REHABILITATION OF UNOXIDISED PYRITIC WASTE ROCK AND TAILINGS AT

MARTHA HILL GOLD MINE, N.Z.

A thesis presented in partial
fulfilment of the requirements
for the degree of

MASTER OF HORTICULTURAL SCIENCE

In Soil Science at

Massey University
Palmerston North, New Zealand

Kathy Anne Mason
July 1996

ABSTRACT

At the Martha Gold and Silver Mine in Waihi, New Zealand, land disturbed by mining operations is required to be revegetated. Areas include pit walls above the natural water level, the slopes of the dam impounding the tailings and the tailings surface. The research work reported in this thesis is concerned with revegetation of acid generating material situated on the pit walls, and tailings revegetation.

Hydroseeding with grass species onto pit slopes comprising unoxidised pyritic rock material proved to be unsuccessful because of acid generation which caused the pH to drop as low as 2.2 on the slope surface. Where calcite veins were present the pH was maintained at higher levels. It was found that a mixed species of hydroseeded grass grew successfully where the pH was 6.0 or above. Clover began to show signs of stress when the pH dropped to 4.5 and when the pH fell as low as 3.6, all grass died.

Boreholes at a diameter of 100 mm were drilled to a depth of 500 mm into the slope surface of pyritic rock material to provide planting holes for native species at 1.5 m intervals. Toetoe, manuka, kanuka, flax and akeake all had acceptable survival rates over a ten month period. Coprosma kirkii was not successful and is not recommended for further plantings. Topsoil placed in the boreholes was found to have a beneficial effect on the overall plant survival rate, more so than the addition of lime or fertiliser. Although survival rates for native plants were acceptable over a ten month period, the objective of providing a vegetation cover that would improve the visual appearance of the slope was not achieved with 1.5 m spacings between plants.

In contrast to the unoxidised pit slope material, tailings were found to have few limitations to plant growth. In 1992, two separate tailings trials were established to investigate the use of native plants as an alternative land use to pasture and the use of compost as an amendment for pasture production and native plant growth. Within the first six months following sowing, pasture dry matter yields from tailings plots with a 50 mm layer of compost applied to the surface were not significantly different from yields from tailings plots without a compost amendment although clover production was visually greater on compost plots. For subsequent cuts, compost-amended plots gave significantly higher pasture dry matter yields than nil-compost plots. Yield differences after the first six months were considered to be due to the improved P status on compost-amended plots.

Yields off nil-compost plots in the first year of the 1992 trial averaged 11,000 kg DM/ha, compared to 9,000 kg DM/ha obtained from an earlier trial on an older tailings deposit (Union Hill). Yields off the compost-amended plots in the 1992 trial averaged 14,000 kg DM/ha, significantly higher than topsoil-amended plots in the Union Hill trial which yielded between 6,000 and 7,000 kg DM/ha in the first year. Yield differences between treatments of the two separate trials may have been due to differences in P status or rainfall.

The survival rate for the native plants in the tailings trial (flax, cabbage tree, kanuka and Pittosporum tenufolium) was 100%. The addition of compost caused significantly higher growth rates in the first six months but beyond six months no significant differences were observed.

A rehabilitation predictive model was developed for tailings rehabilitation which investigated costs and returns over a fourteen year period based on five different rehabilitation scenarios. The scenarios included the use of clay covers, resurfacing with compost in the event of a topsoil shortage, and a comparison between pasture and native plant land uses. It was found that if a clay cap was required on the tailings surface, large quantities of material would be required. Relatively high costs were found to be associated with the need for a clay cap and compost. Rehabilitation with native plant species was found to be more expensive than rehabilitation to pasture, and if treatment of surface water derived from the tailings surface was required, there would be significant added costs. Maintenance costs for natives were also found to be high and where pasture provides some revenue, further trials are required to determine whether revenue from natives timber species is possible.

ACKNOWLEDGEMENT

I wish to extend thanks to the following people for providing ideas, information and support which contributed to the completion of this thesis:

My supervisors, **Professor Paul E.H. Gregg** for his supervision, guidance, patience, encouragement and good advice given on so many occasions, and **Dr Robert B. Stewart** for advice, assistance and encouragement. I am truly grateful.

The staff of Waihi Gold Mining Co. Ltd. Many people have provided help and encouragement. I wish to thank the former Resident Manager, **Richard Carlton**, for initiating the tailings trials, and the current Resident Manager, **Tim Gosling** for his ongoing support and interest.

To the whole environmental team, especially **Keith Brodie**, but also **Adriene Hanna, Ruby Boyd, Donna Fisher, and Kimberley Dunning** for the help you have given me over the past months. Thanks also to **Bob Drury** for your help and support. Special thanks to **Doreen McLeod** for advice, support, and practical, hands-on help, many times, and to **Henk Bange.**

To **Jeff Ruddock** for building the tailings trial ponds, and the mill crew for their help in establishing the plots. Other staff members who have contributed in many ways, offering help, advice and support include **Don McKay, Bruce Morrison, Dean Kennedy, Dean Fredicksen**, and the sampling crew.

To **Taupo Native Plant Nurseries** who supplied the native plants for the tailings trials free of charge, and to **Attwoods Fertilisers**, who provided the compost free of charge.

Costs for the rehabilitation model were supplied by **Jeff Ruddock** (drainage and earthworks), **Duncan Smeaton**, (Agricultural Costs and Returns), and **Wayne Allan** (Native Plant Costs). Thanks also to **Malcolm Lane** for help with the model.

To **Brian Bullen** and **Shane** at Computer Solutions for solving many computer problems, and **Mark Samson** for producing some of the figures.

To my family, especially **Mum** and **Alan**, **Lynley** and **Dave**, **Nina** and **Les**, and **Sonny** - thanks for your support.

And last, but most importantly, special thanks to my fiance **Pete** for support and helpful advice over the past few months. We made it.

TABLE OF CONTENTS.

CHAPTER 1 -

CHAPTER 2 -

THE REHABILITATION OF GOLD MINING TAILINGS AND WASTE MATERIALS - A REVIEW

CHAPTER 3.0 -

THE MARTHA MINE - PROJECT DESCRIPTION, REHABILITATION REQUIREMENTS AND FORMER TESTWORK

CHAPTER 4 -

CHAPTER 5:0 -

CHAPTER 6.0 -

CHAPTER 7.0 -

LIST OF FIGURES

LIST OF TABLES.

LIST OF APPENDICES.

CHAPTER 1 -

INTRODUCTION AND OBJECTIVES.

Probably no aspect of mining causes greater concern to the New Zealand public than that of tailings disposal and of the visual impact resulting from mining. Even people who have never visited the South Island will speak of the waste-land left from the gold dredging operations of a century ago. In the case of the well known Tui Mine at Te Aroha, impacts are not only on-site but also off-site with two adjacent streams being polluted by acid leachate. Given the environmental damage that mining can cause, it is not surprising that there has been a widespread development of public opinion which advocates the 'repair' of the landscape following this form of land use.

Rehabilitation planning in its total context is all about identifying the best practical options for a sustainable land use, given site specific constraints. It involves the identification of potential problems, possible solutions and sometimes compromise. Selection of the final land use, identification of resurfacing and waste disposal options and species selection are all issues which must be addressed.

It is essential that planning for rehabilitation commences prior to mining and is considered as an integral part of mining. This requires the co-operation of a team of people including geologists and geochemists to identify and characterise the waste types produced, soil scientists to identify materials with a potential to sustain plant life, engineers to create the optimum waste disposal facility and landscape architects to ensure the proposed land use can be integrated into the surrounding landscape and provide a pleasing result visually.

Once mining proceeds, planning continues but generally with a change in emphasis to accommodate changes occurring during mining operations. These changes may include:

* Changes in waste types, eg as the pit deepens, sulphide levels within the ore may increase such that the acid generating capacity of tailings increases, and a cover may be required.

* Changes in the mine plan, eg will slopes be steeper than those originally planned? Will the grind size of the tailings remain constant, and if not, will it affect plant growth potential?

* Changes in community expectations, eg preference for native species and wetlands could influence selection of the final land use.

* Economic considerations may affect the final land use, eg who will ultimately own the area and will it need to make a profit?

* Possible extension to the mining project, or change in the gold price leading to a different gold cut-off grade and changing the ratio of ore to waste. This may lead to changes in waste disposal methods including changes to topography and slope.

* Topsoil quantities may be limited and other possible amendments such as overburden, sewage sludge or chicken manure may prove to be potential alternatives. The quantities of alternative materials required to produce an acceptable outcome will then require investigation.

* Whether there are associated environmental considerations, eg will some resurfacing methods produce dust which may affect local crops or human health? Will some resurfacing options have implications regarding water quality generated from the site?

In New Zealand, geochemical testwork and field trials are required prior to the granting of a Mining Licence to provide evidence that the disturbed site can be rehabilitated to an acceptable land use. Evidence is required to show that once mining is complete, the rehabilitated site will be at least as productive as the land use which existed prior to mining. In many cases pasture trials are used. However, Mining Licences generally allow for alternative land uses for tailings dams to those which existed prior to mining. During mining operations, field trials which investigate alternative land use options may provide evidence that new and innovative land uses may exist which may be more acceptable and sustainable than the original land use.

From the point of view of the mining company, it is also important to know the costs of the options which exist for final rehabilitation. Are there likely to be any associated costs, eg will water derived from the final surface require treatment? What time period is required for rehabilitation and how will the costs be spread? Which are the most cost effective options? When will the bond be released?

Drawing together all of the information regarding ongoing geochemical testwork, options for covers and plant growth media, lime/fertiliser or other additives, options for land use, and site specific constraints to develop optimum rehabilitation strategies can seem to be a daunting task. Research must be scientifically defensible for planning tribunal hearings but it must also be able to be practically applied and presented to company directors who are more interested in the costs of achieving a successful outcome.

GENERAL OBJECTIVE:

To identify strategies for the rehabilitation of land disturbed by a surface mining operation at Martha Hill, Waihi, New Zealand.

SPECIFIC OBJECTIVES:

1. To provide a review of literature regarding the rehabilitation of mining waste. This includes potential limitations to plant growth, geochemical testing methods used to characterise the waste materials, and possible remediation strategies.

2. To assess native plant revegetation on acid producing pit slopes, and investigate the growth of native colonising shrubs and pasture with and without compost on tailings from the Martha Mine, Waihi, New Zealand.

3. To provide a rehabilitation planning framework which incorporates a site specific predictive model. The model is to be developed for tailings rehabilitation for the Martha Mine, to allow costs, returns and materials quantities to be calculated over a fourteen year period under various scenarios of land use and resurfacing options identified as being successful from previous trial work.

4. To provide recommendations to Waihi Gold Mining Company Ltd regarding further research on unoxidised pit slopes and to provide recommendations on tailings rehabilitation strategies.

CHAPTER 2 -

THE REHABILITATION OF GOLD MINING TAILINGS AND WASTE MATERIALS - A REVIEW.

2.1. CURRENT REHABILITATION TRENDS IN NEW ZEALAND GOLD MINES.

Gold mining is carried out in very different environments and locations within New Zealand. Most alluvial operations are carried out on the West Coast of the South Island on a wide variety of landforms including coastal dunes, flood plains and riverbeds, lowland hills and high plateaux, and under many vegetation types, eg pasture, "scrub" including manuka and gorse, exotic forest, indigenous forest, "pakihi", and lowland swamp (Ross and Mew 1990). Land use after alluvial mining differs from site to site but generally includes pastoral farming, exotic forestry and conservation management with methods for establishing pasture and exotic forest after mining being well recognised. Restoration techniques for indigenous forest and wetlands require some development (Ross and Mew 1990).

There are three tailings dams presently being formed in New Zealand from hard rock gold mining; the Martha Mine at Waihi, the Golden Cross Mine in the Waitekauri Valley near Waihi, and the Macraes Mine in Central Otago. Substantial rehabilitation bonds were paid prior to mining, the size of which can be increased at any time by the Regional Council. The rehabilitation bonds are often set as conditions of the water rights and "rehabilitation" in this sense includes both resurfacing and the production of water from the site which is acceptable for discharge to the surrounding environment.

The companies will be looking to reclaim the bonds, but realistically perhaps the biggest incentive for rehabilitation is that companies will be continuing to search for other potential mines. Under the Resource Management Act in New Zealand, public consultation is a requirement and if the company has a poor track record for rehabilitation it is unlikely that further permits will be granted. Given current global environmental awareness, it may even be difficult for the company to start mining in other areas of the world if their reputation is poor.

From the perspective of land rehabilitation, all three sites are very different. Climatic conditions vary with an average rainfall of 2200 mm in Waihi township, approximately 3000 mm in the Waitekauri Valley where the Golden Cross mine is situated (Bokich pers comm 1995) and only 550 mm (Drury pers comm 1995) at the site of the Macraes Mine in Palmerston. Temperatures also vary with the Macraes Mine being subject to winter snow. Snow is not a problem in Waihi township but light snow falls have been reported in the Waitekauri Valley, (McLeod pers comm 1995).

The Martha Project is much more publicly visible than the Macraes Project at Palmerston, or the Golden Cross Project. The open pit is located in the middle of Waihi township and the processing plant and waste disposal site are located in a rural area, but are visible from the main highway between Waihi and Tauranga. Progressive rehabilitation of the pit slopes and tailings dam embankment was a Mining Licence requirement due to potential visual and dust effects.

Due to the locations of the operations, climate, availability of local materials with plant growth potential, geochemistry of the waste types produced and site specific constraints imposed by mining methods, land rehabilitation is very site specific even within New Zealand, and Mining Licences vary in the conditions they impose regarding final rehabilitation. It is now being recognised by both the public and the policy makers that restoring land to what it was, simply because of what it was, may not be the best option for these areas when possibilities for landscapes with new and innovative land use opportunities exist. Rehabilitation of at least part of the tailings surface to wetlands and lakes and the planting of native species may be more publicly acceptable, and, depending on the mine, may provide greater long term security to the materials beneath.

The Mining Licence for the Martha Mine specifies that the tailings dam will be rehabilitated in accordance with the detailed work programme, and the detailed work programme requires that the area be returned to productive pasture (the pre-mining land use). In this particular case, there is a requirement to restore rather than rehabilitate the land. McQueen (1982) defines "restoration" as a reinstatement of the original land use, and "rehabilitation" as rendering the mined land useful but not necessarily returning it to its original land use.

The Golden Cross and Macraes operations were permitted after the Martha Project and the final land use for these two dams is much more flexible. In the case of the Macraes operation, the requirement is "to return the area to a sustainable land use, comparable to the previous use unless there are other values to be taken into account" (Squire pers comm 1995).

A similar situation exists for the Golden Cross operation. The licence requires rehabilitation of the site "to a safe, sustainable land use consistent with the need to maintain the long term physical and geochemical integrity of the site, without requiring maintenance additional to that required for the rest of the catchment in order to protect water quality (surface and groundwater), avoid soil erosion, and restore landscape values" (Squire pers comm 1995).

2.2. POTENTIAL LIMITATIONS TO PLANT GROWTH.

2.2.1. CHEMICAL PROPERTIES.

2.2.1.1. ACIDITY.

Acid mine drainage has been described as the most serious problem facing the mining industry today. It has the potential to cause on and off site water quality problems and restoration of acid producing media can be very difficult. Because of this, section 2.3 describes the processes involved in acid generation, geochemical testwork which may be used to identify such materials and options for preventing the onset of acid generation.

Soil acidity affects plants in a number of ways. Jackson (1967), cited in Hoyt and Nyborg (1972) reported that, depending on species, plants may suffer from toxic levels of soluble Al, Mn, and H, and from deficiencies of Ca, Mg, and Mo. The soil pH or the H^+ ion concentration, can be directly toxic to plant roots when the pH is about 4 to 3, (Jackson, 1967, cited in Hoyt and Nyborg 1972).

Legumes tend to be relatively more sensitive to soil acidity. High concentrations of H^+ can affect the process of nodule formation with symbiotic bacteria (Rhizobium) as well as the symbiotic fixation of nitrogen in the nodules. Generally the availability of phosphorus to plants is lower in acid than in neutral soils. Molybdenum is also less available, and a lack of molybdenum affects Rhizobium bacteria, used in symbiotic nitrogen fixation by legumes (Jackson 1967, cited in Hoyt and Nyborg 1972).

Acid soils often lead to other deficiencies and toxicities in the soil. The optimum pH range of the root zone for plant growth depends on the species, but little growth occurs at pH values less than 4.0 due to Al and/or Mn toxicity. When soils are at pH 5.5 to 5.0, soluble aluminium appears, and the solubility of aluminium increases as the pH decreases further, (Hoyt and Nyborg, 1972). Manganese toxicity is another potential problem associated with soil acidity, although only some crops are sensitive to this element. Soluble manganese may be found at toxic levels in soils slightly above pH 5.0, and solubility increases with a decrease in soil pH, (Jackson 1967, cited in Hoyt and Nyborg 1972). One of the important characteristics of aluminium and manganese toxicity is that only slight acidification will affect their solubility. Even very acid tolerant species will have difficulty surviving pH values less than 3.5 to 4.0, (Bell 1990).

The most common metal toxicities in soil are those due to Al and Mn at pH values less than about 4 to 4.5. In tailings and overburden, similar toxicities can occur under similar pH conditions. When pyrite is present in these materials, the extremely acid conditions generated can also result in elements such as Cu, Zn, Pb, Ni and Cr becoming soluble and causing plant toxicity. Metal toxicity has a very specific effect, seriously inhibiting root growth, making plants susceptible to drought and causing nutrient imbalances and phosphate deficiencies (Smith and Bradshaw 1972). The contents of potassium, iron, copper and zinc in plant tissues are much higher at pH 3.4 than at pH 5.0, (Farmer, Richardson and Brown 1976, cited in Fox 1984).

In addition to direct toxic effects, at pH less than 4.5, aluminium, with iron, combines with phosphate, to form insoluble compounds which make phosphate unavailable. Therefore although phosphate fertilisers may render heavy metals insoluble through complexing (Smith and Bradshaw 1972), growing plants may become phosphorus deficient.

Soil acidity may also influence the rate of mineralization of nutrients from soil organic matter. Acid soils restrict microbial activity so that nitrogen release can be very slow (Bradshaw and Chadwick 1980, cited in Fox 1984). Mineralization of phosphorus and sulphur is also decreased in acid soil (Jackson 1967, cited in Hoyt and Nyborg 1972). Nitrification in acid soils does not take place as quickly as in nearly neutral soils. As a generality the formation of nitrates slows markedly at pH 5 and ceases below pH 4.5 to 4.0 (Nyborg 1984). This means that, whereas plants growing in nearly neutral soils feed on nitrates as their source of nitrogen, plants growing on more acid soils tend to feed on ammonium (White pers comm 1989).

An element that appears to be important in land reclamation is calcium, either by virtue of its direct effect, or by its influence on soil pH. Observations that vegetation types and metal uptake are correlated with the calcium content of the soil have led some to conclude that soil pH and Ca can be more important than the heavy metal concentration. Antonovics *et al* (1971), cited in Fox (1984) report that calcium may reduce zinc and copper uptake and ameliorate lead, zinc and nickel toxicity.

Calcium and magnesium deficiency can occur in plants growing on acid soils. Under field conditions calcium deficiency is seldom seen in agricultural soils, except in some crops (tomatoes, potatoes, peanuts). Calcium is normally not deficient until it shows less than 20% base saturation, and for magnesium the value is less than 5% base saturation (Nyborg 1984). Usually soils that have percent base saturations that low are too acid for agricultural use.

In some cases, eg oxidised waste, acidity can be reduced by liming. However unoxidised wastes containing pyrite often cannot be economically limed to pH values satisfactory for plant growth, as rates in excess of 100 t/ha of $CaCO_3$ may be required every few years as a result of continuing pyrite oxidation.

Wherever possible it is best to avoid using pyritic material for resurfacing. Often plant growth is difficult to achieve, water quality from these areas may be poor and water treatment may be necessary prior to disposal. In some circumstances, however, the use of pyritic material as a plant growth medium may be unavoidable. An example is when acid generating material is exposed on steep pit slopes and covering the material is not an option. A trial investigating this problem is discussed in chapters 4 and 5.

2.2.1.2. ALKALINITY.

Examples of high pH materials include the sedimentary overburden overlying much of the coal in the Bowen and Sydney Coal Basins (pH 7.0 - 9.5) and the extremely alkaline wastes resulting from the caustic soda extraction of bauxite to produce alumina (pH 10 -

12) at refineries in the Northern Territory, Queensland and Western Australia. Sodic overburden spoil can be made acceptable for plant growth by the use of gypsum and ammonium fertilisers, whereas the bauxitic wastes are far more difficult to ameliorate (Bell *et al* 1989, cited in Gregg *et al* 1990).

At a pH above 9.0 immobilization of P and micronutrients such as Fe, Cu, Zn and Mn can limit plant growth. Copper and molybdenum were found to be deficient in coal overburden materials in Singleton, Australia, (Hannan, 1978). In some cases, acidification of alkaline materials may improve the availability of phosphorus from fertiliser but may also increase heavy metal toxicity (Moore and Zimmermann 1977, cited in Fox 1984).

2.2.1.3. NUTRIENT DEFICIENCIES.

Nutrient requirements in a soil depend on the nature of the vegetative cover being established. Australian native flora have evolved on low fertility soils, and thus generally have lower nutrient requirements than exotic crop and pasture plants used in agriculture (Bell 1990).

A wide range of nutrient deficiencies has been documented in mine rehabilitation programs in Australia, but nitrogen and phosphorus deficiencies are generally predictable. (Bell 1990). Nitrogen is rapidly leached through the root zone and must be applied annually to crops and grass pastures in the absence of legumes. Where native shrubs and trees are being established on mined land in Australia, nitrogen-fixing Acacia species are normally included in the seed mix; these species can fix up to 20 kg/ha N annually, (Bell 1990). In pasture plots on Martha Hill gold tailings in Waihi New Zealand, it was found that clover fixed at least 240 kgN/ha/yr (Mason *et al* 1993). Where soil is not conserved during the mining operation, nitrogen will be a limiting element for establishment, even for many native Australian species (Bell 1990).

Phosphorus deficiency is acute in most mine wastes and in most Australian soils, and even where the return of native species is required some application of this element is usually necessary. Application rates may vary from 5 to 10 kg P/ha for establishment of native heath species after sand mining to 75 kg P/ha for the establishment of improved pasture on replaced lateritic red earth following bauxite mining (Bell 1990). For establishment of pasture on an oxidised waste bund at Martha Hill Waihi, 6 t of lime per hectare and 1 t of superphosphate per hectare are applied prior to the spreading of 100 mm of topsoil, whereupon 1400 kg/ha of 15% potassic superphosphate is applied. This is equivalent to a total of 240 kg P/ha in the upper 25 cm. Phosphate retention in the topsoil used at the site is very high (Gregg *et al* 1995).

2.2.1.4. SALINITY AND SODICITY.

Establishment of vegetation on many mine wastes in Australia is limited by excessive levels of soluble salts. This is often the case with coal mine overburden spoil in the Bowen and Sydney Basins (Hannan and Bell 1986, cited in Bell, 1990) and with tailings resulting from the processing of ore (Bell *et al* 1989). Additionally, many Australian soils have subsurface horizons which have accumulations of salt, and care needs to be exercised in soil stripping and replacement procedures to ensure either that the subsoil material is not used or that it is covered by surface material (Grundy and Bell 1981).

Toxic levels of salinity in subsoils and sedimentary material overlying coal are often associated with high levels of sodium. High levels of sodium can cause severe surface crusting leading to a reduction in leaching and causing an increase in soluble salts (Bell 1990).

Plants vary in their tolerance to salinity and irrespective of whether the land use goal is to establish crops, pastures, commercial forests or native flora, it is possible to select tolerant species where salinity is a problem. Few plants can tolerate salinity levels in excess of 8 mS/cm (saturation extract) without yield reduction, and few survive at salinity levels greater than about 20 mS/cm (Bell 1990). As coal mine overburden can contain salt levels up to 15 mS/cm and metalliferous tailings up to twice this level, there is clearly a limit to the use of salt-tolerant species; attention must be given to placement of high-salt materials away from the root zone, particularly if they are relatively impermeable. In New Zealand where the effective precipitation is generally higher than in most parts of Australia, leaching of salt from mine wastes would be expected to reduce the impact of salinity problems. Greenhouse trials with fertilised mine wastes have lead to salt toxicity problems however (Mason 1989).

2.2.1.5. HEAVY METALS.

Alloway (1990) defines the group of elements with an atomic density greater than 6 g/cm^3 as the heavy metals. Under this definition, iron is not included.

The most common heavy metal toxicities in soil are those due to Al and Mn at pH values less than about 4.5. Similar toxicities can occur in overburden spoil and tailings, and when pyrite is present the extremely acid conditions generated can also result in the solubilization of other elements such as Cu, Zn, Pb, Ni and Cr (Bell 1990).

The behaviour of heavy metals in soils depends on soil factors such as drainage status, oxidation potential and pH. In general, heavy metal cations are most mobile under acid conditions (Alloway 1991).

The solubility of many metals in mining waste material can be reduced by liming to raise the pH, by adding phosphorus fertiliser or by incorporating organic matter such as sewage sludge to complex the metals (Bell 1990). It is also possible to choose metal tolerant species, however, it should be the aim to avoid having potentially toxic materials in the root zone, particularly if there is the possibility of producing water of poor quality from the site, or, if plant uptake of metals is likely, the land is used for grazing or food crops.

2.2.2. MICROBIOLOGICAL PROPERTIES.

Micro-organisms can influence nutrient uptake/cycling and nitrogen fixation and may directly or indirectly affect plant growth.

Bell (1990) reports that where surface soils are stripped and replaced without stockpiling, there will be little impact on microbiological processes. Stockpiling of soil results in a decline of microbial inoculum and plant growth may be inhibited by lowered concentrations of symbiotic and non-symbiotic micro-organisms.

The microbes and mesofauna active in nutrient cycling will be absent in overburden spoil, but these populations will slowly increase with time under a vegetative cover. In Australia, Rhizobium bacteria may be inoculated to legume seed, and mycorrhiza may be inoculated to seedlings although this is costly (Bell 1990). In New Zealand, clover seed used for pasture rehabilitation is generally inoculated prior to use.

Soil acidity may influence the rate of mineralization of nutrients from organic matter. Acid soils restrict microbial activity so that nitrogen, phosphorus and sulphur release can be very low in acid soils, (Bradshaw and Chadwick 1980, cited in Fox 1984), (Jackson 1967, cited in Hoyt and Nyborg 1972).

2.2.3 PHYSICAL PROPERTIES.

A root zone for plants should have a good available water holding capacity but be sufficiently well drained so as not to affect root growth through lack of aeration. Additionally the medium should not provide mechanical impedance to the expanding root system.

These properties are a function of the pore size distribution in the medium and its stability (Bell 1990). This distribution in turn is determined by the primary particle size distribution (sand, silt and clay content) and the aggregation of these particles.

Neither tailings nor waste are likely to be homogeneous either physically or chemically. Tailings may have a size range from 50% minus 350 um, to 90% minus 74 um at different mines (Down and Stocks 1977, cited in Fox 1984) Most are restricted to the clay (<.002 mm) to coarse sand (0.2 to 2mm) range (Bell 1990).

Where tailings are spigotted on to a tailings dam surface, the finer textured slimes end up in the centre or at distal points. These areas will not readily dry out. Differential settlement may give rise to persistent wet spots with the dam surface unable to support machinery for some years after abandonment. Coarse tailings, in contrast, can result in a low water-holding capacity. Crusting can also be a problem in revegetating tailings, eg asbestos tailings formed a 20 cm crust after 5 years (Moore and Zimmermann 1977, cited in Fox 1984).

Ross and Mew (1990) report that on the West Coast of the South Island in New Zealand, drought is less important than drainage impediments on recontoured tailings followed by soil replacement. The exception is dairy pasture where some imperfectly drained, deeper soils may be required for production during mid-summer drought.

Dry tailings are notorious potential sources of dust (Marshall 1978). When tailings emplacement ceases, measures must be taken to avoid dust generation. If the tailings contain heavy metals and/or pyrites, there is additional reason to prevent dust generation and dispersal.

Particles in the size range 0.05 to 0.5mm are particularly prone to movement by wind and can result in abrasion and coverage of seedlings (Bell 1990). This limitation is an important consideration in rehabilitation programmes in semi-arid and arid parts of Australia, eg Pilbara (iron ore), Kalgoorlie (gold), Broken Hill and Mt. Isa (base metals). In the case of the Waipipi Iron Sands project in New Zealand, a nursery crop of barley or barley/oats was sown to stabilise the topsoil prior to oversowing with a grass mix. This was because high velocity winds would be a major inhibitor to grass establishment

(Connelly *et al* 1981) with young seedlings being battered by wind-carried sand particles.

Waste, on the other hand, can range from 50 t boulders to fine dust (Down and Stocks 1977, cited in Fox 1984). Problem dumps are often created by unplanned dumping. Rocks within waste can interfere with cultivating operations, and may need to be removed from the surface prior to the respreading of topsoil.

The physical nature of waste may cause plant growth problems. Materials may be unduly compacted or loose and exposed to movement. Segregation of particle sizes will result in a gradation of conditions with fine material prone to surface compaction and coarse material with little ability to hold moisture. The spoil may be more liable to wind or water erosion with extremes of moisture and temperature being more severe than at undisturbed locations within the same climatic region.

Bulk density is a useful measure of compaction in relation to root penetration. Surface accumulation of fines in slimes dams may give a bulk density as high as 7.5 g/cm^3 with low infiltration (Ruschena *et al* 1974, cited in Fox 1984). Fine textured, non-aggregating materials such as many types of tailings tend to pack to a high bulk density which results in low infiltration and permeability, and restricted root penetration eg red mud tailings resulting from the production of alumina from bauxite (Bell 1990). The widespread use of heavy tracked machines has resulted in compaction being a major rehabilitation problem.

Potential physical problems depend very much on the land use planned for the site once mining is complete. Pakihi soil mined on the west coast of New Zealand has in the past been rehabilitated to pasture or pines. Where pakihi mining sites have been abandoned, gorse and/or manuka scrub has generally established as a result of the improved drainage and higher fertility conditions resulting from mining (Ross and Mew 1990). It is possible that in the future, restoration of the pakihi soils might be a condition of the mining licences. Analogous to this is the situation with coal mining spoil dumps in the Hunter Valley of New South Wales, where reshaping must be carried out to ensure that no isolated depressions or ponds are formed which could become swampy during wet weather (Hannan 1978). Hence the requirements for rehabilitation may vary depending on the local environment, laws and community expectations.

The physical properties of a medium are often the most difficult to ameliorate, and may dictate the yield potential for plants after the more easily altered chemical or microbiological properties are changed. The low water holding capacity of coarse-textured materials can be increased with the build up of humus under a pasture or with the addition of organic material such as sewage sludge. Poor internal drainage in clay materials is harder to improve, but the addition of organic matter and deep ripping can be effective.

Exposure of sodic strata can cause severe crusting in spoil and this is one of the major limitations to the establishment of vegetation on spoil at many open-cut coal mines in the Bowen and Sydney Coal Basins. Surface crusting in sodic materials can be alleviated by broadcast gypsum applications (2 to 10 t/ha), but improvement in the extremely low permeability of such materials in subsurface layers is made difficult by the need for deep incorporation of the gypsum (Hannan 1979).

2.2.4 ENGINEERING PROPERTIES.

Poor engineering decisions can drastically affect the success of final land rehabilitation. This is because of the effects that engineering can have on the physical and chemical characteristics of the final resurfacing medium, including slope, topography and drainage.

Planning for rehabilitation should commence prior to mining to identify potential problems with final rehabilitation and possible engineering solutions. Where possible, materials with major limitations to plant growth should be disposed of so that they do not form a final medium for resurfacing. These may include acid producing materials, saline, sodic or metals containing materials, or materials with an unfavourable size distribution. Materials such as this are best disposed of beneath a cover if a more suitable cover material is available.

Suitable materials for plant growth should be identified and saved for future rehabilitation operations. Consideration needs to be given to the options available for stripping, storing and maintaining these materials. Widdowson *et al* (1982) found that, contrary to research findings in the United Kingdom, stockpiling of topsoils in Southland, New Zealand, had little detrimental effect on pasture productivity and soil chemical properties. However, stockpiling was found to result in increased compaction and bulk density and decreased porosity, especially macroporosity (McQueen and Ross 1982). These changes were attributed to the influence of earthmoving equipment rather than the overburden effect of stockpiling. A decline in soil aggregate stability on stockpiling was also observed.

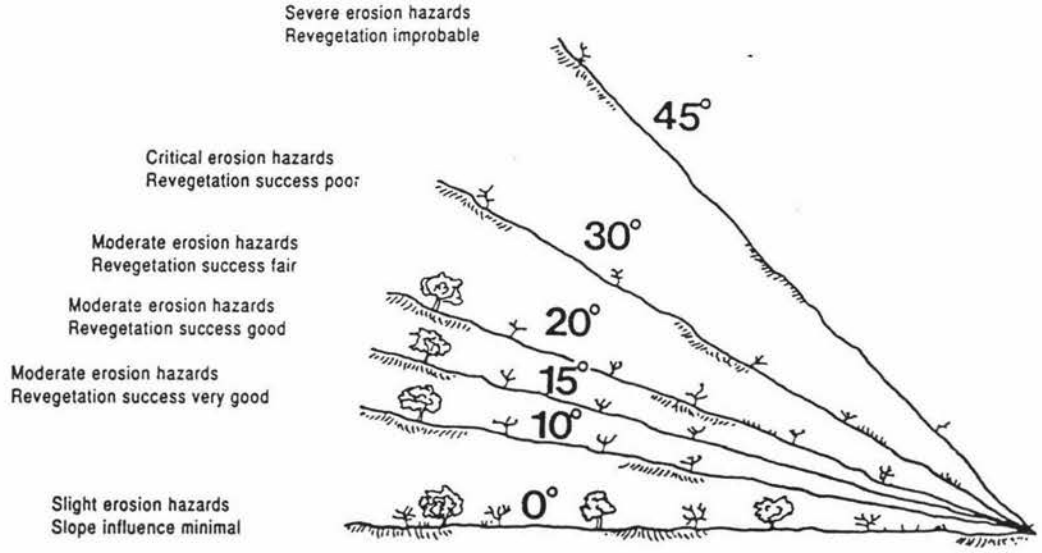
The quantities of materials which must be stored, and the depths required to provide a suitable medium for resurfacing must be considered. For these reasons there needs to be co-operation between geologists, mining engineers and soil scientists to identify the most cost effective and successful options.

Rock, soil and clay coverings are often expensive to apply and it is important to identify potential cover materials and ensure their availability. As well as minimising water percolation, emplacement strategies may need to minimise oxygen access to pyritic material. Placement also needs to account for possible effects on water quality so as to have minimal effect on ground and surface water. Engineering specifications such as compaction, permeability, porosity and depth may be need to be imposed. Covers are not without their problems; where soil is used over tailings slimes, slip zones may develop as the slimes absorb water more slowly (Poynton 1977, cited in Fox 1984).

Because of the swell factor (sometimes 20% to 30%) associated with the excavation and placement of overburden, the post-mining landform may be steeper and more elevated than the original landform, (Bell 1990). Often there is a trade-off that must be considered; whether to clear more area in the surrounding environment to create less steep slopes and support a higher standard rehabilitation, or to establish plant cover on steeper slopes with less encroachment on the surrounds. Recontouring to achieve an acceptable topography is often the major cost in a rehabilitation program; this is particularly the case in strip mines utilising draglines for overburden removal (Bell 1990).

The final topography can affect other factors such as microclimate and erosion potential which have implications on the final land use. Figure 2.1 shows the effect of varying slope on revegetation success and erosion potential of Western Australia.

Figure 2.1 - Influence of Angle of Slope on Revegetation and Erosion (Dept of Mines, 1988).



Pit slopes are generally steep and may provide an inhospitable environment for plants for several reasons, including a lack of soil, acid conditions, nutrient deficiencies/toxicities, and susceptibility to erosion and drought.

Surface hydrology and drainage can be engineered to improve rehabilitation success. Armiger *et al* (1976), cited in Fox (1984), describe a 'lateral groove technique' with terracing serving to hold water and improve the local microclimate for vegetation establishment on slopes. Rehabilitation to exotic forestry on the West Coast can be enhanced by creating small humps and hollows during final ground preparation, (Ross and Mew 1990).

The machinery used for rehabilitation can also affect the final outcome. Heavy mining machinery can cause compaction problems, so agricultural machinery should be used for preparing the final surface. Rippers may be used on compacted areas to fracture and break up surfaces. Offset discs or chisel ploughs and the contour furrow are also used, especially where it is important to reduce runoff (Brown 1977, cited in Fox 1984).

The benefits of ripping have been reviewed by Richardson (1980), cited in Fox (1984). These include improved aeration and water retention, better root penetration and erosion control. Soil amendments may be incorporated more readily. Relief of compaction by deep ripping is strongly recommended on alluvial gold mine tailings for forestry use on the South Island West Coast of New Zealand (Ross and Mew 1990). In Western Australia, ripping not only breaks up compaction but it also creates water catchment areas and improves water infiltration, so important for plant growth in arid climates. The riplines should be deep enough to break through the topsoil layer into the underlying waste material so that the layers mix. For example, if the topsoil is spread to 300 mm, the slope should be ripped to 500 mm, allowing for water infiltration and plant root penetration beyond the topsoil layer (Goldfields Land Rehabilitation Group 1995).

2.3. THE ACID GENERATION PROCESS.

2.3.1 INTRODUCTION.

Acid mine drainage (AMD) has been described as the most important problem facing the mining industry today. It has been identified by the Australian Mining Industry Council (AMIC) as one of the environmental issues which the mining industry needs to address for sustainable development, (Miller pers comm 1994).

Australia has been largely immune from some of the major problems caused by acid mine drainage. This has been largely due to location with most mining operations being situated in dry and remote areas. Rum Jungle (Northern Territory) and Captain's Flat (New South Wales) are examples of areas where acid mine drainage has caused environmental problems in Australia (AMMTEC 1991).

Because of the increasing quantity of sulphides being mined in Australia, the potential for environmental problems caused by AMD is increasing (AMMTEC 1991). Acid mine drainage can degrade surface water and groundwater, destroy the aquatic environment, and the low pH and solubilized aluminium (and other metals) can kill plants. The acidic material erodes easily and can contaminate adjacent land.

AMD is caused by the chemical and bacterial oxidation of sulphides producing sulphuric acid. A waste dump of 10,000 t containing 0.5% sulphur can produce a total of 150 t of sulphuric acid (AMMTEC 1991). Huge quantities of sulphuric acid can be produced from a waste dump, and the slow kinetics of the process ensure that acid production can continue over many hundreds of years.

The best approach for control of AMD is prevention of acid generation. These measures usually rely on preventing oxygen from contacting the sulphides, or controlling the environment around the sulphides such that the acid generation reactions do not occur. In the case of waste rock stacks, more options exist than for steep, acid producing pit slopes, and much more literature is available regarding the rehabilitation of such areas.

The following literature review focuses on the processes involved in acid generation, the effect of soil acidity on plant growth and possible options for rehabilitation of acid soils.

2.3.2 PROCESSES INVOLVED IN ACID GENERATION.

2.3.2.1. ACID MINE DRAINAGE.

Despite a large amount of research effort, as illustrated by Gleeson and Russell (1976) cited in Hutchison and Ellison (1992), not all of the relationships between the various controls on sulphide oxidation are as yet fully understood.

Pyrite and marcasite are abundant in most sulphide-bearing mineral deposits. The oxidation of these sulphides is the major contributor to acid generation from mine wastes. Processes involving reactions of other sulphides and sulphur forms, such as thiosalts, and anaerobic reactions may also play significant roles in acid generation (Smith and Barton-Bridges 1991, cited in Hutchison and Ellison 1992).

a. Pyrite Oxidation.

Under dry conditions, oxidation of pyrites takes place only at temperatures over 100°C, by the following reaction:

$FeS_2 + O_2 \rightarrow FeSO_4$

In the presence of water, pyrite oxidation can occur DIRECTLY from the reaction with air and water, or INDIRECTLY from the reaction with ferric iron, (Hutchison and Ellison 1992). At mining sites, direct oxidation processes and the associated biochemical reactions that occur are considered to be the major contributors to ARD (acid rock drainage). However, depending on site-specific conditions, the indirect oxidation process can also influence the production of ARD. (In the context of this discussion, pyrite is assumed to be synonymous with all other iron disulphides, eg marcasite).

(i) Direct Oxidation.

The direct air and water oxidation of pyrite can be described by three interdependent reactions (Kleinmann *et al* 1981, cited in Hutchison and Ellison 1992):

$$2FeS_2 + 7\,O_2 + 2H_20 = 2Fe^{2+} + 4SO_4^{2-} + 4H^+ \qquad (1)$$

$$4Fe^{2+} + 10H_2O + O_2 = 4Fe(OH)_3 + 8H^+ \qquad (2)$$

$$2Fe^{2+} + O_2 + 2H^+ = 2Fe^{3+} + H_2O \qquad (3)$$

(ii) Indirect Oxidation.

There is an additional reaction (Williams *et al*, 1982, cited in Hutchison and Ellison 1992) where trivalent ferric iron in solution will itself oxidise pyrite, resulting in acid generation, but without oxygen involvement. The equation is:

$$FeS_2 + 14Fe^{3+} + 8H_2O = 15Fe^{2+} + 2SO_4^{2-} + 16H^+ \quad (4)$$

Williams (1982) cited in Hutchison and Ellison (1992) notes that, while trivalent iron in solution is limited, a little ferric iron is a powerful oxidant. Air/water oxidation produces four moles of H^+ (two moles of sulphuric acid) for each mole of pyrite (Reaction 1) while ferric iron oxidation produces 16 moles of H^+ (eight moles of sulphuric acid, Reaction 4) (Hutchison and Ellison, 1992). Therefore, if ferric iron oxidation takes place, it can produce substantially more "acidity" when compared to air/water oxidation. It is evident from chemical analysis of waste rock and tailings and analysis of water samples from mining areas, that there can be many sources of iron to drive this process.

Pyritic sulphide oxidation as described by the previous reactions occurs in three stages:

Stage 1.

Reaction 1 proceeds both abiotically and by direct bacterial oxidation.
Reaction 2 proceeds abiotically and slows as pH falls.
Chemical Conditions: pH above approximately 4.5, high sulphate and low iron concentrations, little or no acidity.

Stage 2.

Reaction 1 proceeds both abiotically and by direct bacterial oxidation.
Reaction 2 proceeds at a rate determined primarily by the activity of T. ferro-oxidans.
Chemical Conditions: Approximate pH range of 2.5 to 4.5, high sulphate levels, acidity, total iron increasing, and a low Fe^{3+}/Fe^{2+} ratio.

Stage 3.

Reaction 3 proceeds at a rate totally determined by activity of T. ferro-oxidans.
Reaction 4 proceeds at a rate primarily determined by rate of Reaction 3.
Chemical Conditions: pH below approximately 2.5, high sulphate levels, acidity, total iron and high Fe^{3+}/Fe^{2+} ratio.

Work by Sugio *et al* (1985) in Silver (1987), cited in Hutchison and Ellison (1992), showed that oxidation of sulphur by ferric chloride can also produce acid:

$$S + 6FeCl_3 + 4H_2O = H_2SO_4 + 6FeCl_2 + 6HCl$$

This acid production process is anaerobic. Elemental sulphur is associated with pyrite and the intermediate products of many of the reactions or partial reactions in the oxidation of sulphides, while chlorides are ubiquitous in mine wastes.

There appears however, to be literature regarding indirect oxidation which is seemingly contradictory. Miller pers comm (1996), reports that Fe^{3+} must be present as dissolved Fe^{3+} to be effective in oxidising pyrite. This is not possible above pH values of approximately 3.5 to 4.0. In the absence of oxygen, pyrite will be rapidly reduced to Fe^{2+} which does not oxidise pyrite. Regarding oxidation by ferric chloride, Miller pers comm (1996) reports that dissolved $Fe3^{+}$ in solution in the absence of oxygen is like dissolved oxygen in water with respect to pyrite oxidation in that they both have a negligible effect.

b. Factors Affecting Pyrite Oxidation.

The reactions involved in pyrite oxidation and acid production can be influenced, modified or inhibited by numerous biochemical or geochemical factors:

(i) Biochemical Processes.

The bacteria Thiobacillus ferro-oxidans is widespread in natural environments and can be expected to play a role wherever acid generation occurs. As with other bacteria, it is likely to be adversely affected by low temperatures which limit both its efficiency and effect.

Kleinmann *et al* (1981), cited in Hutchison and Ellison (1992), demonstrated that T. ferro-oxidans was effective in catalysing the first stage of the reaction (1) above. Knapp (1987), cited in Hutchison and Ellison (1992), showed that at lower pH values of around 3 to 3.5 the rate of the catalysed reaction was much faster than the abiotic rate, and at higher pH values the effect was still present, but the rate of increase (catalysis) was less.

(ii) Geochemical Considerations.

The factors described below affect acid generation from pyrite. Individual factors that influence acid generation vary with time, and development of the ultimate acid generation rate can involve a significant number of years.

Studies by Williams *et al* (1982), cited in Hutchison and Ellison (1992), indicate that the initial rate of acid production at a pH greater than about 4.5 appears to determine whether significant levels of acid ultimately will be produced. A high initial rate indicates a high ultimate rate of production.

(iii) pH

There is no clear understanding of whether pH can control, prevent or affect the reaction rate of pyrite oxidation, or whether it is only an indicator of buffering effects.

Kleinmann *et al* (1981), cited in Hutchison and Ellison (1992) found that if the pH was kept in the range of 6 to 8, the dissolution of pyrite was very slow, producing negligible amounts of acid, despite the presence of bacteria. The imposition of a uniform, high pH condition appeared to override any microenvironments which could be acid generating.

Earlier studies indicated that pyrite oxidation proceeded as a chemical process until the system pH dropped to about 3.5 to 4 but it was later demonstrated that T. ferro-oxidans was also effective in the first stage of the reaction. At pH values of around 3 to 3.5 and below, T. ferro-oxidans catalysed the reaction much faster than the abiotic rate.

(iv) Oxygen.

The amount of oxygen required to drive reactions (1), (2) and (3) is very small, being less than 10% of the oxygen content in the air. Where water is a source of oxygen, dissolved oxygen down to 0.5 mg/l, 5% of its nominal saturation in surface waters, is sufficient for the oxidation process (Hutchison and Ellison 1992).

(v) Alkalinity.

The net effect of alkalinity is to keep the system pH closer to neutral for a longer time than might be expected in an acid generating system. Examples explaining the effects of alkalinity on solution pH and pyrite oxidation are described in Appendix 2.1.

(vi) Pyrite Abundance and Surface Area of Pyrite Grains.

Caruccio and Geidel (1981), cited in Hutchison and Ellison (1992) found an interrelationship between pyrite content, surface area of the pyrite grains and the acid generating capability of mine waste. With all other aspects being equal, the mass rate of acid generation was directly related to the mass of the pyrite and to the surface area of the pyrite. In certain wastes with a low total sulphide content of finely disseminated pyrite the acid generation rate was higher than when a higher content of massive pyrite (with a lower surface area) was present.

Smith *et al* (1987), cited in USEPA (1976), found that the form of sulphide and extent of sulphide encapsulation should also be considered. Disseminated sulphides generally will be stronger acid generators than massive sulphides and the mineral form of the sulphide will influence its reactivity. The extent of sulphide encapsulation is also important; sulphides can be encapsulated in a silicate matrix, particularly in unweathered waste rock. Oxidation reactants cannot reach the sulphide grain so that, despite elevated sulphide levels, the sulphide may be nonreactive due to lack of physical accessibility. Due to destruction of the encapsulating layers, weathered or partially weathered pyrite-bearing wastes may be more efficient acid generators than unweathered wastes, even though their sulphide levels may be lower.

(vii) Temperature.

A change in temperature changes the rate of chemical and biochemical reactions. In general, reaction rates double for a 10°C rise in temperature, over a limited temperature range. Smith and Shumate (1971) cited in Hutchison and Ellison (1992), demonstrated this relationship for pyrite oxidation.

(viii) Microenvironments.

The geochemical systems associated with mine wastes, particularly waste rock material, can be extremely heterogeneous and include a wide variety of microenvironments. The geochemical activities that occur within certain microenvironments can control the acid generating potential of the overall waste. Examples of the more important effects are:

- The formation of local acidic "hot spots" in waste rock piles.
- The inhibition of bacterial action where local acidity due to acid generation is too high (Kleinmann *et al* 1981, cited in Hutchison and Ellison 1992), and
- Formation of gypsum coatings on calcite grains or jarosite on pyrite grains. (Discussed further under "Other Reactions").
- Pyrite Structural Defects and Trace Element Contents.

Evidence for the effects of trace elements incorporated in the pyrite crystal lattice is inconclusive and seemingly contradictory. For example, Richardson (1980), cited in Fox (1984), associates elevated trace element contents in pyrite with a decrease in the oxidation rate of pyrite. However, Hawley (1977) cited in Hutchison and Ellison (1992), implies that incorporation of transition elements in pyrite may distort its crystal structure and that such distortion leads to physical stresses which may make the pyrite more susceptible to chemical attack, such as oxidation.

c. Oxidation of Other Base-Metal Sulphides.

The biochemical oxidation of base-metal sulphides has been reviewed extensively by Silver (1987), cited in Hutchison and Ellison (1992). In general, it is suggested that most base-metal sulphides are oxidisable, either directly by bacteria in the presence of air and water, or indirectly by ferric iron as either Fe^{3+} or ferric sulphate.

The direct oxidation process by bacteria is thought to be a series of reactions (Silver 1987, cited in Hutchison and Ellison 1992), the net result being the production of metal sulphate, sulphuric acid and either a jarositic type of compound or ferrous sulphate and/or ferric hydroxide, depending on redox potential or the pH of the overall system.

