832	96-HCC1	7.0	9.0	90.3	4.9	95.2
H0833	96-HCC1	9.0	11.0	86.0	6.2	92.2
H0834	96-HCC1	11.0	13.0	84.1	7.7	91.8
H0835	96-HCC1	13.0	15.0	88.3	6.6	94.9
H0836	96-HCC1	15.0	17.0	90.5	3.4	93.9
H0837	96-HCC1	17.0	19.0	90.0	4.6	94.6
H0838	96-HCC1	19.0	21.0	88.7	6.6	95.3
H0839	96-HCC1	21.0	23.0	84.1	9.0	93.1
H0840	96-HCC1	23.0	25.0	85.8	8.1	93.9
H0841	96-HCC1	25.0	27.0	86.1	11.3	97.4
H0842	96-HCC1	27.0	29.0	87.1	10.2	97.3
H0843	96-HCC1	29.0	31.0	87.7	6.4	94.1
H0844	96-HCC1	31.0	33.0	84.0	9.1	93.1
H0845	96-HCC1	33.0	35.0	85.2	9.9	95.1
H0846	96-HCC1	35.0	37.0	84.5	11.7	96.2
H0847	96-HCC1	37.0	39.0	81.4	15.8	97.2
H0848	96-HCC2	4.0	6.0	70.4	3.2	73.6
H0849	96-HCC2	6.0	8.0	86.1	2.5	88.6
H0850	96-HCC2	8.0	10.0	78.2	3.4	81.6
H0851	96-HCC2	10.0	12.0	84.6	3.1	87.7
H0852	96-HCC2	12.0	14.0	87.9	2.2	90.1
H0853	96-HCC2	14.0	16.0	82.0	3.8	85.8
H0854	96-HCC2	16.0	18.0	88.2	3.1	91.3
H0855	96-HCC2	18.0	20.0	68.8	4.5	73.3
H0856	96-HCC2	20.0	22.0	79.8	2.7	82.5
H0857	96-HCC2	22.0	24.0	80.1	4.5	84.6
H0858	96-HCC2	24.0	26.0	73.7	10.4	84.1
H0859	96-HCC2	26.0	28.0	78.9	7.3	86.2
H0860	96-HCC2	28.0	30.0	83.1	4.9	88.0
H0861	96-HCC2	30.0	32.0	75.8	7.3	83.1
H0862	96-HCC2	32.0	34.0	78.2	7.2	85.4
H0863	96-HCC2	34.0	36.0	77.1	7.0	84.1
H0864	96-HCC2	36.0	38.0	78.5	8.6	87.1
H0865	96-HCC2	38.0	39.0	80.6	7.4	88.0
H0866	96-HCC4	8.0	10.0	54.0	13.1	67.1
H0867	96-HCC4	10.0	12.0	54.6	20.1	74.7
H0868	96-HCC4	12.0	14.0	69.7	12.2	81.9
H0869	96-HCC4	14.0	16.0	72.4	13.0	85.4
H0870	96-HCC4	16.0	18.0	74.8	10.3	85.1
H0871	96-HCC4	18.0	19.0	75.6	4.6	80.2