Indirect oxidation gives rise to a metal sulphate, ferrous sulphate and elemental sulphur. Both the ferrous sulphate and elemental sulphur produced can be the subject of further oxidation.

d. Oxidation of Other Forms of Sulphur.

Secondary sulphur-bearing species can be of importance in acid generation from mine wastes, not only as intermediate products of reactions, but also as sources of acid. Hawley (1977), cited in Hutchison and Ellison (1992), noted that under certain conditions, sulphides can be partially oxidised to sulphites and thiosulphates, even at neutral or alkaline pH values. These are then subsequently oxidised to polythionate and eventually sulphuric acid. These reactions have the potential to be significant acid generating processes.

A secondary potential source of acidity is the resolution of jarosites, further described under "Other Reactions".

2.3.2.2. ACID CONSUMING PROCESSES.

The presence of either sulphide or reactive sulphide in mine waste does not necessarily indicate that acid will be generated, even if there is sufficient infiltration to cause discharge from the material. Acid generation can be inhibited or its products modified by reaction with other components in the waste or with water infiltrating the waste.

There are three groups of reactions which are important in terms of their effects on acid generation and its products:

a. Reactions with Carbonates.

Carbonates are some of the most widely distributed minerals, occurring in most rock types. They are commonly located in or associated with ore deposits.

Kraus *et al* (1959), cited in Hutchison and Ellison (1992), list three major mineralised groups of carbonate - the calcite, aragonite and malachite groups, all of which include a range of carbonate minerals. The most widespread of the minerals are calcite and dolomite which are from the calcite group.

Carbonates, particularly calcium carbonate (calcite), tend to be sparingly soluble in pure water at pH 7, (Hutchison and Ellison 1992), but at low pH all are highly soluble (Stewart *pers comm* 1996). As acid reacts with the carbonate by the following reaction:

$$CaCO_3 + 2H^+ + SO_4^{2-} \rightarrow Ca^{2+} + SO_4^{2-} + CO_2(gas) + H_2O$$
$$\text{OR } HCO_3^- \text{ (bicarbonate)}$$

the calcium concentration in solution increases. When the concentration of sulphate from sulphide oxidation in the vicinity of the carbonate is high enough to exceed the local calcium sulphate solution product, a gypsum precipitate will be formed (Hutchison and Ellison 1992).

At high pH, ferric hydroxide precipitation on or around the carbonate will be enhanced producing a coating. The potential for coating acid consuming carbonate materials has important implications. While the total acid consuming potential may ultimately become available, its rate of reaction would be limited as it would be controlled by diffusion through, or the actual physical or chemical loss of the coating.

b. Reactions With Aluminosilicates and Other Silicates.

Many silicate minerals and aluminosilicates (aluminium-bearing silicates) have characteristics which make them or their degradation products acid consuming. Hutchison and Ellison (1992) describe the following characteristics:

- In contact with water, they tend to produce an alkaline pH.
- In contact with acids, they tend to degrade, consume hydrogen ions, and produce clay minerals and bicarbonate. Degradation will cease unless the bicarbonate is consumed.
- Some silicates, notably aluminosilicates such as mica, clay minerals, etc. are capable of removing hydrogen ions by ion exchange reactions.

These processes are less effective acid consuming reactions than the carbonate systems described in the previous section. However, if acid generation is slow, the effect is significant due to the sheer mass of silicate minerals in any mine waste or natural environment (Williams *et al* 1982, cited in Hutchison and Ellison 1992).

c. Other Reactions.

Two other processes which have been described by Hutchison and Ellison (1992) as acid consuming processes are the removal of sulphate as gypsum and the removal of sulphate and ferrous iron in jarosites.

(i) Gypsum.

Gypsum precipitation is limited to local areas adjacent to calcite or dolomite particles where there is the necessary solubility control. Williams *et al* (1982), cited in Hutchison and Ellison (1992), found that levels of sulphate around calcite were as low as 400 mg/l, whereas in free solution within the waste studied, sulphate values could be much higher, up to 900 mg/l without any gypsum precipitation.

(ii) Jarosite.

Jarosites are a group of secondary iron minerals which appear commonly as coatings associated with acidic seeps or drainages. The most prevalent jarosite is a potassium type, formed during the hydration of ferric sulphate with available potassium in the system at very low pH values.

Jarosites are stable only within a low and limited pH range of 1.7 to 2.0 (Williams *et al* 1982, cited in Hutchison and Ellison 1992). In most natural systems jarosites will degrade, going back into solution. Redissolved jarosite solutions will be highly acidic and have a low pH in the absence of buffering.

Jarosite formation therefore should not be considered an acid consuming process. It may, however, act as a very temporary storage for acidity, to be subsequently released in solution.

2.3.2.3 RELEASE OF HEAVY METALS.

a. Potential Release.

All rocks contain heavy metals and as a first estimate of the potential for contamination from a mining operation, the content of metals in the waste rock and ore are compared with the average for non-mineralised rocks and soils or the average for country rocks or soils in the particular catchment (Miller 1985). If levels exceed the particular baseline criteria selected for a site, investigations are undertaken to examine the possible release mechanisms and potential for migration into the surrounding environment.

Simply the presence of high levels of heavy metals in mining materials does not constitute a hazard. The metals must be soluble and there must be a pathway for the migration from the site to the surrounding environment for a hazard to exist. The mineralogy of the material and the pH and redox status (degree of oxidation or reduction) of the waste dump environment are major factors in determining solubility. Heavy metals are generally soluble under acid conditions and insoluble under neutral and alkaline conditions (Miller 1985).

b. Actual Release.

The geochemistry of waste materials determines the potential for contaminant release. However, this is only one of the many processes responsible for the actual release. Physical aspects of the area, combined with site specific hydrological and biological processes interact with the geochemistry in a very complex fashion to determine the ultimate quantity and concentration of metals released.

In a tailings dam situation, the usual engineering goals are to minimise oxygen diffusion into a waste rock dump, and to minimise water percolation. Provision of a cover, and limitations on the degree of compaction, permeability, porosity within structural zones and saturation of the cover ensure that these engineering goals can be met.

The absorption capacity of soils and aquifer materials through which any leachate may pass can be extremely high and controlled placement and design of the waste dumps and tailings dams can ensure the long term immobilisation of heavy metals. For example, heavy metals such as Pb, Hg, Zn, Cd and Cu move at only a fraction the velocity of groundwater through soils. In calcareous soils with a high clay content this rate can be tens of thousands times slower than groundwater (Miller 1985).

2.4 GEOCHEMICAL TESTWORK - ASSESSMENT OF ACID FORMING POTENTIAL.

Acid forming potential may be assessed using STATIC or bench tests and KINETIC tests.

2.4.1. STATIC TESTS.

Accurate prediction of which wastes have the potential for acid production, and the extent to which they will produce acid, is the first step in an AMD prevention and control programme (AMMTEC 1991).

Simple or STATIC tests are used as an indication of acid generation. These include net acid production potential (NAPP), net acid generation (NAG), and acid neutralising capacity (ANC), (AMMTEC 1991).

2.4.1.1. NET ACID PRODUCING POTENTIAL.

Acid-base accounts can be used to indicate if a material might be of concern with respect to acid generation in the long term. This involves estimation of both the acid forming and acid neutralising capacities of a sample and calculation of the net acid producing potential (NAPP). The NAPP calculation represents the balance between the acid forming capacity, which is based on the sulphide-sulphur content, and the acid neutralising capacity (ANC), which is measured directly, (Miller pers comm 1994).

If the capacity of the solids to neutralise acid exceeds their capacity to generate acid, then the NAPP of the material is negative and the material is classified as non-acid forming. Conversely, a positive NAPP value indicates the material has a net excess of acid generating capacity and the material is classified as potentially acid forming.

Sulphur assays are used to calculate the maximum acid that theoretically can be generated by a sample. It is assumed (Miller pers comm 1994) that all sulphur not present as sulphate occurs as pyrite and that the oxidation of this pyrite proceeds according to the reaction:

$$FeS_2 + 15/4\ O_2 + 7/2\ H_2O = Fe(OH)_3 + 2H_2SO_4$$

The stoichiometry of this reaction indicates that for every 1% pyritic S in a sample, a maximum of 30.6 kg H_2SO_4 per tonne could form. However, the acid formed from pyrite oxidation will to some extent be neutralised by other minerals, eg calcite and dolomite. The extent of this neutralisation is quantified in terms of the ANC (acid neutralising capacity) which is determined experimentally by reacting acid with the sample for several hours and measuring the amount of acid consumed as kg H_2SO_4 per tonne (Miller pers comm 1994).

2.4.1.2. NET ACID GENERATION.

The NAG test involves the addition of hydrogen peroxide to a sample of rock to oxidise reactive sulphide, then measurement of pH and titration of any acidity produced by the oxidation reaction. In essence, a significant NAG result (ie final NAG pH<4) confirms that the sulphides in a sample are reactive and the test provides a measure of the net amount of acid remaining in the sample after all acid forming and acid neutralising reactions have taken place. Unlike the NAPP calculation, the NAG test provides a direct assessment of the potential for a material to produce acid after a period of exposure and weathering. The NAG test result is usually lower than the NAPP result as it will not include sulphides locked inside inert material and unavailable for oxidation, (AMMTEC 1991).

The kinetics of the NAG test reaction are determined by monitoring temperature and pH trends after addition of hydrogen peroxide to the sample. This provides an indication of the reactivity of the sulphides, nature and capacity of inherent pH buffering in the sample and provides a qualitative assessment of the lag period that can be expected in the field (Miller pers comm 1994).

The NAG test can be used to identify potentially acid forming and non-acid forming materials, high risk and low risk material, and provide an indication of the relative lag (or exposure) period for waste rock types (Miller pers comm 1994).

2.4.1.3. ACID NEUTRALISING CAPACITY.

The amount of acid the sample consumes is determined by titration with acid to pH 7 (Miller pers comm 1994). This is reported in kg H_2SO_4 per tonne. The ANC is due mainly to carbonate minerals in the sample.

If static tests indicate the potential for acid production, then more sophisticated KINETIC tests can be devised to simulate possible rates and amounts of acid production under field conditions.

2.4.2. KINETIC TESTS.

Leaching rates can be determined by column and batch leachate testing under aerobic conditions. Column leaching tests use crushed rock samples placed in columns which are leached with deionised water at a rate scaled to average annual rainfall. Effluent is collected and analysed.

Batch tests involve mixing of rock with water followed by aeration. After a period of around three months, the solutions are extracted for detailed analysis.

The basic objective of these tests is to determine the geochemical processes, and whether solute release is controlled by solubility constraints, ie dependent on leaching volume; or by kinetic processes, ie independent of leaching volume.

2.5. POSSIBLE REMEDIATION STRATEGIES.

There are two basic approaches which can be used for dealing with waste materials identified as having the potential to contaminate waterways or having serious limitations to plant growth. They can be either disposed of such that they do not form resurfacing material, or amended in situ.

2.5.1 PREVENTING EXPOSURE OF MATERIAL WITH SERIOUS LIMITATIONS FOR PLANT GROWTH.

Generally, materials with a high potential to produce an acid leachate should not be used as final resurfacing media because of potential water contamination problems and also because of the difficulties involved in establishing and sustaining plant growth. Many options for preventing exposure of unsuitable materials rely on preventing oxygen from contacting the sulphides or controlling the environment around the sulphides such that acid generating reactions do not occur. However, the following methods may equally be used for materials without a potential to produce acid but having some other factor which may severely affect plant growth.

2.5.1.1 AVOIDING EXPOSURE OF UNFAVOURABLE MATERIAL.

In some cases it may be possible to cut back into material which is a better plant growth medium, allowing successful restoration to take place, eg cutting pit slopes back to a thick ash layer.

2.5.1.2 REDUCING THE AFFECTED AREA.

AMMTEC (1991) describes a gold mine in the south-west of Australia where sulphides are separated from the remainder of the ore and disposed of separately to a double lined tailings dam which is then capped.

2.5.1.3 DISPOSAL UNDER WATER.

This is considered to be the most effective means to prevent oxygen contact with sulphides (AMMTEC, 1991). Because the solubility of oxygen in water and the rate of diffusion of oxygen through water are both low, the rate of acid generation becomes negligible. The site can be made into a wetland area, as has occurred at Capel in Western Australia (AMMTEC 1991). In some areas of the world, disposal of tailings to the sea (eg Bougainville) and to rivers (eg Queenstown, Tasmania) is being practised but it is certainly not an option in New Zealand under current legislation.

2.5.1.4 DRY (SOIL/CLAY/PLASTIC) COVERS.

At Rum Jungle, clay capping with a soil cover has been used successfully (AMMTEC, 1991). The soil cover helps maintain the clay in a saturated condition so that drying out and cracking do not occur.

Orr (pers comm, 1995) reports that plastic lining of potentially acid generating materials is carried out in Indonesia. The placement of a plastic liner requires a high labour input, and for this reason the use of plastic liners may be preferred in countries where the cost of labour is relatively inexpensive. The use of plastic liners to prevent acid mine drainage is relatively new technology and long term performance data appears to be unavailable at present.

2.5.2. OPTIONS FOR AMENDING MATERIALS TO PROVIDE A PLANT GROWTH MEDIUM.

The best strategy for dealing with materials which have severe limitations for plant growth is to avoid using them for resurfacing by the methods previously discussed. However, even with a well managed mine, it is likely that the materials being used for rehabilitation have some limitations for plant growth. In the case of pit slopes for instance, none of the above methods may be practical. There are two alternative strategies which may be considered when faced with this scenario. Amendments may be used to provide more favourable conditions for plant growth, or species may be selected which have some tolerance to adverse conditions, eg to acidity, salinity or concentrations of heavy metals. Both of these strategies have their limitations and a combination of the two may be required.

2.5.2.1. pH CONTROL.

Many waste types, even those which have good potential for plant growth will benefit from a dressing of lime. In the case of oxidised waste from the Martha Hill operation in Waihi, the addition of lime at 6 t/ha to oxidised waste material raises the pH from 5.5 to approximately 6.3 (Gregg and Stewart 1989). Most agricultural crops grow well when the soil pH is between 6.0 and 7.0 (McConnell *et al* 1993). However unoxidised wastes containing pyrite often cannot be economically limed to pH values satisfactory for plant growth, as rates in excess of 100 t/ha of $CaCO_3$ may be required every few years as a result of continuing pyrite oxidation.

The addition of alkaline wastes to potentially acid generating wastes can produce an overall waste mixture which is acid consuming in nature. This process is successfully practised in some coal strip mines in the United States (AMMTEC 1991).

A number of alkaline compounds are used for neutralisation of acid mine drainage from coal refuse and other sulphide materials. The most common of these compounds are hydrated lime (calcium hydroxide), caustic soda (sodium hydroxide) and soda ash (sodium carbonate).

There are other possible reagents such as potassium and ammonium compounds but these are usually considered too expensive or not environmentally acceptable (Sobek *et al* 1990).

Stehouwer *et al* (1994) report that dry flue gas desulphurization by-products can be used to amend a low pH soil due to their neutralising values which may exceed 50% $CaCO_3$ equivalency.

In the case of sodic soils, it may be possible to use gypsum to provide more favourable conditions for plant growth. Van Kraayenoord and Hathaway (1986) suggest that saltiness can be reduced by applying gypsum at rates of 2,000-10,000 kg/ha, or flowers of sulphur at 1,000-5,000 kg/ha prior to grass growth in New Zealand. Presumably the sites referred to are not mine sites with possible acid generation problems, in which case the addition of flowers of sulphur might exacerbate the problem.

2.5.2.2. BACTERICIDES.

Anionic surfactants, organic acids and food preservatives (Onysko *et al* 1984 cited in Splittorf and Rastogi 1995) act as bactericides and kill Thiobacillus bacteria. Anionic surfactants have bactericidal properties at low pH, are biodegradable and extremely effective at low concentrations, thus making them environmentally safe (Sobek *et al* 1990). Evidence indicates that the anionic surfactants alter the semi-permeable properties of the cytoplasmic membrane of T. ferro-oxidans and allow seepage of H^+ into the cell. The bacteria are destroyed by the acid they produce and the bactericidal action of the surfactants is highly selective.

The Thiobacillus ferro-oxidans bacteria catalyse the rate of acid formation by over one million times (Kleinmann *et al* 1981, cited in Hutchison and Ellison 1992). Bactericides therefore effectively control acid production (Watzlaf 1986, cited in Parisi *et al* 1994) since the kinetics of inorganic oxidation of pyrite are extremely slow.

One bactericide, developed by Goodrich in the USA and named ProMac (Products For Mine Acid Control), is used in several ways:

1. The surface of dumps, stockpiles (and presumably pit slopes) can be sprayed with ProMac using a Hydroseeder.

2. A spray bar system can apply bactericide directly to material on a conveyor system as it leaves the mine.

3. Spray applications as described above tend to be effective for short durations because bactericides degrade over time and are lost through leaching and runoff. To overcome the inherent short duration effectiveness of spray applications, controlled release systems to provide the bactericide slowly over a long time period have been developed (Sobek, *et al,* 1978, cited in Parisi *et al* 1994).

Several case studies using ProMac have been described by Sobek *et al* (1990), Splittorf and Rastogi (1995), and Parisi *et al* (1994). In these papers the following benefits of using ProMac are reported.

1. Establishment of Heterotrophic Bacteria.

As well as inhibiting Thiobacillus ferro-oxidans, ProMac aids in the establishment of beneficial heterotrophic bacteria necessary to support revegetation of the site. In a study by Sobek *et al* (1990) cited in Splittorf and Rastogi (1995), it was found that a strong and varied heterotrophic population supported a good vegetative cover and that these micro-organisms proliferated in areas that contained enough preformed organic matter to sustain their growth. It was concluded that in an environment rich in organic matter, Thiobacillus ferro-oxidans are surpassed in growth by heterotrophs (Sobek *et al* 1990 cited by Splittorf and Rastogi 1995).

2. Reduction in Metals Concentrations.

In a study on a coal refuse and ash disposal site by Sobek *et al* (1990) it was found that when ProMac was applied by hydroseeder at a concentration of 100 ppm, acid production was reduced by 80%. The concentration of iron in the leachate was 80% lower and although no other measurements were made it was expected that the same would hold true for other metals.

3. Ongoing Control.

In a trial at Dawmont, West Virginia, ProMac was applied as a powder that begins to react immediately, together with three different time release pellets. The time-release bactericides were encased in plastic pellets, with one formula releasing beneficial ingredients for the first two years, a second formula for up to five years and a third pellet continuing on for up to seven years or longer.

It is claimed in promotional information that three natural processes resulting from strong vegetative cover for three years or more can break the acid production cycle. These processes are:

a. A healthy root system competes for both oxygen and moisture with acid-producing bacteria;

b. Populations of beneficial heterotrophic soil bacteria and fungi are re-established, resulting in the formation of organic acids that are inhibitory to T. ferro-oxidans (Tuttle *et al* 1977, cited by Splittorf and Rastogi 1995).

c. The action of plant root respiration and heterotrophic bacteria activity increases CO_2 levels in the spoil, resulting in an unfavourable microenvironment for growth of T. ferro-oxidans.

The manufacturers claim that by the time the chemicals have released over the seven years, "nature's life cycle will have taken over to maintain vegetation growth and eliminate acid generation." Splittorf and Rastogi (1995) revisited a site in 1995 which had been reclaimed in 1984, and to which half of the area had a controlled release bactericide treatment of Promac applied. It was found that the treated area had, after ten years, better vegetation and consequently more heterotrophic soil organisms, and improved water quality by prevention of acid formation and the resultant leaching of metal contaminants.

It is important to note that a certain amount of lime may need to be added (based on the lime requirement) with ProMac if it is to be used for reclamation work. While ProMac products prevent new acid from forming they do not neutralise existing acid in the material. While ProMac enhances vegetation, it does not serve the nutrient supply of the plant and fertilisers may be necessary.

2.5.2.3. WATER MANAGEMENT.

Irrigation may be used in some situations, eg in a study by Sopper *et al* (1970) cited by USEPA (1976), waste water (municipal sewage effluent) applied as irrigation provided several benefits. These included the leaching of toxic chemicals out of the root zone, dilution of salt concentrations, cooling of spoil surface temperature, and both plant water and nutrient supply.

Drainage may also be used to control acid water tables, keeping the acid water below the root zone.

2.5.2.4 ADDITION OF INERT MINERAL WASTE AMENDMENTS.

Inert mineral wastes from mining and quarrying operations such as limestone chippings and certain colliery wastes may be suitable, especially where upward movement of salts may be a problem. A coarse granular nature deters upward movement of metal salts by capillary action (Johnson *et al* 1976).

2.5.2.5. CHEMICALS WITH POTENTIAL FOR HEAVY METAL REMEDIATION.

Czupyrna *et al* (1989) listed materials used in the treatment of metal-containing wastewaters that had potential to be used as immobilising agents in contaminated soils (Table 2.1). No literature has been found which utilises these techniques to control heavy metals in mining waste but they have been added as possibilities.

Table 2.1 - Possible Chemical Additives For Heavy Metal Contaminated Soils.

Substance	Comments
Standard Cation Exchange Resin	Used successfully to recover contaminant metals from harsh environments, such as chrome plating baths and rinse waters.
Chelate Ion Exchange Resin.	Test data showed a large decrease in the uptake of the heavy metal ions zinc, lead and copper in radishes, strawberries and chervil.
Metal Scavenging Molecules.	Convert mobile metal-laden waste to a stable state where the toxic metal remains immobile.
Natural Materials, Including Clays, Molecular Sieves and Greensand.	The addition of clays such as kaolin, illite and montmorillonite is one option for the immobilization of heavy metals. Molecular sieves are aluminosilicates with zeolite ion exchangers providing cation exchange sites for heavy metals. Greensand is a marine mineral deposit and it is found in New Zealand, (Bosel pers comm 1991).
Hydrated Lime.	Changes the soil pH and acts as a precipitating agent.
Silica Gel.	Used for the removal of heavy metals from electroplating wastewaters.
Insoluble Starch Xanthate.	Mainly for wastewaters - has an affinity for Cd, Cr, Cu, Ni, Zn.
Metal Sorb-7.	Chelating groups complex the heavy metals in the soil and then fix onto the soil completely immobilising the metal.
Ferrous Sulphate.	Used to reduce the very toxic and mobile hexavalent chromium to its less toxic, less mobile trivalent form.

2.5.2.6. SURROGATE TOPSOIL MATERIALS.

Restoration programmes often involve the use of topsoil but in some cases the placement of topsoil may prove difficult due to expense or lack of a local source. Therefore, substitutes have been used.

Various experiments have been carried out with organic amendments. Ludeke (1973) used hay and barley straw on tailings trials at the Pima Mine, 20 miles Southwest of Tucson, Arizona. The straw mulch was found to insulate the surface from both the heat and the cold and "broke up" falling raindrops, permitting the soil beneath to retain moisture. The mulch also created small dams, slowing down the velocity of water which otherwise caused erosion. It was also found to increase the growth of bacteria and micro-organisms.

Hydroseeding at the Pima Mine with a mixture of seed, wood fibre, an adhesive compound (Soil Seal), fertiliser and water was also found to be effective, but the best growth was achieved by using processed sewage effluent from a cattle feed lot. As described by Ludeke (1973), "the manure compost when mixed with the tailings, furnished soil textures conducive to providing better soil, air and water relationships".

Sopper *et al* (1970), cited by USEPA (1976), determined that site amelioration and successful establishment of trees, grasses and legumes could be accomplished on extremely acid strip mine spoil banks by treatment with sewage effluent and liquid digested sludge. Improvements included a significant pH increase, increased N and P and lowered Mn, Fe and Al concentrations. The addition of waste water provided moisture for the growth of vegetation and evaporative cooling, diluted the concentration of salts, and leached toxic chemicals out of the root zone.

McConnell *et al* (1993) found that the addition of composted municipal sewage waste (MSW) to soils increased the water holding capacity. A recommended rate for most mineral agricultural soils of 10 to 15 tons/acre caused an increase in the water-holding capacity of 5 to 10%. Reductions in bulk densities of mineral soils were found to depend on the rate of compost application, soil types and degree of soil compaction. Twenty tons/acre decreased bulk density four percent in a loam soil and 40 tons/acre decreased it by eight per cent (Mays *et al* 1973, and Duggan and Wiles 1976, both cited in McConnell et al 1993).

Composted MSW, neutral to slightly alkaline in pH, applied to acid soils increased the pH and reduced or eliminated aluminium and/or manganese toxicity which occurred when the pH was below 5.5. The changes in pH values of mineral soils following application of composted MSW depended on the pH of the compost and the initial soil pH, with rates of 10 to 20 tons/acre usually increasing pH by 0.5 to 1.0 unit in acid soils (Herando *et al*, 1989, cited in McConnell *et al* 1993), while slightly alkaline soils exhibited little change. Presumably the rate of pH change on mine waste would also be related to the buffering capacity of the waste and the acid generating potential.

The application of composted MSW increased soil cation exchange capacity (CEC). Sandy soils tended to show the greatest increase in CEC values following MSW compost applications, with rates of 15 tons/acre increasing CEC of a sandy soil by almost 10 percent (Hortenstine and Rothwell, 1973, cited in McConnell *et al* 1993). Research results indicate that application at normal agronomic rates of 15 to 30 tons/acre would increase the CEC of most mineral soils used for agricultural purposes by a minimum of 10 percent.

The main value of MSW compost application was found to lie in its enhancement of the physical and chemical properties of soil, rather than its value as fertiliser. The amount of nitrogen in MSW compost depends on the feedstock and processing technology used to produce the compost. Sommers and Giordano (1984), cited in McConnell *et al* 1993, stated that the nitrogen needs of many agronomic crops could be supplied by MSW compost application but would result in excess amounts of phosphorus and insufficient amounts of potassium. For this reason, fertilisers may be needed to supplement MSW compost application to bring soil nutrient levels in balance with crop demand.

The levels of micro-nutrients should be investigated in organic amendments such as composted MSW. Depending on the source, there may be high levels of lead, nickel, cadmium etc. Source separation can greatly reduce the levels of trace metals and an increasing number of municipalities have adopted this technology (Richard and Woodbury, 1992, cited in McConnell *et al* 1993). Similarly, the soluble salts level of the compost should be checked prior to application if salinity has the potential to cause problems at the site.

2.5.3 SELECTING TOLERANT PLANT SPECIES.

It may be possible to choose plants which have some tolerance to unfavourable conditions such as acidity, heavy metals and salinity. There are limitations to this however, as exemplified by enormous amounts of bare land in old mining districts (Ernst 1974, cited in Brooks 1983). As mentioned in section 2.2.1, even very acid tolerant species will have difficulty surviving pH values less than 3.5 to 4.0 (Bell 1990), and few plants will survive if the salinity levels are in excess of 20 mS/cm saturation extract (Bell 1990). Some heavy metals are physiologically essential for plants, but in many cases there is a very fine line between sufficiency and toxicity.

The selection of plant species for a final land use should take into consideration the media that the plants will be growing in. For example, if the land is to be used for grazing, it should be noted that soil ingestion commonly ranges from 1 to 10% of the dry matter intake of grazing cattle and up to 30% for sheep (Alloway 1990), and this may have implications if heavy metal levels are high. The uptake of arsenic by plants is normally low. However, direct ingestion of arsenic from soil can be a major source of dietary arsenic for grazing livestock. It is unlikely that food crops would be grown on these areas, but if so, there would need to be some research carried out to ensure that metals did not accumulate in the edible portions of the plant to the extent that they could detrimentally affect stock or human health.

2.5.3.1 PLANT SPECIES TOLERANT TO LOW pH CONDITIONS.

a. Overseas Work.

Few plants can grow satisfactorily on soils with pH less than 5 so it is normally advisable to add an alkaline material to bring the pH of acidic mine spoils at least to this level and preferably to a value in the range 6 to 8, depending on the species to be planted (USEPA 1976). Even after the soil has been neutralised, oxidation of sulphides to acid sulphates may eventually lower the pH again. Therefore, the best option may be to choose species known to be acid-tolerant for revegetating pyritic spoils, provided that their limitations are realised.

USEPA (1976) suggest that most of the plant species known to tolerate highly acidic sites (pH less than 4) are trees and shrubs. Of the trees, most are conifers, with the exceptions of grey and white birch, red oak, black locust and European alder.

Many commercially important forest trees in North America and northern Europe can tolerate quite a low soil pH, with pines, spruces and firs apparently growing in soils with a pH as low as 3.5. However, the plant species comprising the forest undergrowth have a gradient of tolerance to soil acidity. In Alberta, Canada, Nyborg (1984) carried out measurements on forest soils acidified by windblown elemental sulphur. When soil pH was 5 to 4 the number of species in the undergrowth was reduced, when pH was 4 to 3 only a few species grew and when pH was less than 3 there was no longer any undergrowth.

A study was carried out to assess the suitability of various legume species and varieties for revegetation of acid surface-mined coal spoils in western Kentucky (Daniels and Amos 1982). The legumes evaluated consisted of three varieties of birdsfoot trefoil, seven varieties of alfalfa, four varieties of red clover, four varieties of Sericea lespedeza, two varieties of annual lespedeza, and single species entries of alsike clover, yellow sweet clover, white clover, hairy vetch, and crown vetch. The above listing of species approximately corresponds to the order of their ranking with respect to yield.

Four tree species capable of nitrogen fixing showed promise on very acid (pH 2.8) spoils with the addition of lime (Carpenter and Hensley 1979, cited in Fox 1984). These were Alnus glutinosa, Elaeagnus umbellata, Robinia fertilis and Robinia pseudoacacia. (The literature does not mention where this research was carried out). A. glutinosa was also shown to be very effective in the USSR, (Verbin and Keleberda 1974, cited in Fox 1984).

Plass (1974), cited in Fox (1984) examined responses of seven pine species to coal spoils of pH 2.5 to 8.4. Pinus echinata, P. palustris, P. taeda and P. virginiana emerged at low pH. A Virginia pine was observed growing in Indiana at a pH of 3.5 and a hybrid of pitch and loblolly pine survived at a pH of 2.5 (Limstrom 1964, cited in USEPA 1976). Virginia pine is considered by some to be the most acid tolerant pine (Miles *et al* 1975, cited in USEPA 1976), and is one of the most widely recommended conifers for acid spoils.

USEPA (1976) suggested that the most widely recommended tree for acid sites was European black alder. Like black locust, the alder fixes atmospheric nitrogen and serves as a good nurse crop for other species. It was found to be somewhat less vigorous than locust but it lived longer, had a much better form and, unlike locust, a potential for timber production. It has survived at a pH as low as 3.5 (Ruffner 1966, cited in USEPA 1976). It is subject to damage by drought however, and should not constitute more than one-third of any tree mixture should the site be prone to drought conditions.

Eragrostis curvula (weeping lovegrass) is a short-lived perennial useful as a nurse cover. It has rapid germination, fast growth, a good root system and is tolerant of acid conditions (Armiger *et al*, 1976, cited in Fox 1984). Edgerton *et al* (1975), cited in Fox (1984) reported that weeping lovegrass outperformed other grasses on acid spoils, and it was recommended in pHs of 4 to 4.5. Harper and Spooner (1983) found that tall fescue, switchgrass and weeping lovegrass established easily on bauxite minespoils in Arkansas which were extremely acidic, low in fertility, high in salts, coarse textured, low in microbial population, and with poor water holding capacity. However, they provided poor ground cover, and subsequently, poor soil stabilisation. Bermuda grass was found in their study to produce significantly more ground cover and was therefore better suited than any of the other grasses studied for stabilisation of mine soils.

Carlson and Swanson (1979) evaluated trefoil species for their ability to reduce severe erosion caused by soil disturbance for road construction in the Northwest U.S.A. Different species of trefoil proved valuable for different reasons, including their ability to deep root and spread rapidly by rhizomes, but Lotus corniculatus (birdsfoot trefoil) tolerated acid, wet conditions. Vassileva (1987) found in a study of perennial grasses and legumes on eroded land in the Eastern Rhodopes, Bulgaria that birdsfoot trefoil (Lotus corniculatus) was tolerant of drought and acid soils, giving a yield of 5.3 t DM/ha, and being a good soil conservation species on eroding land.

Often plants tolerant to low pH conditions have developed some tolerance to metal(s). Populations from old mine spoils tend to be more tolerant of the specific toxic metal ion(s) of that particular soil than those populations found on more recent material (Gadgil 1969, cited in Fox 1984). The process of natural selection is particularly rapid in annual grass species and it is from such plants that most progress is reported. Tolerant populations show better root and shoot growth on untreated spoils than do non-tolerant populations (Smith and Bradshaw 1970, cited in Fox 1984). Species particularly characteristic of acid metalliferous soils are Agrostis tenuis and Festuca ovina. It has been noticed in Britain that Agrostis tenuis and Festuca ovina naturally colonise acid waste tips, albeit sparsely (Smith and Bradshaw 1979, cited in Fox 1984). Cultivars have been developed for temperate climates, eg Agrostis tenuis cv Goginan, tolerant of acid lead/zinc wastes; and A. tenuis cv Parys, tolerant to acidic copper materials (Smith and Bradshaw 1979, cited in Fox 1984). Sutton (1970), cited in USEPA (1976) found, however, that at least 15 cm of topsoil cover was required over toxic acid coal mine spoils studied near Caldwell, Ohio, to establish healthy plants of tall fescue cv. Kentucky 31, Korean lespedeza and cocksfoot.

Hannan (1978) found that Cynodon dactylon (couch) was one of the few volunteer species on acid-affected soils at coal mines in New South Wales. Its tolerance of low pH and its spreading habit make it an ideal plant for these sites. The only legume to give useful production in acid areas was Trifolium incarnatum (dixie crimson clover). Trifolium yanninicum cv Trikkala (subterranean variety) was recommended for good growth under conditions of aluminium toxicity in the Tingha district, New South Wales, Australia.

Several acid-resistant shrubs have been cultivated. Arnot bristly locust has been found to provide effective cover for pH greater than 3.5 and is particularly recommended for erosion control on steep outer slopes of spoil banks (McWilliams 1971, cited in USEPA 1976). The "belmont" strain of Japanese fleeceflower grows and reproduces at a pH of 3.5 and tolerates a pH as low as 3.2 (Ruffner and Steiner 1973, cited in USEPA 1976). Horn and Ward (1969), cited in USEPA (1976), found Scotch broom to be the most acid-tolerant shrub they tested, followed by Japanese and bicolor lespedezas and autumn olive. Ruffner (1966), cited in USEPA (1976) suggested that autumn olive may tolerate a pH range of 3 to 4, and Mellinger *et al* (1966), cited in USEPA (1976) rate autumn olive second only to black locust in its ability to provide cover on poor sites.

The USEPA (1976) lists the following species with some tolerance to acid (Table 2.2).

Table 2.2 - Species With Some Tolerance To Acid, (USEPA 1976).

GRASSES

	pH < 4.5	pH < 5.5
Bentgrass	*	*
Bermudagrasses	*	*
Charlottetown 80 (barley)	*	*
Deertongue	*	*
Redtop		*
Ryegrass (annual & perennial)		*
Switchgrass		*
Tall (Kentucky) Fescue		*
Weeping Lovegrass	*	*

(note, tall fescue tolerates low pH but only in soils with little or no aluminium (Vogel & Berg, 1968).

	pH < 4.5	pH < 5.5
LEGUMES		
Birdsfoot Trefoil	*	*
Flatpea (Wagner)		*
Kobe lespedeza	*	*
Sericea lespedeza	*	*
SHRUBS & VINES		
Amur Honeysuckle		*
Autumn Olive	*	*
Bicolor (Natob) Lespedez		*
Bristly Locust	*	*
Flameleaf Sumac	*	*
Indigobush		*
Japanese Fleeceflower		*
Scotch Broom	*	*
Shining Sumac		*
TREES		
Ash (Green & White)		*
Aspen	*	*
Austrian Pine	*	*
Black Locust	*	*
Cottonwood		*
European Alder	*	*
Grey Birch	*	*
Hybrid Poplar	*	*
Jack Pine		*
Japanese Birch		*
Loblolly Pine	*	*
Mugho Pine	*	*
Red Oak	*	*
Red Pine	*	*
Scotch Pine	*	*
Sycamore		*
Virginia Pine	*	*
White Birch	*	*

b. New Zealand Work.

Lambrechtsen (1986) reports that there are some very acid sites, especially in Northland, which are extremely difficult to revegetate. After very large applications of lime (10 to 50 tonnes/ha) grasses that have been found to persist are kikuyu, Yorkshire fog, pampas, sweet vernal, browntop and phalaris. Some growth of the legume, yellow serradella (Ornithopus pinnatus), has been obtained, but probably not enough to supply nitrogen in very nitrogen-deficient environments. Regular applications of lime, nitrogen and phosphorus are necessary to maintain plant cover.

Hydroseeding with native species onto steep acidic slopes at the Golden Cross Mine has been unsuccessful to date (O'Neill pers comm 1995). Similarly, hydroseeding with grass species onto acid generating pit slopes at the Martha Mine has been unsuccessful, with grass initially germinating and growing until acid conditions develop and the plants die. Success has been achieved where the pH is greater than 4.5 on oxidised non pyritic material.

A pot trial was set up in October 1993 by Smale and Rogers (1995) to test germination and growth of three native shrub species from geothermal heathland on four substrates comprising varying amounts of highly acidic overburden (Omahia andesite) from the Golden Cross Mine in the southern Coromandel Range. Seeds of manuka (Leptospermum scoparium), prostrate kanuka (Kunzea ericoides var microflocum) and mingimingi (Leucopogon fasciculatus) from geothermal heathland at Whakarewarewa, Rotorua were sown in propagation trays containing four different mixtures of overburden and loam. (100% overburden, 75% overburden and 25% loam, 50% overburden and 50% loam, and 100% loam). Small seedlings of the same species were planted in pots containing the same four mixtures of overburden and loam. Propagation trays and pots were placed in a shadehouse under a regular watering regime, and examined regularly.

After six months, it was found that the seeds failed to germinate and plants failed to survive in mixtures that were predominantly overburden, due to the extreme acidity (peroxide pH=2.2) of this material. On the 50% overburden and 50% loam mixture, some success was achieved with manuka, with some seeds germinating and growing, and some of the planted seedlings surviving. Kanuka and mingimingi failed in this treatment however.

Morrell *et al* 1995 carried out trials with acid tolerant and non-acid tolerant grass species on acid tailings from the Tui Mine, a former base metal mine situated on the north west flank of Mount Te Aroha, New Zealand. Although the tailings were found to have severe chemical limitations for plant growth, research indicated that the oxidation of sulphide minerals and subsequent leaching of the weathering products had led to the top 200 to 300 mm of the tailings being relatively inert in terms of future acid generation. It was postulated that if the oxidised tailings could be left largely in situ a permanent vegetative cover could be established on the tailings which had some amendment.

At moderate and high rates of lime application (16.5 Mg $CaCO_3$/ha and 112 Mg $CaCO_3$/ha), plant germination rates were reasonably high at around 60%. Despite the high pH, metal tolerant grass species were found to consistently out-compete their non-metal tolerant counterparts. This difference was most significant at the lower of the two liming rates where Agrostis tenuis var. Parys Mountain yielded over ten times the herbage compared with the non-metal tolerant variety. Likewise the metal tolerant Festuca rubra var. Merlin out yielded the non-metal tolerant variety nearly 4 to 1. The performance of Lotus corniculatus (a legume renowned for its acid tolerance and low fertility requirements) was disappointing in the pot trial.

Composted sewage sludge was incorporated into tailings at four different rates; 0, 110, 220 and 440 Mg of sludge per hectare on an oven dry basis. Lime was applied to half the pots to raise the pH to 6.0. Lotus corniculatus again faired poorly. In contrast, F. rubra var Merlin performed extremely well, thriving at the highest sludge rate both with and without the addition of lime. It was found however, that lime addition had a much greater effect on herbage yields at the lower sludge rates. F. rubra var Merlin generally showed a great deal of promise as a potential plant for revegetation of the Tui mine tailings.

2.5.3.2. SELECTION OF HEAVY METAL TOLERANT SPECIES.

a. Characteristic Flora.

Ecological studies at sites containing metalliferous soils have revealed the presence of specific communities or floras which have developed on soils containing elevated levels of metals such as selenium, zinc, copper, nickel and chromium. Some species are restricted to particular metalliferous soils and are thus endemics, whilst others growing on these soils may occur in other distinct areas uncontaminated by metals, and are more a reflection of rock type than mineralization. Relatively few of the floras are endemic, indicating that many of the plants growing on such soils today are relatively recent in origin.

Isolation processes and population selection have produced significant physiological and some morphological changes in plants on derelict mine and smelter waste in a very small number of generations. The reason why many of the grasses have adapted to such conditions, and most legumes have not, has not been adequately explained (Peterson and Nielson 1978, cited in Williamson *et al* 1982).

Characteristic floras include the calciphilous (limestone) floras and the halophyte floras, but the following section illustrates three characteristic floras associated with heavy metals.

(i) Selenium Flora.

Selenium floras of the western United States, Colombia, Canada and Queensland indicate the presence of selenium in the soil. The Australian plants include Neptunia amplixicaulis and Acacia cana (Brooks 1983).

Uranium deposits on the Colorado Plateau are primarily carnotite containing appreciable quantities of selenium. Cannon (1963), cited in Brooks (1983) used Astragalus species for indirect prospecting for uranium because the plants tend to grow in areas of maximum total or available selenium in soils.

(ii) Serpentine Flora.

Serpentine floras are considerably different from normal soils in that they are very rich in chromium, cobalt, iron, magnesium, and nickel, as well as being deficient in the nutrients calcium, molybdenum, nitrogen, phosphorus and potassium. An example of serpentine flora is present in the Dun Mountain of Nelson province, New Zealand, and the differentiation between the serpentine flora and flora of adjacent substrates is striking. Typical examples of the serpentine flora show a general sparseness of vegetation with a shortage of species as well as individuals. There are usually a few species that are endemic to a particular area, such as Myosotis monroi and Pimelea suteri in the Dun Mountain area (Brooks 1983).

Lounanaa (1956) and Robinson *et al* (1935), both cited in Brooks (1983) concluded that the unusual serpentine flora results from excessive amounts of chromium, cobalt, and nickel. Other workers claimed that nickel was particularly responsible for the specialised vegetation. The low calcium content of serpentine soils led Kruckeberg (1954) and Walker (1954), both cited in Brooks (1983) to conclude that the flora of these soils is unusually tolerant of low calcium/magnesium ratios in the substrate. Yet another theory is that survival of plants on serpentine soils depends on their ability to adapt, at least partially, to all the adverse soil factors present.

(iii) Zinc (galmei) flora.

Plant communities growing over soils high in copper, lead, or zinc have a certain similarity with serpentine flora, with plant growth being retarded and stunted, the absence of broadleaved plants, and the presence of endemic forms if the area of mineralization is large enough. Some species such as Agrostis tenuis produce ecotypes morphologically indistinguishable from those growing over serpentine soils (Brooks 1983).

In many cases it cannot be established whether or not the characteristic flora is due to one or all of the three base metals mentioned above, since all three usually are found together in areas of sulphide mineralization. There has been a tendency to classify such communities as zinc or galmei floras, since zinc is usually the main constituent.

b. Metal-Tolerant Plants.

Metal-tolerant plants can be found where metals-containing rock types outcrop at or near the soil surface. These plants are present due to selection processes which enable these colonisers to cope with stress factors. After successful vegetative or generative reproduction of these individuals a population is formed, ie a group of interbreeding individuals of the same plant species that co-exist together in space and time. The offspring of these metal-tolerant plants have the greatest potential for a successful natural revegetation of similarly contaminated land areas.

Despite this, there is an enormous amount of bare land in old mining districts (Ernst 1974, cited in Brooks 1983). These unvegetated land areas indicate that either the colonising species are not sufficiently tolerant of the high levels of heavy metals in the bare tailings sites, or that they have to cope with additional environmental factors such as low soil fertility and a low water-holding capacity.

Methods have been developed to test individual plants for their resistance to heavy metals. Wilkins (1957) developed a technique which compares the response of root growth of the tiller of one individual in a solution with the metal under consideration to that of another tiller of the same individual in a solution without the metal. This technique is used for quantifying resistance to heavy metals and other edaphic factors in grasses but it is less suitable for herbs due to their rooting behaviour. For herbs, Repp (1963) developed the comparative protoplasmatology technique. Small pieces of leaf or shoot tissue are incubated in series with increasing metal concentrations and after one or two days the vitality of the tissue is analysed. By applying both techniques to the plant groups it is possible to detect and select genotypes for commercial breeding, thus creating sufficient plant material for specific revegetation demands.

It should be noted that plants with tolerances to many heavy metals (the multiple metal-tolerant genotypes), have a lower biomass production than genotypes which are tolerant to only one heavy metal. Energy which is invested in the maintenance of tolerance levels is not available for growth and reproduction, hence there is a reduced capacity for these plants to contribute organic matter for soil formation.

2.5.3.3. SALT TOLERANT PLANTS.

Plants vary in their tolerance to salinity and, irrespective of whether the land use goal is to establish crops, pastures, commercial forests or native flora, it is possible to select tolerant species if salinity is a problem. Few plants can tolerate salinity levels in excess of 8 mS/cm (saturation extract) without yield reduction, however, and few survive at salinity levels greater than about 20 mS/cm, (Bell 1990). As coal mine overburden can contain salt levels up to 15 mS/cm and metalliferous tailings up to twice this level, there is clearly a limit to the use of salt tolerant species.

There is a lack of published information on the salt-tolerance of native Australian flora but comprehensive data on the salt-tolerance of agricultural crops and pastures is given by Hart (1974). Van Kraayenoord and Hathaway (1986) suggest that grasses and legumes that grow in salty sites in New Zealand can rarely be obtained, except for tall fescue, chewings fescue, perennial ryegrass, barley, lucerne and sulla. They suggest that the descending order of salt tolerance in some New Zealand grasses and legumes is: Puccinellia spp., Lotus tenuis, Indian Doab, Agropyron elonatum, Thinopyrum junceiforme (Agropyron junceiforme), barley, Parapholis incurva, tall fescue, lucerne, sulla, buffalo grass, kikuyu, chewings fescue, perennial ryegrass, white and strawberry clovers, and Agrostis stolonifera. In addition, various rushes may be planted.

r10

CHAPTER 3 -

THE MARTHA MINE - PROJECT DESCRIPTION, REHABILITATION REQUIREMENTS, GEOCHEMICAL TESTWORK AND REHABILITATION TRIALS.

3.1. PROJECT DESCRIPTION.

Gold was first discovered on Martha Hill in 1878, and mining commenced in 1879 by underground methods. Mining ceased in 1952 due to a combination of reasons, including the fixing of the gold price at US$35 an ounce and a labour shortage after the second world war. From 1879 to 1952 some twelve million tons of ore was extracted (McAra 1988).

Exploration recommenced in 1979 and an Environmental Impact Report was submitted by the Waihi Gold Mining Company Ltd in 1985. In 1987 the Mining Licence and Water Rights were granted with construction commencing shortly after. The first dore bullion pour was in 1988.

Waihi Gold Mining Company Limited is presently owned by two joint venture partners; Otter Gold Mines (Formerly Mineral Resources N.Z) owning 32.94% of the company and Posgold (Australia) owning 67.06%. The Martha Mine is an epithermal deposit, producing approximately 70,000 oz of gold and 400,000 oz of silver annually by open cast methods, providing employment for 150 people and an annual export revenue of $65,000,000.

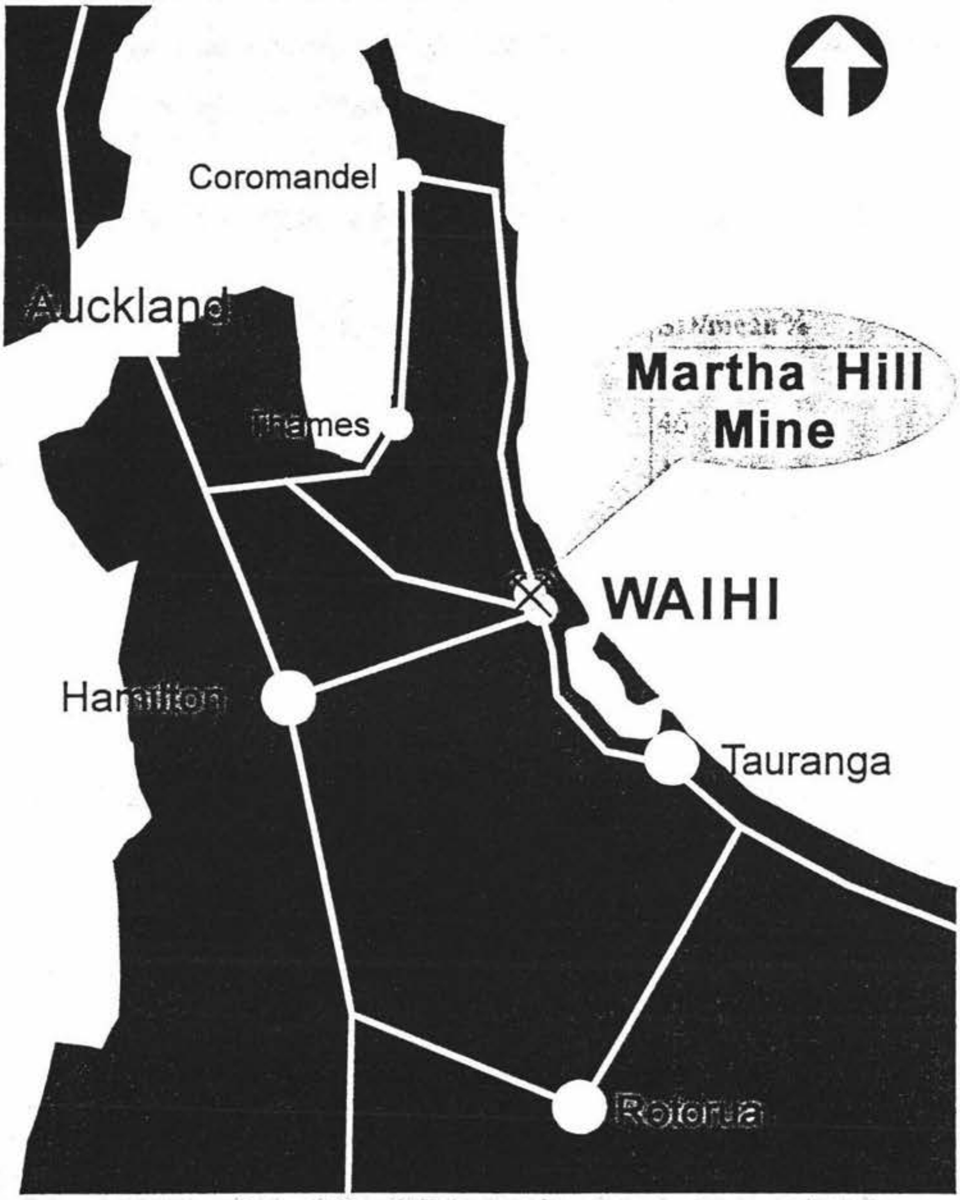
The following is a description of the operation, with most emphasis placed on those aspects relevant to rehabilitation of the waste materials produced.

3.1.1 PROJECT LOCATION.

The Martha Mine is located in Waihi, North Island, New Zealand (Figure 3.1).

The township of Waihi grew around the Martha Mine when it operated between 1879 and 1952 and for some years the town was larger than Hamilton, being second in the Auckland Province to Auckland itself (McAra 1988). At one period the population rose to over 6,000 but the present population is approximately 4,500. The town is a service centre for the rural surrounds, made up largely of pastoral farming and kiwifruit orchards.

Waihi is within ninety minutes drive of half of the population of New Zealand, including the major townships of Hamilton, Auckland and Tauranga, and has become a popular tourist destination. Local areas of natural beauty include the Karangahake Gorge and Waihi Beach. The mining history is reflected by relics such as the historic cyanide tanks on Union Hill and at Waikino. The Cornish Pumphouse built in 1904 to dewater the Martha Mine has become a well recognised symbol of the town. The Karangahake Walkway and Steam Train make good use of facilities such as the old tramway and relics created by former mining. The present Martha mining operation is also popular with 12,500 people being guided around the project each year.



Location of Waihi and the Martha Mine

Fig. 3.1

3.1.2. Meteorology.

The rainfall at Waihi is higher and more frequent than in many North Island regions of New Zealand. This is largely due to its location within a topographic basin at the base of the Coromandel Peninsula close to the East Coast. Table 3.1 shows the seasonal distribution of rainfall from 1898 to 1989.

Table 3.1 - Seasonal Distribution of Rainfall and Variability. (NIWAR 1992).

Season	**Rainfall (mm)**	**SD/mean%**
Summer	407	46
Autumn	568	40
Winter	668	28
Spring	485	31
Annual	2,128	19

The monthly average for screen temperature (1961-1990 records) varies from 18.8°C in January to 9.0°C in July, with an annual mean of 14.0°C, (NIWAR 1992).

Although the warm wet climate encourages plant growth, the number of rain days, as shown in Table 3.2, can make it difficult to carry out restoration operations such as earthworks.

Table 3.2 - Rain Days (more than 1 mm/day) from 1898 to 1989 in Waihi. (NIWAR. 1992).

Season	**Average Number of Days Rain**
Summer	26
Autumn	34
Winter	41
Spring	40
Annual	141

3.1.3 THE MARTHA HILL PROJECT.

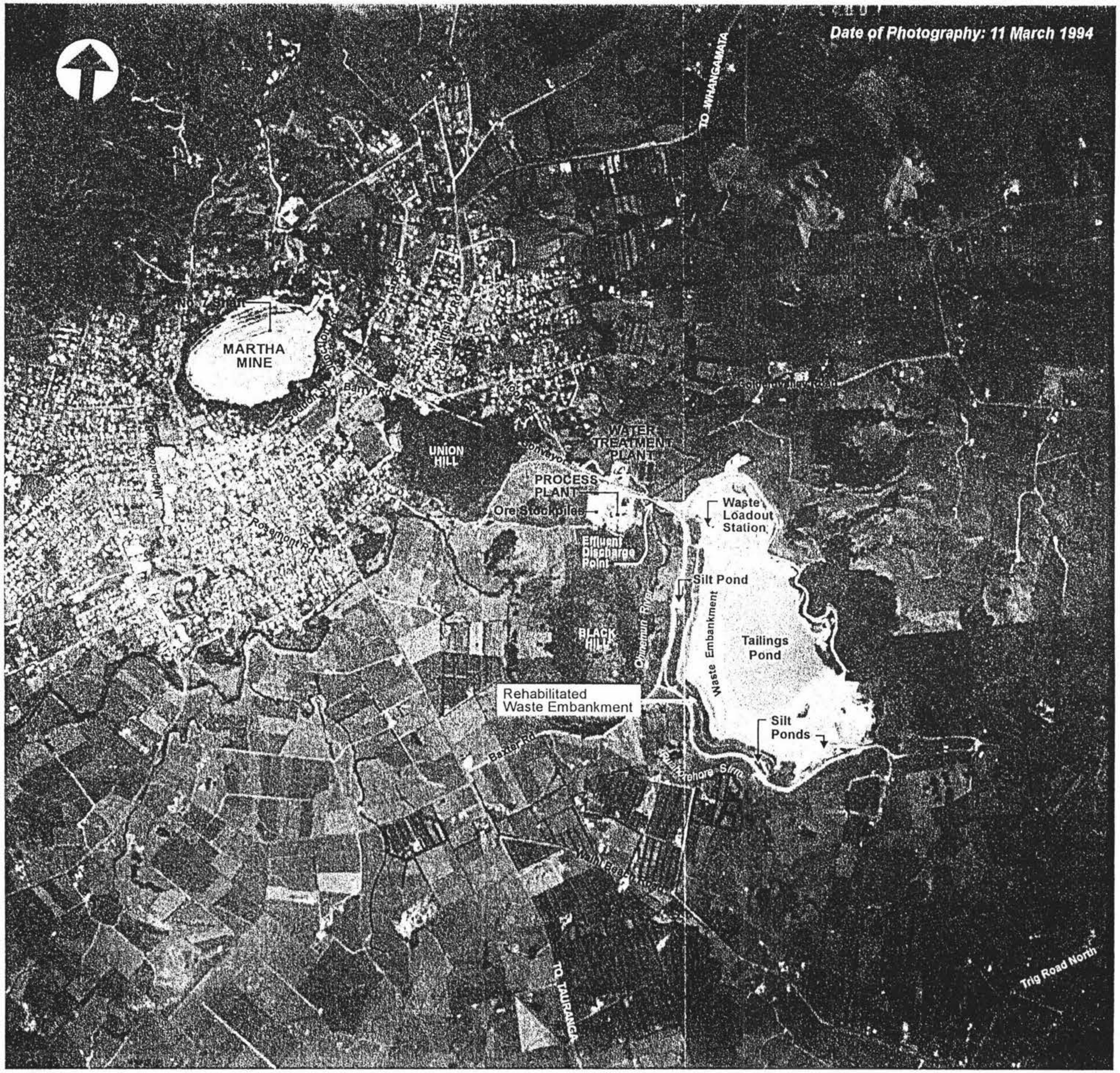
All gold bearing ore and waste is carried 2 km from the mine via conveyor to the ore processing plant and waste disposal site. The ore processing plant, tailings and waste disposal area (development site) and water treatment plant are situated within a rural area, whereas the mine is situated within the town, (Figure 3.2).

The surface area of the pit is approximately 33 ha. Within the pit, ore zones are delineated by channel sampling using a 0.8 g/t gold cut off. The mined ore is transported via conveyor to the ore processing plant 2 km southeast of the open pit. Material with less than 0.8 g/t gold is mined as "waste" and is transported to the dam. Waste rock is variously rhyolitic ash, tuffs, ignimbrites and oxidised or unoxidised andesites (McKay pers comm 1995) and depending on its characteristics may be used in structural areas of the waste embankment, stockpiled for later use on the outer zones of the waste embankment, (Zones G and H), or in the case of unoxidised andesite, encapsulated with low permeability material. (A cross-section of the waste embankment is given in Appendix 3.2).

Gold is extracted by the carbon in pulp method. The ore is ground such that 80% is less than 53 microns in size (Riggir pers comm 1995). A pH of 10 is maintained by adding lime at an average rate of 2.47 kg/t (Riggir pers comm 1995). Cyanide is added to the solution at 700 g/t to extract gold and silver. The gold and silver is then adsorbed onto activated carbon. After stripping from the carbon, the gold and silver is recovered by electrowinning. The bars of bullion produced (which are approximately 10% gold and 90% silver) are sent to Perth for refining prior to selling of the precious metals at the Royal Mint in London. The tailings produced are pumped to the 32 ha tailings pond with the surrounding waste embankment covering an area of approximately 97 ha.

WAIHI GOLD MINING COMPANY

W.G.M



MARTHA HILL PROJECT

Site Layout and Rehabilitated Waste Embankment

Figure 3.2

With such a high rainfall, the project operates with a net surplus of water. This is derived from the mine which is dewatered from the old Number 7 shaft, from the tailings dam where water is decanted from the surface, from stormwater runoff where water collects in silt ponds and from the dam underdrainage system. A water treatment plant treats excess water to a high standard and discharges it to the nearby Ohinemuri River.

3.2 REHABILITATION REQUIREMENTS.

3.2.1 BASELINE STUDIES OF EXISTING SOILS AT THE WASTE DISPOSAL SITE.

Prior to mining, the land at the proposed tailings and waste disposal site was used for dairy farming. Before submitting a Mining Licence application, the applicant needed to show that the tailings and waste produced from mining could be restored to levels of production at least equal to those being achieved on the land prior to mining.

A detailed soil map was constructed of the proposed waste disposal site. The distribution of soil types was found to be diverse with sixteen soil types being mapped. The most versatile and productive soil was found to be the Waihi Sandy Loam with an estimated pasture production in the range of 12,000 to 16,000 kg DM/ha/yr (Waihi Gold Mining Co Ltd, 1985).

3.2.2. FINAL REHABILITATION.

The open pit will become a lake once mining is complete, with steep sides on the North and South walls and lagoon areas at the east and west. The lake will have a depth of approximately 145 m and surface area of 24 ha. The company has indicated that it will apply for consents to extend the mine, and if the extension project is granted, the lake size will increase.

A walkway linking heritage features such as the historic cyanide tanks on Union Hill, and possibly the existing processing plant (should it be retained) could be created using the conveyor corridor.

Several options for the tailings dam were identified in the Environmental Impact Report (Waihi Gold Mining Co Ltd 1985), including agriculture, horticulture and recreation. The Mining Licence work programme states that the tailings and waste will be progressively restored to productive pasture. At present this is a legal requirement, however other land uses for at least part of the dam may be made possible under a Mining Licence variation, possibly associated with the pit extension. Until December of 1994, 19 ha of oxidised waste bund had been restored to pasture.

3.3 GEOCHEMICAL TESTWORK AND PLANT GROWTH POTENTIAL OF WASTE TYPES.

3.3.1 WASTE TYPES PRODUCED.

Mining and processing of gold and silver from the Martha open pit gives rise to three waste products; tailings, oxidised waste, and unoxidised waste. The tailings is the waste product left once gold and silver have been removed from the ore. It is a slurry of approximately 33% solids, with a pH of around 9 and some cyanide present.

Prior to the submission of a mining licence application, the company carried out geochemical testwork on the waste types produced. Miller (1985) carried out pre-mining test work on samples of waste rock collected from drill core to determine which types were potentially acid forming. The waste rock was categorised as unoxidised (potentially acid forming), and oxidised (non-acid forming) materials. From a mining perspective, oxidised waste could be identified by its brown colour, whereas unoxidised waste was blue. The unoxidised blue rock was to be placed within the zoned embankment so that it would not form a resurfacing medium at the tailings dam. Areas of unoxidised rock would however, be exposed on pit slopes above the final lake level, and would require rehabilitation.

The following describes the geochemical testwork (both prior to the submission of a mining licence application and the ongoing testwork) for the unoxidised waste and tailings, as these two materials form the base of the trials described in chapters 4 and 5. This is followed by the pre-mining investigations (physical and chemical properties, pot trial and field trials) of the potential of the waste types to support plant growth. The purpose of this is to lead into the field trials on unoxidised waste and tailings as described in chapters 4 and 5.

3.3.2. GEOCHEMICAL TESTWORK.

Questions are often received from visitors to the mine regarding the long term security of the tailings dam. The main questions relate to its stability, the long term potential for acid generation and the fate of the cyanide introduced during ore processing. Monitoring throughout the life of the project is necessary to answer these questions.

Ongoing geochemical testwork is required to identify whether the ore/waste types being produced have the potential to produce acid, and whether for instance, clay capping will be required over the tailings surface. Identification of changing waste types at an early stage can allow alternative disposal measures to be implemented, avoiding costly remediation at a later stage.

The rates and means by which cyanide degrades in the tailings, and the potential for acid production must also be investigated as they have major implications on the long term use of the dam, the necessity for covers and for water treatment. Geochemical testwork carried out for the unoxidised waste (both pre-mining and recent) is briefly described below.

3.3.2.1 UNOXIDISED WASTE.

a. Acid Producing Potential.

(i) Baseline Studies 1985.

In 1986, Waihi Gold Company commissioned Groundwater Consultants (NZ) Ltd and Stuart D Miller & Associates Pty Ltd to prepare a geochemical evaluation of leachates from waste rock and tailings. Much of this information was used in the preparation of evidence for the water rights hearings prior to permitting of the project. The chemical composition and leaching behaviour of waste rock and tailings, and the capacity of the soils at the proposed disposal site to attenuate contaminants were examined.

Investigations found that the content of sulphur in gold deposits in the Coromandel region was generally less than 5% S, with high sulphur ores confined to base metal deposits similar to the Tui site, where the rock has an average total sulphur content of 17.5% (Miller 1985). Martha Hill unoxidised waste rock was estimated to have an average total sulphur content of approximately 1.5% S (range 0.07 - 3.5%) and was confirmed as potentially acid forming from the results of column and batch leaching tests (Miller 1985).

The column leaching tests examined the leaching behaviour of the oxidised and unoxidised waste rock at Martha Hill. Essentially the column leaching tests could be described as accelerated weathering tests, where the environmental conditions were controlled to allow both chemical and biological oxidation to occur under highly favourable conditions. The columns were approximately 800 mm long and contained 3 kg of sample crushed to a nominal 4 mm in size. The columns were leached daily at a rate equivalent to the annual rainfall at Waihi. The leaching test results showed that the oxidised waste was non-acid forming and heavy metals were not released from this waste type. However if unoxidised material was exposed to a moist, oxidising environment for an extended period, acid leachate would be produced which would contain a high level of soluble sulphate and elevated concentrations of some metals, especially Mn.

The maximum and final (at day 700) values for selected parameters observed in the column leachate from unoxidised "blue" rock are shown in Table 3.3.

Table 3.3 - Levels of Selected Parameters Observed in Column Leachate From Unoxidised Rock (Miller 1985).

PARAMETER	MAXIMUM	FINAL
pH	Not Applicable	2.5
SO_4 g/m3	15,500	4,900
Mn g/m3	1,355	23
Zn g/m3	18	2.25
Fe g/m3	5,030	1,070
EC dS/m	9.6	4.61

Maximum concentrations were observed in the unoxidised rock column after about 220 days, which indicates a rapid rate of sulphide oxidation and acid generation.

Based on the results of the batch and column leaching test results the initial, maximum and final sulphate release rates from unoxidised "blue" rock were calculated (Table 3.4).

Table 3.4 - Sulphate Release Rates From Unoxidised Rock (Miller 1985).

INITIAL	MAXIMUM	FINAL
8 g SO_4/tonne/day	70 g SO_4/tonne/day	20 g SO_4/tonne/day

These calculated rates were considered to be typical of reactive acid forming waste rock where acid drainage problems occur (Miller 1985). As such they confirmed the need for active control strategies at the site to prevent unacceptable acid generation in waste rock dumps. This was taken into account in the design of the waste disposal facility.

The exposure period required for acid conditions to become established, ie the field lag period, was predicted from the test results to be of the order of 15 to 20 weeks for unoxidised waste rock. It was predicted that during the construction phase leachate from unoxidised rock in open areas of the waste dumps could have an acid pH (less than 4) and contain up to 5 000 g/m^3 SO_4 and 500 g/m^3 Mn. The results indicated a high risk of acid generation in the unoxidised waste rock.

Detailed analysis of the results of the leaching and geochemical testing showed that leaching of the Martha Hill unoxidised waste under moist aerobic conditions occurs in four stages:

Stage 1: Initial flush of readily soluble constituents.

Stage 2: Steady state release due to chemical oxidation of sulphur and neutralisation of acid produced. In this stage, the pH remains above 3.5 and the rate of release of heavy metals and soluble salts is very low.

Stage 3: Bacterially catalysed sulphide oxidation resulting in a high concentration and rate of release of heavy metals and oxidation products (SO_4 and Fe). In this stage the pH falls below 3.5.

Stage 4: Bacterially catalysed sulphide oxidation continues however the rate of heavy metal release declines due to depletion of the source, i.e. the low content of heavy metals in the rock limits the rate and amount released.

Under the optimum oxidation conditions of the leaching tests it took approximately 14 weeks for the bacterially catalysed oxidation to become effective and for the pH to decline. As the pH fell the solubility of the relevant heavy metals increased.

(ii) Ongoing Studies.

Waihi Gold Company has continued to test materials for acid generating potential. Ongoing static testwork (bench tests) confirmed that blue, unoxidised rock is generally acid producing, unless it contains logged calcite. In this case the rock has a significant acid neutralising capacity (ANC) and strongly negative net acid producing potential (NAPP), and the rock is acid consuming in nature. Mixed waste (a mixture of blue/brown) is treated as blue material within the waste disposal facility. Waihi Gold Company is also carrying out kinetic testwork in the form of column leachate tests to assess the acid generation capacity of waste types in the long term.

3.3.2.2. TAILINGS.

a. Baseline Studies 1986.

(i) Acid Generation.

The ore was originally predicted to have low total sulphur levels, ranging from 0.005 to approximately 1% S, (Miller *et al* 1986), and the chemical composition of the tailings would be determined from the ore. With freshly deposited tailings having a pH of 10, $CaCO_3$ would initially be the stable mineral phase, but the formation of $CaCO_3$ would cause the pH to drop by the following equation:

$Ca^{2+} + CO_2 + H_2O = CaCO_3 + 2H^+$

As the pH approached 8, gypsum would begin to form and both calcite and gypsum would co-exist with the pH between 7.5 and 8. The long term tailings seepage chemistry was therefore predicted to be controlled by gypsum and calcite solubility with acid generation not likely to occur. The pH would be approximately 7.5 to 8 and the concentration of metals in seepage would be low because of the generally low content in the ore and the alkaline pH of the tailings environment.

(ii) Leachate Production.

The tailings tested originated from a bulk sample collected from a trial pond at Union Hill, Waihi, produced by the Union Hill processing plant in 1983. Batch tests examined the mechanism and rate of leachate generation in the tailings. For the batch tests, tailings samples were saturated with deionised water and humidified air was passed through the sample to ensure that maximum oxidising conditions were maintained. Oxidation products were extracted weekly for six weeks, upon which the results confirmed the leaching mechanism and the trial was terminated.

The results shown in table 3.5 show that essentially very low or undetectable levels of metals were leached. The pH of leachates varied from 7.4 to 8.5 which supports the predictions based on calcite/gypsum criteria.

Table 3.5 - Estimated Composition of Tailings Seepage (Miller *et al* 1986).

(All results are in mg/l except for pH).

PARAMETER	OPERATING PHASE	LONG TERM
pH	7.5-10.5	7.5-8
Total CN	1-10	<0.1
Cl	10	10
SO4	300-500	300-500
Al	1-10	<0.1
Sb	0.02-0.08	<0.1
As	0.02-0.08	<0.1
Cd	0.01-0.05	<0.1
Ca	2000-2500	1000-1500
Co	1.0-4.0	<0.01
Cu	2.0-5.0	<0.1
Fe	1.0-10.0	<0.01
Pb	0.1-0.7	<0.01
Mg	10-50	5-20
Mn	1.0-10.0	<0.01
Hg	0.002-0.006	<0.001
Ni	5-15	<0.1
K	100-200	50
Na	300-400	50-200
Zn	10-20	<0.1

The expected composition of tailings seepage given in Table 8 suggested that long term seepage from tailings would not be an environmental problem at Waihi. The early operational phase applied to seepage when the tailings were first placed and the retention time for water within the tailings was small. The retention time was expected to increase as the mass of tailings increased. This would allow sufficient time for chemical reactions within the tailings mass to modify the chemistry of seepage and further reduce the concentration of metals and cyanide in the tailings seepage. Since lime and gypsum were expected to control the geochemistry of the tailings the equilibrium between these minerals was expected to provide strong buffering to further pH change.

(iii) Cyanide Degradation.

It was not expected that cyanide levels within the tailings would remain at high levels in the long term. Miller *et al* (1986) reported that it is well documented that natural degradation of cyanide by volatilisation in tailings supernatant water was highly effective in reducing cyanide concentrations. Also, precipitation reactions and microbial action within the tailings mass would further reduce the concentration of cyanide in the seepage.

(iv) Sorption Capacity of the Tailings.

Sorption is probably the major factor controlling the movement of constituents in leachates through subsurface systems and into groundwater aquifers, and is defined as the physical/chemical bonding (ion exchange and chemical reaction) of constituents in the leachate to solid particles. Sorption capacity depends on the predominant minerals and the pH of the soil. Anion retention can be large in soils derived from volcanic ash and in particular those soils containing appreciable amounts of allophane such as occurs at Waihi.

The chemical, physical and mineralogical characteristics of the tailings were investigated, and the tailings were found to be dominated by quartz, with a low cation exchange capacity (CEC). Tailings were leached with test leachate solutions to measure their attenuation capacity for cyanide, metals, and selected cations and anions. Metals and cyanide were found to be strongly attenuated by the tailings and not desorbed when leached with water. The tailings were extremely efficient at removing manganese from the leachate. They were also most efficient at neutralising acid, but did not retain sulphate, with magnesium and potassium being only weakly adsorbed.

In summary, due to the low sulphur content of the ore and the alkaline nature of the tailings, long term leaching of toxic metals and specific ions from the tailings was not predicted to occur. Leachates were however expected to contain sulphate salts of the major cations.

(b) Ongoing Testwork.

(i) Acid Generation Potential.

The major geochemical issue as to whether the tailings will require a cover is the potential for acid generation in the surface. This will be determined by the ore types and sulphur grade of the ore mined during the later stages of the operations.

The sulphur content of tailings produced from gold mines may be expected to increase as open pits or underground mines deepen, or if more sulphide ore is mined, eg if the gold price goes up, leading to a change in the ore cut-off grade. At other mines there has been sulphide segregation across tailings deposition beaches with higher concentrations occurring near the dam wall (Miller pers comm 1996). Geochemical testwork continues to investigate whether any of the above factors may necessitate a full or partial cover of Martha Hill tailings.

If the potential for acid generation in sections of the tailings storage is confirmed, a cover will be needed. Oxygen exclusion of the tailings could be achieved by a permanent water cover or alternatively by placement of a compacted cover of similar characteristics to that required for the waste embankment.

Ongoing testwork is being carried out to assess the likely acid producing potential of the tailings in the long term. The acid producing potential of the tailings forming the final surface will be of most importance with respect to rehabilitation, and will depend on the nature of the ore being mined at the time. This is expected to depend on such factors as whether the pit extension is granted, and whether sufficient quantities of oxidised ore will be available to provide a final tailings cover.

(ii) Cyanide Degradation.

Investigations carried out by Waihi Gold Mining Company Ltd to determine the nature and fate of cyanide within the stored tailings involved the collection of depth profile samples in 1995. The CNwad (Weak Acid Dissociable) concentration in the decant liquor ranged up to 100 g/m^3 at the time of sampling at the active beach and decreased to less than 30 g/m^3 at about 4m depth. Below 12 m the concentration was less than 10 g/m^3 and it continued to decrease below this depth. Copper shows a similar trend decreasing from about 16 g/m^3 at the active beach surface to about 2 g/m^3 at 16 m depth. (Miller pers comm 1995).

The data suggests that in the upper 4 to 6 m of the active tailings storage, volatilisation of free cyanide is the dominant decay mechanism. However, below this depth, the remaining CN wad is present mainly as copper cyanide complexes and further decay of CNwad is most likely related to transformation process from copper cyanide to the non-toxic iron cyanide form and insoluble CuCN and copper oxides. (Miller pers comm 1995). These processes have been observed in other similar tailings and limit long term leaching of CNwad from the storage.

The testwork confirmed that residual cyanide within the tailings storage was not expected to be of concern for closure or final rehabilitation.

3.3.3 EARLY TRIALS REGARDING PLANT GROWTH POTENTIAL ON WASTE AND TAILINGS.

Widdowson *et al* (1984) investigated the plant growth potential of tailings (Union Hill) and waste materials (Martha Hill), as part of the baseline studies carried out before the Mining Licence was granted. The investigation involved the determination of physical and chemical properties of the tailings, as well as waste materials comprising ignimbrite, oxidised, mixed and pyritic (unoxidised) waste. Glasshouse pot trials were also carried out to determine the plant growth potential of tailings and the four waste materials.

3.3.3.1. Physical Properties Of Waste Types.

a. Texture.

The coarse texture of the waste materials raised doubts as to whether they contained sufficient fines to be able to sustain plant growth. An approximate textural analysis was carried out on all waste samples as received, ie in an air-dry state. Widdowson *et al* (1984) suggested that a material to be used as a rehabilitation surface should be relatively fine-grained with at least 50% of the material less than 2 mm in diameter, and preferably of a loamy texture.

Fine textured (<2 mm) materials comprised 48% of the pyritic waste and 31% of the mixed waste. In comparison, fine materials comprised 71% of the oxidised waste and 41% of the ignimbrite. The mixed waste was the most coarse-textured material with the least suitable particle size distribution for sustaining plant growth. Despite this, it was concluded that all of the waste materials examined had sufficient contents of fines (<2 mm) to warrant further investigation of their suitability as plant growth media for rehabilitation after mining.

b. Moisture Retention.

Water holding relationships of the tailings, oxidised waste and ignimbrite were found to be similar and in this regard, all of these materials would be suitable for creating a final medium for plant growth. In contrast, the moisture retention characteristics of the mixed and pyritic wastes were found to be inferior to the other materials which suggested that they may be prone to drought.

c. Bulk Density, Porosity.

Bulk densities were estimated from reconstituted cores, and were found to range from 1.07 t/m^3 for the ignimbrite waste to 1.43 t/m^3 for the mixed waste, (Widdowson *et al* 1984). In comparison, values of bulk density of 1 to 1.4 g/cm^3 are typical for well-aggregated loamy soils (White 1987).

The mixed and pyritic wastes had high macroporosities of around 30%, however the combined effect of high macroporosity and low moisture retention in the mixed and pyritic waste supported the contention that these materials would be prone to drying out. The ignimbrite waste also had a high macroporosity, but it had the desirable characteristics of both good aeration and good water retention, and was described as being physically the most suitable material for use as a plant growth medium.

Although the tailings and oxidised waste had good water retention properties, the marginal to low macroporosities achieved suggested that compaction and lack of aeration could be major problems if these materials were used for land rehabilitation.

d. Soil Structure.

The waste materials did not appear to show any surface crusting problems in this study, but it was acknowledged that soil structural problems and compaction could occur if these materials were handled at high moisture contents (Widdowson *et al* 1984).

The tailings used in the trials was comprised of finely textured andesitic materials, with negligible organic matter and little if any natural macro-aggregation. Widdowson *et al* (1984) suggested that, in a field situation, surface crusting could result .

3.3.3.2. CHEMICAL PROPERTIES OF WASTE TYPES.

The chemical properties of the tailings and waste rock samples are shown in Table 3.6. The ratings for these properties according to Blakemore *et al* (1981) are given in Appendix 3.1.

Table 3.6 - Chemical Properties of Tailings and Waste Rock, (Widdowson *et al* 1984).

	Tailings	Oxidised Waste	Ignimbrite Waste	Mixed Waste	Pyritic Waste
pH (H_2O)	9.2	5.2	5.2	3.7	4
pH (H_2O_2)	9.3	4.2	6.4	2.2	2.2
CEC (me%)	4.9	14.4	6.9	8.1	6.6
B.S. (%)	100	26	42	100	100
Ca me%	Free lime	0.2	2.3	5.3	0.72
Mg me%	0.58	3	2.1	3.7	5.4
K me%	0.14	0.42	0.25	0.27	0.32
Na me%	1.33	0.22	0.25	0.11	0.12
KCl extr Al me%	0	8.54	0.25	2.27	1.97
$CaCO_3$ %	1.1	-	-	-	-
Olsen P ppm	6.2	0.1	1.8	9.4	6.3
Extr S ppm	29	35	90	1,137	812
Soluble salts %	0.07	0.01	0.02	0.4	0.31

Micronutrient analysis was carried out on the fine fraction (<2 mm) of the waste materials and the results are given in Table 3.7.

Table 3.7 - DTPA Extractable Micronutrients in Tailings and Waste Materials (Widdowson *et al* 1984).

Material	Fe ppm	Mn ppm	Cu ppm	Zn ppm
Tailings	26	11	1.1	1.9
Oxidised Waste	1.0*	10.3	0.2*	.6*
Ignimbrite Waste	3.4*	16.8	2.1	6.8
Mixed Waste	153	207	14	12
Pyritic Waste	122	219	17	15

* Deficiency Level.

Results showed that CEC values were low for all wastes, except the oxidised waste which was moderate, indicating a low capacity to retain nutrient cations. Base saturations were 100% in the mixed and pyritic wastes, and the sum of the exchangeable bases was low throughout. Calcium was very low in the pyritic waste. Potassium was very low in all materials except the oxidised waste with magnesium levels adequate in all materials.

Olsen P ranged from very low to low in all the material types tested. Phosphate extractable sulphur levels were extremely high in the mixed and pyritic wastes and moderate in the oxidised and ignimbrite waste and tailings.

DTPA extractable micronutrients showed that levels of available Fe, Mn, Cu and Zn were high in the mixed and pyritic wastes, and levels of Mn, Cu and Zn were moderate in the tailings and ignimbrite. Fe was deficient in the ignimbrite. Oxidised waste was deficient in Fe, Cu and Zn.

The mixed and pyritic wastes were extremely acid and contained appreciable levels of exchangeable aluminium which were likely to have an inhibiting effect on the growth of plants. The oxidised and ignimbrite wastes were strongly acid with the tailings being extremely alkaline.

Oxidation of pyrites to sulphate was thought to be the cause of moderate to high soluble salt contents in the mixed and pyritic wastes. These were considered likely to be harmful to the growth of plants. The mixed and pyritic wastes therefore, were considered to be most unfavourable media for plant growth because of extreme acidity and high levels of exchangeable aluminium and soluble salts. The other wastes and the tailings had low levels of soluble salts.

3.3.3.3. POT TRIAL.

Glasshouse pot trials were carried out by Widdowson *et al* (1984) to assess the potential of tailings and waste materials for plant growth. Ryegrass and white clover were sown onto the waste types with various treatments including major and micronutrients and lime. The tailings were found to have few physical and chemical limitations to plant growth. While they were deficient in major plant nutrients and had a low capacity to retain nutrients against leaching, such limitations could be overcome by the application of fertilisers.

In the case of the waste materials, ignimbrite waste, apart from its strong acidity and deficiency of major nutrients, was found to have relatively few physical and chemical limitations for plant growth. Glasshouse pot trials confirmed that the material had the potential for good growth of ryegrass, provided acidity was corrected and major nutrients added.

Oxidised waste was shown to have good potential for ryegrass growth once acidity and nutrient deficiencies were corrected. A micro-nutrient deficiency predicted from soil tests was verified in pot experiments when added Fe, Mn, Cu and Zn gave significant yield increases in both ryegrass and white clover.

On the mixed waste and pyritic waste ryegrass failed completely in the absence of lime. As well as being prone to drought and deficient in plant nutrients, mixed and pyritic waste had multiple toxicity problems. There was an early response to added nutrients in the presence of lime, but growth was thought to be largely inhibited again by a high content of soluble salts.

While liming could overcome existing acidity, continuing oxidation of pyrites made the estimation of lime requirements difficult. Because of the combination of very high acidity, associated aluminium toxicity and the high soluble salt content, the mixed and pyritic waste were found to be unsuitable as plant growth media.

3.3.3.4. Field Trials.

One of the questions that arose when the present mining operation was proposed was the quantity of topsoil needed to successfully establish pasture on the oxidised waste and tailings. In 1985, field trials were initiated on tailings and oxidised waste (with a reference treatment of disturbed topsoil) by Drs P.E.H Gregg and R.B. Stewart, Department of Soil Science, Massey University. The trials investigated the use of topsoil at depths of 0 mm, 50 mm, 150 mm, and 250 mm over each of the above materials. Field trials were not carried out on unoxidised waste because it was recognised as being unsuitable for plant growth and was to be disposed of such that it would not form a resurfacing medium at the tailings dam site.

The research programme consisted of field trials at three sites within 2 km of one another. One site was at Martha Hill where oxidised waste was available. Another site was at Union Hill where an 8 year old tailings deposit existed and the third site (Baxter Rd original undisturbed soil reference site) was adjacent to the planned disposal area for tailings and waste. Pasture plots (sown at 50 kg seed per ha) were constructed which were subjected to frequent harvesting for dry matter yield and pasture composition determinations.

All plots used topsoil depths of 0 mm, 50 mm, 150 mm and 250 mm, and all had the same surface fertiliser application prior to seeding in Autumn and again the following spring, so that by the end of Autumn 1986, 150 kg P/ha, 160 kg K/ha and 180 kg S/ha had been applied as potassic superphosphate to the surface (Gregg *et al* 1995). Thereafter yearly (spring) 15% potassic superphosphate was applied at 700 kg/ha. Approximately 50% of the clippings were returned after each cut, and topdressed with urea and KCl after every second cut.

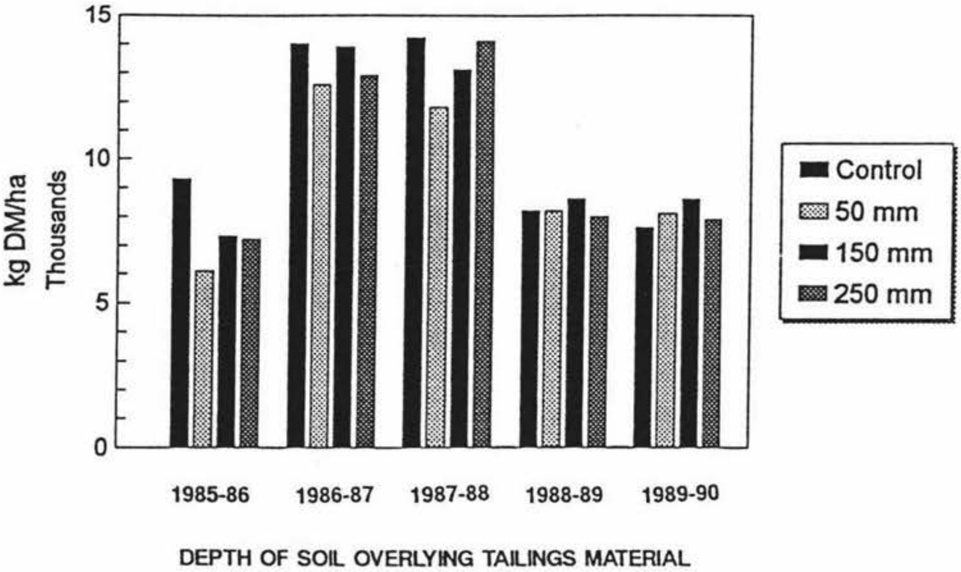
The topsoil depth treatments at the Martha Hill site were similar to the tailings trial but additional treatments were incorporated. Where topsoil was placed on waste, one half of the plot was modified by having lime (6t/ha) and superphosphate (1t/ha) incorporated into the upper 150 mm of the waste before soil placement.

Pasture growth on the tailings and oxidised waste plots is described in detail in Gregg *et al* (1990) and summarised below.

1. Tailings.

Yield differences between topsoil treatments for the first five years of the tailings field trial were small with the nil soil treatment performing well, as shown by Figure 3.3.

Figure 3.3 - Yields in the Union Hill Tailings Field Trial (Gregg *et al* 1990).



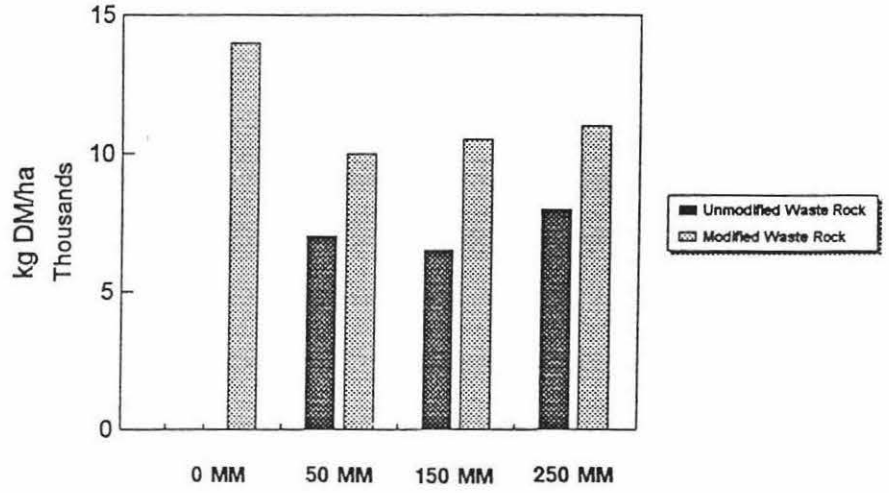
Yields in the last two years (1988-89, 89-90) declined as the tailings site received less frequent harvesting and one replicate was invaded by moss due to shading (Gregg *et al* 1990).

In the first year some difficulty occurred in establishing clover on the nil soil plots, (Gregg pers comm), and they had to be resown several times. The reasons for the poor clover establishment were not investigated at the time.

2. Oxidised Waste.

Modification of the underlying waste with lime and superphosphate substantially increased yield by almost 4,000 kg DM/ha as shown in Figure 3.4.

Figure 3.4 - Yields in Martha Hill Oxidised Waste Field Trial - Year 1 (Gregg *et al* 1990).



Where no topsoil was used, the highest level of pasture production occurred. This level was higher than the reference treatment yield (Baxter Rd original undisturbed soil site). Evidence from both soil tests and pasture analyses indicated that the higher yield from the nil topsoil treatment may have resulted from a more favourable soil P status, although less weeds and a lower population of soil borne pathogens were present on this treatment. By the end of the third year, annual dry matter yields indicated no differences in pasture production between the modified and unmodified waste treatment at any topsoil depth.

A number of physical properties including bulk density, resistance to penetration, macroporosity, saturated hydraulic conductivity and infiltration rate were measured on the Martha Hill plots, (Horne *et al* 1990). Bulk density and resistance to penetration were much greater on plots with waste rock at the surface than for plots covered with soil. The data indicated that at the Martha Hill site both waste rock and overlying soil were good physical media for plant root growth. The waste material had a poor ability to store water, however this was not considered to be a major problem at Martha Hill where rainfall is both high and regular.

Good grazing management would be imperative to avoid potential physical problems if waste and tailings were subjected to intensive pastoral use.

3.3.4. REHABILITATION OF THE TAILINGS DAM EMBANKMENT (BUND).

Restoration of the bund commenced in 1990, and 19 ha had been rehabilitated up until December 1994. Guidelines for restoration of the bund were developed by Gregg and Stewart (1989) and were based on the results of the oxidised waste rock field trials initiated in 1985 prior to the application for a Mining Licence. In brief, a layer material (zone H) is spread on the outer surface of the embankment, to form a subsoil. Initially zone H had a depth of 1m but the depth has since been reduced to 0.5m. Stones are removed from the surface prior to ripping. Lime is applied at a rate of 6 t/ha, and 1 t/ha superphosphate fertiliser is worked into the surface of the material. Approximately 100 mm of stockpiled topsoil (stripped from the surface of the site before dam construction commenced) is spread and "fingered in" to the subsoil. This is fertilised with 1,400 kg/ha 15% potassic superphosphate, limed if necessary, and sown with a ryegrass, clover, lotus seed mix. Barley may be added if the area is thought to be at risk of erosion due to rain, or if sowing is carried out at a less than optimum time of year. The area is carefully grazed with light dairy stock to avoid damage.

After the first year, annual topdressing in autumn occurs with a mixture of potash and monoammonium phosphate applying 50 kgP/ha and 50 kgK/ha. Earthworms are introduced approximately one year after sowing, after which time a food source has accumulated.

Wire cages are used to measure dry matter production off the restored areas and a pasture control area situated nearby. The pasture control area was cultivated and resown at the time rehabilitation commenced on the bund, and provides a good comparison. As can be seen by Table 3.8, yield results compare favourably with the most versatile and productive soil to be found in the area (the Waihi Sandy Loam) which was described in the baseline studies as having an estimated pasture production of 12,000 to 16,000 kg dry matter per hectare per year.

Table 3.8 - Comparative Pasture Dry Matter Yield Results Off Restored Oxidised Waste and an Adjacent Control Area.

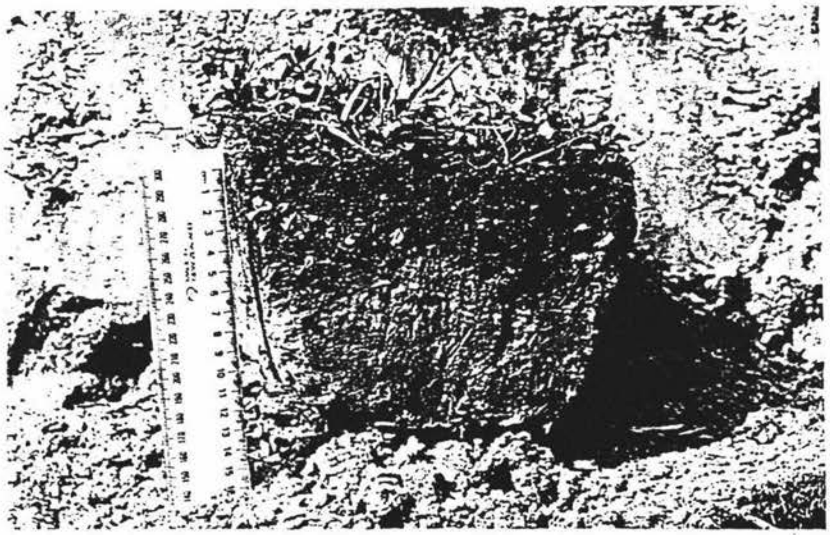
	kg dry matter per ha/yr	
	Control	Restored
30/6/92 - 8/7/93	17,678	13,934
8/7/93 - 7/7/94	19,913	17,943
7/7/94 - 26/5/95	13,822	12,474

3.4 SOIL FORMATION RATES AND NUTRIENT LOSSES ON TAILINGS.

Mason *et al* (1993) carried out a study to investigate leaching losses and the rate of soil formation on tailings pasture plots (Union Hill) with no topsoil addition after seven years of regular mowing and fertilising. The amount of nutrient applied in regular fertiliser additions was known, and the amount of nutrient return to the plots in clippings could be estimated. Regular soil tests provided data which could be used to measure rates of nutrient accumulation and soil formation, and leaching losses.

After seven years a dark soil horizon had built up on the surface of the plots to 7.5 cm depth as shown in Figure 3.5. Associated with this was an increase in phosphate and sulphur concentrations of approximately 2.5 times, while nitrogen increased approximately seven fold and carbon six fold. Assuming that increases in C and N are linear, it would take about 24 years to reach the original C and N levels of the soil at the disposal site.

Figure 3.5 - Soil Formation in the Upper 75 mm of a Union Hill Tailings Plot (Sept 1992).



The amount of nitrogen fixed by clovers was estimated to be at least 240 kg N/ha. Losses of S at 72% (or 81 kg S/ha/yr) and of P at 28% (or 19.8 kg P/ha/yr) were high, (Mason *et al* 1993). It was concluded that if large areas of tailings were to be restored to pasture, leaching losses would need to be kept in mind when selecting fertiliser types and frequency of application.

3.5 ASSESSMENT OF TAILINGS AND OXIDISED WASTE AS HORTICULTURAL PLANT GROWTH MEDIA.

Mason, (1989) carried out four glasshouse pot trials in order to design a suitable plant growth medium from tailings and oxidised waste for the growth of horticultural produce. Experiments one to three used combinations of tailings and oxidised waste material and composted chicken manure to investigate the growth of broad beans and lettuces. Experiment four used varying amounts of solid fertiliser on a 50:50 tailings/oxidised waste mixture to determine a suitable nutrition system for growing horticultural crops on mine waste material.

In experiment one to three, six media treatments were used. These were:

* 100% tailings.
* 50:50 tailings/ oxidised waste.
* 75:25 tailings/ oxidised waste.
* 50:50 tailings/ manure.
* 75:25 tailings/ manure.
* Manawatu fine sandy loam topsoil.

In experiment one, lettuces were grown with two fertiliser rates applied to the above six media. Salt toxicity caused by overfertilisation caused the plants to die. The reason for overfertilisation was the manner in which the fertiliser quantity was calculated, based on area rather than the pot volume. No more pot trials with lettuce were attempted.

Experiment two was essentially the same as experiment one, except that broad beans were used instead of lettuces. A salt problem also occurred in this trial, but broad beans appeared less susceptible than lettuces as the symptoms took longer to develop.

In experiment three, liquid fertiliser was used instead of solid fertiliser. Highest yields were obtained from the tailings/manure treatments and Manawatu soil. The addition of composted poultry manure, even at the low rate of 75:25 tailings/manure, resulted in large yield increases. The increased yield may have been due to improved physical properties of the rooting media or a more favourable nutrient status. Low yields in the tailings and tailings/waste treatments could have been due to an insufficient supply of nutrients provided by the liquid fertiliser. The plants grown in tailings and tailings/waste materials were found to have high concentrations of zinc and it is possible that zinc may have caused a yield reduction in these treatments. Mercury uptake was found to be relatively high in the 50:50 tailings/waste treatment, and it was suggested that a possible reason could be the pH reduction occurring when waste was added to tailings. The zinc and mercury results were derived from one-off tests however, and further testwork would be necessary to confirm the results.

In experiment four, seven fertiliser treatments were used on a 50:50 tailings/waste mixture. Two of the fertiliser treatments used Osmocote slow release pellets to determine whether there would be less salt damage and higher yields with this form of fertiliser treatment. (Extra superphosphate and potassium sulphate were applied to the Osmocote treatments to provide the same nutrients allowing direct comparison between Osmocote and the solid fertiliser additions).

Highest yields were obtained from two fertiliser treatments (no significant difference between the two). One treatment involved the addition of calcium ammonium nitrate, superphosphate and potassium sulphate, at a rate of 0.56 gN/pot, 0.8gP/pot and 1.6 gK/pot, and the other treatment involved the addition of Osmocote and small amounts of superphosphate and potassium sulphate to supply 1.1 gN/pot, 1.6 gP/pot and 2.99 gK/pot. At higher rates of fertiliser addition, yields reductions appeared to be due to salt toxicity, and at lower rates, yield reductions were due to nutrient deficiencies.

In conclusion, it was found that the addition of composted chicken manure to tailings showed potential and field testing was warranted.

3.6 COMPARISON OF OLD TAILINGS WITH RECENT TAILINGS.

Bent (1991) carried out studies to compare "old" tailings used for the field trials described above and "recent" tailings as collected in 1991. The old tailings were derived from Union Hill and were the same tailings used in previous field trials. The recent tailings were collected from the tailings beach at the dam.

Three studies were carried out, one to compare a number of soil physical and chemical properties, another to determine the seed germination capacity of ryegrass and legumes on the leachates from recent and old tailings, and another to investigate seedling germination rates for ryegrass and legumes under two moisture regimes, (wet and dry) on the recent and old tailings. It was observed in the Union Hill tailings field trials that germination of clover had been poor in the plots without topsoil and this study was initiated in part to investigate that problem.

The studies indicated that the chemical properties of both tailings samples were similar, and there were no differences in seed germinating ability of ryegrass or legumes on the recent and old tailings.

No differences were found in ryegrass and clover germination in the wet tailings, however in the dry tailings treatment the overall clover germination percentage and rate of germination was significantly less than ryegrass.

It was concluded that the old and recently collected tailings were similar chemically and physically, and that poor initial clover establishment in field trials was most likely to be due to physical factors. Earlier research gained from the old tailings was therefore relevant to tailings being produced at the time.

3.7 GRASS GROWTH ON BLUE ROCK EXPOSED ON THE PIT SLOPES.

Tomlin (1993) reported on five glasshouse experiments with Lotus and Browntop on unoxidised rock from two locations; within the Martha open pit, and an outcrop on a twelve year old road cutting adjacent to the pit on Bulltown Rd. The experiments were designed to investigate the reasons for unsuccessful revegetation by hydroseeding of unoxidised rock, and to provide a strategy which would enable successful revegetation of these areas to take place.

Experiment one involved north wall blue rock with an initial pH of 7.7, sieved to 5 mm. Browntop and lotus were sown separately with nutrient solution applied. Both species germinated and established successfully in this experiment, but lotus had a considerably higher yield at harvest than browntop. Over the four months that the trial was run, the pH decreased to approximately 6.9 in the top 4.5 cm.