Table 3 continued

SAMPID	BHID	FROM	TO	CaCO3	MgCO3	Total CO3
H0872	96-HCC5	10.0	12.0	39.7	19.8	59.5
H0873	96-HCC5	12.0	14.0	50.0	6.3	56.3
H0874	96-HCC5	14.0	16.0	50.9	5.3	56.2
H0875	96-HCC5	16.0	18.0	56.4	4.8	61.2
H0876	96-HCC5	18.0	20.0	57.7	5.9	63.6
H0877	96-HCC5	20.0	22.0	64.8	1.9	66.7
H0878	96-HCC5	22.0	24.0	71.3	2.1	73.4
H0879	96-HCC5	24.0	26.0	76.2	1.6	77.8
H0880	96-HCC5	26.0	28.0	81.6	1.7	83.3
H0881	96-HCC5	28.0	30.0	71.3	1.6	72.9
H0882	96-HCC6	4.0	6.0	62.9	1.7	64.6
H0883	96-HCC6	6.0	8.0	77.8	1.7	79.5
H0884	96-HCC6	8.0	10.0	70.7	1.8	72.5
H0885	96-HCC6	10.0	12.0	68.3	1.3	70.6
H0886	96-HCC6	12.0	14.0	74.7	1.7	76.4
H0887	96-HCC6	14.0	16.0	77.3	2.8	80.1
H0888	96-HCC6	16.0	18.0	79.8	4.8	84.6
H0889	96-HCC6	18.0	20.0	82.4	1.5	83.9
H0890	96-HCC6	20.0	22.0	78.1	1.4	79.5
H0891	96-HCC6	22.0	24.0	65.4	1.8	67.2
H0892	96-HCC6	24.0	26.0	71.3	1.6	72.9
H0893	96-HCC6	26.0	28.0	73.5	1.8	75.3
H0895	96-HCC6	30.0	32.0	59.1	7.1	66.2
H0896	96-HCC6	32.0	34.0	68.2	1.6	69.8
H0897	96-HCC6	34.0	36.0	69.0	1.7	70.7
H0898	96-HCC6	36.0	38.0	65.3	4.3	69.6
H0899	96-HCC6	38.0	39.0	58.0	2.7	60.7
H0901	96-HCC7	2.0	4.0	84.0	5.1	89.1
H0902	96-HCC7	4.0	6.0	89.1	4.9	94.0
H0903	96-HCC7	6.0	8.0	90.2	4.2	94.4
H0904	96-HCC7	8.0	10.0	91.2	4.1	95.3
H0905	96-HCC7	10.0	12.0	91.8	3.5	95.3
H0906	96-HCC7	12.0	14.0	91.0	3.7	94.7
H0907	96-HCC7	14.0	16.0	88.2	4.7	92.9
H0908	96-HCC7	16.0	18.0	92.6	4.2	96.8
H0909	96-HCC7	18.0	20.0	89.7	4.9	94.6
H0910	96-HCC7	20.0	22.0	91.2	6.2	97.4

Drill holes 96 HCC-4 and -5 show an increase in grade with depth but 96 HCC-6 shows the opposite trend. In the southernmost holes, 96 HCC-1, -2 and -7, a consistent high $CaCO_3$ grade is maintained from surface to bottom hole. This pattern is best explained by a combination of sedimentary facies and locally deeper than average weathering exerting the main controls on $CaCO_3$ content. Grade control assays of blast hole samples will be necessary to maintain high grade limestone feed.

Table 4
Reactivity and sulphur assays

Interval	Sample ID	Analabs % CaO (av.)	Analabs % MgO (av.)	Average CaO + MgO	Reactivity % CaO	Reactivity % $CaCO_3$	% S
96 HCC-1 1 - 9	H 0829 - H 0832	48.62	4.03	52.65	50.58	90.27	0.015
9 - 17	H 0833 - H 0836	48.84	2.84	51.68	51.34	91.62	0.000
17 - 25	H 0837 - H 0840	48.80	3.37	52.17	50.23	89.67	0.047
25 - 33	H 0841 - H 0844	48.28	4.40	52.68	51.34	91.62	0.061
33 - 39	H 0845 - H 0847	46.87	5.94	52.81	50.75	90.57	0.015
96 HCC-2 4 - 14	H 0848 - H 0852	45.61	1.38	46.99	48.03	85.72	0.077
20 - 22	H 0856	44.63	1.69	46.32	45.28	80.81	0.061
22 - 30	H 0857 - H 0860	44.22	3.22	47.44	48.03	85.72	0.063
30 - 39	H 0861 - H 0865	43.70	3.58	47.28	48.20	86.02	0.053
96 HCC-4 8 - 14	H 0866 - H 0868	33.27	7.21	40.48	38.50	68.70	0.000
14 - 19	H 0869 - H 0871	41.60	4.43	46.03	46.32	82.67	0.045
96 HCC-5 10 - 20	H 0872 - H 0876	28.71	4.86	33.57	31.26	55.79	0.047
20 - 30	H 0877 - H 0881	40.92	0.85	41.77	40.49	72.26	0.067
96 HCC-6 4 - 14	H 0882 - H 0886	39.68	0.88	40.56	40.52	72.31	0.044
14 - 22	H 0887 - H 0890	44.47	1.25	45.72	45.68	81.52	0.058
22 - 30	H 0891 - H 0894	39.06	1.44	40.50	40.24	71.81	0.061
30 - 39	H 0895 - H 0899	35.80	1.66	37.46	39.37	70.26	0.032
96 HCC-7 0 - 8	H 0900 - H 0903	49.09	2.27	51.36	51.34	91.62	0.035
8 - 14	H 0904 - H 0906	51.15	1.80	52.95	54.12	96.58	0.053.
14 - 22	H 0907 - H 0910	50.63	2.39	53.02	51.71	92.27	0.052