Experiment two involved the application of dolomite at rates of 600 kg/ha and 1,200 kg/ha and nutrient solution to rock material from the twelve year old road cutting. Application of 600 kg/ha dolomite raised the pH from 3.1 to 5.7 in the top 1.5 cm of the pots, and application of 1200 kg/ha raised the pH to 6.3. Germination of brown top was found to significantly increase at the higher rate of dolomite application, and yields of both brown top and lotus were found to increase at the higher rate.

Experiment three compared metal-tolerant and non metal-tolerant browntop, with and without a dolomite application, grown on material from the twelve year old road cutting. Where dolomite was added, the metal tolerant species were superior in germination but where no dolomite was added no differences were detected in germination percentage. The short term nature of this experiment did not allow full evaluation of the effectiveness of metal tolerant species.

Experiment 4 was carried out to determine at what point in time the pH level of the unoxidised material would begin to significantly decline, and at what rate this would occur, using unoxidised material from the pit sieved to 5 mm. The initial pH of the material was 7.7, and after approximately three months it was 7.4. It was concluded that the trial should be run for a longer period of time. (The presence of calcite in the rock may have influenced these results).

Experiment 5 investigated the effect of various application rates of dolomite on the road cutting material, by incubating mixtures of dolomite and pyritic material taken from the surface of the outcrop. Five gram samples of unoxidised material were placed in separate sealed bags, with dolomite added at rates approximating 150 kg/ha, 600 kg/ha and 1200 kg/ha, and a control with no dolomite addition. The pH of the material with no dolomite addition was 2.76. This was significantly different to the 150 kg/ha dolomite addition, which had a pH of 6.06. The treatments with 600 kg/ha and 1200 kg/ha dolomite addition were not significantly different from each other with a pH of 7.7, but were significantly different to the treatments with no dolomite addition, and 150 kg/ha dolomite addition.

Based on all of these results, it was concluded that the unoxidised slopes should be left unvegetated until acid production ceased in the surface layers. These areas could then be hydroseeded with the standard hydroseed mix currently used at the mine, which contained 600 kg/ha of dolomite. A repeat application within a short time period to apply another 600 kg/ha of dolomite was recommended.

CHAPTER 4.0 -

METHODOLOGY.

4.1. INTRODUCTION.

The review of current and past rehabilitation research indicated that further research was required within the open pit and at the waste disposal site. This was particularly so for the pit slopes containing unoxidised rock where a problem had been identified regarding the revegetation of the upper slopes. Several land use options had been identified in the Environmental Impact Report for the tailings, but pasture was the only land use investigated in scientific trials. It was considered that further opportunities for research existed at both sites, and the following describes the trials initiated.

4.1.1. UNOXIDISED PIT SLOPE TRIAL.

Revegetation of the upper pit slopes is a requirement of the Mining Licence which specifies that "any land faces within the pit perimeter that may be exposed to view from neighbouring land within the areas of the territorial authorities, and are not subject to the workings of the project shall be neatly trimmed and revegetated." The Mining Licence also states that "the upper pit slopes shall be treated to ensure revegetation as soon as possible in the mining programme." The work programme states that "during construction and operations the open pit, overland conveyor, process plant site and waste disposal area will be screened using grassed bunds and tree screening to limit the visual impact of the project." The Clean Air Licence also has a requirement to revegetate the upper pit slopes.

In order to meet these conditions, the company commenced hydroseeding on the upper slopes of the west wall of the pit in 1990. This was to be carried out on all walls above the final lake level, ie above 1105 mRL. Hydroseeding was found to be successful for revegetating slopes containing fully oxidised materials. Hydroseeding of unoxidised "blue" rock exposed on the North Wall of the pit was initially successful but it was noticed that large areas of grass began to die off after several weeks. Repeated attempts at hydroseeding these areas were unsuccessful. pH tests of the rock and the water ponded below confirmed that acid generation was taking place.

Given that hydroseeding was largely unsuccessful on acid generating slopes, but that revegetation of the pit slopes was a condition of the Mining Licence and Clean Air Licence, company management considered it necessary to establish a trial to investigate what could be grown on these areas. An area on the North Wall was selected as a potential trial area. The advice of several employees was sought and it became obvious that consideration would need to be given to site and operational conditions unique to the trial area proposed for this particular project.

One major problem was going to be the practicalities involved in establishing a trial on the steep pit slopes. The slopes varied, depending on the competency of the rock types. In general, areas above 1120 mRL (and where the trial was to be established) had a slope of 38°. The northwest corner, however had a slope of 50 to 55°, and the western wall had a slope of 38° above 1105 mRL with the slope steepening below that to 42°. Figure 4.1 shows the location of the trial area within the pit.

Martha Mine and Native Plant Trial Area

Figure 4.1

(Date of Photography: 15 Feb. 1995)

It was acknowledged that, aside from acidity, the acid producing slopes form a harsh environment for the following reasons:

1. Susceptibility to Drought.

Although Waihi has a relatively high, evenly spread rainfall, the pit slopes when freshly uncovered consist of solid rock. Over time and with hydroseeding, a soil does develop but this is usually variable in depth and often very shallow. As part of the early studies that were carried out by Widdowson *et al* (1984), a drought potential was identified on the pyritic waste material.

2. Erosion.

It was noted that plants could be physically knocked over or buried by material being washed downslope. The species selected would need to be able to withstand intermittent burial, and preferably have some ability to re-sprout from the base should the top be snapped off.

3. Wind.

The proposed site was exposed to mainly westerly winds, strong at times.

4. Temperature Extremes.

It was anticipated that the site could be very hot in summer and very cold in winter, and that large diurnal variations were possible.

5. Aspect.

The North Wall tends to receive more morning sun and the South Wall more afternoon sun. The South Wall at the Western end tends to be the most sheltered area.

By placing seed on the surface as with hydroseeding, it was considered that the plant was exposed to the very worst of the problems listed above and to acidity which was expected to be worse at the surface. It was considered that by using rooted plants instead of seeds, the roots would be placed at a greater depth and the plants may be less affected by some of these factors.

Colonising plants, preferably nitrogen fixers, were investigated initially. Suggestions that tutu or gorse could be planted drew criticism from several employees who perceived a public relations problem, despite the fact that both these species grow within the pit area naturally. The use of these plants in a trial was rejected by management and attention focused on native plants.

The New Zealand flora is not well endowed with species that can be regarded as early colonisers or pioneers, but the species that do colonise are tenacious. Native species can colonise severely eroded sites with poor nutrient status, and in some cases a relatively low pH (Pollock 1986). It was considered that a trial with colonising native species may be acceptable to local residents, and that if successful, rehabilitation with native plant species could possibly be a sustainable long term land use.

The decision was made to use Coromandel seed sourced plants if possible to eliminate potential provenance effects. In theory, these plants should be better adapted to the climatic conditions of Waihi, and be able to produce viable seed, allowing a sustainable community to develop. To some extent, this limited the choice of species and plant grade available. The species chosen were Cortaderia toetoe (Toetoe), Phormium cookianum (Mountain Flax), Leptospermum ericoides (Kanuka), Leptospermum scoparium (Manuka), and Dodonaea viscosa (Akeake), all Coromandel seed-sourced.

The surveyors suggested that a species of creeping plant, which may be able to establish in the more favourable areas for plant growth, and grow over the areas that were less favourable be investigated. For this reason, a native creeper, Coprosma kirkii, was also selected. Due to a lack of availability, these plants were not Coromandel seed-sourced. Characteristics of the chosen plant species are described in Appendix 4.1. Table 4.1 summarises the environmental tolerances expected for the species chosen.

Table 4.1 - Environmental Tolerances Expected For The Chosen Species.

Species	Form	Wind	Drought	Frost	Waterlogging
Toetoe	Grass	High	Mod	Mod	Mod
Flax	Herbaceous	High	Mod	High	High
Kanuka	Shrub/tree	Mod	High	High	Mod
Manuka	Shrub	Mod	(High)	High	(High)
Akeake	Shrub/tree	High	High	Mod	Low
C. kirkii	Creeping	(High)	(Low)	Mod	Low

Brackets indicate uncertainty or can be read as meaning occasionally. Environmental tolerances often vary within a species and with time of year. Tolerances also depend on the growth stage and adaptation or acclimatisation to a particular environment.

4.1.2 TAILINGS TRIALS.

Although the present Mining Licence requires rehabilitation of the tailings surface to productive pasture, it is recognised that other land use options may exist. The Environmental Impact Report (1985) described five possible rehabilitation concepts ranging from productive end use to a multiple use recreation option. Land use options possible on the recontoured and grassed site included combinations of horticulture, dairying, grazing, forestry, agroforestry and recreation.

In 1992, company management was interested in initiating revegetation trials using tailings produced at that time to investigate alternative uses for tailings. Discussions commenced as to possible trial areas and strategies. Eventually it was decided to trial pasture and native colonising plants on bare tailings, and tailings with a compost amendment. The reasons for this are described below.

Pasture had been successfully grown on "old" tailings at Union Hill, with and without the addition of topsoil, and it was of interest to compare the yields of the nil topsoil plots with those of the "new" tailings. Also, in the Union Hill tailings trial plots, poor initial germination of clover on the nil topsoil plots had been noted, (Gregg pers comm 1992) and resowing with clovers was required. It was of interest to investigate whether poor clover germination would occur on the "new" plots and what effect the addition of an organic matter source might have on improving clover germination. For these two reasons, pasture trials were selected.

To investigate other land use options for the tailings area, it was decided to trial colonising native plant species. At the time, the Waikato Regional Council had just produced "Vision 2000" which was a planning document based on comments received at community meetings. The local Vision 2000 meeting was held in Paeroa and it was clear that the community wanted protection and enhancement of wetlands and native plantings. It was considered that at least a small amount of the tailings area could eventually be planted in native plant species, and this could then form the basis of a protected area, encouraging birdlife and creating a community asset. Another benefit of using native plants was that there may be less disturbance to the land than if it was rehabilitated to pasture, although it was acknowledged that the effect of the roots of native trees on the tailings may require further investigation

After deciding to use native plant species, advice was sought from the Taupo Native Plant Nursery. They suggested that colonising native plants would have a greater chance of success and would normally be used as a first step in rehabilitating bare sites with other species being planted at a later date, once the colonisers were established. Another land use option, ie native timber could be investigated at a later date, with species such as rimu and kahikatea being possible options for supplementary planting among the colonising native species to be used in this trial.

Original suggestions included the possible use of tree lucerne or tutu to provide a nitrogen source and nurse shelter. Tree lucerne was ruled out upon the advice of the Taupo Native Plant nursery staff who believed it was not necessary. Tutu is not favoured by the Waihi community because of its possible deleterious effects on honey quality, and for this reason, it too was ruled out.

Freshly deposited tailings were observed to be relatively poorly drained, and it was decided to choose native colonising plants which could withstand waterlogged conditions. Landcare Research provided a list of indigenous plants which may be suitable for wet, high pH conditions in the Coromandel area. Based on the combined recommendation of Taupo Native Plant Nursery and Landcare Research, four species were chosen, taking into account the availability of plants that were seed-sourced from the Coromandel area. The species chosen were <u>Leptospermum</u> <u>ericoides</u> (kanuka), <u>Pittosporum</u> <u>tenuifolium</u> (kohuhu), <u>Phormium</u> <u>tenax</u> (flax), and <u>Cordyline</u> <u>australis</u> (cabbage tree). Further details regarding these species can be found in Appendix 4.2. Note that these plant species are not nitrogen fixers.

At the time that the tailings trials were being set up, it was anticipated that there may be a shortage of oxidised waste and possibly topsoil to use as tailings resurfacing materials once mining was complete. As well as investigating the two land use options of pasture and native plants, it was decided to trial a locally available organic matter source which may have potential as a surrogate topsoil material.

Several alternatives were investigated as follows -

1. Sewage Sludge.

Hauraki District Council was contacted regarding sludge but the council used oxidation ponds at the time, and only very limited quantities of sludge were available. It was considered that large quantities would be not be available in the long term for use as a tailings amendment, and other options were sought.

2. Cowshed Effluent.

This was a viable alternative, with reasonably large quantities likely to be available in the future. However it would have to be applied as a slurry, and because of this there would be practical difficulties applying the material only to selected plots and with even and consistent depths.

3. Chicken Manure.

This was available locally in reasonably large quantities and could have been used if necessary.

4. Compost.

This was being produced at the Tauranga landfill site from selected materials including vegetation and chicken manure. It was available free of charge for trial purposes, and was likely to be available in large quantities in the long term. Upon inspection it was found to have good structure, and chemical analyses suggested it would be suitable for trialling as a tailings amendment. It was able to be easily and evenly spread to selected plots. For these reasons, compost was chosen as a tailings amendment for both grass and the native plants in the tailings plots.

4.2. METHODOLOGY.

4.2.1. BLUE ROCK TRIAL.

Only limited information could be found regarding the nutritional requirements of New Zealand native plant species. It was considered likely that acidity would be a problem, and that organic matter and major plant nutrients were likely to be low on the trial area. Chemical analyses of a bulk sample of material from the newly cut proposed North Wall trial area confirmed this, (Table 4.2).

Table 4.2 - North Wall, Freshly Exposed Unoxidised Rock Analysis (March 1993).

Parameter	Result
pH (H_20)	7.2
pH (H_2O_2)	2.8
Olsen P, ppm	1
Exch K, me%	0.13
SO_4, ppm	400

The results of pH (H_2O_2) showed that the material had a high potential for acid generation, with low levels of plant available phosphate and potassium. It was decided to trial additions of topsoil, lime and fertiliser in the combinations specified in Table 4.3, giving five treatments of growing medium.

Table 4.3 - Additions of Topsoil, Lime and Fertiliser on the Blue Rock Trial.

Treatment	Lime	Fertiliser	Topsoil
A	Yes	Yes	No
B	Yes	Yes	Yes
C	No	Yes	Yes
D	Yes	No	Yes
E	No	No	Yes

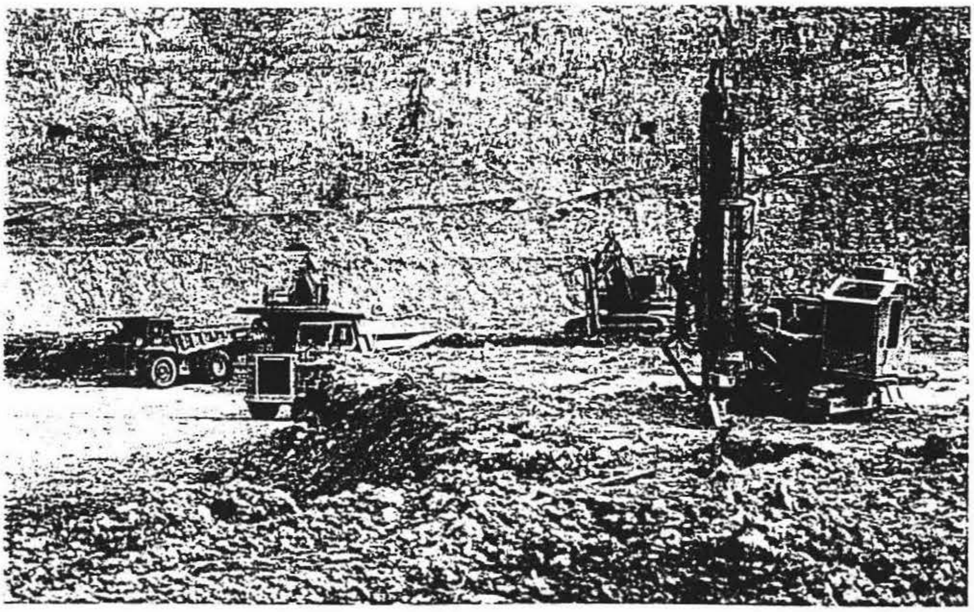
Notes:

1. Treatment A plants received no topsoil amendment. Drill cuttings of the blue rock were used as planting backfill.
2. Agricultural lime was used at the rate of approximately 120 g (one handful) applied to the base of the planting hole.
3. The fertiliser used was in the form of Agriform plant tablets. Each plant had one 10g tablet per plant, placed adjacent to the base of the root ball at planting.
4. Topsoil was taken from a stockpile on the edge of the pit.

Agriform was recommended by Brown, pers comm, (1993) who has used it successfully in native plantings, some of which have been on nutritionally poor sites and compacted areas. Promotional information as given in Appendix 4.3 describes Agriform as providing nutrients for up to two years while having very low initial salinity and potential acidity. It is used in many large public works contracts both in New Zealand and overseas, including the reforestation of TiriTiri Matangi Island in the Hauraki Gulf. Appendix 4.3 shows an analysis of the tablets.

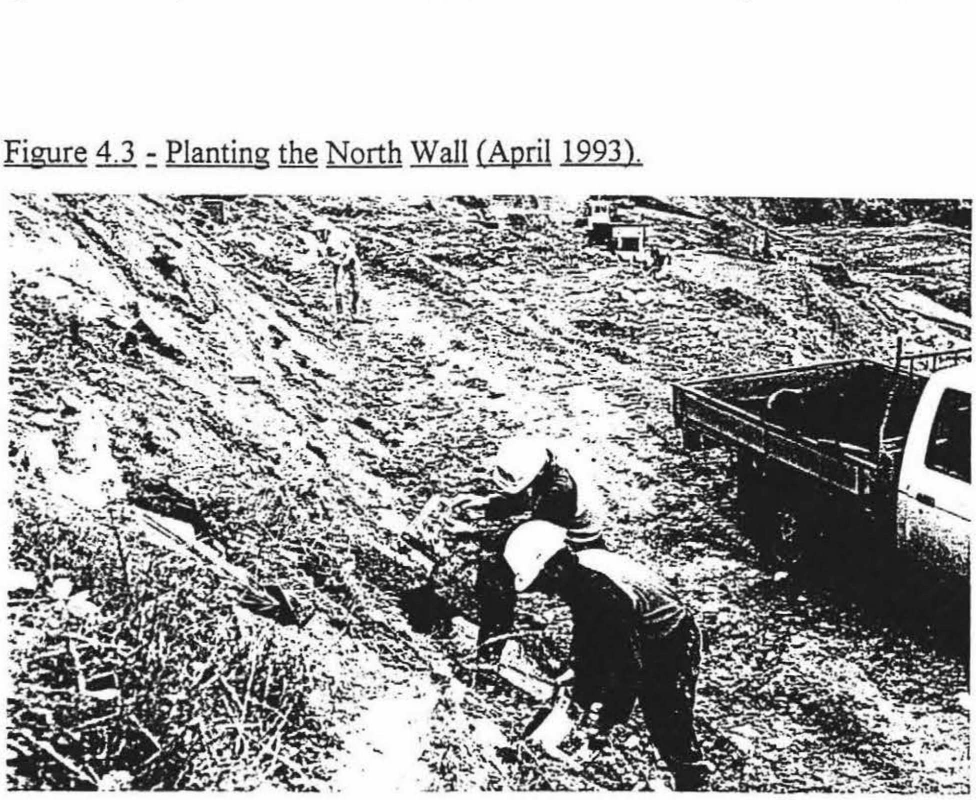
The exposed rock was very hard, and for planting to occur, an air track drill was used to create planting holes on the trial area, (Figure 4.2). These holes were vertically drilled to diameter 100 mm and depth approximately 500 mm.

Figure 4.2 - Air Track Drills with North Wall in Background (September 1994).



Planting was carried out shortly after the pit slopes were cut back in April of 1993, (Figure 4.3). Akeake and Toetoe were purchased as PB3 sized plants and the other species were purchased as root-trainers with a considerably smaller root volume.

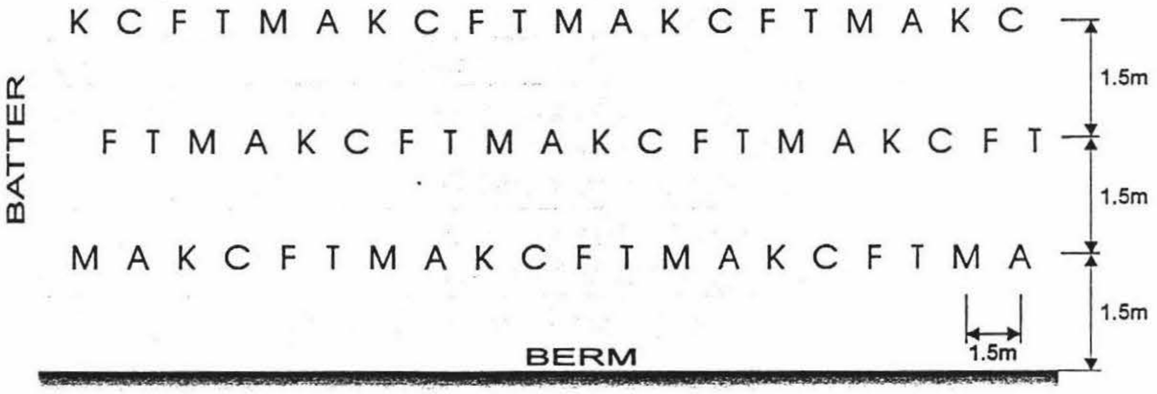
Figure 4.3 - Planting the North Wall (April 1993).



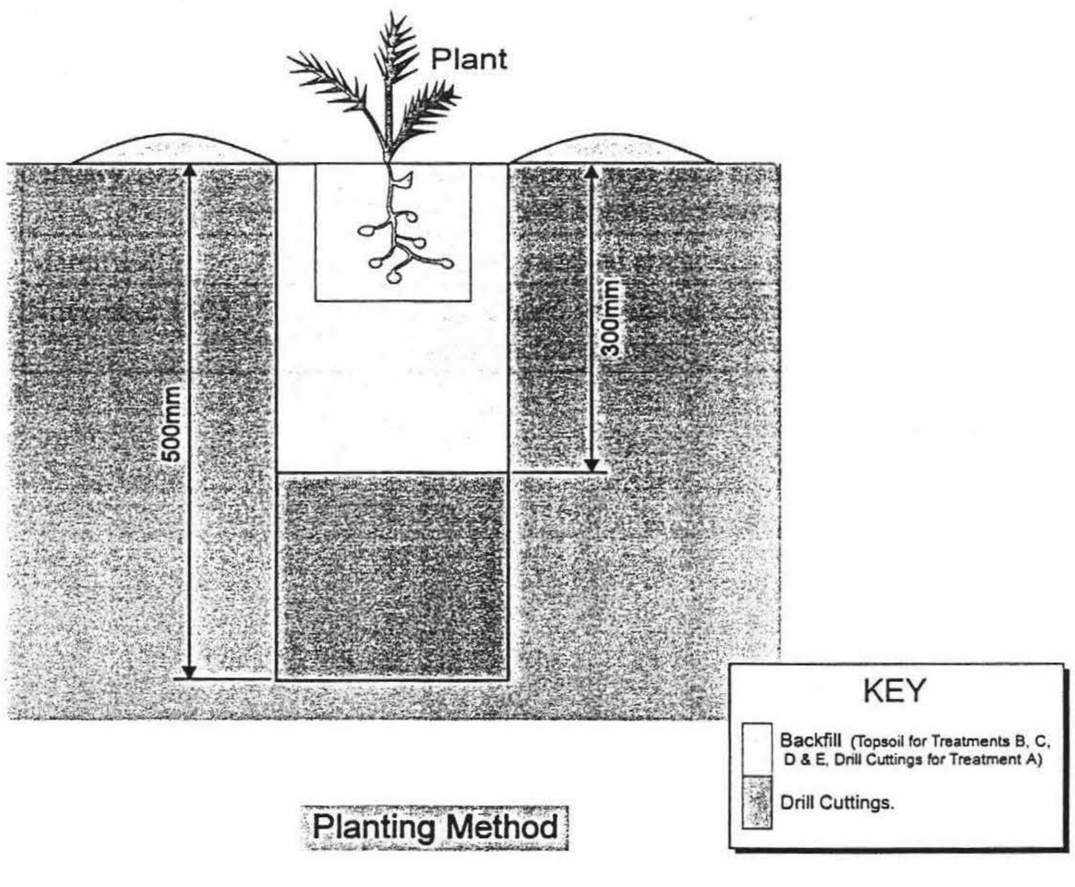
The drill could only reach to 4.5 m up slope from where the machine sat on the berm, and for this reason only three rows were drilled across the slope (Figure 4.4). Holes were approximately 1.5 m apart. Each growing medium treatment contained approximately sixty plants made up of approximately ten plants of each of the six species, planted as a set sequence of six, ie Kanuka (K), Coprosma (C), Flax (F), Toetoe (T), Manuka (M) and Akeake (A) also shown by figure 4.4. The whole trial area used a total of 314 plants.

Following planting, the plants were sprayed with "Treepel" - a rabbit and possum repellent. The size of the plants was then measured shortly after planting in April 1993, and in October 1993 and February 1994 the number of plants surviving, and size of the surviving plants were recorded. For toetoe and flax, the length of the longest leaf and number of leaves were measured as an indication of growth rate. For the creeping coprosma, the total length of all the branches was recorded and with the akeake, manuka and kanuka, total height was recorded. Unfortunately the trial area was hydroseeded following planting and some of the plants, particularly akeake, suffered from salt damage and dropped their leaves. Grass established in patches on the trial area from this hydroseeding event and its survival was observed.

Soil sampling was carried out at various times. The first sampling event was in March of 1993 when a bulk sample was taken from the North Wall area shortly after it was cut back. This has been previously described and the results given in Table 4.2. In November of 1993 it was noticed that areas of hydroseeded grass on the trial area were beginning to die, and soil sampling was carried out to investigate the cause of this. In January of 1995, soils were sampled in areas where grass and natives had both survived, where the grass had died but the natives were surviving and where all plants had died, to attempt to establish what differences in the media may have caused these effects. In March 1995, soils were sampled at various depths on the trial area to determine whether pH varied throughout the depth of the root zone. And in November 1995, soil was sampled within the boreholes of surviving plants within each treatment, to determine the pH. Table 4.4 summarises the sequence of events and methods used for the blue rock trial area.



Planting Sequence



Planting Method

Typical Planting Sequence and Method for North Wall Treatments

Fig. 4.4

Table 4.4 - Activities Associated With Conduct of The Blue Rock Trial.

Date	Event
March 1993	Cutting back of the North Wall trial area commences. A bulk sample is taken from the freshly exposed North Wall Trial Area for soil analysis.
April 1993	Cutting back of the North Wall trial area is complete. Holes drilled and planting carried out.
April 1993 (shortly after planting)	Plants measured and sprayed with Treepel.
May 1993	Plants sprayed accidentally with hydroseed mix. Many akeake plants suffer from salt burn and drop their leaves.
October 1993	Plants are observed and measured for survival and growth.
November 1993	Soils are sampled after hydroseeded grass begins to die in large patches on the trial area.
February 1994	Plants are again measured for survival and growth rates.
January 1995	Soils are sampled in each area, where all plants are alive, grass is dead but natives alive and all grass dead.
March 1995	Soils are sampled at various depths on the trial area.
November 1995	Soil sampled within the boreholes of surviving plants within each treatment.

4.2.2. TAILINGS TRIALS

4.2.2.1. POND CONSTRUCTION.

An area was selected at the south end of the dam where the trials could be established. Two ponds were excavated, the idea being that one would be a "dry" pond and the other would be a "wet" pond.

Following excavation, the ponds were filled by directing the tailings line to the top of the dry pond. Tailings flowed into this pond and then overflowed into the lower wet pond. This occurred several times until each pond had an approximate depth of two metres of tailings. The Waikato Regional Council was contacted prior to commencing filling and based on those discussions, a shallow bore situated on farmland south of the trial area was sampled several times and tested for cyanide. None was found to be present. Figure 4.5 and 4.6 show the filling of the ponds with tailings.

Figure 4.5 - Filling the Ponds With Tailings. (April 1995).
(Note Pipeline at the Top Left Corner).

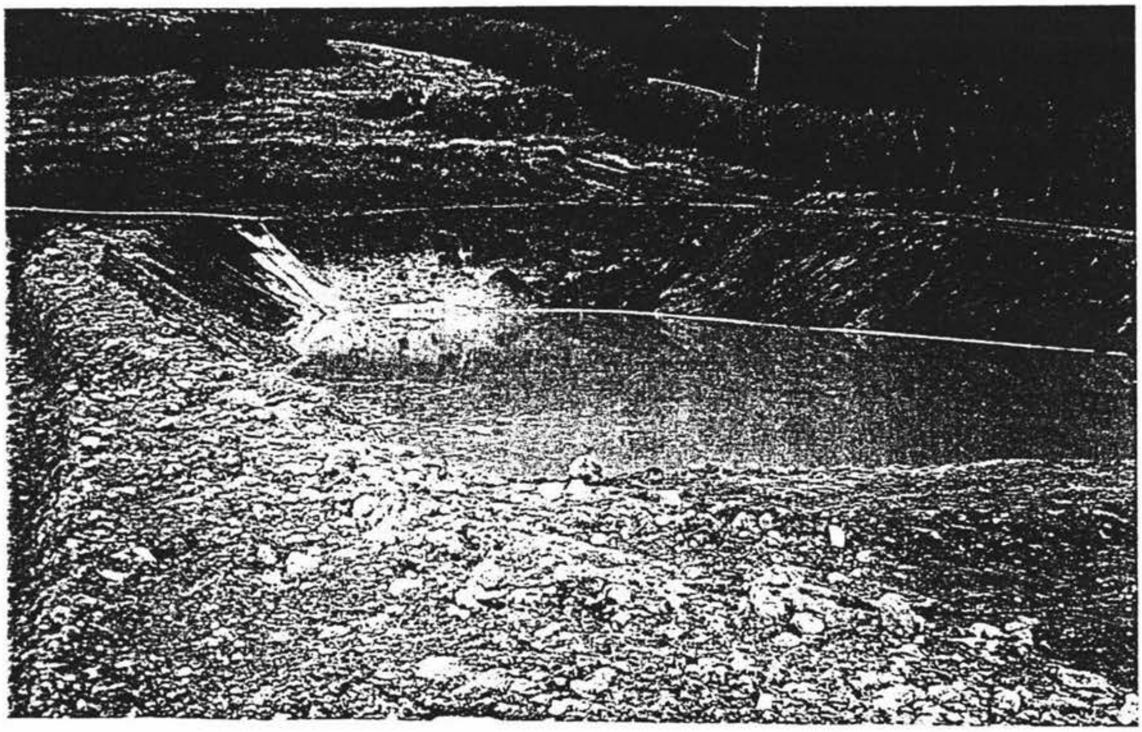
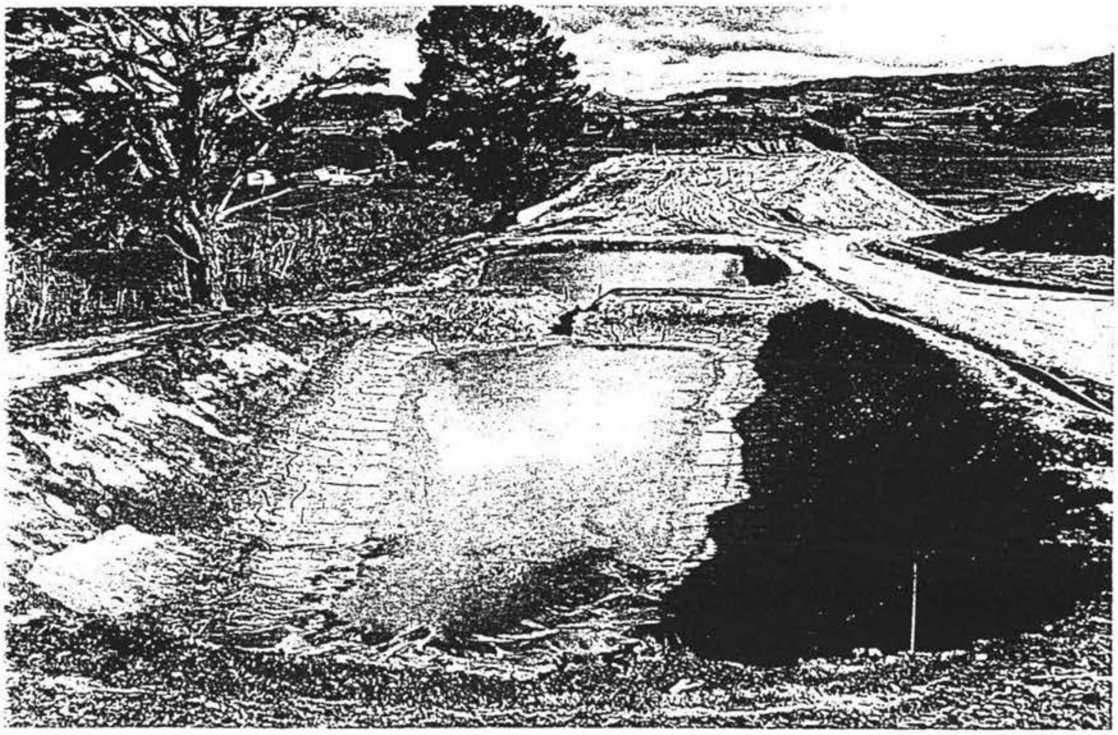


Figure 4.6 - Both Ponds Filled With Tailings. ("Dry" Pond in Foreground).

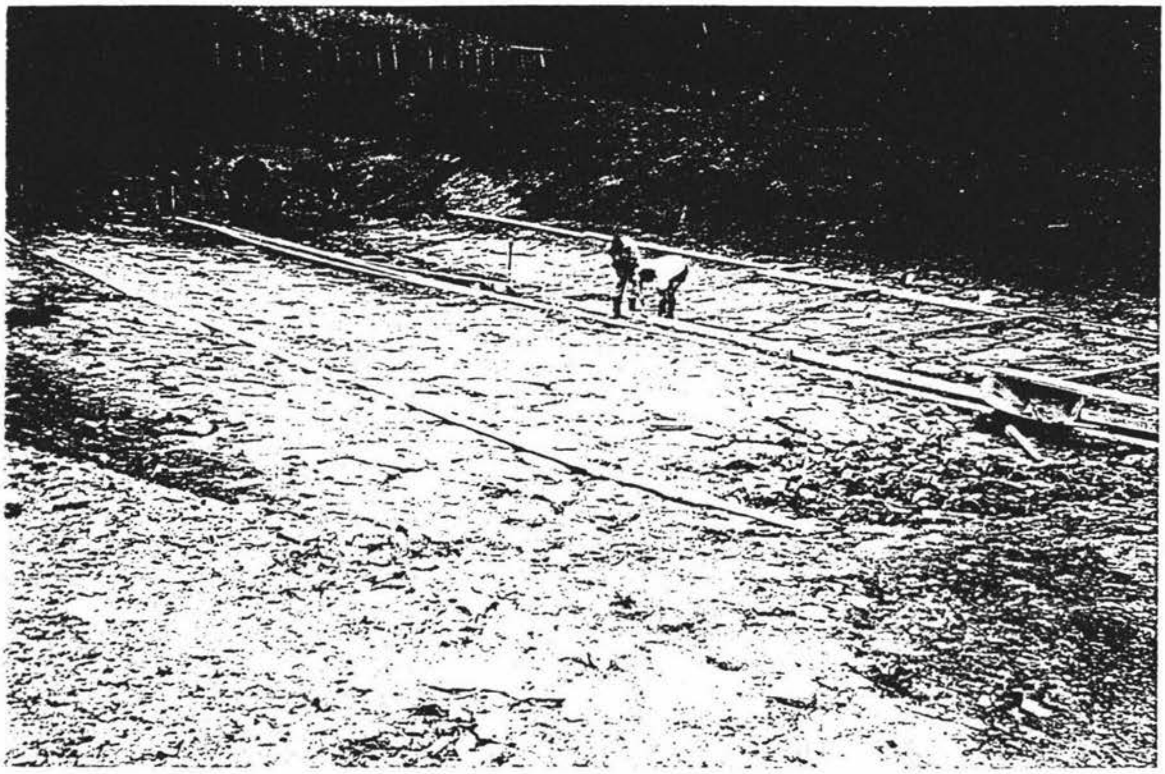


By 30 April 1992, the ponds were full, and were left to dry out such that they could be walked upon to install drainage. A cutoff drain was installed around the outside of the dry pond and a pipe was installed down the middle of the dry pond to divert water to the wet pond, (Figure 4.7). Although planting was carried out in the wet pond, the plants were not measured. For the purposes of this thesis, only the dry pond will be considered.

In February of 1993, boards were laid to mark out the plots. At this stage, tailings settlement had commenced with cracking to 30 cm evident as shown by Figure 4.7. All plots were completely dug over by hand to remove the cracks prior to preparation for sowing and planting.

Figure 4.7. Marking Out the Tailings Plots. (April 1993).

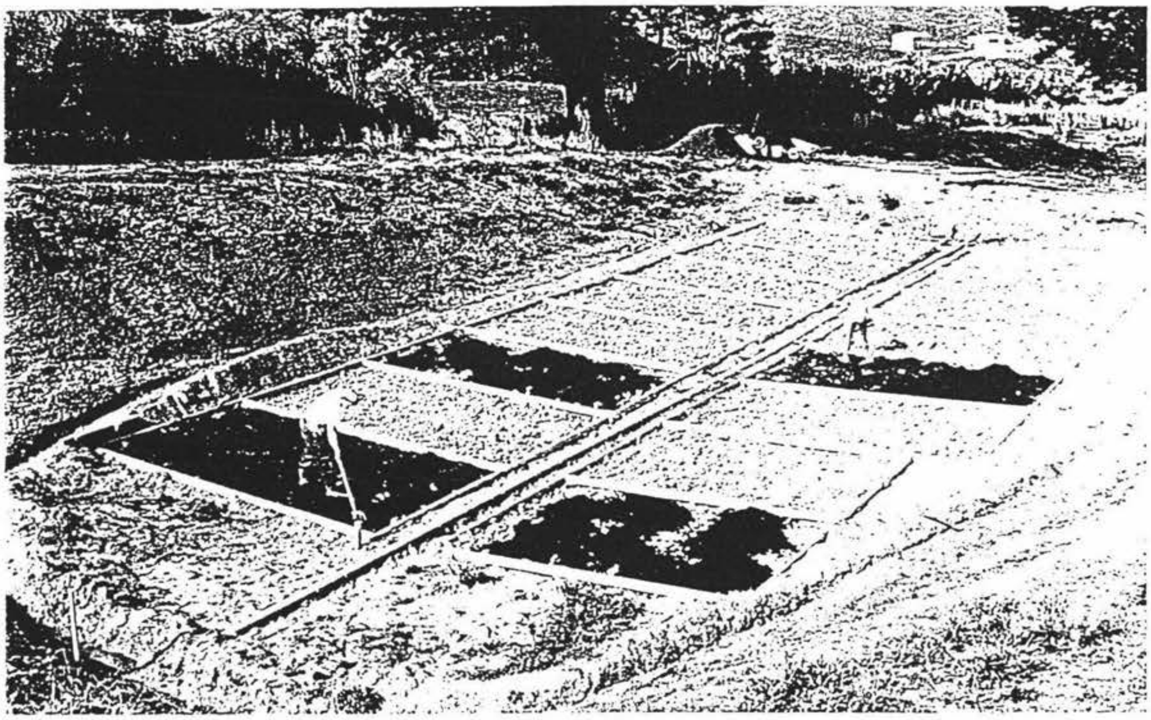
(Note cracking of the surface).



4.2.2.2. GRASS TRIAL.

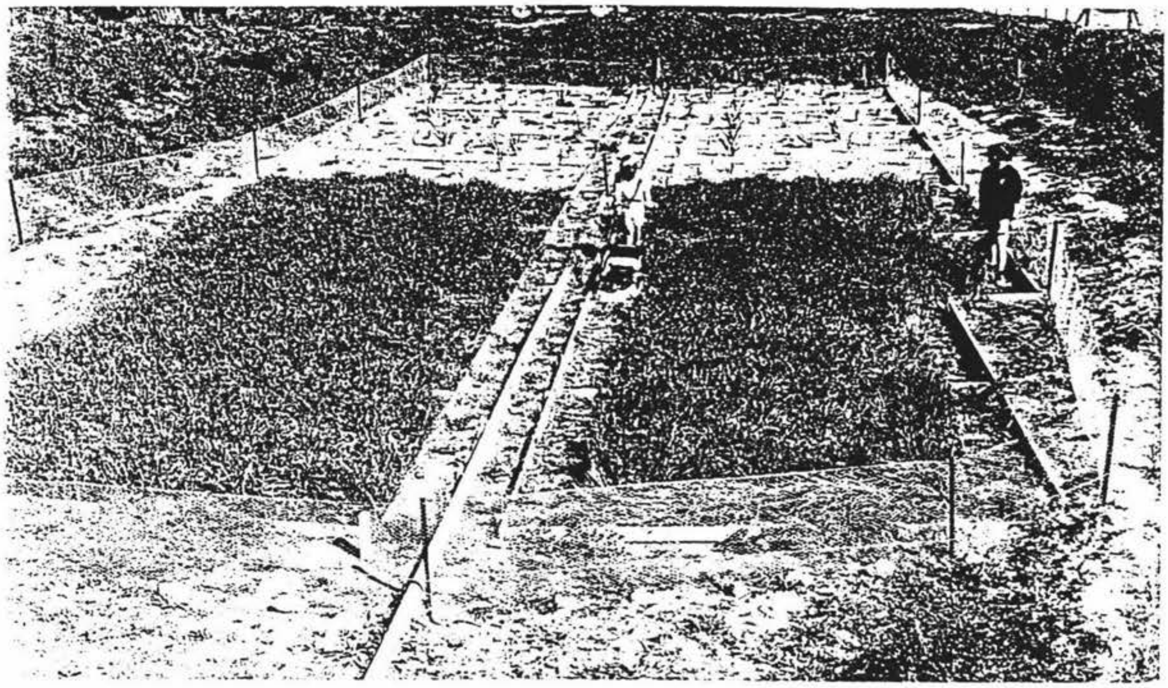
Because of the way the ponds were constructed, two of the grass plots had to be smaller in area than the rest. Once the plots had been dug over, half of them had compost applied to a depth of 50 mm, (0.8 m^3 on the longer plots), as shown by figure 4.8.

Figure 4.8 - Applying Compost to the Tailings Plots (May 1993).



All plots were then fertilised with 700 kg/ha 15% potassic superphosphate, followed by raking in to form a firm seed bed. Grass seed (ryegrass and clover) was sown at a rate of 50 kg/ha on 24 May 1993. Figure 4.9 shows the grass plots three months after establishment.

Figure 4.9 - Tailings Pasture Plots (October 1993).



Growth Measurements.

When grass growth reached 10 cm, the pasture plots were mown, with approximately 50% of the clippings returned to each plot. Five cuts were taken between 4 October 1993 and 4 November 1994. In 1994, stockpiles of resurfacing material were being placed around the plots and at the end of 1994, some of this material washed onto them, to a depth of approximately 10 cm. At this point the grass trial was terminated as all plot vegetation was covered by resurfacing material. The sequence of events associated with trial conduct is summarised in table 4.6.

4.2.2.3. NATIVE PLANT TRIAL.

It was decided that the native plants with a compost treatment would have compost applied in a defined area around the roots. The plants used were of PB3 size, ie 3 pint volume, except for the flaxes which were bare-root stock. PB3 plants have a possible root volume of 13cm diameter x 13cm depth. The decision was made to dig out an extra 6 cm depth and width for each planting hole to allow backfilling with compost as shown in Figure 4.10.

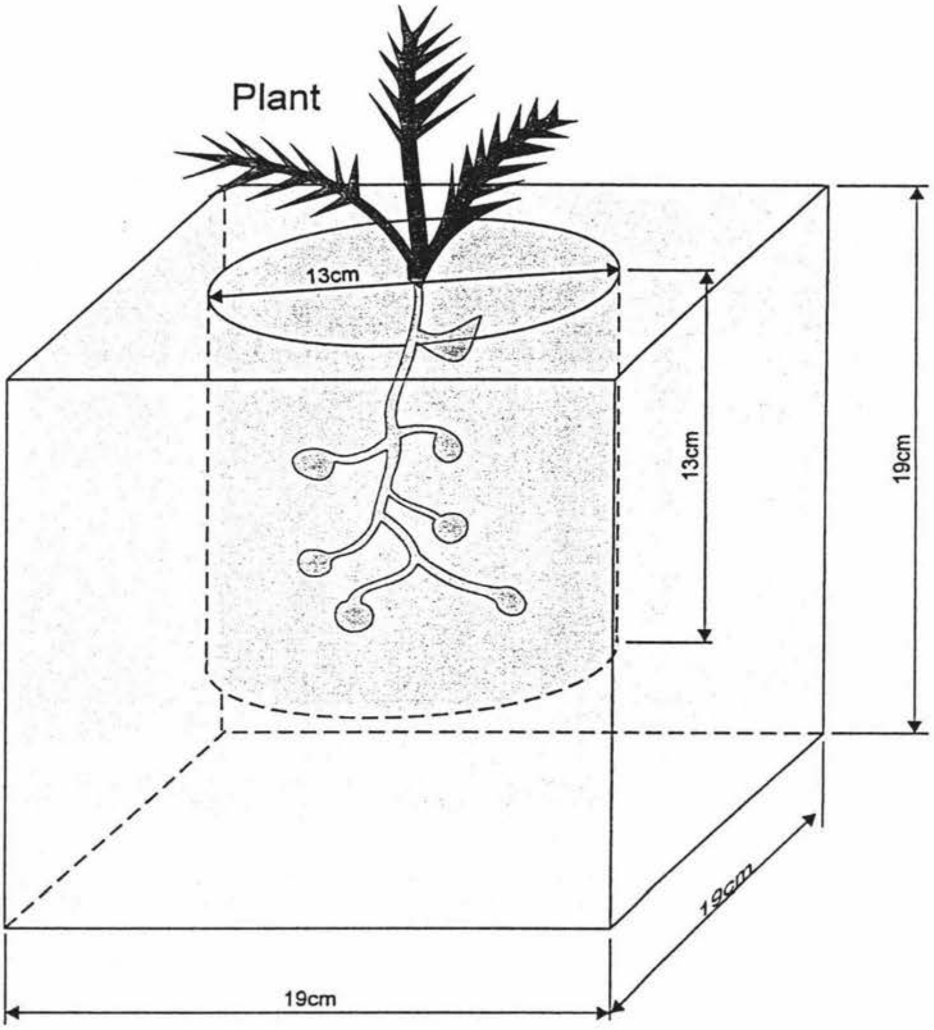
To avoid physically biasing the plants amended with compost, the plants backfilled with tailings had the same sized planting holes prepared. The flaxes had the same sized planting holes as other species, but some required a greater quantity of backfill given that they were bare rooted plants.

Plants were randomised within plots, with each plot having sixteen plants, and four of each species, as shown by figure 4.11.

The Taupo Native Plant Nursery staff were consulted regarding the fertiliser that could be used on the native plants used in the tailings trial. Based on their advice, it was decided that following planting, all plants would be fertilised with 16 g Plantacote fertiliser, applied to the soil surface close to the plants. Details regarding Plantacote fertiliser are given in appendix 4.4.

Measurements of the native plants were undertaken shortly after planting in November 1993, May 1994 and December 1994. Kanuka, pittosporum and cabbage tree were measured for total height and for flax, the longest leaf and number of leaves per plant were recorded.

Table 4.6 summarises the sequence of methods used.



KEY

☐ Backfill material (tailings or compost).

For PB3 plants
volume applied as backfill = 6 litres,
For bare rooted plants
volume applied as backfill = 8 litres.

Dimensions of Plant Root Volume
and Planting Hole
for Natives on Tailings Trial

Figure 4.10

Figure 4.11 - Native Plant Trial Plots on Tailings (October 1993).

Table 4.6 - Activities Associated With Conduct of the Tailings Trial.

Date	Event
By 30 April 1992	Plants Filled With Tailings
February 1993	Boards Laid to Mark Out Plots, Analysis of Compost and Tailings.
April-May 1993	Plots dug over, compost and fertiliser applied to grass plots.
24 May 1993	Grass seed sown
August 1993	Planting and fertilising of native species
4 October 1993	First grass cut
19 October 1993	Herbage sampled from grass plots
November 1993	Native plants measured
18 November 1993	Second Grass Cut
11 February 1994	Third Grass Cut, Plots Sampled for Moisture Content
May 1994	Native plants measured second time
24 August 1994	Fourth Grass Cut
4 November 1994	Fifth Grass Cut
December 1994	Native plants measured third time
December 1994	Grass Plots Soil Sampled

CHAPTER 5.0 -

RESULTS AND DISCUSSION.

5.1. UNOXIDISED ROCK TRIAL

Although the original objective of this trial was to investigate the growth of native plants on an acid producing pit slope, the trial area became an investigation of grass growth also. Hydroseeding was carried out on the trial area after planting, to the detriment of some native plants used in the trial, particularly the akeakes which suffered salt burn. However visual observations of the survival of the grass and subsequent soil tests provided some interesting information on how grass growth was affected by the pH of the substrate. The following results therefore, refer to the survival and growth of both native plants and grass on the North Wall trial area.

5.1.1 NATIVE PLANT TRIAL.

5.1.1.1. SPECIES SURVIVAL RATE OF THE NATIVE PLANTS (OVER ALL TREATMENTS).

Measurements of the native plants were carried out shortly after planting in April 1993, and again in October 1993 and February 1994. Survival rates were calculated over three time periods, to investigate which species survived the first six months, which survived the following four month summer period, and which survived the overall ten month period. The results, (given in appendix 5.1.1) were statistically analysed using the analysis of variance. Species with different letters for the T grouping are significantly different. Species survival rates are shown in Table 5.1.1.

Table 5.1.1 - Overall Species Survival Rates on the North Wall. (Alpha = 0.05, df = 20, Critical Value of T = 2.09)

Interval 1 - April 1993 to October 1993. (MSE = 0.016022, LSD = 0.167).			Interval 2 - October 1993 to February 1994. (MSE = 0.022608, LSD = 0.1984).			Interval 3 - April 1993 to February 1994. (MSE = 0.018593, LSD = 0.1799).		
Species	Ratio Surviving	(5%) T Grouping	Species	Ratio Surviving	(5%) T Grouping	Species	Ratio Surviving	(5%) T Grouping
Toetoe	0.9800	A	Toetoe	0.9800	A	Toetoe	0.9600	A
C. kirkii	0.8392	BA	Kanuka	0.9333	A	Flax	0.6753	B
Akeake	0.7565	BC	Manuka	0.9214	A	Akeake	0.6483	B
Flax	0.7533	BC	Flax	0.8931	A	Manuka	0.5567	CB
Manuka	0.6000	DC	Akeake	0.8432	A	Kanuka	0.4200	C
Kanuka	0.4422	D	C. kirkii	0.4810	B	C. kirkii	0.4103	C

Toetoe was significantly the best survivor over all treatments over the entire ten month period. Akeake, despite being obviously damaged by hydroseeding, survived relatively well as did flax. Several akeake plants were snapped off by rocks rolling downslope but appeared to be able to regenerate well from the base.

Kanuka and manuka had relatively poor survival rates over the first six months, but those plants that did survive had good survival rates over the following summer. In contrast the creeping coprosma (C. kirkii) survived well in the first six months but tended to die out over summer. This is consistent with the advice of Brown pers comm (1995) that C. kirkii requires regular watering.

Brown, pers comm (1994) reports that larger plants are able to tolerate physiological stress better than smaller plants. With akeake and toetoe being purchased as PB3 size, they may have had some size advantage over the other species purchased as root-trainer size.

5.1.1.2. EFFECT OF TREATMENT ON SPECIES SURVIVAL RATE.

The following table shows the differences in survival rate within each treatment for the time intervals from planting to October (first six months), October to February (following four months) and from planting to February (overall ten months).

Table 5.1.2 - Effect of Treatment on Survival of Native Plants. (Alpha = 0.05, df = 20, Critical Value of T = 2.09).

	Interval 1 - April 1993 to October 1993. (MSE = 0.016022, LSD = 0.1524)		Interval 2 - October 1993 to February 1994. (MSE = 0.022608, LSD = 0.1811)		Interval 3 - April 1993 to February 1994. (MSE = 0.018593, LSD = 0.1642).	
Area	Proportion Surviving	(5%) T Grouping	Proportion Surviving	(5%) T Grouping	Proportion Surviving	(5%) T Grouping
E - topsoil	0.8827	A	0.9833	A	0.8660	A
D - topsoil + lime	0.7481	AB	0.8681	AB	0.6315	B
C - topsoil + fert	0.7127	B	0.7540	B	0.5418	CB
B - topsoil + fert + lime	0.6666	B	0.8571	AB	0.5630	CB
A - fert + lime	0.6299	B	0.7475	B	0.4549	C

Over the first six months, treatment E (topsoil) showed significantly better survival rates than treatments C (topsoil + fert), B (topsoil + fert + lime) and A (fert + lime). Over the following four months of summer (interval 2), survival was significantly better for treatment E (topsoil) than for treatment C (topsoil + fert) and treatment A (fert + lime).

Over the first ten months (interval 3), treatment E (topsoil) showed significantly higher survival rates than all other treatments. Treatment D (topsoil + lime) showed a significantly better survival rate than treatment A, (fert + lime), but differences between treatments B (topsoil + fert + lime), C (topsoil + fert) and A (fert + lime) were not significant.

The results suggest that the addition of topsoil only to the planting holes had a beneficial effect on the overall survival of native plants, more so than the addition of lime and fertiliser in this trial. One question that arose however, was the possible variability of the blue rock across the trial area and its effect on treatments. Soils were sampled to determine possible differences in the rock type between treatments - (see section 5.1.3.2.)

5.1.2. GROWTH MEASUREMENTS OF CORTADERIA TOETOE.

With toetoe being the best survivor, it was decided to investigate the mean rate of growth over the first six months, and following four months. This was carried out by comparing the mean number of leaves measured shortly after planting, six months following in October 1993, and in February 1994. A full set of results is given in appendix 5.1.2. The results of the Analysis of Variance statistical test is summarised in Table 5.1.3.

Table 5.1.3. Mean Leaf Number of C. toetoe. (Alpha = 0.05, df = 134, MSE = 382.0469, Critical Value of T = 1.98, LSD = 7.7317).

Time of Measurement	Mean Leaf Number	T Grouping
April 1993	24.3	B
October 1993	38.1	A
February 1994	42.6	A

The results show that C. toetoe made significant growth over the first six months. Over the four months of summer, significant growth was not made.

5.1.3. GRASS TRIAL.

After the native plant trial had been established, the whole of the North Wall exposed at that time was hydroseeded. This included the native plant trial area. It was noticed that within several months, patches of hydroseeded grass were beginning to die. In some cases there was a definite boundary between healthy grass, and dead grass (Figure 5.1.1). The shallow soil which had formed on the rock surface was sampled, based on plant health, and analysed for pH to determine why some of the grass was dying (described in section 5.1.3.1).

Figure 5.1.1 - Patchy Grass Survival on Treatment Area A of the North Wall Trial.

5.1.3.1. Soil Analyses 1993.

When well defined areas of dead grass were noticed on the North Wall, soil samples were taken in an effort to determine the cause of plant death. It was decided that sampling should include the native plant trial area, but it should also extend to the most western and eastern sides of the North Wall to incorporate ash materials present at these locations. Samples were taken based on plant health, with the colour of the substrate being noted. The results are given in table 5.1.4.

Table 5.1.4 - Soil pH and Plant Health, North Wall, 10 November 1993. (Sampling from East to West).

LOCATION/ MATERIAL TYPE.	PLANT HEALTH.	pH (H_20).	pH (H_2O_2).
Ash on Eastern Corner.	Grass Growing Well.	3.9	2.3
Blue Material.	Grass Dead.	2.2	1.4
Blue Material - start of Treatment A.	Grass Dead.	2.3	1.4
Blue.	Grass Dead.	2.2	1.5
Blue/brown.	Grass Dead.	2.3	1.5
Blue rock turning brown, very hard, above boulders.	Grass Alive.	6.6	2.5
Blue - above boulders.	Grass Dead.	2.4	1.6
Blue rock turning brown above boulders.	Grass Dead.	3.6	1.9
Treatment B. Blue rock with brown staining.	Grass alive but surrounded by dead. See below	6.1	1.7
Treatment B. Blue rock with brown staining.	Grass growing in definite patches. Dead just here.	2.8	1.4
Blue. Treatment C.	Grass growing well.	7	2.5
Blue. Treatment D.	Taken from healthy area but patches dying.	7	3.8
Blue and wet. Treatment D.	Healthy grass.	6.3	2.2
Treatment E. Blue with brown staining.	Some healthy clover, some red and small.	4.5	3.9
Blue/reddish brown mixture.	Grass dead.	2.3	1.7
As above.	Grass dead.	2.4	2.1
Blue. Eroding, sandy texture.	Healthy grass, clover, lotus	6.5	4.9
Blue with brown staining.	Grass dead.	2.3	1.7
Blue. Fine texture.	Healthy ryegrass/clover.	6.5	3.4
Blue rock outcrop similar to South Wall. Turning brown.	Grass dead.	2.4	2
As Above.	Grass dead.	2.5	2
Edge of Acid Area.	Grass dead.	2.5	2.2
Steep western corner. Brown, fine texture material.	Healthy grass.	4.5	3

In all cases, grass was healthy where the pH of the underlying material was above 6.0. On ash at the eastern end of the trial area, and brown oxidised rock at the western end of the trial area, healthy grass was growing in a pH of 3.9 and 4.5 respectively. However on the blue rock areas, clover began to show poor growth at a pH of 4.5, and at a pH of 3.6 and below, all grass was dead.

It was interesting to note that after seven months since cutting back the North Wall, some areas of the trial had decreased in pH to as low as 2.2. These results are consistent with the work of Miller (1985) who showed that after 220 days in a leachate column, unoxidised pyritic waste produced a leachate of pH 2.5.

Variability in the pH of the blue rock substrate was thought to be due to the presence of calcite veins in the host rock, which had the effect of increasing the pH in localised areas. Calcite veining is shown in figure 5.2.

Figure 5.1.2 - Calcite Veining on the North Wall (August 1994).

5.1.3.2. ADDITIONAL INVESTIGATIONS.

When the native plant trial was initiated, it was assumed that all blue rock material was homogeneous in its ability to produce acid. When grass after hydroseeding began to die in patches, and large pH differences were noted between dead and live grass, further questions were raised. These questions were:

1. Although local variations in pH were known to exist, were there differences between the treatment areas such that the trial may be biased? (This was particularly so for treatment A which looked to have visibly less live grass than area E).

And:

2. Did the native plants require the same pH conditions for survival as the grass, or were native plants more tolerant of low pH conditions?

To attempt to answer these questions, soil samples were taken from the trial area in 1994. (The term "soils" is used loosely to describe the thin surface soil developing on the rock surface). Grab samples were taken in an endeavour to be representative of each treatment, testing areas where grass and native plants were surviving, (since only a small amount of grass was surviving in Area A, no sample was taken), where everything had died and where the grass had died but native plants had survived. A separate sample was also taken from the oxidised waste noise bund on Junction Rd outside the mine, where various tree and shrub species including toetoe, flax and manuka were growing well. (Note that this area was limed before planting).

Samples were tested for bulk density (in the laboratory, not the field), and a range of chemical tests as described below. The laboratory sheets and methods of analysis for these tests are contained in Appendix 5.1.3. This would allow question one above to be investigated.

Answers to question two were complicated by the fact that the material in the boreholes containing the native plant roots could conceivably be quite different to the surface soil samples taken to investigate rock type variability between treatments, and described below. For this reason, soil samples were collected from within the boreholes in November 1995 and tested for pH, with the results described in Section 5.1.4.

a. Bulk Density.

Results for bulk density are given in Table 5.1.5. They are very similar to those measured in reconstituted cores by Widdowson *et al* (1984). It should be noted that these samples were scraped from the surface, and not taken with a cylinder as with a normal soil bulk density taken in the field. The results, therefore, tend to make the bulk density look more favourable than the field situation. In practice, the roots tend to form a mat over weathered surface material, and appear unable to penetrate the harder rock beneath, at least in the early stages after cutting back and grassing. The bulk density of the underlying rock is expected to be higher than that measured in surface samples.

Table 5.1.5 - Bulk Density and pH in Relation to Plant Health, North Wall.

Area	Plant Health	Bulk Density (g/ml)	pH (H_20)
a	Grass & Natives Dead	1.05	2.2
b	Grass & Natives Dead	0.99	2.2
c	Grass & Natives Dead	0.89	4.8
d	Grass & Natives Dead	0.98	2.2
e	Grass & Natives Dead	1	2.7
b	Grass & Natives Alive	0.93	6.9
c	Grass & Natives Alive	1.03	6.7
d	Grass & Natives Alive	0.87	6.3
e	Grass & Natives Alive	0.88	6.2
a	Grass dead, Natives Alive	1.11	2.3
b	Grass dead, Natives Alive	0.89	2.2
c	Grass dead, Natives Alive	0.93	3.7
d	Grass dead, Natives Alive	0.97	3
e	Grass dead, Natives Alive	1.02	3.5
Junction Rd bund	Healthy flax, toetoe etc	0.77	6.4

b. pH.

As shown by Table 5.1.5, grass growth was found to be healthy where the pH was approximately 6 or higher, confirming the results taken in November 1993 and previously described. The native species were surviving in material with a surface pH as low as 2.2 which is recognised as being extremely acid (Blakemore 1981).

Where the native plants survived but the grass was dead, the pH tended to be lower towards the east of the trial area (ie towards treatment area A) than the west (ie towards treatment E). This may account for the better survival rates in Area E than Area A, particularly if the plant roots were moving out of the boreholes and being affected by the surrounding material.

Sampling was undertaken to investigate the variation of pH in blue rock with depth and these results are shown in Table 5.1.6.

Table 5.1.6 - pH Measurements Over Various Depths on the Trial Area, (15 March 1995).

Description	pH (H_2O)
Area A. Surface sample, 0 - 5 cm. Grass dead.	2.8
Same area as above but 5 cm depth into dark brown material. Hit rock at 7 to 8 cm.	2.9
Area A, next to boulders, 0 - 5 cm depth. See next two samples.	2.6
Area A next to boulders, about 6 cm deep.	2.4
Area A next to boulders, 15 cm deep. Hit rock at 19 cm.	2.3
Area E surface sample. Grass dead. Brown material.	2.3
Area E, as above but 7 cm deep. At the blue/brown boundary.	2.3
Area E, depth 17 cm. Grass dead. Mostly blue material, almost to rock.	2.3
Area A, next to healthy flax but grass dead. Surface sample.	2.3
Area A, next to healthy flax but 5 cm deep into brown soil.	2.3

The last two measurements are interesting because it was noted that the flax plant had no surface roots at all in the top 5 cm, where the pH was 2.3. The roots appeared to be moving down the drill hole. The pH within the drillhole was not measured, but it is possible that there may have been calcite at depth or in the back fill material.

c. Exchangeable Calcium.

When interpreting the results of the chemical tests, it must be kept in mind that many of the standard analytical procedures for Ca, Mg, K and P were designed for use with weathered natural soil systems, and care must be taken in their application when blasted or sheared rock fragments are the growing medium.

Levels of exchangeable calcium were in all cases very high in surface soil samples taken in the areas of treatment C (topsoil and fertiliser), D (topsoil and lime) and E (topsoil), (see table 5.1.7). This was independent of plant survival. Area A had a low exchangeable calcium content where the plants were dead and a medium level where the grass was dead but natives were alive. Area B had a medium level where all plants had died, a high level where the grass had died but natives survived, and a very high level where grass and natives were growing. This tends to support the theory that the trial was biased, with the areas on the eastern end (around Area A) possibly having less calcite to produce calcium than towards the western end (around treatment E). Visual observation by a geologist of the rock types tends to confirm this (Fredricksen pers comm 1994). In terms of grass growth and survival and the health of the native plants, the visual effect is evident between areas A and E as shown in the following figures.

Figure 5.1.3 - General View of Treatment A Area (December 1994).

Figure 5.1.4 - General View of Treatment E Area (December 1994).

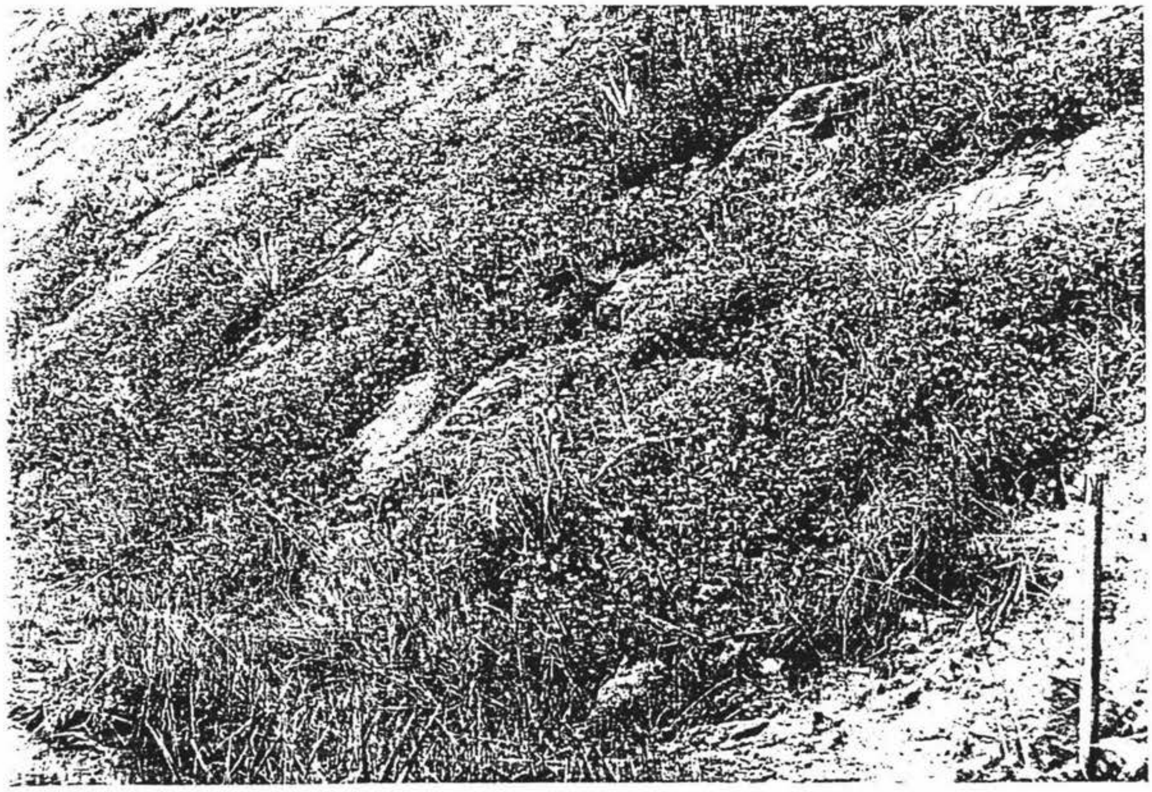


Table 5.1.7 - Levels of Exchangeable Ca, Mg, K, and Na and Their Ratings According to Soil Levels. (From Blakemore *et al.* 1981).

Treatment Area	Plant Health	Ca me/100g	Rating	Mg me/100g	Rating	K me/100g	Rating	Na me/100g	Rating
a	GND	3.8	Low	0.63	Low	0.15	V low	<0.05	V low
b	GND	7.4	Med	1	Low	0.16	V low	<0.05	V low
c	GND	27.2	V high	1.11	Med	<0.1	V low	<0.05	V low
d	GND	35.7	V high	1.41	Med	<0.1	V low	<0.05	V low
e	GND	53.6	V high	1.18	Med	<0.1	V low	<0.05	V low
b	GNA	38.7	V high	1.1	Med	0.23	V low	0.06	V low
c	GNA	37.1	V high	1.28	Med	0.18	V low	0.05	V low
d	GNA	42.5	V high	1.29	Med	0.29	V low	<0.05	V low
e	GNA	25.7	V high	1.46	Med	0.21	V low	<0.05	V low
a	GDNA	5.1	Med	0.53	Low	0.1	V low	<0.05	V low
b	GDNA	16.3	High	1.07	Low	0.1	V low	0.08	V low
c	GDNA	21.4	V high	0.78	Low	0.13	V low	<0.05	V low
d	GDNA	64.5	V high	0.81	Low	<0.1	V low	<0.05	V low
e	GDNA	25.7	V high	1.23	Med	<0.1	V low	<0.05	V low
J Rd bund	Healthy flax etc	12.1	High	1.67	Med	0.4	Low	0.07	V low

where: GND = Grass and Natives Dead
GNA = Grass and Natives Alive
GDNA = Grass Dead, Natives Alive

d. Exchangeable Magnesium.

Table 5.1.7 shows a similar trend for exchangeable magnesium as for exchangeable calcium. Where the plants all died, magnesium was low in surface samples taken in the areas of treatments A and B, and at medium levels taken in the areas of treatments C, D and E. Where all plants had survived, exchangeable magnesium was at medium levels, and in areas where the grass had died levels were generally low except for the sample taken in the area of treatment E which was medium.

e. Exchangeable Potassium.

Exchangeable potassium levels were in all cases very low. Torckler pers comm (1995) suggested that total levels of potassium, magnesium and sodium in unoxidised waste material would initially be relatively low on exposure of the pit slope, but that K_2O could be present as the minerals adularia or illite in this system.

Combined with low initial total potassium levels, it is assumed that potassium is being bound within the soil, (by far the greatest part, perhaps 90-98% of all soil potassium in a mineral soil is in relatively unavailable forms) and therefore shows a very low value as exchangeable potassium. This could happen in a number of ways including fixation by clay minerals, or fixation caused by high levels of calcium carbonate. Applications of lime may result in an increase in potassium fixation by soils, (Brady 1984) and potassium deficiencies have been noted in soils with excess calcium carbonate. It is also noted that jarosite contains potassium. Jarosite was present at the base of the pit slopes. Palmer (1978) found that at low pH levels in colliery wastes, potassium was precipitated as jarosite and the level of plant available potassium was greatly reduced.

f. Exchangeable Sodium and the Implications For Soluble Salts.

Sodium is present at very low levels in all the samples taken. Soluble salts were not tested for, however Hill pers comm (1995) stated that given the very low levels of sodium and potassium in these tests, there would almost certainly be no problem with soluble salts affecting plant growth and survival. The only problem that may arise would be with $CaSO_4$ (gypsum), however this is sparingly soluble. eg a saturated solution of $CaSO_4$ has a conductivity of 2.2 mS/cm at 25°C. This is approximately half the value deemed to be critical for glasshouse tomatoes. Gypsum does appear on the pit walls, as shown by Figure 5.1.5.

Figure 5.1.5 - Gypsum Precipitation on the North Wall (August 1994).

It is interesting to note that Widdowson *et al* (1984) found that soluble salts were likely to cause major problems in this material. It would be worth carrying out soluble salts tests, should further trials be established. It may be that in high rainfall conditions such as those in Waihi, soluble salts may not be a problem compared to those experienced in a glasshouse pot trial.

g. Cation Exchange Capacity (CEC) and Base Saturation Percentages.

As shown by Table 5.1.8, total base saturation percentages tend to increase moving from east to west across the trial area. The lower total base saturation percentages appear to be directly related to lower base saturation percentages for calcium.

Table 5.1.8 - Cation Exchange Capacities and Base Saturations For the Trial Area.

Area	Plant Health	CEC me/100g	Rating	B. Sat %	Rating	Ca %BS	Mg %BS	K %BS	Na %BS
a	GND	20	Med	23	Low	19	3.1	0.7	0.1
b	GND	34	High	25	Low	22	3	0.5	0.1
c	GND	38	High	75	High	72	2.9	0.2	0.1
d	GND	62	V High	60	High	58	2.3	0.2	0.1
e	GND	71	V High	77	High	76	1.7	0.1	<0.1
b	GNA	40	High	100	V High	97	2.7	0.6	0.1
c	GNA	39	High	100	V High	96	3.3	0.5	0.1
d	GNA	44	V High	100	V High	96	2.9	0.7	0.1
e	GNA	27	High	100	V High	94	5.3	0.8	0.1
a	GDNA	26	High	22	Low	20	2.1	0.4	0.1
b	GDNA	45	V High	49	Med	37	2.4	0.2	0.2
c	GDNA	35	High	63	High	61	2.2	0.4	<0.1
d	GDNA	86	V High	77	High	75	1	0.1	<0.1
e	GDNA	36	High	74	High	71	3.4	0.2	<0.1
J Rd bund	Healthy flax etc	14	Med	100	V High	85	11.7	2.8	0.5

Where both grass and native plants are surviving, there is a much higher total percentage base saturation, and this is dominated by calcium. There are no major differences, however between areas of different vegetation for CEC. This is surprising, given that the cation exchange capacity for most soils increases with pH, (Brady 1984). It would be reasonable to expect the CEC of the soils not sustaining grass growth to be relatively low due to the low levels of organic matter and presumably low levels of clay minerals in the soil matrix.

However, Daniels and Amos (1982) reported a significant increase in CEC over six months in an overburden experiment due to carbonate dissolution. It is possible that the apparently high levels for CEC in all of the North Wall samples may be artificially elevated due to the extraction of calcium from calcite, Gregg (pers comm). According to Fredricksen (pers comm) there is more calcite towards the western end of the trial area, which could explain the apparent increase in CEC from East to West where all the plants had died (GND).

h. Carbon and Nitrogen Status.

Organic carbon levels measured in surface samples from the trial area are shown in table 5.1.9. As expected, carbon levels were higher where the grass was growing, and were similar to carbon levels of around 2.3% which can be expected in a humid temperate region surface soil, (Brady 1984). It is important to realise however that these results were from the surface soil and were no more than approximately 40 mm deep. Levels of organic carbon would be expected to be less outside the boreholes of the native plants. The levels on the Junction Rd bund, were also very low, but the native plants growing in this area appeared to be healthy and growing, suggesting that soils with low levels of organic matter can sustain reasonable growth in native colonising plants.

Table 5.1.9 - Levels of Organic C, TKN, NH4-N, and NO3-N, in Relation to Plant Health on The North Wall.

TREATMENT	PLANT HEALTH	ORG C%	TKN %	NH4-N mg/kg	NO3-N mg/kg
a	GND	0.9	0.1	1.9	0.05
b	GND	1.2	<0.1	1.3	0.6
c	GND	1.4	0.1	1.4	0.38
d	GND	1.3	0.1	1.6	0.4
e	GND	0.7	0.1	1.4	0.43
b	GNA	2.3	0.1	1	0.34
c	GNA	2	0.1	0.7	0.38
d	GNA	2	0.1	2.2	1.1
e	GNA	2	0.1	2.8	1.07
a	GDNA	0.7	0.1	1.6	0.6
b	GDNA	1.2	0.1	0.8	0.43
c	GDNA	1.1	0.1	1.3	<0.05
d	GDNA	1.6	0.1	1.5	<0.05
e	GDNA	0.8	0.1	1.4	<0.05
J Rd bund	Healthy flax, etc	1.5	0.1	3	2.3

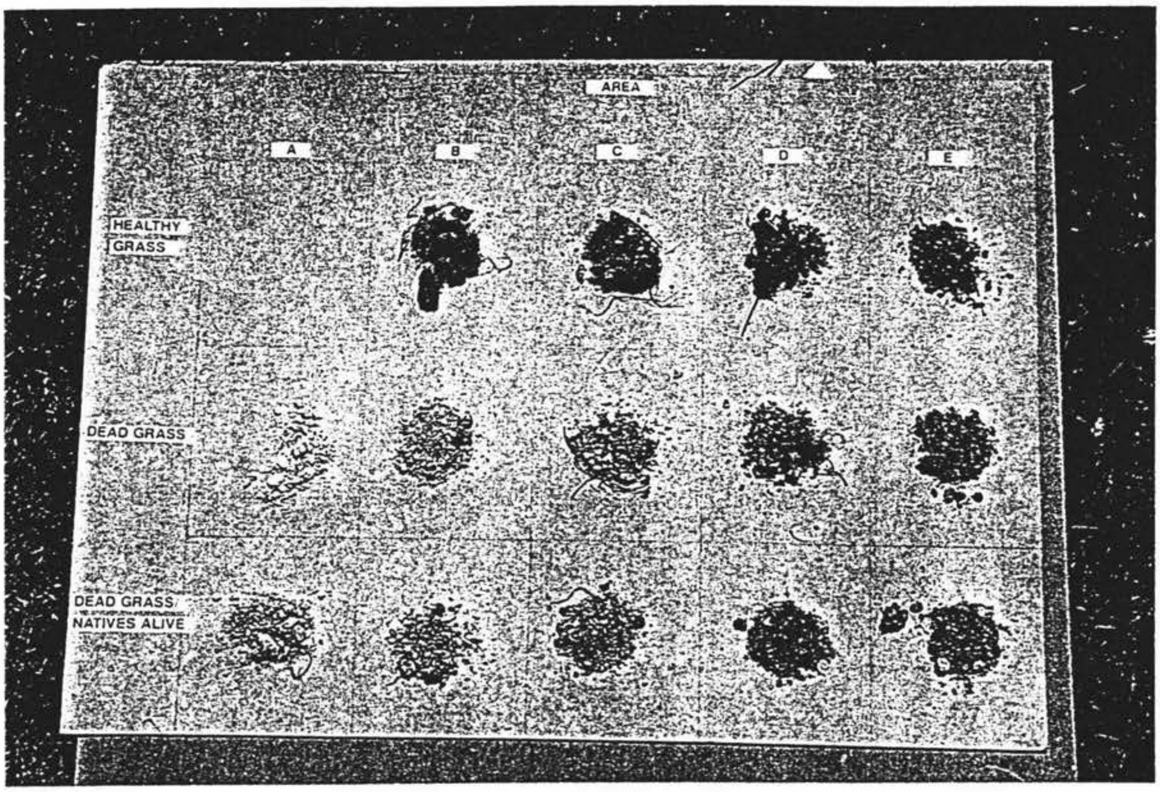
where: GND = Grass and Natives Dead

GNA = Grass and Natives Alive

GDNA = Grass Dead, Natives Alive

Colour changes were observed when the soils were sampled, reflecting the differences in carbon levels, and these are shown in Figure 5.1.6 below.

Figure 5.1.6 - Colour Differences Between Areas Supporting and Not Supporting Grass Growth (January 1995).



As shown in table 5.1.9, total Kjeldahl nitrogen did not show any trends either across treatments or between vegetation types. All levels were very low and were either at, or less than the laboratory detection limit. In comparison a level of 0.15% N is given as a typical value for a cultivated mineral surface soil in a humid temperate region (Brady 1984). In a trial with Waihi tailings, nitrogen levels climbed to 0.14% N in the top 3 cm of a plot which had been sown to pasture for seven years (Mason *et al* 1993). Most nitrogen in surface soils is associated with organic matter, with only 2-3% being mineralised under normal conditions. Given the low levels of organic matter found in these soils, levels of total kjeldahl nitrogen would be expected to be low.

Other sources of nitrogen in a soil include soluble ammonium and nitrate compounds, which seldom make up more than 1 to 2% of the total present (Brady 1994). Ammonium nitrogen levels in the North Wall trial area tests (Table 5.1.9) tend to be substantially higher than nitrate levels, but they are low when compared to the Junction

Rd bund. Ammonium nitrogen levels show no major trends, except that they are possibly higher in treatments D and E where both grass and native plants survived.

Young plants of almost all kinds are able to use ammonium nitrogen, although they seem to grow better if some nitrate is present (Brady 1984). Nitrate levels from the trial area are in all cases low when compared to the Junction Rd bund. Several soil conditions affect the rate of nitrification. They are, a presence of adequate ammonia for oxidation, aeration, temperature, moisture, lime, fertiliser salts and the carbon to nitrogen ratio. Nitrification proceeds most readily where there is an abundance of exchangeable bases. Acidity itself tends to have little influence on nitrification when adequate bases are present (Brady 1984). These analyses show no major trends regarding the relationships between the levels of exchangeable bases and the nitrate present.

i. Phosphate and Sulphur.

As shown in table 5.1.10 below, Olsen P was in general low to very low for all samples. It was found, however, that Olsen P was lower towards the western end (treatment E) of the area sampled. This is the opposite trend to what was found for exchangeable calcium. Similarly, Olsen phosphate levels were lowest where all of the plants were alive (also where calcium levels were very high). It is that it is likely that there was some analytical interference by calcium on the Olsen phosphate test whereby phosphate levels were lowered by calcium complexing with phosphate in the extracting solution, hence giving lower Olsen P values than would be the case in the field (Gregg pers comm 1996).

Soil factors may also have partially contributed to the results seen. Within a soil, the availability of inorganic phosphorus depends on soil pH, soluble iron, aluminium and manganese, the presence of iron, aluminium and manganese-containing minerals, amount and decomposition of organic matter and the activities of micro-organisms. It is possible that one or more of these factors may also be at least partly contributing to the decreasing Olsen phosphate levels from east to west, possibly by one of the following mechanisms.

Most inorganic phosphorus compounds in soils fall into one of two groups: those containing calcium and those containing iron and aluminium. The apatite minerals are extremely insoluble and the phosphorus contained within is largely unavailable (Brady 1984), hence the Olsen P level would be expected to be low if apatite minerals were being formed.

Hydroxy phosphates are phosphorus compounds containing iron and aluminium which are most stable in acid soils and also relatively insoluble, (Brady 1984). Iron was not tested for but it is worth noting that Widdowson *et al* (1984) found levels of iron to be 153 ppm for mixed waste and 122 ppm for pyritic waste, so it is possible that hydroxy phosphates could render phosphorus unavailable to plants in this material. Similarly, aluminium levels, as described in section j (ii), were also found to be high.

Table 5.1.10 - Levels of Phosphate and Sulphur Measured in North Wall Surface Samples.

Area	Plant Health	Olsen P ug/ml	Rating	Total S mg/kg	Sulphate S mg/kg	Rating
a	GND	19	Low	16,300	1,100	V High
b	GND	18	Low	22,200	400	V High
c	GND	10	V Low	38,800	400	V High
d	GND	10	V Low	33,200	1,200	V High
e	GND	10	V Low	18,800	2,100	V High
b	GNA	6	V Low	42,700	800	V High
c	GNA	8	V Low	44,700	200	V High
d	GNA	8	V Low	42,700	1,300	V High
e	GNA	7	V Low	25,700	800	V High
a	GDNA	21	Medium	15,100	1,400	V High
b	GDNA	17	Low	22,000	1,100	V High
c	GDNA	11	Low	30,100	1,000	V High
d	GDNA	11	Low	54,600	1,300	V High
e	GDNA	7	V Low	10,800	2,800	V High
J Rd bund	Healthy flax etc.	3	V low	400	400	V High

where: GND = Grass and Native Plants Dead
GNA = Grass and Native Plants Alive
GDNA = Grass Dead, Natives Alive

In general, the levels for total sulphur are lower at opposite ends of the trial area, ie at the areas of treatment areas A and E. Unfortunately, total sulphur was not measured for each treatment area when the trial commenced. For this reason, it is unknown whether total sulphur was always lower in the areas of treatments A and E. It may be that sulphate has been released more quickly in Area A, resulting in a lowering of total sulphur levels, and that the area associated with treatment E always had lower total sulphur levels, but in the absence of total sulphur results when the trial commenced this is purely speculation.

Sulphate sulphur is in all cases rated as very high for plant requirements. However sulphate concentrations range from 200 to 2800 mg/kg. Williams *et al* (1982) reported that levels around calcite in a trial were as low as 400 mg/l whereas levels in free solution within the waste without gypsum precipitation were much higher, at 900 mg/l. This could partly explain the results seen in this trial as calcite is present in discrete areas and surface sampling did not discriminate between areas with and without carbonate and gypsum.

j. Micronutrient Analysis.

(i) Essential Nutrients.

As shown by table 5.1.11, deficiencies of manganese, zinc and copper would not be expected in these soils.

Interpretation of the toxicity levels is complicated by the use of total levels rather than soluble levels. At low pH, the solubility of metals would be expected to increase and this may be expected to detrimentally affect plant growth, more so than with high total levels with a relatively high pH. This is demonstrated by the high levels of total metals where the grass is growing and the pH is the highest, suggesting that relatively high total levels are not causing plant death in these areas. It is possible however, that toxicity might eventuate should the pH fall.

Table 5.1.11 - Levels of Selected Essential Micro-Nutrient Metals.

Area	Plant Health	pH	Total Mn mg/kg			Total Zn mg/kg			Total Cu mg/kg		
			Defic Level	Trial Level	Toxic Level	Defic Level	Trial Level	Toxic Level	Defic Level	Trial Level	Toxic Level
a	GND	2.2	1	107	1,000	0.8	24	100	0.2	9.4	100
b	GND	2.2	1	230	1,000	0.8	43	100	0.2	10.2	100
c	GND	4.8	1	400	1,000	0.8	57	100	0.2	14.9	100
d	GND	2.2	1	620	1,000	0.8	40	100	0.2	16.2	100
e	GND	2.7	1	280	1,000	0.8	25	100	0.2	14.4	100
b	GNA	6.9	1	1,300	1,000	0.8	102	100	0.2	44	100
c	GNA	6.7	1	1,310	1,000	0.8	79	100	0.2	26	100
d	GNA	6.3	1	1,010	1,000	0.8	63	100	0.2	33	100
e	GNA	6.2	1	490	1,000	0.8	50	100	0.2	20	100
a	GDNA	2.3	1	106	1,000	0.8	28	100	0.2	16.4	100
b	GDNA	2.2	1	230	1,000	0.8	40	100	0.2	9.9	100
c	GDNA	3.7	1	560	1,000	0.8	71	100	0.2	18.1	100
d	GDNA	3	1	420	1,000	0.8	41	100	0.2	21	100
e	GDNA	3.5	1	158	1,000	0.8	23	100	0.2	21	100
J Rd bund	Healthy flax etc	6.4	1	670	1,000	0.8	40	100	0.2	22	100

where: GND = Grass and Native Species Dead.

GNA = Grass and Native Species Alive.

GDNA = Grass Dead, Native Species Alive.

and: Deficiency Level = Concentration at which a plant response might be expected with addition of the nutrient, (Blakemore *et al* 1981).

and: Toxic Level = Trigger Level For Rocks and Soils, (Bowen 1979, Bresler E, McNeal & Carter 1982 and Lindsay 1979, cited in Miller *et al* 1986). Note that trigger levels vary according to various literature sources. These levels tend to be lower than those reported by Alloway (1990) and have been chosen as the more conservative levels.

(ii) Non-Essential Elements.

As shown in table 5.1.12, the levels of extractable aluminium are likely to be inhibiting to plants in the areas where the grass is not growing and the pH is low. Conversely, where the pH is high, extractable aluminium levels are very much lower and grass is able to survive. Note that there do not appear to be any critical levels set for total aluminium in the literature.

It is noteworthy that where the pH is higher (GNA), total nickel levels tend to be higher towards the eastern end of the trial area (treatment B).

Table 5.1.12 - Levels of Selected Non-Essential Metals.

Area	Plant Health	pH	Total Al mg/kg	Extractable Al mg/kg		Total Nickel mg/kg	
			Trial Level	Trial Level	Toxic Level	Trial Level	Toxic Level
a	GND	2.2	22,000	320	0.1-30	18.6	100
b	GND	2.2	28,000	280	0.1-30	25	100
c	GND	4.8	23,000	120	0.1-30	46	100
d	GND	2.2	22,000	270	0.1-30	54	100
e	GND	2.7	18,900	290	0.1-30	23	100
b	GNA	6.9	53,000	9	0.1-30	145	100
c	GNA	6.7	26,000	<9	0.1-30	97	100
d	GNA	6.3	27,000	<9	0.1-30	93	100
e	GNA	6.2	19,200	9	0.1-30	38	100
a	GDNA	2.3	18,600	360	0.1-30	18.4	100
b	GDNA	2.2	29,000	310	0.1-30	21	100
c	GDNA	3.7	24,000	190	0.1-30	47	100
d	GDNA	3	29,000	220	0.1-30	62	100
e	GDNA	3.5	21,000	270	0.1-30	29	100
J Rd bund	Healthy flax etc	6.4	31,000	<9	0.1-30	24	100

where: GND = Grass and Native Species Dead.

GNA = Grass and Native Species Alive.

GDNA = Grass Dead, Native Species Alive

Figures 5.1.7 and 5.1.8 show the results for total and extractable aluminium plotted against pH respectively for all treatments. Figures 5.1.9, 5.1.10, 5.1.11 and 5.1.12 show total manganese, zinc, copper, and nickel graphed as a function of pH. As expected, extractable aluminium is relatively high at low pH, and vice versa. It may be expected that the manganese, zinc, copper and nickel results would have looked similar, if extractable analyses had been carried out for these metals.

The graphs for total metals also show that for Al, Mn, Cu and Zn, total levels at the high end of the pH range are larger for the treatments towards the eastern end of the trial area, ie treatments B and C have higher total metals at a high pH than treatments D and E, which tends to indicate that the trial was biased with respect to the amounts of metals present between overall treatments.

Figure 5.1.7 - Total Aluminium Versus pH For All Treatments.

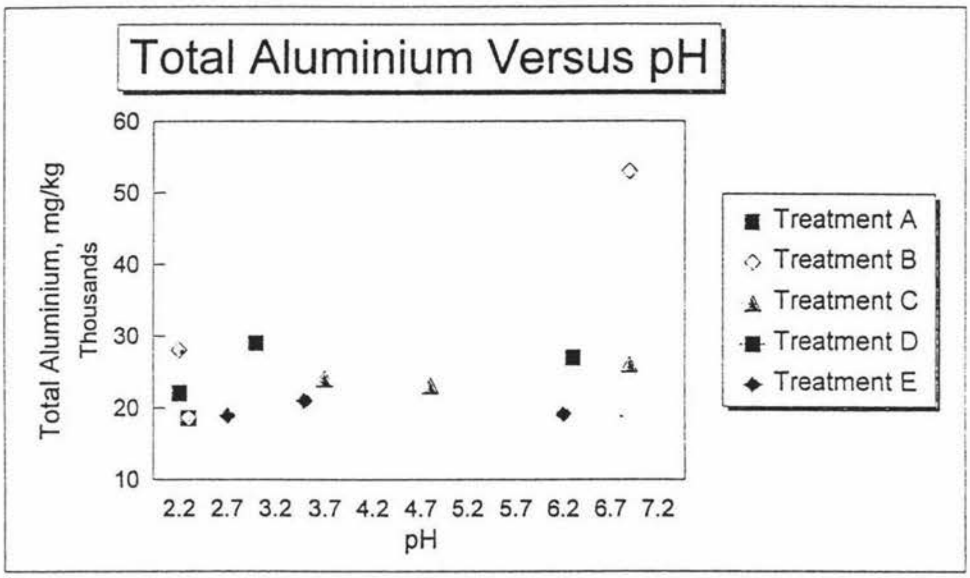


Figure 5.1.8 - Extractable Aluminium Versus pH For All Treatments.

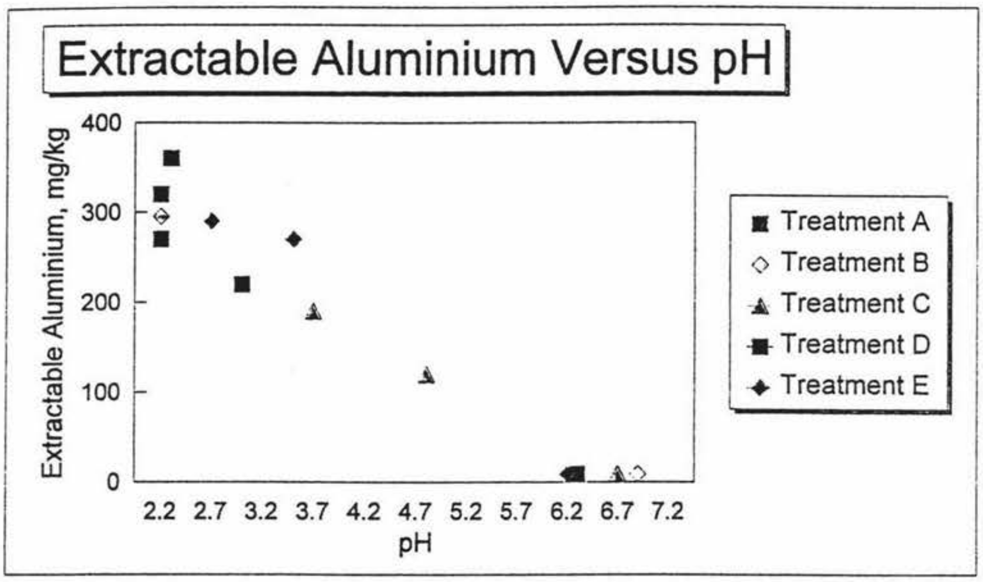


Figure 5.1.9 - Total Manganese Versus pH For All Treatments.

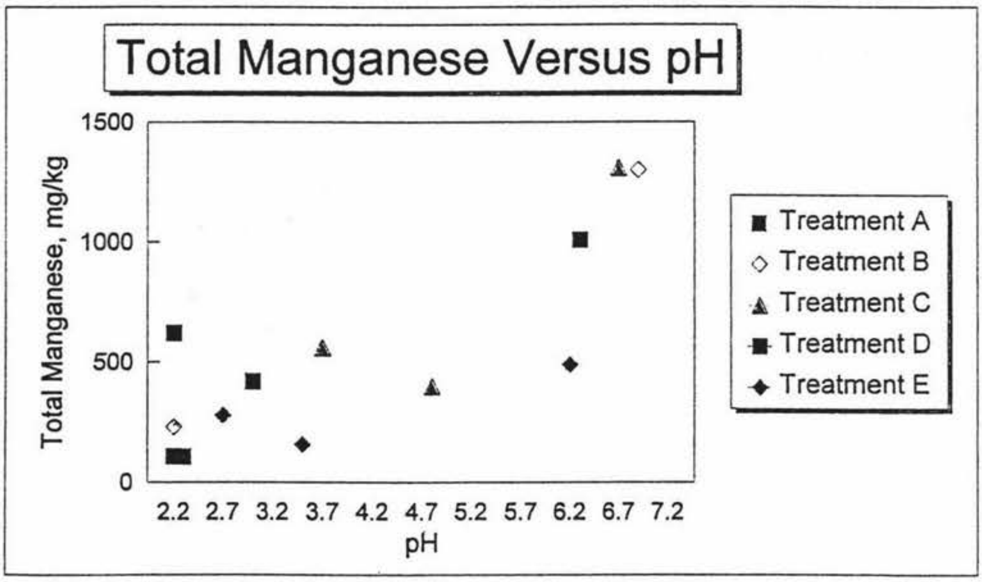


Figure 5.1.10 - Total Zinc Versus pH For All Treatments.

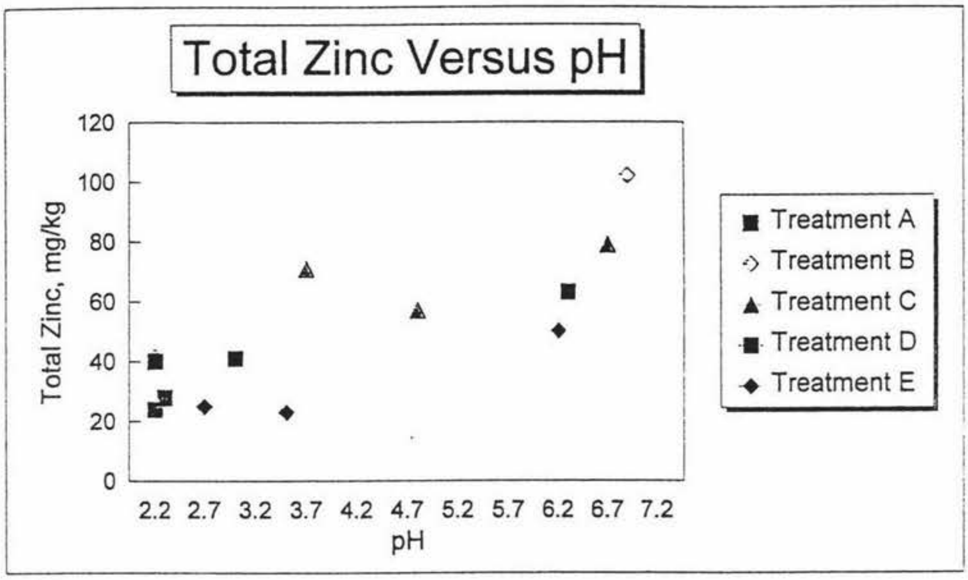


Figure 5.1.11 - Total Copper Versus pH For All Treatments.

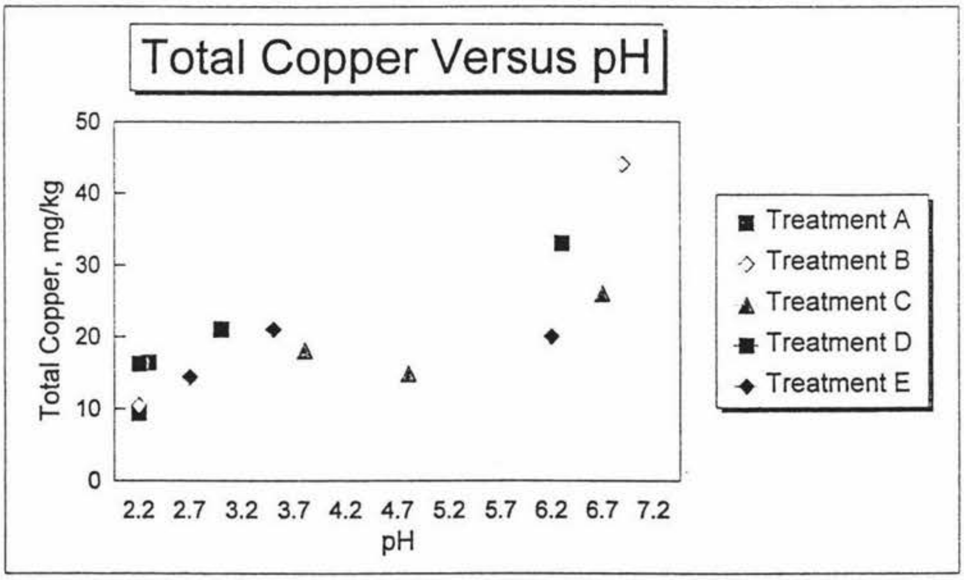
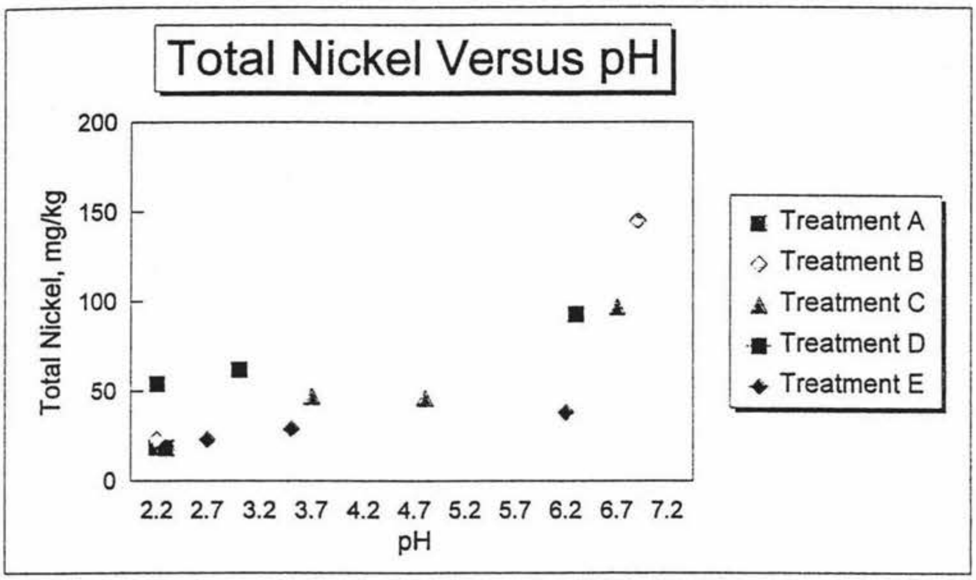


Figure 5.1.12 - Total Nickel Versus pH For All Treatments.



It would appear that native plants are more tolerant to low pH and extractable aluminium than the grasses used in the hydroseed mix. However, the question was raised as to whether the roots of the plants were being affected by the rock type outside of the borehole, discussed below.

5.1.4. SOIL TESTS WITHIN THE BORE HOLES.

Having demonstrated that the rock type on the North Wall where the trial was established was less favourable for plant growth toward the treatment A area than the treatment E area, questions were raised regarding the pH of the soil within the boreholes, and whether the native plant roots were being affected by the surrounding rock type. In November 1995, samples were taken around healthy plants in the vicinity of the boreholes, adjacent to the plant roots. No samples were taken for treatment B because very few healthy plants remained. The samples taken were bulked together for each treatment. Treatment A had a small number of very healthy plants. The native plants in treatments D and E were visibly better than those of the other treatments. The results are shown in table 5.1.13.

Table 5.1.13 - Results of Soil Sampling Within Boreholes.

Treatment	pH (H_2O)
A - no topsoil, fert + lime	2.7
C - topsoil + fert	3.2
D - topsoil + lime	4.6
E - topsoil	6

It would appear that at least in November of 1995, the soil within the borehole was being affected by the surrounding rock type. For treatment A, where no topsoil was added, the pH was the lowest. The original topsoil used was not tested for pH prior to the trial, however it would be expected that the soil would have had a pH of around 5.2 when used for planting. These results tend to reinforce earlier findings which suggested that the trial was biased

What is clear is that material within the borehole was affected by acidity from the surrounding rock type between planting in 1993, and sampling within the boreholes in 1995. What is not clear is the length of time it took for this effect to take place. Within seven months, hydroseeded grass on the area was beginning to die on the surface, so it is probably reasonable to assume that acid generation would not have limited plant growth in the first six month measurement interval, but it may have affected the following four month summer period after which further measurements were taken.

5.1.5. SUMMARY AND CONCLUSIONS.

When considering a strategy for revegetating acid slopes, it is important to realise that arguably the most important reason for doing so, particularly on the North Wall of the pit, is to reduce visual effects. Normally the quickest way to do this would be to sow in grass, which the company attempted by way of hydroseeding.

It was subsequently found that seven months after cutting back of the North Wall, grass was beginning to die in patches, and in some areas the pH had decreased to as low as 2.2. Soluble aluminium was much higher at low pH and it is considered that other metals would follow the same trend.

The rock type was sampled where grass had died, and where it had grown successfully. In all cases, grass was healthy where the pH was above 6.0. Clover began to show poor growth at a pH of 4.5, and at a pH of 3.6 and below, all grass was dead. Carbon levels, as expected, were higher where the grass was growing. As with many mine wastes, phosphorus, potassium and nitrogen were found to be low. Variability in the pH of the blue rock substrate was thought to be due to the presence of calcite veins in the host rock, which had the effect of increasing the local pH.

In the trial with planted native species, the best survivor was Cortaderia toetoe with a 96% survival rate over the first ten months, and a significant growth rate over the first six months. Growth rate was not significant over the following four months and reasons for this could include the onset of acid generating conditions or drought. Manuka and kanuka survival rates were relatively low in the first six months, but those plants that did survive had good survival rates over the following four months. This appears to be common in native plantings, with approximately 50% of the native species planted on the oxidised waste bund in November of 1994 dying due to moisture stress over summer. On the whole, toetoe, manuka, kanuka and flax were considered to be successful; Coprosma kirkii was considered to be unsuccessful and would not be recommended for planting in unoxidised material in the future.

With akeake and toetoe being purchased as a PB3 size, and the other species being purchased as root-trainers, akeake and toetoe may have had some advantage over the other species.

The results suggest that the addition of topsoil to the planting holes had a beneficial effect on the overall survival of native plants, more so than the addition of lime and fertiliser in this trial. The benefits of topsoil were evident over the first six months following planting, and in the subsequent four month summer period. Similarly, Smale and Rogers (1993) found that germination and growth of manuka occurred in a 50% loam, 50% acidic overburden material from the Golden Cross Mine, but no germination resulted in acidic overburden alone. Morrell (1995) found that the addition of composted sewage sludge significantly improved the growth of acid tolerant Festuca rubra var. Merlin on very acidic tailings material. It appears that in general, the addition of organic/soil amendments has a beneficial effect on the growth of grasses and natives in material of a very acidic nature (less than pH 3) from hard rock mining wastes studied in New Zealand.

Elemental analyses of acidic blue rock on the trial area indicated that it is an extremely hostile environment for plant growth. Extractable aluminium was found to increase significantly with reductions in pH, and it was expected that other metals such as manganese, zinc, nickel and copper might behave in the same way. Grass was only surviving in areas with a pH of above 6.0 and pH levels of 4.8 and below were associated with toxic levels of aluminium.

The eastern end of the trial area was found to contain significantly less calcite, less exchangeable calcium and magnesium, lower CEC and percentage base saturation, and possibly more sulphur, total Mn, Zn, Al and Ni than the western end of the trial area. Because of this, the plants growing in treatment A would be expected to be worse off than the plants in treatment E from the perspective of acid generation. This should be considered in the design of further trials, as it tended to bias the treatments.

Of interest, is that some healthy native plants were growing in apparently acid material on treatment A after two years. This raises the following questions:

- How are these plants able to tolerate such low pH conditions?
- How long will they continue to survive and grow?
- How are the roots arranged, ie do they follow discrete areas of calcite? Are they concentrated at depth? What is the moisture regime around the roots of these plants, ie are they tapping into a water supply at depth, or is most moisture obtained from the surface? Is there a mycorrhizal association?
- Is it possible that soil sampling around the roots may not accurately reflect the soil conditions around the roots due to dilution of calcite-containing material with pyritic material?

In considering the success of the native plant trial, it is necessary to reconsider the major reason for revegetating the north wall, which was to reduce negative visual impacts. If a quick cover is desired, the trial showed that this could not be achieved with native species planted at 1.5 m spacings. It was noted however that manuka, kanuka, akeake and toetoe produced seed within the first two years of planting. The viability of this seed was not tested, however plants with the ability to reproduce in an area are worth investigating further due to evidence of sustainability. For this reason, it is considered further research of native species is worthwhile. Recommendations to the company regarding this research are given in Chapter 7.

5.2. TAILINGS TRIALS.

5.2.1 TAILINGS AND COMPOST ANALYSES.

Sampling and analysis of newly delivered compost and freshly deposited tailings within the trial ponds was carried out in February of 1993 . The results are shown in table 5.2.1 below.

Table 5.2.1 - Analyses of Tailings and Compost and Comparison With Ratings of Chemical Properties for New Zealand Soils as Used by Soil Bureau, (Blakemore *et al* 1981).

	Tailings	Rating	Compost	Rating
pH (H_20)	9.2	Very High	5.3	Moderately acid
pH (H_2O_2)	8.1	-	-	-
Olsen P ug/g	15	Low	276	Very High
Sulphate ug/g	123	High	148	High
CEC. meq/100g	-	-	41	Very High
Exch K meq/100g	0.62	Medium	5.9	Very High
Exch Ca meq/100g	9.3	Medium	14	High
Exch Mg meq/100g	1.63	Medium	4.8	High

The compost was moderately acid, with high levels of sulphate, exchangeable calcium and exchangeable magnesium. It had very high levels of Olsen phosphate and exchangeable potassium, and a very high CEC.

The tailings had a very high pH. The pH (H_2O_2) was also very high, indicating that the tailings did not have the potential to oxidise and form an acid medium for plant growth. The level of sulphate was high with medium levels of exchangeable potassium, calcium and magnesium. The levels of sulphate, Olsen phosphate, exchangeable potassium, calcium and magnesium are all higher than those measured by Widdowson *et al* (1984), possibly due to differing rock types or degree of oxidation in the ore causing variability within the tailings. (The samples tested by Widdowson *et al* (1984) were received in slurry form, so it unlikely that leaching would have resulted in lower levels of sulphate or cations).

5.2.2 GRASS TRIAL RESULTS AND DISCUSSION.

It was observed that the compost plots had a significantly larger initial clover seed strike than the unamended tailings, and that this continued throughout the trial such that upon mowing, the compost amended plots were almost entirely clover dominant, whereas in the unamended plots the clover component was much smaller. This is covered further in section 5.2.2.6.

It was also observed that within the nil-compost plots, the clover strike was much better towards the middle of the pond where the moisture content was higher. Possible reasons for this are described following the grass yield, soil test and herbage analysis data.

5.2.2.1. DRY MATTER YIELDS.

Five cuts of the grass plots were taken. The results of these cuts were statistically analysed using the analysis of variance and are summarised in table 5.2.2, with the raw data given in appendix 5.2.1.

Table 5.2.2 - Yield Results From the Grass Cuts. (Alpha = 0.05, df = 3, Critical Value of T = 3.18).

	Compost-Amended Tailings Plots		Nil-Compost Tailings Plots	
	Dry Matter Yield (kgDM/ha)	(10%) T Grouping	Dry Matter Yield (kgDM/ha)	(10%)T Grouping
Cut 1, 4 Oct 93, MSE = 79881.83, LSD = 636.02	3,037	A	2,751	A
Cut 2, 18 Nov 93, MSE = 65068.17, LSD = 574.02	3,023	A	2,940	A
Cut 3, 11 Feb 94, MSE = 786903, LSD 1996.2	6,749	A	4,668	B
Cut 4, 24 Aug 94, MSE = 32708.17, LSD = 406.98	1,952	A	1,477	B
Cut 5, 4 Nov 94, MSE = 6949.833, LSD = 187.6	2,029	A	1,246	B
Total, MSE = 1184895, LSD = 2449.5	16,790	A	13,082	B

A reasonable estimate of dry matter production for the first twelve months (sowing was carried out in May 1994) based on the above results is 11,000 kg/ha dry matter for the unamended plots, and 14,000 kg/ha dry matter for the compost amended plots. These yields can be compared with those from the earlier Union Hill tailings pasture trials, established in 1985 which investigated yields from topsoil depths of 0 mm, 50 mm, 150 mm and 250 mm overlying the tailings. Yields for the first year for tailings plots with no topsoil addition were around 9,000 kg/ha dry matter at Union Hill (Gregg *et al* 1995), slightly lower than yields obtained from the unamended plots described above.

The compost treatment had much higher yields in the first year at 14,000 kg/ha dry matter than the Union Hill topsoil treatments, which ranged between approximately 6,000 and 7,000 kg/ha dry matter. With phosphate retention high in the topsoil used in the Union Hill plots, and phosphate availability high in the compost, it is possible that yield was higher in the compost treatment than the topsoil treatment because the grass/legume pasture had more available phosphate. There may have also been differences due to rainfall between the Union Hill tailings trial and the later tailings trial. In the first six months after sowing, yields between the compost amended tailings and the unamended tailings were not significantly different despite a visually higher clover component in compost-amended plots throughout the period of the grass trial. By the ninth month after sowing, the compost amended tailings had significantly higher yields than the unamended tailings plots. These differences continued for subsequent cuts. Over the eighteen months that the plots were harvested, the total yield off the compost amended tailings treatment was significantly higher than from the unamended tailings treatment.

This raised questions as to why the compost amended plots gave better yields, ie were the compost amended plots more favourable physically or chemically? Herbage analyses and soil tests give some indication of whether the yield differences may have been due to chemical differences between the two treatments and are considered in 5.2.2.2 and 5.2.2.3.

5.2.2.2. HERBAGE ANALYSES, OCTOBER 1993.

On 19 October 1993, herbage was taken from each plot and bulked for each treatment. The results of the herbage analyses follow, (Table 5.2.3). It is important to realise that at the time the herbage was sampled, there were no significant yield differences between the two treatments.

Table 5.2.3 - Herbage Analysis of Tailings Plots With and Without a Compost Amendment.

Analysis	Normal Range (As defined by RJ Hill Laboratories)	Compost		Tailings	
		Level Found	Nutrient Status	Level Found	Nutrient Status
Nitrogen (%)	4.0-5.0	3	Low	3.4	Low
Phosphorus (%)	0.35-0.45	0.41	Medium	0.32	Low
Potassium (%)	2.5-3.0	3.4	High	3.6	High
Sulphur (%)	0.30-0.40	0.35	Medium	0.33	Medium
Calcium (%)	0.45-1.00	0.57	Medium	0.56	Medium
Magnesium (%)	0.20-0.25	0.17	Low	0.16	Low
Sodium (%)	0.15-0.25	0.58	High	0.75	High
Iron (ug/g)	10-250	291	High	393	High
Manganese (ug/g)	40-150	235	High	294	High
Zinc (ug/g)	30-50	29	Low	52	High
Copper (ug/g)	9-12	11	Medium	10	Medium
Boron (ug/g)	10-15	8	Low	10	Medium
Molybdenum (ug/g)	0.50-2.00	1.66	Medium	0.92	Medium

Nitrogen levels in the herbage for both the compost amended tailings and the non amended tailings were found to be very similar and low. This was surprising, as it was expected that the nitrogen status would have been better for compost-amended plots due to higher amounts of clover and soil organic matter. However Foth (1978) reports that the nitrogen supplying power of a soil is intimately related to the organic matter content and mineralization rate, with mineralization of soil organic matter being the major source of available nitrogen for plants, the extent being dependant on the C:N ratio. It is possible that the carbon to nitrogen ratio of the compost treatment may have been such that appreciable quantities of nitrogen were not being mineralised, but were instead being locked up in the body structure of micro-organisms in the compost treatment.

Of particular interest in the non-amended tailings treatment is the possible contribution of cyanide as a nitrogen fertiliser (Smith and Mudder 1991). Towill *et al* 1978, cited in Smith and Mudder (1991), report that cyanide salts move only a short distance through soil before being either biologically converted under aerobic conditions to nitrates (microbial degradation to ammonia, then conversion to nitrate) or being fixed by trace metals through chelation. Fuller (1984) reported that cyanide up to 200 ppm was readily converted to fertiliser nitrogen in the soil. In fact, plants responded to cyanide applications nearly identically as they did to sodium nitrate or ammonium nitrate, both common components of fertilisers.

The Martha tailings plots were sampled shortly after the ponds were filled and it was found that they contained 150 ppm of total cyanide. This is equivalent to 81 ppm of total nitrogen, or 81 kgN/ha/10 cm depth if the tailings bulk density is $1 g/cm^3$. If this total nitrogen mineralises to ammonium and nitrate nitrogen, this is a substantial amount of plant available nitrogen.

The level of phosphorus in the herbage of the compost amended plots was higher than in the herbage of the unamended plots, to the extent that the percentage of phosphorus in the herbage in October 1993 was rated as medium in the compost amended plots and low in the unamended plots. This difference in P status tends to reflect the very high Olsen P value found in the compost, and low Olsen P in the tailings for the soil tests analysed prior to the start of the trial.

Phosphorus was added however as 15% potassic superphosphate at a rate of 700 kg/ha prior to seeding, and herbage P levels from unamended plots were not expected to be low only five months following fertiliser application. It suggested that plant available phosphorus was low in the unamended plots and reasons for this could be either rapid loss due to leaching, locking up as insoluble compounds, or a combination of these two processes as described below.

In a study carried out on Union Hill tailings plots (unamended) by Mason *et al* (1993), it was found that leaching losses of applied phosphorus were high, with 28% of applied phosphorus being leached below a 7.5 cm soil depth over a seven year period. This was probably due to the low P retention in the tailings and high rainfall. It is likely that in this later tailings trial, rapid leaching of phosphorus may have occurred in the unamended plots.

It is also possible that phosphorus may be being locked up as insoluble calcium compounds, particularly in unamended tailings plots. It is known that in soils with a high level of calcium, calcium-phosphate compounds may form, (Brady 1984). The simplest compounds of calcium, such as mono and dicalcium phosphates are readily available for plant growth, however some calcium compounds including the apatite minerals are largely insoluble and unavailable.

In contrast, the levels of potassium was found to be very similar (and rated as high) in the herbage for both compost amended and unamended plots. This is to be expected as the soil tests showed medium levels of potassium in the unamended tailings and very high levels in the compost amended tailings, and with potassium being applied as 15% potassic superphosphate, potassium was expected to be readily available for plant uptake.

The levels of sulphur, calcium, magnesium and sodium were similar in compost amended tailings herbage and unamended tailings herbage. All were rated as medium in the herbage except for magnesium which was rated as low for both treatments. During (1984) presents a table showing the percentage of magnesium on a dry matter basis in grasses and clovers and it is noted that in the late winter-early spring period magnesium levels tend to be lower than in the summer and autumn, hence although magnesium levels in herbage are rated as low in the herbage for both treatments, they are normal compared to other New Zealand soils given that they were sampled in October.

Iron and manganese in the herbage were high for both treatments and appear to be slightly higher for the unamended tailings plots, however they may not be statistically different. Brady (1984) reports that at the high end of the soil pH range, with good drainage and aeration, deficiencies of iron and manganese may occur. The interaction of acidity and soil aeration is of great practical importance in determining micronutrient availability. The micronutrient cations are generally more available under conditions of restricted drainage, and with the tailings plots having poor internal drainage it is possible that this may have influenced the high levels of iron and manganese in the pasture.

The level of zinc was high in the herbage of the unamended tailings plots, and low in the compost amended plots. Boron was low in the herbage of the compost amended plots and medium in the unamended plots. It appears that the addition of compost reduced zinc and boron uptake in the grass, possibly due to the organic matter content of the compost. The mechanism of reduced zinc uptake is difficult to qualify, as the chemical nature of the organic phase in soils is extremely complex (Alloway 1990). Solid phase humic substances such as humic acids adsorb heavy metals by forming chelate complexes, as well as being involved in cation exchange reactions. Low molecular weight organic ligands can form soluble complexes with metals and prevent them from being adsorbed or precipitated. Humic compounds with suitable reactive groups, eg hydroxyl, phenoxyl and carboxyl form co-ordination complexes with metallic ions (Alloway 1990). Other reactions, such as co-precipitation, interactions of the metals with other trace elements and environmental factors, eg differences in soil temperature, air and moisture associated with compost addition may be involved.

Although copper and molybdenum were rated as medium in the herbage for both treatments, the molybdenum level in the compost amended plots was almost twice the level as that in unamended plots. Molybdate ions, unlike most other metal ions including copper, tend to become more mobile (and hence plant available) under high pH conditions, (Brady 1984). It appears that the compost may have had a relatively high molybdenum content (molybdenum content was not tested in the compost).

It is worth noting that these plant analyses were taken in October 1993, and despite the differences in species composition and the chemical differences in the herbage between treatments, yield was not significantly different. Yield differences between the two treatments were not significant until after November 1993. Soil tests taken after November 1993 provide some possible explanations for yield differences occurring after that date.

5.2.2.3. SOIL TESTS, DECEMBER 1994.

The results of soil tests taken for the tailings pasture plots in December 1994, nineteen months after the plots were sown with grass seed, are given in table 5.2.4.

Table 5.2.4 - Soil Test Results, December 1994.

	Compost Replicates.				Tailings Replicates.			
	C1	C2	C3	C4	T1	T2	T3	T4
pH	7.6	7.6	7.7	7.2	8.2	8.2	8	8.1
Rating	Mod alk	Mod alk	Mod alk	Slightly alk	Mod alk	Mod alk	Mod alk	Mod alk
Olsen P, ug/g	31	42	28	62	7	7	6	6
Rating	High	High	High	High	Very low	Very low	Very low	Very low
SO4 ug/g	32	35	53	39	60	56	35	49
Rating	Medium	Medium	High	Medium	High	High	Medium	Medium
Exch.K meq/100g	0.28	0.36	0.44	0.47	0.33	0.29	0.39	0.39
Rating	Very low	Low	Low	Low	Low	Very Low	Low	Low
Exch. Ca meq/100g	12.2	13.3	11.8	14	10.6	10.3	8.9	9.8
Rating	High	High	High	High	High	High	Medium	Medium
Exch. Mg meq/100g	3.09	3.62	3.17	3.74	2.89	2.9	2.67	2.77
Rating	High	High	High	High	Medium	Medium	Medium	Medium
Exch. Na meq/100g	0.2	0.3	0.2	0.2	0.3	0.3	0.2	0.3
Rating	Low	Low	Low	Low	Low	Low	Low	Low

Comments: CEC unable to be determined due to pH>7.

These results can be used to:

a. Interpret possible reasons for yield differences between the two treatments.

b. Investigate changes in the chemical properties of the tailings over 22 months when sown to pasture, fertilised and subjected to mowing with a limited return of clippings.

5.2.2.4. POSSIBLE REASONS FOR YIELD DIFFERENCES BETWEEN TREATMENTS.

For the first nine months of grass growth there were no significant differences in dry matter yield between treatments. However subsequent to that, all cuts showed significantly higher dry matter yields for the compost amended tailings treatment.

It is possible that the compost amended plots had greater yields due to more favourable physical conditions. Yield differences between treatments first occurred over summer and one question which was raised was whether summer moisture content might have been more favourable in the compost amended plots. Samples were taken in February of 1994 to investigate moisture levels for both treatments. The summer of 93/94 was relatively wet in Waihi, with rain occurring at least every ten days throughout the summer period. The samples were taken on 11 February 1994. This was five days after a previous rainfall event in which 3.4 mm of rain fell. By this stage the tailings were beginning to settle and it was noticed that the middle of the pond appeared wetter after rainfall.

Core samples (10 x 7.5 cm depth) were taken at both the "wet" and "dry" ends of the plots on 11 February 1994 and bulked for each treatment to give the following results (Table 5.2.5).

Table 5.2.5 Moisture Content in Tailings Plots, 11 February 1994. (Mean of 4 reps/treatment).

	"Wet" End	"Dry" End
Unamended Tailings Plots	16	16
Compost Amended Tailings Plots.	19	14

It is worth noting that at the wet end of the tailings plots, water tended to pond on the surface after rain, and core sampling is possibly not the best way of measuring the moisture content on the surface as identified by visual observation. In any event, the summer of 1993 - 94 was relatively wet, and it is considered that yield differences between treatments were not likely to be due to differences in moisture content. On the compost treatment, plant roots were observed to move through the compost and into the underlying tailings where adequate quantities of moisture should have been available.

It is possible that yield differences may have been due to other physical characteristics such as aeration and bulk density. However, if major physical factors were responsible for yield differences, it would have been expected that yield differences would have been seen in the first six months when the roots were growing actively. It is considered more likely that a chemical deficiency may have reduced yields in the unamended plots after the first six months of growth.

Based on the results of the December 1994 soil tests above, Olsen phosphate shows the greatest difference between treatments, being high in the compost amended treatment and very low in unamended tailings. It is likely that the lack of phosphate may have caused a reduction in yield in unamended plots. There may also have been a long term effect from the lower clover component in the unamended plots, with nitrogen becoming more limiting with time.

5.2.2.5. Chemical Changes In The Tailings Plots Over 22 Months.

The first soil tests of the tailings and compost were carried out in February 1993. Changes in the chemical characteristics of the tailings plots (both compost amended and unamended) sown to pasture, fertilised and subjected to five harvests can be determined after 22 months by comparing the tailings analysis measured in February 1993 with the results of the December 1994 soil tests of the plots, and by consideration of the compost analysis of February 1993. This data is summarised below in table 5.2.6.

Table 5.2.6 - Comparison of Tailings Chemical Analysis Prior to Grass Establishment And Following 22 Months of Pasture Establishment.

	Compost	Tailings	Compost Replicates, Dec 1994				Tailings Replicates, Dec 1994			
	Feb 93	Feb 93	C1	C2	C3	C4	T1	T2	T3	T4
pH	5.3	9.2	7.6	7.6	7.7	7.2	8.2	8.2	8	8.1
Rating	Mod Acid	V high	Mod alk	Mod alk	Mod alk	Slightly alk	Mod alk	Mod alk	Mod alk	Mod alk
Olsen P, ug/g	276	15	31	42	28	62	7	7	6	6
Rating	V high	Low	High	High	High	High	Very low	Very low	Very low	Very low
SO4 ug/g	148	123	32	35	53	39	60	56	35	49
Rating	High	High	Med	Med	High	Med	High	High	Med	Med
Exch.K meq/100g	5.9	0.62	0.28	0.36	0.44	0.47	0.33	0.29	0.39	0.39
Rating	V high	Med	Very low	Low	Low	Low	Low	Very Low	Low	Low
Exch. Ca meq/100g	14	9.3	12.2	13.3	11.8	14	10.6	10.3	8.9	9.8
Rating	High	Med	High	High	High	High	High	High	Med	Med
Exch. Mg meq/100g	4.8	1.63	3.09	3.62	3.17	3.74	2.89	2.9	2.67	2.77
Rating	High	Med	High	High	High	High	Med	Med	Med	Med

a. pH.

The tailings trial plots showed several chemical changes following fertiliser application, sowing to pasture and mowing over a 22 month period. The very high initial pH of 9.2 dropped to an average of 8.0 in the unamended plots, and to an average of 7.5 in the plots modified with compost. The tailings material could be expected to have little buffering against pH changes, with its low CEC (as described by Widdowson *et al* 1984) and low organic matter content. It could be argued that the addition of compost with a pH of 5.3 could explain the pH drop in the compost amended tailings simply because of dilution in the 7.5 cm depth sample, however the pH dropped in the unamended tailings suggesting that it was not only caused by dilution with compost. Other possible reasons follow:

- leaching of bases. Leaching encourages acidity because bases that have been replaced from the colloidal complex or dissolved by percolating acids are removed in drainage waters, (Brady 1984). With the relatively high rainfall in Waihi, leaching of bases has the potential to cause a pH drop.

- Nitrification of ammonia can increase acidity by the following reaction, (Brady 1984):

  $NH_4^+ + 2O_2 \rightarrow 2H^+ + NO_3^- + H_20$

- Microbial oxidation of organic matter produces humic residues with acidic carboxyl and phenolic groups, and organic and inorganic acids, the simplest being carbonic acid.

- Sulphuric acid and nitric acids are potent suppliers of H^+ ions in the soil, and may be formed not only by organic decay processes but also from microbial action on certain fertiliser materials. In the tailings, the oxidation of iron pyrites could cause a pH reduction, however previous testwork carried out by the company suggests that in the bulk of the tailings, if not all of it, this is unlikely to occur (Miller pers comm 1996).

* The presence of neutral salts such as sulphates and the chlorides of Na, K, Ca and Mg have the tendency to increase the activity of the H^+ ion and consequently decrease the soil pH (Brady 1984).

Mason *et al* (1993) reported a decrease in pH of three units (pH 9 to pH 6) over a seven year period in unamended tailings pasture plots on Union Hill. It is considered most likely that the drop in pH in unamended plots in both this and the Union Hill trial was associated with an increase in organic matter and the leaching of bases.

b. Olsen Phosphate.

Olsen phosphate increased when compost was applied to the tailings, but decreased in the unamended tailings over the 22 month period. The reasons for the decrease in the unamended plots may include leaching, adsorption, and removal in vegetation.

Relatively high leaching losses of phosphate of 28% occurred in similar tailings plots at Union Hill, Waihi over a seven year period (Mason *et al* 1993). It can be assumed that phosphorus applied as superphosphate may have leached from the unamended plots in this trial.

Brady (1984) reported that 15-70% of soil P may exist in the strongly adsorbed or insoluble inorganic forms, so it is possible that P may have been locked up eg as calcium phosphates. In the Union Hill trial on nil topsoil tailings plots, it was found that the amount of total phosphorus in the top 7.5 cm of the plot increased as the level of carbon increased, as P accumulated as organic P.

Over the twenty two month period, the plots were only topdressed once with superphosphate and it is likely that the removal of vegetation could have depleted the Olsen P levels.

c. Sulphate.

The level of sulphate dropped significantly in the tailings for both amended and unamended treatments over 22 months. There are four forms of sulphur within a soil - sulphides, organic forms, sulphate and elemental sulphur. Sulphate is the form in which plants absorb most of their sulphur from soils, however this ion is quite soluble and is readily leached through the soil. Although most soils retain some sulphate, the quantity held is generally small and its strength of retention is low compared to that of phosphate in a soil.

In the case of tailings, sorption is very, very low and large leaching losses would be expected, (Gregg pers comm). Combined with this, if soil pH (and consequently the amount of hydroxyl ions) is high, sulphate will be released (Brady 1984). In the Union Hill trial as described by Mason *et al* (1993) above, sulphate losses were high at 72% over seven years in tailings plots without topsoil. It is likely that leaching losses could be the main mechanism of sulphate loss within the tailings in the later trial.

d. Potassium.

The exchangeable potassium level in the tailings was initially medium, and levels of exchangeable potassium in the compost were found to be very high when the trial commenced. Although potassium was applied to the plots as potassic superphosphate, by December 1994, levels of exchangeable potassium were low and very low in both the compost amended and unamended plots. The possible reasons for the low potassium levels found after 22 months in the plots are discussed below.

Most mineral soils are comparatively high in total potassium, but the quantity of potassium held in an easily exchangeable form at any one time often is very small (Brady 1984). Most of it is held rigidly as part of the primary minerals or is fixed in forms that are at best only moderately available to plant growth. Competition by micro-organisms for this element contributes at least temporarily to its unavailability to higher plants.

Several soil conditions markedly influence the amounts of potassium fixed. Among these are the nature of the soil colloids, wetting and drying, freezing and thawing and the presence of excess lime (Brady 1984). Clays of the 2:1 type such as vermiculite, smectite, and fine-grained mica (illite), fix potassium very readily and in large amounts. Even silt-sized fractions of some micaceous minerals fix and subsequently release potassium (Brady 1984).

Alternate wetting and drying, and freezing and thawing has been shown to result in the fixation of potassium in nonexchangeable forms as well as its ultimate release to the soil solution. Although the practical importance of this is recognised, its mechanism is not well understood (Brady 1984).

Perhaps of more importance to this trial, is that applications of lime sometimes result in an increase in potassium fixation in soils, provided clays are of the appropriate type (Gregg pers comm 1996). Furthermore, high calcium levels in the soil solution may reduce potassium uptake by the plant (however the herbage analyses suggest that potassium has been taken up by the plant at high levels). Brady (1984) reports that where potassium deficiency has been noted in soils with excess calcium carbonate, cation ratios may have some influence.

Most potassium however is lost by leaching, with some lost by crop removal (possible in this trial as not all clippings were returned to the plots). With the low CEC of the tailings it could be expected that leaching losses of potassium may be high. It is considered that leaching and possibly to a lesser extent fixation could be responsible for the low and very low levels of exchangeable potassium found for both treatments after 22 months.

e. Calcium.

Exchangeable calcium levels in the tailings prior to sowing to pasture were very similar to the levels found in both the compost amended and unamended plots in December

1994. Calcium losses within a soil occur by leaching and crop removal and it is likely that these losses have occurred, but with the high pH and presence of free lime in the tailings, exchangeable calcium is able to be replenished. Some calcium would also have been added when the 15% potassic superphosphate was applied prior to sowing.

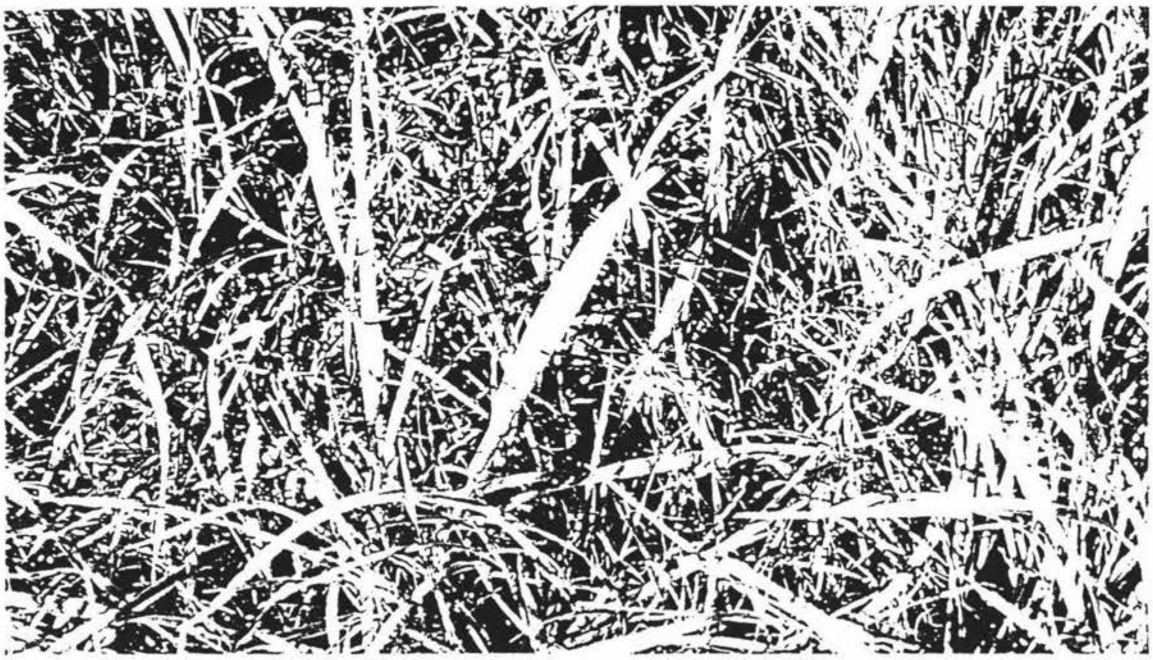
5.2.2.6. POSSIBLE REASONS FOR REDUCED CLOVER STRIKE ON UNAMENDED TAILINGS PLOTS.

The clover strike and growth rate on the compost amended plots was observed to be very successful. In fact the compost amended plots became clover dominant, in contrast to the unamended plots which had a poor clover strike, and consequently a much smaller component of clover, (Figure 5.2.1)

Figure 5.2.1 - Clover Dominance in the Compost Amended Plots Compared to Unamended Plots (October 1993).

(a) Compost Amended Tailings Plot.

(b) Unamended Tailings Plot.



The possible reasons for the poor germination of clover in particularly the drier areas of the unamended plots were investigated. During (1984) reports that copper is extremely toxic to clover rhizobia, and with 5 ppm of copper in the tailings decant water, it is possible that this could have some effect. In general however, micronutrients become more plant available with poor drainage, and as the clover tended to grow more successfully on wetter parts of the unamended plots, it does not appear likely that copper was detrimentally affecting clover growth.

There is some evidence that even brief contact of clover seed with freshly made, slightly moist superphosphate may lower the capacity of these seeds to germinate (During 1984). It was found in a trial with soil at Rukuhia (near Hamilton) that superphosphate at 375 kg/ha and a randomly selected line of serpentine-superphosphate at 500 kg/ha drilled with clover seed significantly decreased clover germination, (During 1984). The germination of ryegrass seed was not affected. It is possible that poor germination of clover seed in the dry areas of the unamended plots may have been due to germination injury by superphosphate. However Bent (1991) carried out germination trials with ryegrass and clover investigating this theory. Blotting pads containing leachate from a 750 kg/ha 15% potassic superphosphate application were used to germinate seed and it was found that the high rate of fertiliser application was not responsible for reduced clover growth.

Germinating seed can be damaged by dissolved salts, and germination injury is often more severe if seed is drilled into a dry soil which through light showers, becomes just damp enough to permit germination but not wet enough to allow appreciable diffusion of soluble salts away from the seed. Bent (1991) found that tailings produced in 1992 had high levels of soluble salts, however the trials carried out did not confirm that soluble salts were responsible for poor clover germination.

It was thought that poor germination of clover in the Union Hill tailings plots may have been due to a lack of moisture. Bent (1991) in a study of Martha tailings found no differences in ryegrass and clover germination in wet tailings, however in the dry tailings treatment the overall clover germination percentage and rate of germination was significantly less than ryegrass. This could explain the relatively poor germination of clover noted on unamended tailings plots, generally towards the outer, drier edges. Bent (1991) concluded that poor initial clover establishment in the Union Hill trials as reported by Gregg pers comm (1991) was most likely due to physical factors rather than chemical factors.

It appears that even on agricultural soils a similar situation has been observed in that clover seed is able to germinate and grow on areas with relatively higher levels of organic matter or wetness. During (1984) reports that on strongly nitrogen-deficient soils, poorly inoculated clover plants without functioning root nodules generally become stunted and die one to two months after emergence. However a few plants nearly always acquire healthy nodules, survive and may be growing quite vigorously. Commonly, these healthy plants occur in moist hollows or on old dung pads.

The observations made regarding clover growth on compost amended and unamended tailings plots tend to confirm the work of Bent (1991). Given that similar observations have been made in pasture growing on agricultural soils, it appears that clover seed requires greater amounts and a more sustained supply of water than ryegrass to germinate, which could explain why clover plants tended to germinate better where the substrate was wetter, or had a greater organic component and presumably a greater water holding capacity.

5.2.3. NATIVE PLANT TRIAL.

All native plants in the tailings trial survived, and growth measurements were carried out three times over a thirteen month period. The results of the growth measurements were statistically analysed using the analysis of variance over three time intervals, with interval one being from November 1993 to May 1994, Interval two from May 1994 to December 1994 and Interval 3 being the overall growth from November 1993 to December 1994. The following results interpret treatment differences and species differences over the three time intervals.

5.2.3.1. Treatment Differences.

Table 5.2.7 below shows the overall differences in growth between plants growing on the two treatments. Full statistical results are given in Appendix 5.2.2. As with the blue rock trial, different letters for the t grouping indicate significant differences.

Table 5.2.7 - Overall Growth Differences in Natives Growing in Compost Amended and Unamended Plots. (Alpha = 0.1, df = 117, Critical Value of T = 1.66).

	Mean Height Increase Over Time Interval (cm)			
	Compost Treatment	t grouping (at 10% level of probability)	Unamended Tailings Treatment	t grouping (at 10% level of probability)
Interval 1 - November 1993 to May 1994, MSE = 246.5844, LSD = 4.6024.	38.45	A	33.77	B
Interval 2 - May 1994 to December 1994, MSE = 329.7866, LSD = 5.3226.	23.19	A	19.09	A
Interval 3 - November 1993 to December 1994, MSE = 471.1888, LSD = 6.3621.	61.64	A	52.86	B

In the first growth interval of summer to autumn (November 1993 to May 1994), significantly higher growth rates occurred in the compost amended plots than in the unamended plots. Over the second growth interval of winter and spring (May 1994 to December 1994), growth rates between the two treatments were not significantly different, however over the total thirteen months growth was significantly different between the two treatments. These results are quite different to the results for grass growth in that for grass, no significant differences occurred between treatments in the first six months of growth, but following the first six months significant differences between treatments occurred.

The significantly larger growth rates in the first six months for the compost amended tailings treatment may be due to an improved physical or chemical status. Physically it is possible that the plants growing in the compost may have been better supplied with water, as the differences in growth occurred over the summer to autumn period. This is not likely however as the tailings tend to hold water, and rainfall during the summer of 1993/94 was generally well spread, and it is not expected that growth would have been checked by a lack of water. It may be possible that the young roots were able to move more easily into the compost than in to the tailings or that any mycorrhiza on the roots may have performed better in the compost than the tailings.

There are several reasons why the compost treatment may have been more favourable chemically for the growth of native plants in the first six months after planting. These include a lower pH in the compost than the tailings, and an increased supply of nutrients such as phosphate, sulphate, exchangeable potassium, calcium and magnesium.

It appears however that the benefits of compost addition were only temporary, and although measurements of root growth were not taken, it is likely that once the plant roots moved out of the compost and into the tailings, there were no further benefits for plant growth.

5.2.3.2. Species Differences.

The following table shows species differences over both treatments for the three growth intervals.

Table 5.2.8 - Species Growth Differences in Native Plants on the Tailings Plots. (Alpha = 0.1, df = 117, Critical Value of T = 1.66).

	Mean	(10%) t grouping
INTERVAL 1 - NOVEMBER 1993 TO MAY 1994, MSE = 246.5844, LSD = 6.5088.		
Pittosporum	49.844	A
Kanuka	45.594	A
Cabbage Tree	24.750	B
Flax	24.250	B
INTERVAL 2 - MAY 1994 TO DECEMBER 1994, MSE = 329.7866, LSD = 7.5272.		
Flax	26.719	A
Pittosporum	25.344	AB
Cabbage Tree	18.937	BC
Kanuka	13.563	C
INTERVAL 3 - NOVEMBER 1993 TO DECEMBER 1994, MSE = 471.1888, LSD = 8.9974.		
Pittosporum	75.188	A
Kanuka	59.156	B
Flax	50.969	BC
Cabbage	43.688	C

In the first six months pittosporum and kanuka put on significantly more growth than cabbage tree and flax. In the second growth interval, flax and pittosporum put on significantly more growth than kanuka, and the growth rates for pittosporum and cabbage tree were not significantly different. Overall, pittosporum had a significantly higher growth rate than the other three species investigated in the trial and kanuka had a faster growth rate than cabbage tree.

5.2.4. SUMMARY AND CONCLUSIONS.

The Union Hill trials established in 1985 had provided evidence that pasture could be grown on tailings with and without a topsoil amendment. Waihi Gold Mining Company Ltd was interested in investigating alternative land uses and plant growth amendments, and in 1992 discussions regarding further tailings trials.

At the time that the trials were being designed, it was thought that there may be a lack of topsoil available for amending the tailings upon completion of mining. Previous pot trials with broad beans had shown significantly higher growth rates when tailings were amended with composted chicken manure, and field trials with a similar form of material were considered to be warranted. (Mason 1989). The planting of native species on tailings was considered to be an acceptable alternative form of land use to the local community. Trials were initiated to investigate the growth of pasture and colonising native species with and without a compost amendment.

It was found that in the first year, tailings without a compost amendment (unamended tailings) gave slightly higher grass yields at 11,000 kgDM/ha than the earlier Union Hill tailings plots without a topsoil amendment (9,000 kgDM/ha). The compost amended plots gave significantly larger yields at 14,000 kgDM/ha than the earlier Union Hill topsoil amended plots which yielded between 6,000 and 7,000 kgDM/ha. It was considered that a possible reason for this was one of phosphate availability, with compost having very high levels of available phosphate and topsoil having a high phosphate retention, hence the highest yields from compost amended tailings, followed by unamended tailings, followed lastly by tailings amended with topsoil. It is likely however, that long term all three treatments would produce acceptable yields provided fertiliser was applied at the required rates and frequencies. Other considerations such as the amount of topsoil available, the quality of water produced from the rehabilitated tailings surface and the Mining Licence may determine which option would be ultimately selected.

No yield differences existed between treatments in the first six months following seeding despite the fact that the compost amended plots had a larger clover component than the unamended plots. Significant yield differences between treatments were observed in subsequent cuts. Yield differences between treatments after six months following sowing were most likely to be due to differences in nutrient status, particularly phosphate, with compost supplying nutrients for a longer period of time. The better establishment of clover plants in the compost amended plots may also have provided some long term yield benefit, possible due to the improved nitrogen status associated with the clover plants.

Herbage analysis showed that the phosphorus status in grass growing on unamended tailings was low six months after sowing, however at this stage yield differences were not significant between the two treatments. It appears that phosphate is rapidly leached, and possibly locked up as insoluble calcium compounds in unamended tailings plots. Losses of exchangeable potassium in both treatments were high, and it is possible that like phosphorus, losses could be due to leaching and fixation. Sulphate losses were also high for both treatments and it was thought that leaching is responsible for this also.

Clover germination and growth was observed to be better in the compost amended plots, and towards the low points of the unamended plots where it was wetter. Reasons for the poor strike of clover on relatively dry, unamended plots could include salt toxicity, but are more likely to be due to a moisture limitation in these areas when clover germination was taking place.

The native species trial on tailings was considered to be highly successful with all plants surviving. Compost amended plants grew significantly faster over the first six months than unamended plants. In the following seven months however, no significant differences in growth occurred.

Growth differences between treatments in the first six months may have been due to chemical or physical differences. Little is known about the nutrition of natives and it was difficult to know what fertiliser to apply, and whether what was applied was sufficient to maximise growth. There is also a lack of information regarding the growth rate of native plants which may be considered acceptable. This raises another question, as to whether maximisation of growth of natives is necessary.

When planting out areas with native species, a mixture of species is generally used to create a natural looking and sustainable land use. For that reason, the relative growth rates of the species used in this trial may be less important than the fact that the species tested survived and grew. Growth rates tend to be important if the area is to be used for some form of productive land use, when yields and rate of growth become more important. However if a quick growing native shelter species was required on the tailings area, trial results suggest that pittosporum would tend to be selected in preference to kanuka, cabbage tree and flax.

CHAPTER 6 -

REHABILITATION PLANNING AND MODELLING OF OPTIONS FOR MARTHA TAILINGS.

6.1. A REHABILITATION PLANNING PROCESS.

For successful rehabilitation to occur, many factors need to be taken into account and decisions made prior to and during a mining project. In particular, investigations of the geochemical properties of the waste types needs to commence before mining, to allow design of the optimum waste disposal facility.

A successful rehabilitation plan however relies on flexibility to allow unforeseen changes during the life of the mine to be incorporated. These may be many and varied and are likely to include:

1. A Change in the Ore Cutoff Grade.

This could give rise to more or less tailings than originally anticipated. In New Zealand tailings dams, waste rock is used to build the embankments, and embankment design may need to be changed if more or less tailings are to be produced than allowed for in the original planning. A change in the ore cutoff grade may lead to materials shortages or oversupply, which can affect topography and slope of the final landform.

2. Materials Shortages.

Shortages of capping and resurfacing materials on site may lead to investigations of possible alternatives off site. Costs can be considerably reduced if suitable materials can be sourced in close proximity to the mine, and it may be environmentally advantage to use another industry's waste, e.g. an organic matter source such as chicken manure or compost. Trial work is generally required to determine which sources have potential, how they should be applied, and the quantities required.

A materials shortage may also result in the need to reduce the depth of covering and/or resurfacing material. This will require consideration of possible environmental problems such as erosion, and the ability of the cover to reduce oxygen diffusion to materials beneath if they have the potential to generate acid. It may also be necessary to ensure that there will be no reduction in the versatility and productivity of land use, caused for example by a decreased rooting depth.

3. Changes in the Geochemistry/Grind Size of the Ore/Waste Types.

It is possible that as a mine increases in depth, total sulphur levels may rise, leading to possible acid generation in tailings and waste which were not previously acid generating. In tailings, this can also occur if, for instance, the gold price rises and the ore cutoff grade drops, so that more sulphide ore is being mined, giving rise to tailings with a higher sulphur content. Similarly, areas of calcite may be encountered which can render a waste type acid consuming in nature.

Changes in the grind size of the tailings may affect the final land use or the timing of rehabilitation operations, e.g. a reduction in the grind size may lead to reduced internal drainage.

4. Changes in Community Expectations.

Community expectations may change over the life of a project such that land uses, for example wetlands and native plantings, may be more acceptable now than they were ten years ago.

5. Associated Environmental Implications.

Changes in the law, regarding for example the required quality of water discharged from site, may influence the final land use as well as plant growth amendments and fertilisers used.

6. Changes in Species Types.

Rehabilitation of the waste embankment of the Martha tailings dam provides an example of changes in species types. If areas are restored to grass at less favourable times of the year, species such as barley may be introduced to provide a quick cover, and possibly reduce erosion of topsoil. Changes in land use will generally require consideration of alternative plant species.

6. Economic Considerations.

Economic considerations may affect the final land use for a site. There are many "unknowns" at present, not just for mining companies but for many industries faced with rehabilitation of disturbed sites. Some of the unknowns facing Mining Companies at present include:

- Who will ultimately own the site?
- Will the site be able to be sold?
- For how many years will the company have to maintain the site, and at what cost?
- Who will be liable, long term, for environmental costs?
- Will the site be required to return a profit?
- Why would anyone want to own a site if does not return a profit?
- If native species were planted on the tailings surface, would it be possible to sell the dam and the surrounding farmland owned by the company so

that the area as a whole becomes an economic unit? Could covenants be placed to ensure that the tailings dam area is never disturbed by farming operations?

- When will the bond be released?
- Is the law relating to all of the above factors likely to change?

Answers to these questions are beyond the scope of this thesis but have been identified to illustrate that planning around this uncertainty becomes a difficult exercise.

Ultimately, selection of the final land use requires input from engineers, scientists, lawyers, landscape architects, company management and possibly the local community. With so many people involved and issues to consider, selection of the final rehabilitation plan becomes complex. In order to objectively consider rehabilitation methods a rehabilitation planning process is proposed (Figure 6.1). The aim of the process is to consider all of the aspects identified in the literature review in chapter two of this thesis, and provide focus to an ongoing rehabilitation plan to achieve an acceptable result for all concerned.

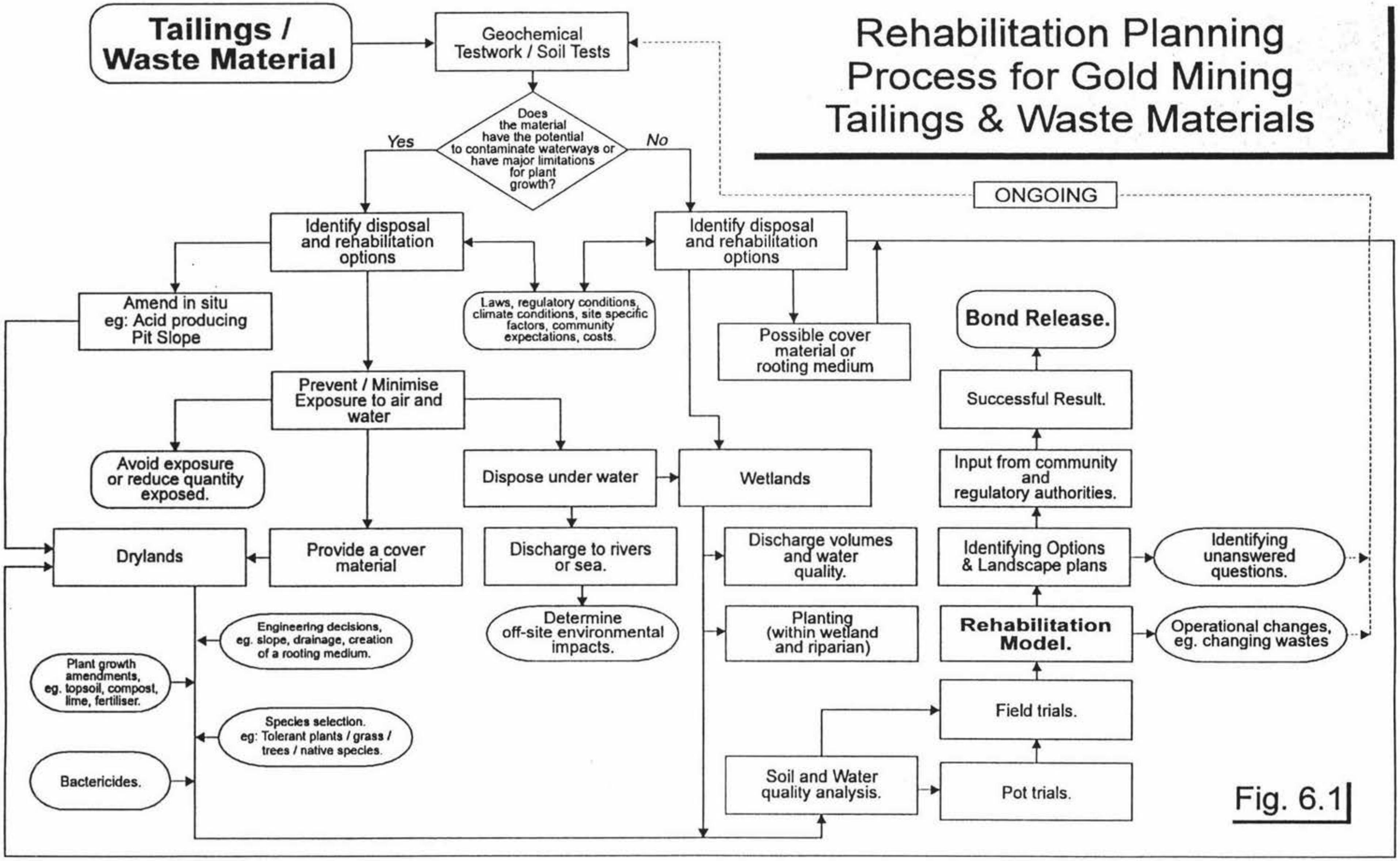

Rehabilitation Planning Process for Gold Mining Tailings & Waste Materials

Fig. 6.1

An important part of the proposed planning process is a site specific predictive model. The purpose of the predictive model is to look at possible rehabilitation options and costs associated with those options, and identify potential problems such as a shortage of cover materials which may require further research. The model is site specific and can be developed for a whole site, or used for a specific part of the project where several options exist.

As an example, a predictive model for tailings revegetation has been developed for the Martha Hill project. In describing the model, it is necessary to consider the assumptions made and the possible options for rehabilitation of Martha tailings, and how these have been incorporated into the model. A description is given below.

6.2. A PREDICTIVE MODEL FOR MARTHA TAILINGS REHABILITATION.

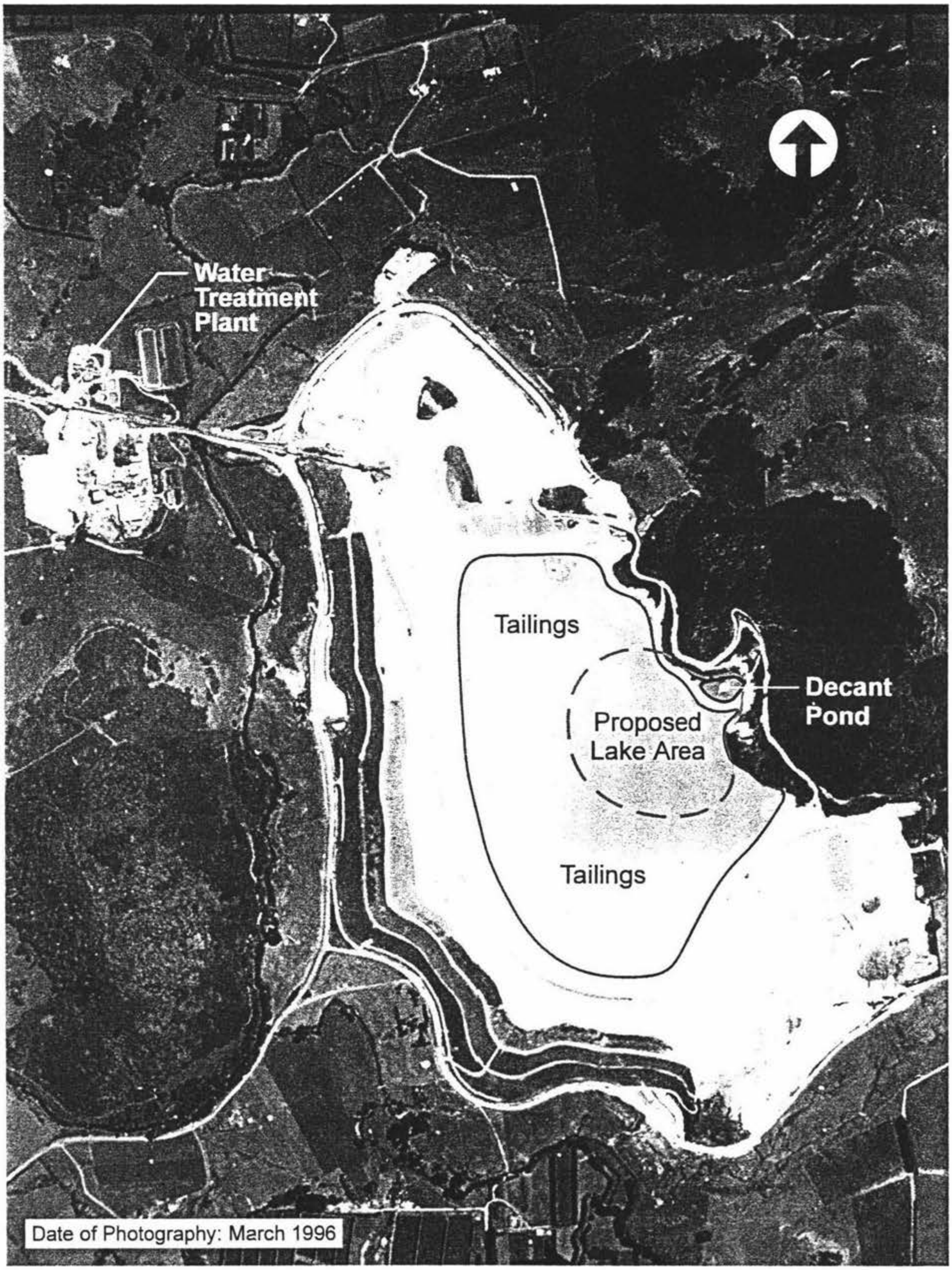
6.2.1 Assumptions.

1. The Waste Embankment.

It is assumed that the waste embankment has been restored to pasture and is grazed by light stock, and that all water derived from the waste embankment is diverted away from the tailings surface.

2. Tailings Lake.

Once tailings deposition ceases, it is assumed that the existing decant pond (shown in Figure 6.2) would be the low point of the tailings area and as such a lake could be created. It has been suggested (Ruddock pers comm 1995) that the finer tailings abutting the hill will tend to dry out less quickly, and that an opportunity exists to retain a lake in this area.



Position of Existing Decant Pond in relation to Proposed Lake and Surrounding Tailings.

Figure 6.2

The lake would collect water derived from the tailings surface only, i.e. rainfall landing directly on the lake and runoff water derived from the tailings surrounding the lake. It is likely that water spilling from the lake would initially require treatment at the water treatment plant, at least until the tailings had been flushed by water and until rehabilitation had progressed sufficiently to improve water quality. The amount of time for this process to occur can be stipulated by the user. Lake water could either spill and flow by gravity towards the water treatment plant, or be pumped directly from the lake. Once water quality became acceptable for discharge without treatment, the lake could be retained as a wildlife or amenity area, and in spill events water could be directed towards a nearby tributary of the Ohinemuri River.

3. Treatment of Water Derived From the Tailings Surface.

It is important to know what quantities of water might be discharged from the lake to allow an investigation of how much water would require treatment, and the associated costs. Also, if the company wished to pump the lake down, a pumping system could be devised based on the amount of water likely to require treatment.

The model calculates the amount discharged from the lake based on the lake size, initial lake R.L and freeboard, rainfall, areas rehabilitated and runoff coefficients, all entered by the user. It relies on the user entering fourteen years of rainfall data. This would allow rainfall variations to be inspected, e.g. how much more water would require treatment in a wet year than a dry year and the associated cost implications, and the effect on lake level fluctuations that wet, dry, and average rainfall years would have.

4. Lake Level Fluctuations.

If the lake was to be retained as an amenity or wildlife area in the future, and riparian planting was planned, lake level fluctuations would be important. The model graphs lake level fluctuations assuming that the lake has steep sides. In reality the lake would probably be dish-shaped beneath, but this is not known at present. A change in the lake bottom profile can be easily incorporated into the model.

5. Necessity For a Clay Cover Over the Tailings.

It is unknown at present whether any of the tailings will require clay capping. The model allows the user the option of providing a clay cover over all or part of the tailings surface if required. It is assumed that if a clay cover is required, some form of subsoil material will also be required, (similar perhaps to the 0.5 m depth of zone H material used on the waste embankment). It is assumed that the cost of spreading a clay cover is similar to the cost of spreading the zone H material.

6. Land Use Scenarios.

Two scenarios of land use have proven to be successful in field trials on tailings, and these two scenarios, (pasture and native species) have been incorporated into the model. However as shown below, the model is flexible enough to investigate other land use options.

It is assumed that the tailings area, if rehabilitated to pasture, could be grazed with the same light stock as for the waste embankment, thereby becoming part of the existing farming operation. The user specifies what area of the tailings is to be restored to pasture and the model automatically calculates the timing and associated costs of related practices, e.g. harrowing, fertilising and seed sowing. The model makes the assumption that one year after sowing to grass, earthworms will be introduced and fencing will be carried out, and these costs are automatically calculated.

Another land use option which the model can incorporate is the planting of native species. This may be either riparian planting around the lake, or other plantings on the tailings surface. It is standard practice to establish colonising native species prior to the planting of larger trees such as totara and rimu. The model assumes that supplementary planting of larger species is carried out four years after the establishment of the colonising species, and automatically calculates the costs involved.

It is assumed that no revenue exists for native species, however it is possible to enter a revenue figure into the model if necessary. For this reason, any other crop, e.g. exotic forestry species, could be substituted for native plants. (Trial work has proven that pasture and native species grow successfully in tailings and if other crops were suggested, trial work would need to be carried out to ensure that they would grow successfully, and could be considered as an acceptable land use. This is identified by the Rehabilitation Planning Process, Figure 6.1).

7. Plant Growth Media.

Three types of plant growth media have proven to be successful on tailings in field trials with pasture and native colonising plants. These include sowing or planting directly into tailings, or amending with topsoil or compost. The model allows the user to select any of these three combinations, and also allows the depth of topsoil or compost to be selected.

8. Drainage.

It is assumed that the tailings are sufficiently drained to allow access by machinery and people to carry out rehabilitation operations. In practice, this assumption requires further research. The user of the model is required to stipulate the areas requiring agricultural drainage. Note that lakeside plantings may not require agricultural drainage - the model is flexible enough to incorporate this option.

9. Timing.

The model operates over a fourteen year time period, but requires that all drainage, earthworks, seeding and initial planting of natives are carried out within ten years. This is further described below, under "CONSTANTS".

10. Calculations.

Once the user has selected a rehabilitation scenario, the model calculates the quantities of materials necessary, and the expected costs and returns over a fourteen year period for that scenario.

6.2.2 The Model.

The model was developed as a Lotus 1-2-3 file, (Release 5). A copy of the model is located in the back pocket of this thesis. The file was too large to transfer to disk and has been zipped. PKUNZIP is necessary to view the model. The model consists of four pages, (see appendix 6.1 for examples of the four pages) and the pages contain the following:

Page 1 - INSTRUCTIONS -

The Instructions sheet lists the assumptions made when developing the model. It also provides a guide to the user of how the model is to be operated.

Page 2 - CONSTANTS -

The Constants sheet allows the user to select rehabilitation options and the years in which operations are to be carried out. Rehabilitation may be required to be carried out as soon as possible, or may be scheduled over a number of years. In any case, the model requires all drainage, earthworks, pasture seeding and planting of colonising native species to be carried out within ten years. The model then calculates extra costs such as supplementary planting of natives, earthworm seeding etc., fencing, maintenance costs and returns for years ten to fourteen.

Page 3 - WATER -

The water sheet allows the user to enter rainfall data for mean, wet or dry years, and evaporation data over a fourteen year period. This allows the magnitude of lake discharge events and the fluctuations in lake water level to be calculated. The lake level is graphed to allow lake level fluctuations to be determined under different scenarios of wet, dry and mean years.

Page 4 - COSTS -

The Costs sheet begins by summarising the quantities of clay, compost and topsoil required, and then calculates all costs for rehabilitation practices and water treatment and the returns from pasture.

A copy of the model is held by Waihi Gold Mining Co Ltd. Several scenarios were investigated using the model with the results described below.

6.3. TAILINGS REHABILITATION SCENARIOS AND COST IMPLICATIONS.

The model allows for the investigation of a very large range of scenarios, given all of the possible combinations of:

- Areas requiring drainage,
- Necessity for a clay cover,
- Amendments of topsoil or compost, (or seeding or planting directly into unamended tailings),
- The depths of clay, topsoil or compost required,
- Rehabilitating the site to natives or pasture, or another land use,
- The size of the areas that could be devoted to each of these operations,
- The length of time that water treatment is necessary and the changes in costs over time e.g. as less water treatment reagents are required,
- Scheduling of rehabilitation options and costs (and possibly labour) over time.

Five scenarios have been chosen for the rehabilitation of Martha tailings. For each scenario a final tailings surface area of 36.5 ha was used. The lake size was assumed to be 10.5 ha, with a freeboard of 1 m at day one, and it was assumed that water spilling from the lake would require treatment for the first two years only.

It was assumed that runoff coefficients from the unrehabilitated tailings surface would initially be high. Within the first three years of planting or seeding, the runoff coefficient would decrease only slightly, but would reduce considerably as the pasture thickened up and the native plants began to spread, forming a canopy and reducing runoff. Appendix 6.1 gives a comprehensive list of the costs, and expected returns from pasture used in the model.

Another assumption made was that the company wished to incur all costs as soon as possible. For this reason, it was assumed for the following scenarios that the lake would be established in year 1, and that any drainage required would be carried out in year 1. All earthworks, seeding and planting would be carried out in year 2.

Scenario 1.

This investigates the scenario whereby the whole of the tailings area not covered by the lake (26 ha) requires a total clay cover 1m deep, a subsoil layer (zone H) 0.5 m deep, and topsoil applied to a depth of 100 mm. The whole area is then fertilised, harrowed and sown to pasture. One year after seed sowing, fencing and earthworm seeding are carried out.

Scenario 2.

This is the same as scenario 1 except that no clay cap or zone H material are required. The 26 ha tailings surface is topsoiled to a depth of 100 mm, and rehabilitated to pasture as described for scenario 1.

Scenario 3.

In this scenario, no clay cap is required, hence no subsoil material is required. However there is a shortage of topsoil and the company has decided to use compost instead of topsoil, at 50 mm depth. Again, the 26 ha of tailings surface is rehabilitated to pasture as described for scenario 1.

Scenario 4.

In this scenario, no clay cap or subsoil material is required. No topsoil is available. The company is able to prove however, that acceptable pasture growth can be achieved by seeding directly into tailings. The peer review panel and regional council have approved this option. Pasture seed is sown directly into tailings with harrowing, fertiliser, fencing, and earthworm seeding carried out as for scenario 1.

Scenario 5.

In this scenario, no clay cap is required. It has been decided that for long term geochemical security, the tailings will be totally planted in native species to avoid disturbance which could occur if pasture was the ultimate land use. No compost or topsoil is required. Colonising natives are planted in year 1 followed by supplementary planting in year 4.

For each scenario, a breakdown of the rehabilitation options and associated costs is given in table 6.1. (A further breakdown of scheduled operations, and costs and returns used in for the five scenarios is given in appendix 6.2). Costs have been broken down into fixed costs, maintenance costs, and water treatment costs as described below:

Fixed costs include drainage, the spreading of clay covers, zone H material and topsoil/compost, costs associated with establishing pasture (harrowing, fertiliser, seeding, introducing earthworms, fencing, water supply), planting natives (followed by supplementary planting five years later).

Maintenance costs include the costs of maintaining the native plants and pasture.

Water treatment costs refer to the costs of treating water spilling from the lake.

Returns refer to the returns expected from pasture.

Table 6.1 - Materials Quantities Required and Costs For Scenarios 1 to 5.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Rehabilitation Options. (ha)					
Lake Area	10.5	10.5	10.5	10.5	10.5
Area Drained	26	26	26	26	26
Area clay capped	26	0	0	0	0
Area topsoiled	26	26	0	0	0
Area compost amended	0	0	26	0	0
Area unamended	0	0	0	26	26
Area in pasture	26	26	26	26	0
Area in natives	0	0	0	0	26
Material Requirements (m3)					
Clay	390,000	0	0	0	0
Topsoil	26,000	26,000	0	0	0
Compost	0	0	13,000	0	0
Costs $					
Fixed costs (a)	1,534,000	364,000	819,000	286,000	646,750
Water Treatment Costs (b)	994,663	994,663	994,663	994,663	994,663
Total fixed costs (a) + (b)	2,528,663	1,358,663	1,709,663	1,280,663	1,641,416
Maintenance costs over 14 years (pasture & natives)	67,600	67,600	67,600	67,600	1,498,380
Returns					
Returns from pasture over 14 years	261,196	261,196	261,196	261,196	0

6.4. DISCUSSION.

By comparing scenarios 1 and 2 above, it can be seen that a clay cap over the tailings significantly increases the costs. To apply a clay cap of 1 m depth and an associated subsoil layer of 500 mm depth over an area of 26 ha requires an extra $1,170,000 than if no clay cap is necessary. Substantial quantities of clay are required for this option, (390,000 m^3) and it is recommended that the company ensure that suitable material will be available upon closure if it is likely that clay capping is required.

By comparing scenarios 2, 3 and 4, the costs of adding different organic amendments to the tailings can be examined. Using compost as an amendment is a very expensive option compared to topsoil. (Note that only 50 mm of compost is used compared to 100 mm of topsoil). The cost of buying in the required amount of compost is $494,000, however the cost of spreading 50 mm of compost is only half that of spreading topsoil, hence the compost option costs $455,000 more than the topsoil option.

The cheapest option (Scenario 4) is to apply neither compost nor topsoil, however it may be that water treatment costs could be reduced by covering the tailings with topsoil. Also, given that clover germination problems have occurred in unamended tailings trial plots, and frequent applications of superphosphate and possibly resowing may be necessary, it may prove more cost effective to pay an extra $78,000 and apply 100 mm (or possibly less) of topsoil, should it be available on site, rather than sowing into tailings with no compost or topsoil amendment. (Note that the Union Hill tailings trials incorporated a 50 mm topsoil depth treatment and dry matter yields were found to be satisfactory).

Comparing scenario 4 with scenario 5 allows comparison of the costs of rehabilitating to native species rather than the alternative land use of pasture. The fixed costs of rehabilitating the area to natives (including supplementary planting) is more than twice as much as pasture. It should be noted however that for a 26 ha area, this amounts to approximately $350,000 more, which may be considered a relatively small extra cost when compared with the costs of water treatment and clay capping if they are needed.

The cost of maintaining native plants is also very high compared to pasture, being \$1,498,380 for natives and \$67,600 for pasture for a 26 ha area over 14 years. (Note that if natives were planted directly into tailings, there may be less weed seeds, and maintenance costs could therefore be reduced).

In contrast to the lack of revenue associated with planting 26 ha of native species, total revenue for 26 ha restored to pasture over a fourteen year period amounts to \$261,196. Obviously if sale of the tailings area is considered, expected returns from the land could be a major consideration to the purchaser. If planting the area in natives reduces long term environmental risk however, this option may be more attractive to the company.

6.5. SUMMARY AND CONCLUSIONS.

A rehabilitation predictive model can be an effective planning tool for a company facing rehabilitation of a site. Rehabilitation options can be investigated using the model, and potential problems such as a shortage of materials can be identified. Further research may need to be undertaken prior to major shortages occurring, to investigate possible alternative sources and strategies for covering and resurfacing. The model also allows costs to be predicted for various scenarios which is important to a mining company for budgeting reasons.

As already mentioned, rehabilitation planning will involve a team of experts including lawyers, soil scientists, engineers, landscape architects, environmental specialists and geochemists. The local community may also wish to be involved. On top of this, many and varied unforeseen changes may occur during mining and a rehabilitation plan must be flexible.

An ongoing rehabilitation planning process incorporating a site specific predictive model is considered to be one way of incorporating the views of all involved, while giving the mining company concerned some practical information regarding the quantities of materials required, possible materials shortages and the likely costs for various rehabilitation scenarios.

CHAPTER 7 -

SUMMARY AND RECOMMENDATIONS.

7.1 SUMMARY.

The rehabilitation of areas disturbed by mining is a requirement for all three hard rock gold and silver mining projects currently operating in New Zealand. Open pits will generally become lakes upon the completion of mining, with some requirement to revegetate the lake surrounds. In the case of tailings dams, licence conditions generally allow some flexibility in selection of the final land use. Trials are generally required to investigate alternative land use options.

The rehabilitation of areas disturbed by mining must be considered on a site specific basis. In some cases, few options exist, and in other cases many options may exist. Examples of both of these scenarios were investigated with field trials carried out at the Martha Hill gold mining operation. One trial involved a steep, unoxidised pit slope where rehabilitation options were limited, and a second trial involved tailings which had few limitations to plant growth and many resurfacing and land use options.

Hydroseeding of a variety of grass species onto unoxidised andesitic pit slopes at Martha Hill was largely unsuccessful. Acid generation within the substrate caused the pH to drop as low as 2.2 in some areas within five months of cutting back the slope. Where the substrate contained calcite, the pH was elevated and at a pH of 6.0 or above a variety of grasses including ryegrass and clover were able to survive. Clover began to show signs of stress when the pH dropped to 4.5 and when the pH fell as low as 3.6, all grass species died. Unvegetated areas were erodible and visually unpleasant, and the consideration of alternative revegetation options was considered necessary.

Because of the position of the slope above final lake level, and because of the steepness of the slope, the use of dry and wet covers was not practical. The only options existing were amendments in situ, and the selection of species which might grow. Native colonising species were chosen, as it was believed that they would be acceptable to the local community, and may have some tolerance to the extremely harsh conditions for plant growth on the pit slopes.

An air track drill was used to bore holes into the pit slope, and six species of native plants were introduced with various combinations of topsoil, drill cuttings from the boreholes, lime and topsoil added. Toetoe, manuka, kanuka, flax and akeake all had reasonable survival rates, and are worthy of further investigation, but Coprosma kirkii was unsuccessful. Topsoil was found to have a beneficial effect on the overall plant survival rate, more so than the addition of lime and fertiliser. Although survival rates were acceptable in this trial, the plants did not grow quickly and provide a visual screen at the plant spacings used. Further work is considered necessary to identify ways and means of producing an acceptable result.

In contrast to the unoxidised pit slope material, tailings were found in earlier studies to have a good potential for plant growth once nutrient deficiencies were corrected. In 1992, tailings field trials commenced which would investigate the growth of pasture and colonising native plants, with and without a compost amendment. In doing so, an alternative land use, i.e. native plants, and an alternative amendment i.e. compost were being investigated. An alternative amendment to topsoil was chosen for field trials in anticipation of a possible topsoil shortage.

Within the first six months following sowing, pasture dry matter yields from fertilised tailings plots with a 50 mm layer of compost applied to the surface were not significantly different to yields from fertilised tailings plots without a compost amendment. For subsequent cuts, compost amended plots gave significantly higher pasture dry matter yields than unamended plots. Yield differences after the first six months were thought to be due to the improved phosphate status on compost amended plots.

Pasture yields from the 1992 tailings field trial were compared to a similar trial established in 1985, (the Union Hill trial). In the Union Hill trial, plots were established on tailings produced from a former mining operation, and treatments involved the addition of 0 mm, 50 mm, 150 mm and 250 mm of topsoil above the tailings. Where pasture was sown directly into tailings in the 1992 trial, first year yields were slightly higher at 11,000 kg DM/ha than the corresponding Union Hill treatment without topsoil (9,000 kg DM/ha). The topsoil treatments yielded between 6,000 and 7,000 kg DM/ha in the first year of the Union Hill trial, compared to 14,000 kg DM/ha on the 1992 compost amended treatment. Differences in P status may explain the yield differences as the topsoil used in the trial had a high P retention, although differences in rainfall between the 1992 and Union Hill trials may have had some effect. Yield differences between treatments in the Union Hill trial were temporary and it may be assumed that long term productivity would be acceptable from pasture grown with or without compost or topsoil amendments, provided adequate fertiliser was provided at the necessary intervals.

Colonising native plants (kanuka, flax, cabbage tree and Pittosporum tenuifolium), planted in the tailings, with and without a compost amendment, were very successful with all plants surviving. The addition of compost caused significantly higher growth rates in the first six months, but beyond six months no significant differences were observed. It is unknown how the growth rates would compare with other native species growing locally, as no data exists to compare results, however it is considered that the growth rate of native plants is less important than that of grass, as productivity is less of an issue. The most important result was that native plants survived and grew in tailings with and without a compost amendment. All of the species used in the trial would be used ultimately in a mixed planting of native species. If a quick growing shelter material was required, Pittosporum tenuifolium would be selected in preference to the other species used in the trial.

A rehabilitation planning process was proposed for gold and silver mining waste materials. The process incorporates a site specific predictive model. With material such as Martha tailings where many land use and resurfacing options exist, the challenge becomes choosing the best option where many options may exist, i.e. producing an acceptable, and sustainable land use while taking account of costs and how costs are best spread both in the short and long term. A rehabilitation predictive model for Martha tailings was developed to investigate options for tailings rehabilitation, and their associated cost implications.

Five scenarios were tested in the model. It was found that if capping of the tailings surface was required, large amounts of capping material were necessary. For example, if 26 ha of the surface was clay capped to a depth of 1 m and 0.5 m of subsoil was applied, 390 000 m3 of suitable material would be required, and the cost of application would be $1,170,000.

Compost was found to be an expensive option. The cost of buying in and spreading compost to a depth of 50 mm on a 26 ha tailings surface was $455,000 more than the cost of spreading topsoil available on site to a depth of 100 mm. The cheapest option was to apply no compost or topsoil, however water treatment costs may be reduced significantly if topsoil was used, providing a barrier between the tailings surface and rainwater. This however, requires further research. Given that clover germination problems have occurred in unamended tailings and that resowing may be necessary, topsoil tends to be the most cost effective long term option.

The costs of planting to natives (including supplementary planting four years later), were found to be more than twice as much as pasture, and maintenance costs were found to be very high for natives compared to pasture. Pasture provided a revenue which may prove important if the area was to be sold as a productive unit. Native plants however, may provide a land use less likely to be disturbed in the long term.

Based on the information gathered from the field trials and the model, the following recommendations to the company were developed.

7.2 RECOMMENDATIONS.

Recommendations to Waihi Gold Mining Company Ltd have been split into two parts. Part 7.1 makes recommendations regarding future trial work for acid producing slopes, based on all the relevant information presented in this thesis. Part 7.2 makes recommendations regarding final rehabilitation of the tailings surface, based on all trial work carried out so far, and the conclusions that can be drawn from the predictive model.

7.1. CONSIDERATIONS REGARDING REVEGETATION RESEARCH OF ACID PRODUCING PIT SLOPES.

Acid producing pit slopes are difficult to revegetate. Due to the steepness of slope, covering the batters with clay, soil or some other amendment is not practical. Slopes above the ultimate lake level can not be covered with water.

As well as the effects of acid generation, other factors exist which limit plant growth. Lack of an adequate rooting volume and the associated problems of a limited soil and nutrient supply, coupled with physical damage by erosion, make acid producing pit slopes very difficult to revegetate. The only practical rehabilitation options are:

1. To vary the engineering design such that the area exposed is minimised. Taking this to the extreme, it may be possible to cut back pit slopes to better plant growth material, or at least reduce the amount of acid producing material exposed.

2. To vary the engineering design, e.g. reduce the slopes to allow a clay cover or rooting material to be applied, or create flat areas e.g. berms where a cover could be applied and plants introduced in selected areas.

3. To amend the material, with organic amendments, lime, fertiliser and/or a bactericide such as Promac. There are practical difficulties in applying these amendments to ensure that they do not wash off steep slopes.

4. To select plants with some tolerance to acid or heavy metals. These have their limitations.

In practice, various combinations of the above may be employed.

Based on the information presented in this thesis, the following recommendations are made to the company regarding revegetation of the acid pit slopes.

Recommendation 1 - Further Research.

Waihi Gold Mining Co. Ltd has provided funding to a PhD student to carry out research and revegetation trials on acid pit slopes. It is recommended that this continues. The acid pit slopes are very inhospitable for plant growth and it is necessary to continue research in a co-ordinated manner.

Recommendation 2 - Investigation of Engineering Options.

It is important to recognise that providing amendments for plant growth on steep, acid producing pit slopes present particular difficulties in high rainfall areas such as Waihi. Amendments are easily washed away or liable to be covered with material eroding from the above.

It is strongly recommended that the Mining Engineers look at ways of providing flat areas for plant growth. This could involve reducing slope angles, or providing flat areas on the slope where trials with covers and amendments can be carried out. Due regard must be taken of other factors such as slope stability, costs, and integration of design within an overall mine plan.

Recommendation 3 - Investigation of the Rate of Weathering.

Morrell (1995) carried out studies on the distribution of heavy metals, sulphate and total sulphur with depth in Tui Mine tailings and found that the top 200-300 mm had been extensively weathered since deposition. It is recommended that similar studies be carried out at Martha Hill to determine whether the surface of the slopes may, with time, weather such that the surficial acid generation capacity is lowered, and amendment in situ is possible. If so, it may be feasible to delay hydroseeding until the first flush of metals has moved out of the material prior to hydroseeding.

Tomlin (1993) concluded that Martha Hill unoxidised slopes should be left unvegetated until acid production ceased. Hydroseeding could then be carried out with the standard hydroseed mix used at the mine, which at the time contained 600 kg/ha of dolomite. A repeat application within a short time period to apply another 600 kg/ha of dolomite was recommended. The practicality of this option would depend on the amount of time taken for weathering to occur such that acid generation was lowered sufficiently in the surface for revegetation to commence.

Recommendation 4 - Species and Plant Selection.

Morrell (1995) had success with metal tolerant Festuca rubra var. Merlin on Tui Mine tailings. This is a grass species which could be used in further trials with acid rock at Martha Hill. It is noted however that even metal-tolerant species have their limitations and in very acid conditions, other actions may be necessary, e.g. liming, addition of organic amendments, addition of bactericides.

If native species were to be used, toetoe, manuka, kanuka, flax and akeake are all recommended. Coprosma kirkii is not recommended as it tended to die out over summer in acid producing rock on the North Wall. Toetoe and flax appeared to have the ability to tolerate intermittent burial, and akeake was able to resprout from the base. Replanting should be considered if plant deaths occur, as native plant mortality can be high and it is considered standard practice to revisit an area and replant where deaths of native plants have occurred.

One question which arises is whether grass, native plants, or exotic trees should be used. This is not stipulated in the Mining Licence. It is suggested that on steep acidic pit slopes as with Martha Hill, a combination of plants should be selected for trials and possible long term use. Strong grass growth provides a quick visual screen and serves to build up organic matter relatively quickly. Organic matter has the ability to complex metal ions and it is difficult to effectively apply organic amendments to steep pit slopes. Grass growth is an effective way of increasing organic matter levels.

Native species, if they are able to set seed, could provide a more long term and sustainable land use for vegetation above the lake. Grass could provide a medium to trap seeds from native plants, which would otherwise be washed away. It is acknowledged that grass competes with natives and native plants may require releasing if grass growth is vigorous.

If a decision is made to plant in selected areas, it may be beneficial to include some quick growing species such as wattles to provide a quick screen. Wattles growing on the west side of the pit in oxidised material reached a height of up to 8 m in six years which is an appreciable growth rate compared to many native species. A mixture of native species and wattles may achieve the objectives of quick visual screening, while providing native species which may be more acceptable to the local community in the long term.

It is also recommended that if native or exotic plants are to be used, plants of a PB3 size are used rather than root-trainer sized plants. Brown pers comm (1995) reports that larger native plants are able to withstand environmental stress better. It is recommended also that the plants are produced from eco-sourced seed. Because of this, early consultation with nurseries is suggested.

Recommendation 5. Investigation of Bactericides.

The benefits of Promac have been reviewed in this thesis, and it is considered that further trial work should incorporate a Promac treatment. Application to pit slopes would however be very difficult. It is unknown whether a method exists whereby slow release pellets could be injected into the slope, and whether this would be effective - but it is definitely worth trialling. Promac application may be limited to flatter areas, where it can be incorporated in the rooting medium.

Recommendation 6. Investigation of Surviving Natives Plants on Acid Rock.

Some plants have been able to survive where no topsoil amendment was applied, and in December of 1995 they were observed to be healthy. It is recommended that these plants be investigated more closely to determine whether their roots are concentrated around areas of finely disseminated calcite, or whether they have some form of tolerance mechanism which allows survival.

Recommendation 7. Trial Design.

It was discovered that there was less calcite in rock on the eastern end of the North Wall native plant trial area, than towards the western end. Because treatments were grouped across the slope, the trial may have been biased by differences in overall acid generation across the face.

It is recommended that if a similar trial was initiated, replicates should be grouped across the face, and that treatments be randomised within replicates.

PART 7.2 - RECOMMENDATIONS FOR TAILINGS REHABILITATION.

Tailings rehabilitation is quite different to acid pit slope rehabilitation. Native plants and grasses will grow well on tailings if supplied with adequate amounts of fertiliser and many options exist for final rehabilitation. The difficulty is in choosing the best options to provide an acceptable and sustainable land use while taking account of costs.

It is acknowledged that there are unanswered questions relating to tailings rehabilitation such as the long term acid producing potential of the tailings, drainage and settlement issues and economic considerations, which are beyond the scope of this thesis. It is understood that Waihi Gold Mining Co. Ltd is carrying out studies to address these issues. The following recommendations deal entirely with the final surface rehabilitation options.

Recommendation 1 - Suggested Amendment For Pasture.

Field trials showed that compost amended plots outperformed unamended plots and topsoil amended plots (in the Union Hill trial) after the first nine months of harvesting. This was probably due to the improved phosphate status of the compost amended plots. Yields from all three treatments are expected to be comparable long term.

At this stage, it is recommended that if pasture is used, a topsoil amendment (possibly 50 to 100 mm) is provided. This decision is not based on pasture yield, but on water quality factors.

Losses of phosphate were estimated to be very high on the compost amended and unamended plots. Losses were not investigated on the topsoil amended Union Hill plots, however it is expected that phosphate leaching would be less of a problem with the phosphate retention being high in the topsoil. With phosphorus being of concern for eutrophication of waterways, it may be the best option to provide a topsoil layer to reduce the phosphorus load in runoff water from the tailings.

A topsoil layer may also improve water quality by providing a boundary between incident rainfall and the tailings surface. The predictive model identified large water treatment costs from runoff water derived from tailings, should this water require treatment. Topsoil addition could be a long term cost saver if it reduces water treatment costs.

The least cost option was to apply no amendment at all to the tailings. However, clover germination in dry tailings has been found to be poor in trial work and it is likely that resowing would be necessary. Fertiliser application may need to be more frequent in the early years until organic matter forms and leaching losses are reduced. The performance of unamended tailings when sown to pasture and grazed has not been tested, although pasture could be used for hay or silage with limited grazing being carried out. All round, topsoil is probably the cheapest and most environmentally sound option if pasture is sown on the tailings.

Recommendation 2 - Suggested Amendment For Native Plants.

Native species are different to pasture in that growth rates are less important. Compost as applied in the trials would improve growth in the first year, but costs would be high. It is suggested that native plants should be planted directly into tailings, because trials show that they will survive and grow. Maintenance costs may be significantly less than if compost or topsoil were used because no weed seeds would be present in the tailings, at least initially.

Recommendation 3 - Materials Quantities.

The availability of on site materials such as clay for capping, and topsoil should be investigated. If capping material is in short supply, and capping is found to be necessary, there are major cost implications.

Similarly topsoil quantities should be investigated. It is possible that in the event of a topsoil shortage, compost could be used. In this case it may be in the best interests of the company to investigate producing their own compost using locally available chicken manure and vegetative waste from the local landfill site. This could be a cheaper way of obtaining compost than trucking it in and could also be a good public relations exercise. Phosphorus in drainage water from tailings rehabilitated to pasture could still be a problem however.

Recommendation 4 - Further Trials.

Given that a lake may exist on the tailings pond, it is recommended that native species that could be grown around the lake edge be investigated . The "wet" trial pond, currently unused, could be used for this purpose.

Supplementary planting of native tree species such as rimu, totara and kahikatea could be carried out within the native colonising plants which presently inhabit part of the "dry" tailings pond. In this case, yields would be important and revenue could be obtained from the site by harvesting the trees as timber some time in the future.

Investigation of the effects of planting native species onto capped tailings may be required. Roots of the native species grown on tailings were extensive, and the cabbage trees were observed to form a strong, deep tap root. It is unknown what effect the rooting behaviour of native species might have on capping material.

References.

Alloway, B.J. (1990). Heavy Metals in Soils. Blackie and Sons. London.

AMMTEC (1991). Minerals and Metals Processing News. Newsletter No 8. Australian Metallurgical & Mineral Testing Consultants Pty Ltd.

Antonovics, J., Bradshaw A.D., Turner R.G. (1971). Heavy Metal Tolerance in Plants. Advances in Ecological Research 7, 1-85.

Armiger W.H., Jones J.N., Bennett O.L. (1976). Revegetation of Land Disturbed by Strip Mining of Coal in Appalachia. Report, US Agricultural Research Service No. ARS-NE-71.

Bell L.C. (1990). Assisting the Return of the Living Environment After Mining - An Australian Perspective. IN: Gregg, P.E.H., Stewart, R.B., & Currie, L.D., eds (1990). Proceedings of the Workshop, Issues in the Restoration of Disturbed Land. Massey University, Palmerston North, 20-21 February 1990. Fertiliser and Lime Research Centre.

Bell, L.C., Ward, S.C., Kabay, E.D. & Jones, C.J. (1989). Mine Tailings Reclamation in Australia - An Overview. IN: Walker, D.G., Powter, C.B. & Pole, M.w. (Eds). Proceedings of the Conference - "Reclamation, a Global Perspective." 27-31 August, 1989, Calgary. Report No. RRTAC 89-2. Alberta Land Conservation and Reclamation Council, Edmonton, Alberta.

Bent, E.M. (1991). The Suitability of Tailings as a Plant Growth Medium. A Research Report Presented in Partial Fulfilment of The Requirements For The Degree of Bachelor of Horticulture (Technology) at Massey University.

Blakemore, L.C., Searle, P.L., Daly, B.K. (1981). Methods for Chemical Analysis of Soils. NZ Soil Bureau Scientific Report 10A.

Bowen, H.J.M (1979). Environmental Chemistry of the Elements. Academic Press Inc.

Bradshaw A.D. & Chadwick M.J. (1980). The Restoration of Land: The Ecology and Reclamation of Derelict and Degraded Land. Oxford, Blackwell Scientific Publications.

Brady, N.C. (1984). The Nature and Properties of Soils, 9th edition. MacMillan Publishing Company, New York.

Bresler E, McNeal B L and Carter D L (1982). Saline And Sodic Soils - Principles - Dynamics - Modelling. Springer-Verlag.

Brooks, R.R. (1983). Biological Methods of Prospecting For Minerals. John Wiley and Sons. Canada.

Brown, D. (1977). Handbook. Equipment for Reclaiming Strip Mined Land. Missoula, Montana, USDA Forest Service Equipment Development Centre. 58p.

Cannon, H.L. (1963). Biogeochemistry of Vanadium. Soil Science, 96: 196-204.

Carlson J. & Swanson S. (1979). Trefoils: Backbone of Erosion Control. Soil Cons. Serv. Washington.

Carpenter P.L. & Hensley D.L. (1979). Utilising N_2-fixing Woody Plant Species For Distressed Soils and the Effect of Lime on Survival. Botanical Gazette 140, Supplement S76 - S81.

Caruccio, F.T. and Geidel, G. (1981). Estimating the Minimum Load That Can B Expected From a Coal Strip Mine. Symposium on Surface Mining Hydrology, Sedimentation and Reclamation. Lexington, N.Y. 1981.

Czupyrna, G., MacLean, A.I., Levy, R.D., Gold, H., (1989). In Situ Immobilisation of Heavy-Metal-Contaminated Soils. Pollution Technology Review No 173. Noyes Data Corporation. 1989.

Connelly, L.P., Wein, V.S. and Denize P.R. (1981). Land Rehabilitation Practice at Waipipi Iron Sands Limited. Prepared For The Australian Institute of Mining and Metallurgy - New Zealand Branch. 1981 Annual Conference 'Mining and the Environment', Thames, 19-21 August 1981.

Daniels, W.L., Amos, D.F. (1981). Mapping, Characterization and Genesis of Mine Soils on a Reclamation Research Area in Wise County, Virginia. IN: Proceeding, 1981 Symposium on Surface Mining Hydrology. Sedimetnology and Reclamation. University of Kentucky, Lexington, Kentucky. 1981. pp 261-265.

Department of Mines, Western Australia. (1988). Guidelines for Environmental Management of Mining in Arid Areas.

Down and Stocks (1977). Environmental Impact of Mining. New York. John Wiley and Sons. 361 pgs.

Duggan, J.C. and Wiles, C.C. (1976). Effects Of Municipal Compost And Nitrogen Fertiliser On Selected Soils And Plants. Compost Science. 17(5): 24-31.

During, C. (1984). Fertilisers and Soils in New Zealand Farming. Ruakura Agricultural Research Centre, MAF. Government Printer, Wellington, NZ.

Edgerton, B.R., Sopper, W.E., Kardos, L.T. (1975). Revegetating Bituminous Strip-Mine Spoils With Municipal Wastewater. Compost Science 16, 20 - 25.

Ernst, (1974). Schwermetallvegetation der Erde. Gustave Fischer, Stuttgart.

Farmer E.E., Richardson B.Z., & Brown R.W. (1976). Regeneration of Acid Mining Wastes in Central Idaho. Research Paper, Intermountain Forest and Range Experiment Station, USDA Forest Service No. INT - 178.

Foth, H.D. (1978). Fundamentals of Soil Science, 6th edition. John Wiley and Sons, New York.

Fox J.E.D. (1984). Rehabilitation of Mined Lands. Forestry Abstracts Review Article. Sept 1984. Vol 45. No 9. School of Biology, Western Australian Institute of Technology, Western Australia.

Fuller, W., (1984). Cyanides in the Environment with Particular Attention to the Soil. Cyanide and the Environment. Vol I Colorado State University, Fort Collins, Colorado pp 19-46 1984.

Gadgil, R.L. (1969). Tolerance of Heavy Metals and the Reclamation of Industrial Waste. Journal of Applied Ecology 6, 247 -259.

Gleeson, V. and Russell, H.R. (1976). Mine Drainage Bibliography 1910-1976. Coal and the Environment Abutment Series, Bituminous Coal Research Institute.

Goldfields Land Rehabilitation Group (1995). Rehabilitation of Mine Waste Dumps in the Goldfields of Western Australia. Publication. Goldfields Land Rehabilitation Group , P.O. Box 2412, Boulder, W.A. 6432.

Gregg, P.E.H., Stewart, R.B. (1989). Guidelines For Restoration. Consultant Report to Waihi Gold Mining Co Ltd.

Gregg, P.E.H., Stewart, R.B., Stewart, G. (1990). Determination of a Suitable Plant Growth Medium on Gold and Silver Mining Waste, Martha Hill, Coromandel Peninsula - I. Agronomic and Soil Chemical Aspects. IN: Proceedings of the Workshop "Issues in the Restoration of Disturbed Land". Massey University, Palmerston North, 20-21 February 1990. Eds, Gregg, P.E.H., Stewart, R.B., Currie, L.D.

Gregg, P.E.H., Stewart, R.B., & Currie, L.D., eds (1990). Proceedings of the Workshop, Issues in the Restoration of Disturbed Land. Massey University, Palmerston North, 20-21 February 1990. Fertiliser and Lime Research Centre.

Gregg, P.E.H., Stewart, R.B., Mason, K.A. (1995). Pastoral Reclamation of Tailings and Overburden Material from a New Zealand Open Cast Gold Mine. Proceedings of Sudbury 95 - Mining and the Environment. May 28th to June 1st, Sudbury, Ontario, Canada. Vol 3. pp 1249 to 58.

Grundy, M.J., & Bell, L.C., (1981) IN: Bell, L.C. (1990). Assisting the Return of the Living Environment After Mining - An Australian Perspective. IN: Gregg, P.E.H., Stewart, R.B., & Currie, L.D., (1990). Proceedings of the Workshop, Issues in the Restoration of Disturbed Land. Massey University, Palmerston North, 20-21 February 1990. Fertiliser and Lime Research Centre.

Hannan, J.C. (1978). Rehabilitation of Coal Mines in the Hunter of New South Wales. IN: Rummery, R.A. and Howes K.M.W. eds (1979). Management of Lands Affected by Mining. Division of Land and Resource Management. CSIRO, Australia.

Hannan J.C. & Bell L.C.(1986). Surface Mine Rehabilitation. IN: Australasian Coal Mining Practice. Australasian Institute of Mining and Metallurgy, Parkville Victoria. pp 233-252.

Harper, J. & Spooner, A.E. (1983). Establishment of Selected Herbaceous Species on Acid Bauxite Minerals. Proc. 1983 Symposium on Surface Mining, Hydrology, Sedimentology and Reclamation. Ed by Graves D.H.

Hart, B.T., (1974). A Compilation of Australia Water Quality Criteria. Australian Water Resources Council Technical Paper No. 7, Australian Government Publishing Service, Canberra.

Hawley, J.R. (1977). The Problem of Acid Mine Drainage in Ontario. The Ontario Water Resources Commission.

Herando, S., Lobo, M.C. and Polo, A. (1989). Effect Of The Application Of Municipal Refuse Compost On The Physical And Chemical Properties Of A Soil. Sci. Total Environ. 81/82: 589-596.

Horn M.L. & Ward W.W. (1969). The Revegetation of Highly Acid Spoil Banks in the Bituminous Coal Region of Pennsylvania. Pennsylvania State Univ. Special Research Report.

Horne, D.J., Stewart, R.B., Gregg, P.E.H. (1990). Determination of a Suitable Plant Growth Medium on Gold and Silver Mining Waste, Martha Hill, Coromandel Peninsula - II. Physical Properties. IN: Gregg, P.E.H., Stewart, R.B., & Currie, L.D., (1990). Proceedings of the Workshop, Issues in the Restoration of Disturbed Land. Massey University, Palmerston North, 20-21 February 1990. Fertiliser and Lime Research Centre.

Hortenstine, C.C., and Rothwell D.F. (1973). Pelletized Municipal Refuse Compost As A Soil Amendment And Nutrient Source For Sorghum. J.Environ.Qual. 2(3):343-344.

Hoyt, P.B. & Nyborg M. (1972). Can.J.Soil.Sci. 52, 163-167. IN: Muller A, Krebs, B eds (1984). Studies in Inorganic Chemistry 5. Sulphur. Its Significance For Chemistry, for the Geosphere, Biosphere and Cosmosphere & Technology. Elsevier Science Publisher. Amsterdam.

Hutchison I.P.G & Ellison R.D. (1992). Mine Waste Management. Lewis Publishers, Michigan.

Jackson, M.L. (1967). Soil Chemical Analysis. Prentice-Hall, Inc., pp. 362-363.

Johnson, M.S., Bradshaw, A.D., and Handley, J.F. (1976). Prevention of Heavy Metal Pollution From Mine Wastes by Vegetative Stabilisation. Department of Botany, Liverpool.

Kleinmann, R.L.P., Crerar, D.A., and Pacilli R.R. (1981). Biogeochemistry of Acid Mine Drainage and a Method to Control Acid Formation. Min. Eng., 33:300-304.

Knapp, R. (1987). Bio/Geochemistry of Acid Generation in Sulphides Tailings and Waste Rock. Proceedings of the ARD Seminar/Workshop. Environment Canada, Halifax, Nova Scotia.

Kraus, E.H.; Hunt, W.F.; and Ramsdell, L.S. (1959). Mineralogy. New York: McGraw-Hill.

Kruckeberg, A.R. (1954). The Ecology of Serpentine Soils: A Symposium. III. Plant Species in Relation to Serpentine Soils. Ecology 35: 267-276.

Lambrechtsen (1986). IN: Pollock (1986). Plant Materials Handbook For soil Conservation. Soil Conservation Centre, Aokautere.

Limstrom, G. A. (1964). Revegetation of Ohio's Strip-Mined Land. Ohio Journal of Science 64 (2), 112 (1964).

Lindsay, W. L. (1979). Chemical Equilibria in Soils. John Wiley and Sons, 449 p.

Lounamaa, K.J. (1956). Trace Elements in Plants Growing Wild on Different Rocks in Finland. A Semi-Quantitative Spectrographic Survey. Annls. Bot. Soc. Zoo. - bot. Fenn Vanamo 29: 1-196.

Ludeke, K.L. (1973). Vegetative Stabilisation of Tailings Disposal Berms. Mining Congress Journal. January 1973.

McAra J.B. (1988). Gold Mining at Waihi, 1878 - 1952. Martha Press, Doreen McLeod, 61 Consols St, Waihi.

McConnell, D.B., Shiralipour, W., and Smith W.H. (1993). Compost Application Improves Soil Properties. Biocycle, April 1993.

McQueen, D.J., (1982). Land Reclamation - Physical Restoration Of Soil After Mining. IN: Ross, C., & Mew, G., (1990). Land Restoration After Mining on the West Coast, South Island. IN: Gregg, P.E.H., Stewart, R.B., & Currie, L.D., (1990). Proceedings of the Workshop, Issues in the Restoration of Disturbed Land. Massey University, Palmerston North, 20-21 February 1990. Fertilizer and Lime Research Centre.

McQueen, D.J. & Ross C.W. (1982). Effects of Stockpiling Topsoils Associated With Opencast Mining. 2. Physical Properties. New Zealand Journal of Science, 1982, Vol. 25: 295 - 302.

McWilliams, J.L. (1971). Annual Technical Report - Plant Materials Field Plantings. USDA, Soil Conservation Service, Big Flats NY 1971, 10 pages.

Marshall, J.K., Morrissey, J.G., Richmond, P.C., (1978). Control of Dust From Slime Dumps at Kalgoorlie. IN: Rehabilitation of Mined Lands in Western Australia: Proceedings of a meeting held in Perth on 11th October 1978 (JED Fox, Editor). South Bentley, Western Australia Institute of Technology, pp 63-67.

Mason, K.A. (1989). Aspects of Land Rehabilitation at Waihi Gold Mine. A Thesis Submitted in Partial Completion of a B.Hort.Sc (Hons) Degree. Department of Soil Science, Massey University, Palmerston North.

Mason, K.A., Gregg, R.B., Stewart, R.B., (1993). Soil Formation on Tailings, Waihi. IN: The Changing World of Mining. The Australasian Institute of Mining and Metallurgy (AusIMM) New Zealand Branch. 27th Annual Conference, Wellington. 24 to 27 August 1993. p251.

Mays, D.A., Terman, G.L, and Duggan, Jc. (1973). Municipal Compost: Effects On Crop Yields And Soil Properties. J.Environ. Qual. 2(1): 89-92.

Mellinger, R.H., Glover, F.W., & Hall, J.G. (1966). Results of Revegetation of Strip Mine Spoil in Soil Conservation Districts in West Virginia.

Miles, V.C.; Ruble, R.W.; Bond, R.L. (1975). Performance of Plants in Relation to Soil Classification in Pennsylvania. IN: Ecology and Reclamation of Disturbed Land. Vol 2. R.J. Hutnik and G. Davis (eds), Gordon and Breach, NY 1973, pp 13-31.

Miller S.D. (1985). Mining and Heavy Metals, Development of Control Strategies. For N.Z. Mining and Exploration Association. Report to R. Craddock, Waihi Gold Mining Co. Ltd, Waihi.

Miller, S.D. & Associates Pty, Ltd and Groundwater Consultants (NZ) Ltd (1986). Geochemical Evaluation of Leachates From Waste Rock and Tailings, Final Report. Waihi Gold Mining Co Ltd.

Moore, T.R., & Zimmermann, R.C., (1977). Establishment of Vegetation on Serpentine Asbestos Mine Wastes, Southeastern Quebec, Canada. Journal of Applied Ecology 14, 589-599.

Morrell, W.J., Gregg, P.E.H., Stewart, R.B., Bolan N., and Horne, D. (1995). Potential for Revegetating Base-Metal Tailings at the Tui Mine Site, Te Aroha, New Zealand. Proceedings of Pacrim Congress 1995 - Exploring the Rim. 19-22 November 1995, Auckland, New Zealand. Eds J.L. Mauk & J.D. St George. AusIMM Publication Series No 9/95.

NIWAR (1992). Waihi Climate Data. Atmospheric Division, 30 Salamanca Rd, Kelburn, Wellington.

Nyborg, M. (1984). Sulfur Pollution in Soils. IN: Muller, A., Krebs, Bl, eds (1984). Studies in Inorganic Chemistry 5. Sulphur. Its Significance For Chemistry, for the Geosphere, Biosphere and Cosmosphere and Technology. Elsevier Science Publishers. Amsterdam.

Onysko, S.J., Kleinmann R.L.P. and Erickson P.M. (1984). Ferrous Iron Oxidation by Thiobacillus ferrooxidans: Inhibition With Benzoic Acid, Sorbic Acid and Sodium Lauryl Sulfate. Applied and Environmental Microbiology 48(1). pp. 229-231.

Palmer, M.W. (1978). Acidity and Nutrient Availability in Colliery Spoil. Dept of Bio. University of New York.

Parisi D., Horneman, J., Rastogi, V. (1994). Use of Bactericides to Control Acid Mine Drainage From Surface Operations. Paper Presented at the International Land Reclamation and Mine Drainage Conference and the Third International Conference on the Abatement of Acidic Drainage, Pittsburgh. April 24-29 1994.

Peterson, H.B., & Nielson, R.F. (1978). Heavy Metals in Relation to Plant Growth on Mine and Mill Wastes. IN: Environmental Management of Mineral Wastes, ed. G. T. Goodman & M. J. Chadwick, 297-309, NATO Advanced Study Inst., Series E, No. 7, Sijthoff & Noordhoff, Netherlands.

Plass, W.T. (1974). Factors Affecting the Establishment of Direct-Seeded Pine on Surface-Mine Spoils. Research Paper, North Eastern Forese Experiment Station, USDA Forest Service No. NE-290.

Pollock, K.M. (1986). Plant Materials Handbook for Soil Conservation. Volume 3: Native Plants. Soil Conservation Centre, Aokautere. Ministry of Works and Development, Palmerston North.

Poynton, R.J. (1977). Tree Planting In An Urbanising South Africa. South African Forestry Journal No. 100, 43-49.

Repp, G., (1963). Die Kupferresistenz des Proto Plasmas Hoherer Pflanzen. Protoplasma 57.

Richard, T.L. Woodbury, P.B. (1992). The Impact Of Separation On Heavy Metal Contaminants In Municipal Solid Waste Composts. Biomass and Bioenergy 3(3-4):195-211.

Richardson, B.Z. (1980). Reclamation Of Acid-Producing Spoils On A Western Surface Mine. IN: Proceedings: High-altitude revegetation workshop No. 4, February 26-27, 1980 (C.L. Jackson & M.A. Schuster, Editors). Colorado State University Water Resources Institute, pp. 101-112.

Robinson, W.O., Edgington, G., and Byers, H.G. (1935). Chemical Studies of Infertile Soils Derived From Rocks Generally High in Magnesium and Generally High in Chromium and Nickel. U.S. Dept. Agr. Bull. 471: 1-29.

Ross, C., & Mew, G., (1990). Land Restoration After Mining on the West Coast, South Island. IN: Gregg, P.E.H., Stewart, R.B., & Currie, L.D., (1990). Proceedings of the Workshop, Issues in the Restoration of Disturbed Land. Massey University, Palmerston North, 20-21 February 1990. Fertilizer and Lime Research Centre.

Ruffner, J.D.; and Steiner, W.W. (1973). Evaluation of Plants For Use on Critical Sites. IN: Ecology and Reclamation of Devastated Land. Vol 2, R.H. Hutnik and G. Davis (eds). Gordon and Breach, NY, 1973 pp 3-12.

Ruffner, J.D. (1966). An Evaluation of Species Planted on Coal Strip Mine Spoil in West Virginia for Stabilisation Purposes, 1955-1965. Soil Conservation Service. Morgantown, W.Va. (1966).

Ruschena, L.J., Stacey, G.S., Hunter, G.D., Whiteman, P.C (1974). Research into the revegetation of concentrator tailing dams at Mount Isa. Parkville, Victoria, Australasian Institute of Mining and Metallurgy. 16 pp.

Salmon, J.T. (1991). Native New Zealand Flowering Plants. Reed Books, Auckland.

Silver, M (1987). Aquatic Plants and Bog Covers to Prevent Acid Generation - Base Metal Tailings. Proceedings of the ARD Seminar/Workshop. Halifax. March 1987.

Smale, M.C., Rogers, G.M. (1995). Germination and Growth of Native Geothermal Heathland Species on Varying Mixtures of Golden Cross Mine Overburden and Loam. Report to Coeur Gold. From Russell Squire, Environmental Officer, Coeur Gold.

Smith, R.A.H., Bradshaw, A.D. (1970). Reclamation of Toxic Metalliferous Wastes Using Tolerant Populations of Grass. Nature, UK 227, 376-377.

Smith, E.E. and Shumate, K.S. (1971). Sulfide to Sulfate Reaction Mechanism. A Study of the Sulfide to Sulfate Reaction Mechanism as it Relates to the Formation of Acid Mine Waters. Report by Ohio State Universtiy Research Foundation to the United States Federal Water Pollution control Administration, PB-213 876. 1971.

Smith, R.A.H., & Bradshaw, A.D. (1972). Stabilisation of Toxic Mine Wastes by the Use of Tolerant Plant Populations. Transactions, Institution of Mining and Metallurgy 81A, 230-237.

Smith, R.A.H., & Bradshaw, A.D. (1979). The Use of Metal Tolerant Plant Populations For the Reclamation of Metalliferous Waste. Journal of Applied Ecology 16, 595-612.

Smith, R.M., Twiss, P.C., Krauss, R.K. and Brown, M.J. (1987). Dust Deposition in Relation to Sige, Season and Climatic Variables. Soil Science Society of America, Proceedings Vol 34, No 1, 1970, pp 113-117.

Smith, A. and Barton-Bridges, J.B. (1991). Some Considerations in the Prediction and Control of Acid Mine Drainage Impact on Groundwater From Mining in North America. Proceedings EPPIC Conference, Johannesburg, South Africa. May 1991.

Smith, A. & Mudder, T. (1991). Chemistry and Treatment of Cyanidation Wastes. Mining Journal Books. London.

Sobek, A.A., Schuller, W.A., Freeman, J.R., Smith, R.M. (1978). Field and Laboratory Methods applicable to Overburdens and Mine Soils. EPA 600/2-78-054, U.S. Environmental Protection Agency, Cincinnati, OH.

Sobek, A.A., Benedetti, D.A. and Rastogi, V. (1990). Successful Reclamation Using Controlled Release Bactericides: Two Case Studies. American Society for Surface Mining and Reclamation Conference. Charleston, WV. April 23-26, 1990, pp 33-41.

Sommers, L.E.and Giordano P.M. (1984). Use Of Nitrogen From Agricultural, Industrial And Municipal Wastes. IN: Nitrogen in crop production. ASA-CSSA-SSSA. 677 South Segoe Rd, Madison, WI 53711.

Sopper, W.E., Dickerson, J.A., & Hunt, C.F. (1970). Revegetation of Strip Mine Spoils Banks Through Irrigation with Municipal Sewage Effluent and Sludge. Compost Science, 11. No 6, pp 6-11.

Splittorf, D. and Rastogi, V. (1995). Ten Year Results From Bactericide-Treated and Reclaimed Mine Land. Paper presented at the 1995 National Meeting of the American Society for Surface Mining and Reclamation, Gillette, Wyoming, June 5-8, 1995.

Stehouwer, R.C., Sutton, P., Pick, W.A. (1994). Dry Flue Gas Desulfurization Byproducts as Amendments For Acid Agricultural Soils. Proc. of the Int Land Reclamation and Mine Drainage Conference, Pittsburgh. April 1994, Vol 3.

Sugio T, et al (1985). "Role of Ferric Iron-Reducing System in Sulphur Oxidation of Thiobacillus Ferro-Oxidans." Journal of Bacteriology 44. (1985). 1401-1416.

Sutton, P. (1970). Reclamation of Toxic Coal Mine Spoilbanks. USEPA, Ohio Report, 55(5), 99 (1970).

Tomlin, K. (1993). The Revegetation Of Blue Rock At Martha Hill Gold Mine. A research report presented in partial fulfilment of the requirements for the degree of Bachelor of Horticulture (Technology) at Massey University, Palmerston North.

Towill, L., Drury, J., Whitefield, B., Lewis, E., Galyan, E., and Hammons, A. "Reviews of the Environmental Effects of Pollutants: V. Cyanides", EPA-600/1-78-027, USEPA, Cincinnati, Ohio, 1978.

Tuttle, J.H., Dugan P.R. and Apel, W.A. (1977). Leakage of Cellular Material from Thiobacillus ferrooxidans in the Presence of Organic Acids. Applied and Environmental Microbiology 33. pp. 459-469.

U.S.E.P.A. (1976). Vegetative Stabilisation of Mineral Waste Heaps. EPA-600/2-76-087. National Technical Information Service. Springfield. Virginia 22161.

Van Kraayenoord, C.W.S., and Hathaway, R.L. eds. (1986). Plant Materials Handbook For Soil Conservation. Volume 2: Introduced Plants. Soil Conservation Centre, Aokautere, Ministry of Works and Development, Palmerston North, Wellington 1986.

Vassileva, T. (1987). Soil-Conserving And Water-Regulating Ability Of Some Perennial Grasses Grown On Slightly To Moderately Eroded Lands. Language: Bulgarian, Summary Language: English. Complex Exp. Sta., K"rdzhali, Bulgaria. Pochvoznanie, Agrokhimiya i Rastitelna Zashchia 1987. 22(3): 60-65.

Verbin, A.E., & Keleberda,T.N. (1974). Trial Plantations For Land Reclamation. IN: Fox J.E.D. (1984). Rehabilitation of Mined Lands. Forestry Abstracts Review Article. Sept 1984. Rehabilitation of Mined Lands. Forestry Abstracts Review Article. Sept 1984. Vol 45. No 9. School of Biology, Western Australian Institute of Technology, Western Australia.

Vogel, W.G. & Berg, W.A. (1968). Grasses and Legumes For Cover on Acid Strip-Mine Soils. J.Soil & Water Conservation. 23. No 3,89.

Waihi Gold Mining Co Ltd, (1985). Martha Hill Project Environmental Impact Report, Waihi Gold Company, March 1985.

Walker, R.B. (1954). The Ecology of Serpentine Soils. II. Factors Affecting Plant Growth on Serpentine Soils. Ecology 35: 259-266.

Watzlaf, G.R. (1986). Control of Acid Mine Drainage From Mine Wastes Using Bacterial Inhibitors. p 123-130. IN: Proceedings of the American Society for Surface Mining and Reclamation, 1986 Annual Meeting.

White, R.E. (1987). Introduction to the Principles and Practice of Soil Science. 2nd edition. Blackwell Scientific Publications, Oxford, London.

Widdowson, J.P., Gibson, E.J., Healy, W.B., (1982). Effects of Stockpiling Topsoils Associated With Opencast Mining. 1. Chemical Properties and the Growth of Ryegrass and White clover. New Zealand Journal of Science, 2982, Vol 25: 287-294.

Widdowson J.P., Ross C.W., McQueen D., Watts H.M. (1984). Plant Growth Potential of Tailings and Waste Materials From Martha Hill, Waihi. NZ Soil Bureau, DSIR, Lower Hutt.

Wilkins, D.A. (1957). A Technique For the Measurement of Lead Tolerance in Plants. IN: Salomen and Forstner, J.Sci.Fd.Agric (17).

Williams, E.G., et al (1982). Factors Controlling the Generation of Acid Mine Drainage. Report to the United States Bureau of Mines, Research Grant No. G5105086. 1982. 256.

Williamson, N.A., Johnson, M.S., and Bradshaw (1982). Mine Wastes Reclamation. Mining Journal Books. 15 Wilson Street, London.

Appendix 2.1 - A Description of Alkalinity By Example,
(Hutchison & Ellison, 1992).

Example 1: Using a completely unbuffered (zero alkalinity) oxygen-saturated water to oxidise pyrite, the resultant pH will be about 3.2 given no external source of oxygen.

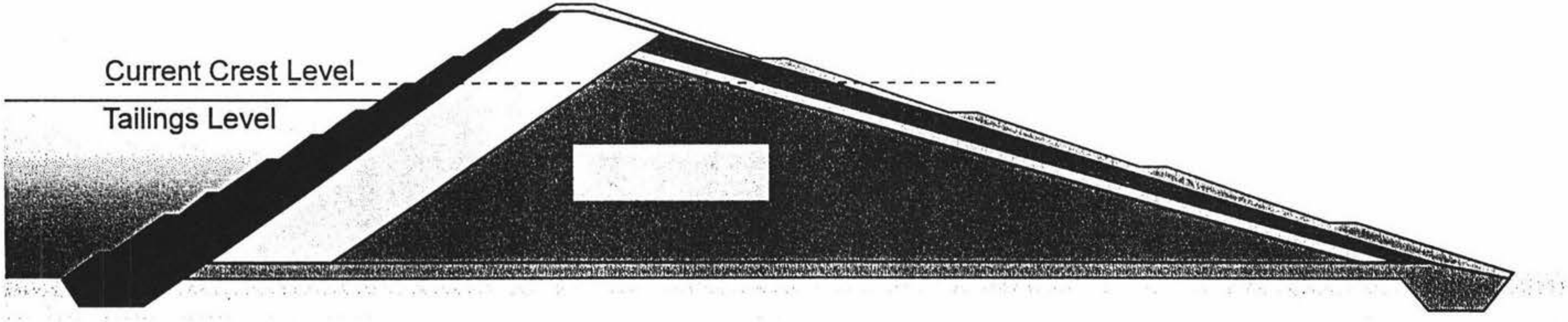
Example 2: In the presence of and at equilibrium with calcite, the oxygen in oxygen-saturated water would oxidise pyrite, but the final pH, once all the oxygen was used, would be about 7.4. The alkalinity would not only consume the acid produced, but would leave residual alkalinity capable of further acid consumption.

Appendix 3.1 - Ratings For Soil Chemical Properties According to Blakemore *et al* (1981), IN: Widdowson *et al* (1984).

The following ratings of chemical properties are used by Soil Bureau for New Zealand Soils:

Rating	pH (1:2.5 soil:water)	Olsen P (ppm)	Phosphate extractable S (ppm S)	Soluble salts (%)
	>9.0 (extremely alkaline)			
Very high	8.4-9.0 (strongly alkaline)		>150	>0.7
	7.6-8.3 (moderately alkaline)			
High	7.1-7.5 (slightly alkaline)	>30	50-150	0.3-0.7
	6.6-7.0 (near neutral)			
Medium	6.0-6.5 (slightly acid)	21-30	15-50	0.15-0.3
	5.3-5.9 (moderately acid)			
Low	4.5-5.2 (strongly acid)	11-20	5-15	0.05-0.15
Very low	<0.5 (extremely acid)	0-10	<5	<0.05

Rating	Cation-Exchange Properties.						
				Exchangeable			
	CEC (me%)	TEB (me%)	BS (%)	Ca (me%)	Mg (me%)	K (me%)	Na (me%)
Very high	>40	>25	80-100	>20	>7	>1.2	>2
High	25-40	15-25	60-80	10-20	3-7	0.8-1.2	0.7-2
Medium	12-25	7-15	40-60	5-10	1-3	0.5-0.8	0.3-0.7
Low	6-12	3-7	20-40	2-5	0.5-1	0.3-0.5	0.1-0.3
Very low	<6	<3	<20	<2	<0.5	<0.3	<0.1



LEGEND

Zone A	▨	For internal leachate and foundation seepage control.	**Zone E**	□	Softest and wettest waste rock.
Zone B	■	For seepage control and strength.	**Zone F**	□	Forms a transition zone between waste rock and final rehabilitation surface.
Zone C	□	Forms transition between zones B and D.	**Zone G**	■	Controls seepage through the downstream shoulder.
Zone D	▨	Provides structural strength.	**Zone H**	▨	Final rehabilitation cover.

Appendix 3.2 - Diagram of the Waste Embankment in Cross-Section.

Appendix 4.1 - Plant Species Used in the Acid Rock Trial.

Selection of native species took into account the limitations of the site described above. All information regarding these species is taken from Pollock 1986 unless otherwise stated.

Cortaderia toetoe (toetoe).

C. toetoe is one of four endemic species and is New Zealand's largest endemic grass. C. selloana (pampas grass) is an introduced species from South America. The plume-like flowers of the toetoe are up to 3 m high and flowering occurs from November through March, (Salmon 1991).

C. toetoe occurs in the North Island from Auckland southwards on wet ground, in forest clearings, along roadsides, and on sand plains and dunes. Its habitat is mostly lowland, up to 600 m. It tolerates low fertility, especially low availability of phosphorus. C. toetoe takes on the role of an early coloniser should the opportunity exist.

Toetoes are only slightly drought hardy and grow best where there is an abundant water supply and except perhaps for C. splendens, are moderately frost hardy.

Toetoes are especially useful for early revegetation of slip debris, earthworks and other freshly exposed soils or subsoils in moist habitats throughout their respective ranges. C. toetoe can be used for low shelter, but the larger, introduced pampas grass is most commonly used for this purpose. Toetoes can provide a good nurse crop for other native seedlings but these seedlings will have to be situated to avoid abrasion from the rough-edged toetoe leaves.

Phormium cookianum (Mountain Flax, Wharariki).

This is a large-leaved monocotyledonous herb, very shrub-like in physical dimensions and up to 2m tall. The flowers appear from November to January, and the seeds ripen from February to March.

Phormium cookianum is found in shrublands, on hillsides and along streamsides from coastal to subalpine and low alpine regions throughout the North, South and Stewart Islands, but is most common in mountain regions. Its altitudinal range is sea level to 1400 m. It is as common on the coasts as it is in the mountains and can be found on rocks close to the water or, more often, on steep cliffs and rocky areas, (Salmon 1991). It generally grows in wet and occasionally waterlogged ground in montane and subalpine regions but can tolerate seasonally dry conditions very well.

The species is suitable for revegetation of wetlands, including those at higher altitudes, or for restoration of other wet sites. It is good for secondary planting between coastal dunes once initial stabilisation has been achieved. Mountain flax is useful also for planting on streambanks and alongside drains to stabilise the banks and lessen weed growth. It provides good low shelter but usually the larger and more erect p. tenax is used for this purpose.

Leptospermum ericoides, also known as Kunzea ericoides. (**Kanuka**, White Tea Tree, often called manuka in Northland). .

Shrub of varying form, or medium-sized and spreading tree up to 15 m. Clusters of leaves soft to the touch as opposed to the harsher feel of L. scoparium (manuka). The small flowers, up to 5 mm across, clothe the branches in great profusion from September into February and the seeds, similar to those of manuka, remain on the tree until the following year.

Leptospermum ericoides is abundant throughout lowland and montane scrub and forest margins of the North and South Islands, and occurs from sea level to 900 m. It often establishes thickly after clearing of forest or on abandoned pasture in some areas. It grows well on all but waterlogged soils. There is some exotypic variation within the species which allows it to exploit a wide range of habitats from moist montane forest to the semi-arid montane valleys of Central Otago. Kanuka is very drought and frost tolerant. Seedlings often establish readily on bare subsoils.

Kanuka and manuka are the two most important pioneering native shrubs. Kanuka has a life span of more than 100 years and during this time provides an excellent nurse crop for many native plants and forest trees including timber species. It is very suitable for revegetation of bare or eroded surfaces.

Lowland forms have good potential for use in recreational environments and parkland settings where compaction of the soil in the root zone occurs and sheet erosion is a threat. Prostrate layering forms, such as L. ericoides var microflorum (Northland) and others, may have some potential for erosion control on mudflow debris and other wet bare soil.

Establishment trials using seed-bearing kanuka slash have been successful on pumice, ash and clay soils. This method consists of laying seed-bearing branches on the ground surface to form a mat 30 to 40 cm thick and dense enough to provide 80 to 95% shade.

Leptospermum scoparium (Manuka, Red Tea Tree).

Shrub of diverse habit up to 4 to 5 m. Leaves similar to L. ericoides but stiffer and more pungent (needle-like point) giving the branches a rougher feel. Manuka flowers normally are about 12 mm across but the variety keatleyi has flowers 2 cm across. Flowers occur from September till February, in the wild usually white. Flowers of the related tree kanuka, are borne much more densely, and the stamens spread more than they do in manuka flowers. Seeds ripen during April and May but persist on the tree until the following year, (Salmon 1991).

Leptospermum scoparium is common throughout the North, South and Stewart Islands in lowland to low alpine regions, and occurs from sea level to 1400 m. Habitats are diverse and include bogs, wetlands, river gravels and dry hillsides. Individual plants have wide tolerances but ecotypic differentiation also occurs within the species. It is very tolerant of drought, waterlogging and frost. Manuka tends to grow on poorer, colder, wetter or more acidic sites than kanuka but they also frequently occur together.

Manuka is very useful for restoration of native vegetation along roadsides, earthworks and eroded areas. Some cultivars may be used for low shelter. Other prostrate cultivars can provide useful ground cover on some bare soils alongside roads and tracks.

Laying down seed-bearing slash can also be recommended (as for L. ericoides) but often the material is infested with manuka blight which will infect seedlings and reduce their vigour.

Dodonaea viscosa (Akeake).

Erect but spreading shrub or small tree with a fairly open crown, up to 7m. Flowering occurs from September to January, and the sexes occur on different trees, (Salmon 1991).

Akeake is common in coastal and lowland scrub and forest throughout the North Island and in the South Island as far south as Greymouth and Banks Peninsula. It also occurs on the Chatham Islands. Its altitudinal range is sea level to 550 m. Akeake is grown in most lowland districts where frosts are not a problem although some plants have grown where frosts are moderate to severe, eg Taupo. It ocurs on coastal sites where it withstands strong winds and salt spray, and occasionally very dry conditions. On Banks Peninsula it grows well on drought-prone loessial soils. It also grows well on coastal dunes. The fibrous spreading root system, rapid growth and spreading canopy make it an ideal soil stabiliser in coastal dune areas. It may also be used in the control of gully erosion and for general revegetation where hard frosts are not likely to occur. It will not tolerate heavy or waterlogged soil.

Coprosma kirkii.

Very little written information could be found regarding this creeper. It was recommended by Kiwiflora nursery staff who suggested that it may be successful when the site conditions were described.

Brown (1995) reports that Coprosma kirkii is a naturalised hybrid which was discovered growing over rocky cliff faces around Wellington. It prefers free draining soils and grows vigorously but requires water all year round and constant feed. It can tolerate frosts to 8°C, but is essentially a coastal plant.

Appendix 4.2 - Plant Species Used in the Tailings Trial.

The species chosen are described below:

(a) Leptospermum ericoides, also known as Kunzia ericoides. (Kanuka, White Tea Tree, often called manuka in Northland).

This can appear as a shrub of varying form, or a medium-sized spreading tree up to 15 m in height. Clusters of leaves are soft to the touch as opposed to the harsher feel of L. scoparium (manuka). The small flowers, up to 5 mm across, clothe the branches in great profusion from September into February and the seeds, similar to those of manuka, remain on the tree until the following year.

Leptospermum ericoides is abundant throughout lowland and montane scrub and forest margins of the North and South Islands, and occurs from sea level to 900 m. It often establishes thickly after clearing of forest or on abandoned pasture in some areas. It grows well on all but waterlogged soils. There is some exotypic variation within the species which allows it to exploit a wide range of habitats from moist montane forest to the semi-arid montane valleys of Central Otago. Kanuka is very drought and frost tolerant. Seedlings often establish readily on bare subsoils.

Kanuka and manuka are the two most important pioneering native shrubs. Kanuka has a life span of more than 100 years and during this time provides an excellent nurse crop for many native plants and forest trees including timber species. It is very suitable for revegetation of bare or eroded surfaces.

Lowland forms have good potential for use in recreationsl environments and parkland settings where compaction of the soil in the root zone occurs and sheet erosion is a threat. Prostrate layering forms, such as L. ericoides var microflorum (Northland) and others, may have some potential for erosion control on mudflow debris and other wet bare soil.

Establishment trials using seed-bearing kanuka slash have been successful on pumice, ash and clay soils. This method consists of laying seed-bearing branches on the ground surface to form a mat 30 to 40 cm thick and dense enough to provide 80 to 95% shade.

(b) Pittosporum tenuifolium, also known as Kohuhu.

This is a variable species with a wide range of forms but it is generally a small tree up to 10 m with a densely foliaged crown. It often hybridises with P. colensoi and P. crassifolium. It is common from North Cape to Southland but does not occur west of the Main Divide in the South Island. It is found mostly along forest margins, streamsides and in regenerating forest or scrubland, and occurs from sea level to 920 m. Various wild forms and cultivars are commonly cultivated in all lowland districts. It is a very hardy species and tolerates most soil conditions except waterlogging and extreme drought. It is frost tolerant and reasonably wind tolerant. Persistent strong winds will damage the new growth. Young plants are not stable in wet and poorly coherent soil.

It is good for shelter, and its habit of producing foliage down to near ground level makes it most suitable for filling in gaps under taller shelter trees. Its most practical use, however, is as a nurse crop and as early vegetative cover on earthworks and deforested areas.

(c) Phormium tenax, also called Flax or Harekeke.

This is a large, fairly erect stiff-leaved herb. Some forms have leaves up to 3 m long. There are many forms and varieties which differ in leaf colour, stiffness and length.

Phormium tenax is abundant in coastal and lowland swamps, alluvial ground and montane regions of the North, South and Stewart Islands, and occurs from sea level to 1400m. Many cultivars and wild forms are in cultivation throughout the country.

This species has a very wide habitat range and climatic tolerance. Most forms are very tolerant of frost, drought, wind and salt spray. Some ecotypic differentiation can be expected. It tolerates very wet and waterlogged soils or dry hillsides. It does not have a deep no wide-spreading root system but it will grow and maintain roots below the water table.

An excellent species for stabilising the banks of drains and small streams, it is suitable for planting in gully systems where there is seasonal waterlogging. Some of the taller more erect forms are recommended for low shelter, especially in wet lowland areas, coastal swamps or estuaries, and on seasonally dry, wind-swept hillsides.

(d) Cordyline australis. Cabbage tree, Ti Kouka.

Small tree of variable growth form, 5 to 13 m tall. Generally sparingly branched with leaves clustered at branch tips. Occasionally plants are more numerously branched which gives them a more bushy habit.

Cordyline australis is common throughout open places and scrubland of the North and South Islands but rare on Stewart Island. It is found at altitudes from sea level to 800m. Habitats vary from wet swampy ground to dry windy hillslopes on heavy to light soils. It can even grow reasonably well in pure sand or gravel if moisture is not too limiting.

The tap-root of the cabbage tree is believed by some to aid in holding steep slopes from soil slip erosion. The tree is suitable for planting on other, ungrazed slopes where stabilisation is required.

Appendix 4.3 - Guaranteed Analysis of Agriform Planting Tablets 20-4.3-4.1, (N-P-K).

TOTAL NITROGEN Derived from urea-formaldehyde	20.00%
AVAILABLE PHOSPHORIC ACID Derived from calcium phosphate	10.00%
SOLUBLE POTASH K_2O Derived from potassium sulphate	5.00%
COMBINED CALCIUM Derived from calcium phosphates	2.60%
COMBINED SULPHUR Derived from ferrous and potassium sulphates	1.60%
IRON (expressed as elemental Fe) Derived from ferrous sulphate	0.35%

Potential acidity: 5% or 100 lbs Calcium Carbonate Equivalent per ton.

The initial salinity of an Agriform planting tablet is extremely low (about 1/20th of ammonium nitrate) so that the risk of burning is virtually eliminated, (Manufacturers information).

Appendix 4.4 - Plantacote Fertiliser Analysis.

(Taken from the label of the packet - Yates Plantacote General Purpose Fertiliser, Slow Release Granules).

Yates Plantacote General Purpose Fertiliser is a slow release granule which provides plants with a balanced supply of nutrients for 8 to 9 months.

Nutrient content:

16% nitrogen, 5% phosphate, 10% potassium, 1% magnesium. Trace elements 0.02% boron, 0.046% copper, 0.062% iron, 0.052% manganese, 0.015% molybdenum, 0.01% zinc.

The 8 to 9 month release time is based on average soil temperatures of 20°C. Shorter terms can be expected in warmer conditions and longer terms in cooler conditions.

Appendix 5.1.1. Raw Data For Survival of Native Plants on the Acid Rock Trial.

Obs	Species	Area	Apr	Oct	Feb	INT 1	INT 2	INT 3
1	Kanuka	A	10	2	2	0.20000	1.00000	0.20000
2	Kanuka	B	8	4	4	0.50000	1.00000	0.50000
3	Kanuka	C	9	3	2	0.33333	0.66667	0.22222
4	Kanuka	D	10	4	4	0.40000	1.00000	0.40000
5	Kanuka	E	9	7	7	0.77778	1.00000	0.77778
6	Manuka	A	10	4	3	0.40000	0.75000	0.30000
7	Manuka	B	12	7	7	0.58333	1.00000	0.58333
8	Manuka	C	10	7	6	0.70000	0.85714	0.60000
9	Manuka	D	10	5	5	0.50000	1.00000	0.50000
10	Manuka	E	10	8	8	0.80000	1.00000	0.80000
11	Coprosma	A	10	7	1	0.70000	0.14286	0.10000
12	Coprosma	B	9	7	3	0.77778	0.42857	0.33333
13	Coprosma	C	6	6	3	1.00000	0.50000	0.50000
14	Coprosma	D	10	9	3	0.90000	0.33333	0.30000
15	Coprosma	E	11	9	9	0.81818	1.00000	0.81818
16	Flax	A	9	6	6	0.66667	1.00000	0.66667
17	Flax	B	10	7	6	0.70000	0.85714	0.60000
18	Flax	C	10	6	5	0.60000	0.83333	0.50000
19	Flax	D	10	8	7	0.80000	0.87500	0.70000

20	Flax	E	10	10	9	1.00000	0.90000	0.90000
21	Akeake	A	16	13	9	0.81250	0.69231	0.56250
22	Akeake	B	13	7	6	0.53846	0.85714	0.463154
23	Akeake	C	14	9	6	0.64286	0.66667	0.42857
24	Akeake	D	18	16	16	0.88889	1.00000	0.88889
25	Akeake	E	10	9	9	0.90000	1.00000	0.90000
26	Toetoe	A	10	10	9	1.00000	0.90000	0.90000
27	Toetoe	B	10	9	9	0.90000	1.00000	0.90000
28	Toetoe	C	10	10	10	1.00000	1.00000	1.0000
29	Toetoe	D	10	10	10	1.00000	1.00000	1.0000
30	Toetoe	E	10	10	10	1.00000	1.00000	1.0000

Appendix 5.1.2 - Raw Data For Growth of Cortaderia toetoe.

OBS	AREA	MONTH	REP	LEAVES
1	1	1	1	18
2	1	1	2	27
3	1	1	3	35
4	1	1	4	16
5	1	1	5	41
6	1	1	6	27
7	1	1	7	30
8	1	1	8	6
9	1	1	9	32
10	1	1	10	20
11	1	2	1	23
12	1	2	2	51
13	1	2	3	18
14	1	2	4	24
15	1	2	5	41
16	1	2	6	42
17	1	2	7	33
18	1	2	8	6
19	1	2	9	67
20	1	2	10	14
21	1	3	1	6
22	1	3	2	52
23	1	3	3	6
24	1	3	4	21
25	1	3	5	29
26	1	3	6	33
27	1	3	7	0
28	1	3	8	8
29	1	3	9	9
30	1	3	10	9
31	2	1	1	14
32	2	1	2	21
33	2	1	3	20
34	2	1	4	20

35	2	1	5	32
36	2	1	6	21
37	2	1	7	21
38	2	1	8	33
39	2	1	9	41
40	2	1	10	19
41	2	2	1	31
42	2	2	2	31
43	2	2	3	50
44	2	2	4	40
45	2	2	5	59
46	2	2	6	0
47	2	2	7	35
48	2	2	8	83
49	2	2	9	60
50	2	2	10	29
51	2	3	1	17
52	2	3	2	50
53	2	3	3	73
54	2	3	4	53
55	2	3	5	80
56	2	3	6	0
57	2	3	7	52
58	2	3	8	123
59	2	3	9	83
60	2	3	10	36
61	3	1	1	32
62	3	1	2	38
63	3	1	3	36
64	3	1	4	40
65	3	1	5	17
66	3	1	6	21
67	3	1	7	30
68	3	1	8	29
69	3	1	9	15
70	3	1	10	25
71	3	2	1	51

72	3	2	2	91
73	3	2	3	55
74	3	2	4	77
75	3	2	5	24
76	3	2	6	34
77	3	2	7	61
78	3	2	8	57
79	3	2	9	16
80	3	2	10	28
81	3	3	1	73
82	3	3	2	113
83	3	3	3	76
84	3	3	4	121
85	3	3	5	30
86	3	3	6	39
87	3	3	7	95
88	3	3	8	57
89	3	3	9	17
90	3	3	10	39
91	4	1	1	16
92	4	1	2	15
93	4	1	3	15
94	4	1	4	17
95	4	1	5	23
96	4	1	6	22
97	4	1	7	25
98	4	1	8	38
99	4	1	9	16
100	4	1	10	22
101	4	2	1	38
102	4	2	2	40
103	4	2	3	42
104	4	2	4	47
105	4	2	5	48
106	4	2	6	18
107	4	2	7	29
108	4	2	8	43

109	4	2	9	39
110	4	2	10	39
111	4	3	1	54
112	4	3	2	54
113	4	3	3	43
114	4	3	4	1
115	4	3	5	49
116	4	3	6	36
117	4	3	7	38
118	4	3	8	30
119	4	3	9	24
120	4	3	10	36
121	5	1	1	20
122	5	1	2	18
123	5	1	3	15
124	5	1	4	15
125	5	1	5	10
126	5	1	6	26
127	5	1	7	34
128	5	1	8	31
129	5	1	9	24
130	5	1	10	36
131	5	2	1	19
132	5	2	2	23
133	5	2	3	41
134	5	2	4	22
135	5	2	5	28
136	5	2	6	35
137	5	2	7	11
138	5	2	8	43
139	5	2	9	26
140	5	2	10	44
141	5	3	1	25
142	5	3	2	27
143	5	3	3	14
144	5	3	4	33
145	5	3	5	42

146	5	3	6	49
147	5	3	7	15
148	5	3	8	78
149	5	3	9	43
150	5	3	10	40

(For the above table, the "area" numbers 1 to 5 refer to treatments A to E. The numbers given under "month" refer to the first, second or third measurement).

Appendix 5.1.3 - Laboratory Sheets and Methods of Analysis For North Wall Soil Tests.

R J Hill Laboratories Ltd.

Client: Waihi Gold Company Contact: Kathy Mason Lab Number: 90938

amended.

Note: This report replaces that sent out on the 6/1/95, following which the units for exchangeable cations have been reported as mg/kg rather than me/100g.

Sample Type: *Environmental Solids, Soil.*

Sample Name	Lab No	Ammonlum Nitrogen* (mg/kg)	Nitrate-N* (mg/kg)	Total Manganese* (mg/kg)	Total Zinc* (mg/kg)	Total Copper* (mg/kg)
WG 3440	90938/1	1.3	0.6	230	43	10.2
WG 3441	90938/2	0.8	0.43	230	40	9.9
WG 3442	90930/3	1.3	<0.05	560	71	18.1
WG 3443	90938/4	1.6	0.6	106	28	16.4
WG 3444	90938/5	1.9	0.05	107	24	9.4
WG 3445	90938/6	2.8	1.07	490	50	20
WG 3446	90938/7	1	0.34	1,300	102	44
WG 3447	90938/8	1.4	<0.05	158	23	21
WG 3448	90938/9	1.4	0.43	280	25	14.4
WG 3449	90938/10	2.2	1.1	1,010	63	33
WG 3450	90938/11	3	2.3	670	40	22
WG 3451	90938/12	1.5	<0.05	420	41	21
WG 3452	90938/13	0.7	0.38	1,310	79	26
WG 3453	90938/14	1.4	0.38	400	57	14.9
WG 3454	90938/15	1.6	0.4	620	40	16.2

*This test is not Telarc Registered.

Sample Name	Lab No	Bulk Density (g/mL)	Olsen P (mg/kg)	Exchangeable Potassium (mg/kg)	Exchangeable Sodium (mg/kg)	Exchangeable Calcium (mg/kg)
WG 3440	90938/1	0.99	18	62	< 10	1,460
WG 3441	90938/2	0.89	19	39	20	3,300
WG 3442	90938/3	0.93	12	51	< 10	4,300
WG 3443	90938/4	1.11	19	39	<10	1,020
WG 3444	90938/5	1.05	18	45	<10	760
WG 3445	90938/6	0.88	8	82	< 10	5,100
WG 3446	90938/7	0.93	6	90	10	7,700
WG 3447	90938/8	1.02	7	<40	<10	5,100
WG 3448	90938/9	1	10	<40	<10	10,700
WG 3449	90938/10	0.87	9	113	<10	8,500
WG 3450	90938/11	0.77	4	156	20	2,400
WG 3451	90938/12	0.97	11	<40	<10	13,000
WG 3452	90938/13	1.03	8	70	10	7,400
WG 3453	90938/14	0.89	11	<40	<10	5,400
WG 3454	90938/15	0.98	10	<40	<10	7,100
Sample Name	Lab No	Exchangeable Magnesium (mg/kg)	Cation exchange capacity (mEqulv/100g)	Lime requirement (kg/Ha)	Base saturation for potassium (%)	Base saturation % for calcium
WG 3440	90938/1	122	34	18,800	0.5	22
WG 3441	90938/2	130	45	19,500	0.2	37
WG 3442	90938/3	95	35	12,300	0.4	61
WG 3443	90938/4	65	26	18,100	0.4	20
WG 3444	90938/5	77	20	630	0.7	19
WG 3445	90938/6	178	27	1,460	0.8	94
WG 3446	90938/7	134	40	1,100	0.6	97
WG 3447	60938/8	150	36	1,230	0.2	71
WG 3448	90938/9	144	71	1,180	0.1	76

WG 3449	90938/10	157	44	1,290	0.7	96
WG 3450	90938/11	204	14	1,670	2.8	85
WG 3451	90938/12	99	86	810	0.1	75
WG 3452	90938/13	156	39	0	0.5	96
WG 3453	90938/14	135	38	7,700	0.2	72
WG 3454	90938/15	172	62	21,000	0.2	58

Sample Name	Lab No	Bass saturation% for magnesium (%)	Base saturation % for sodium (%)	Total Kjeldahl Nitrogen (TKN)* (mg/kg)	Total aluminium * (mg/kg)	Extractable aluminium* (mg/kg)
WG 3440	90938/1	3	0.1	1,200	28,000	280
WG 3441	90938/2	2.4	0.2	1,200	29,000	310
WG 3442	90938/3	2.2	< 0.1	1,300	24,000	190
WG 3443	90938/4	2.1	0.1	1,600	18,600	360
WG 3444	90938/5	3.1	0.1	1,500	22,000	320
WG 3445	90938/6	5.3	0.1	2,100	19,200	9
WG 3446	90938/7	2.7	0.1	1,600	53,000	9
WG 3447	90938/8	3.4	<0.1	1,500	21,000	270
WG 3448	90938/9	1.7	<0.1	1,500	18,900	290
WG 3449	90938/10	2.9	0.1	1,900	27,000	<9
WG 3450	90938/11	11.7	0.5	1,300	31,000	<9
WG 3451	90938/12	1	< 0.1	1,600	29,000	220
WG 3452	90938/13	3.3	0.1	1,500	26,000	<9
WG 3453	90938/14	2.9	0.1	1,300	23,000	120
WG 3454	90938/15	2.3	0.1	2,000	22,000	270

*This test is not Telarc registered.

Sample Name	Lab No	pH (pH Units)	Total nickel* (mg/kg)
WG 3440	90938/1	2.2	25
WG 3441	90939/2	2.2	21
WG 3442	90938/3	3.7	47
WG 3443	90938/4	2.3	18.4
WG 3444	90938/5	2.5	18.6
WG 3 445	90938/6	6.2	38
WG 3446	90938/7	6.9	145
WG 3447	90938/8	3.5	29
WG 3448	90938/9	2.7	23
WG 3449	90938/10	6.3	93
WG 3450	90936/11	6.4	24
WG 3451	90938/12	3	62
WG 3452	90938/13	6.7	97
WG 3453	90938/14	4.8	46
WG 3454	90938/15	2.2	54

*Tthis test is not Telarc Registered.

Summary of Methods Used and Detection Limits.

The following table gives a brief description of the methods used to conduct the analyses for this job.

Parameter	Method Used	Detection Limit
Ammonium Nitrogen	Test not Telarc Reg.	0.1 mg/kg
Nitrato-N	Calcium sulphate extraction, cadmium reduction, colorimetry Test not Telarc Reg.	0.05 mg/kg
Total manganese	Acid digestion, flame AA spectroscopy Test not Telarc Reg.	0.4 mg/kg
Total zinc	Acid digestion, flame AA spectroscopy Test not Telarc Reg.	0.4 mg/kg
Total copper	Acid digestion, flame AA spectroscopy Test not Tolarc Reg.	0.4 mg/kg
Bulk density	Gravimetry of air-dried and ground subsample	0.05 g/mL
Olsen P	0.5M NaHC03 extn, pH 8.5, 1:20 ratio, 30 min, Colorimetry.	2 ug/mL

Exchangeable potassium	1M ammonium acetate extn, AA spectroscopy.	0.05 mEquiv/100g
Exchangeable sodium	1M ammonium acetate extn, AA spectroscopy.	0.05 mEquiv/100g
Exchangeable calcium	1M ammonium acetate extn, AA spectroscopy.	0.5 mEquiv/100g
Exchangeable magnesium	1M ammonium acetate extn, AA spectroscopy.	0.05 mEquiv/100g
Lime requirement	Calculation: to achieve 70% base saturation	1 kg/Ha
Base saturation for potassium	Calculated from exchangeable K and CEC	0.1 %
Base saturation % for calcium	Calculated from exchangeable Ca and CEC	1 %
Base saturation % for magnsium	Calculated from exchangeable Mg and CEC	0.1 %
Base saturation % for sodium	Calculated from exchangeable Na and CEC	0.1 %
Total Kjeldahl Nitrogen (TKN)	Kjeldahl digestion, phenol/hypochlorite colorimetry Test not Telarc Reg.	40 mg/kg
Total aluminium	Acid digestion, flame AA spectroscopy Test not Telarc Reg.	1 mg/kg
Extractable aluminium	at ASL Test not Telarc Reg.	N/A
pH	pH meter, 1:2.6 v/v water and soil APHA 4500-H+B	0.1 mg/kg
Total nickel	Acid digestion, flame AA spectroscopy Test not Tolarc Reg.	0.4 mg/kg

Appendix 5.2.1 - Raw Data For Tailings Grass Plot Yields.

OBS	TRT	REP	CUT1	CUT2	CUT3	CUT4	CUT5	TOTAL
1	C	1	2887	3097	5795	1927	2006	15712
2	C	2	3230	2786	7603	1717	2301	17637
3	C	3	3066	3612	6987	2100	1867	17632
4	C	4	2963	2596	6612	2065	1942	16178
5	T	1	3143	3279	3490	1200	1290	12402
6	T	2	2716	2263	4185	1598	1441	12203
7	T	3	2418	3382	4774	1558	1213	13345
8	T	4	2727	2837	6224	1551	1038	14377

Appendix 5.2.2 - Raw Data For the Tailings Native Plant Trial.

OBS	REP	TRT	SPECIES	SP_REP	NOV	MAY	DEC	GROWTH_1	GROWTH_2	GROWTH_3
1	1	Compost	Kanuka	1	60	90	123	30	33	63
2	1	Compost	Kanuka	2	64	136	143	72	7	79
3	1	Compost	Kanuka	3	62	90	112	28	22	50
4	1	Compost	Kanuka	4	79	132	140	53	8	61
5	1	Compost	Pittospo	1	38	89	103	51	14	65
6	1	Compost	Pittospo	2	44	88	121	44	33	77
7	1	Compost	Pittospo	3	38	108	132	70	24	94
8	1	Compost	Pittospo	4	51	116	156	65	40	105
9	1	Compost	Cabbage	1	35	71	105	36	34	70
10	1	Compost	Cabbage	2	42	64	90	22	26	48
11	1	Compost	Cabbage	3	45	72	126	27	54	81
12	1	Compost	Cabbage	4	42	60	62	18	2	20
13	1	Compost	Flax	1	72	118	125	46	7	53
14	1	Compost	Flax	2	72	97	133	25	36	61
15	1	Compost	Flax	3	64	94	89	30	-5	25
16	1	Compost	Flax	4	78	116	160	38	44	82
17	1	Tailings	Kanuka	1	74	149	149	75	0	75
18	1	Tailings	Kanuka	2	56	88	90	32	2	34
19	1	Tailings	Kanuka	3	52	118	121	66	3	69
20	1	Tailings	Kanuka	4	59	99	99	40	0	40
21,	1	Tailings	Pittospo	1	49	86	90	37	4	41
22	1	Tailings	Pittospo	2	38	74	114	36	40	76
23	1	Tailings	Pittospo	3	43	78	89	35	11	46
24	1	Tailings	Pittospo	4	33	89	90	56	1	57
25	1	Tailings	Cabbage	1	37	79	85	42	6	48
26	1	Tailings	Cabbage	2	20	39	30	19	-9	10
27	1	Tailings	Cabbage	3	41	50	81	9	31	40
28	1	Tailings	Cabbage	4	49	58	88	9	30	39
29	1	Tailings	Flax	1	69	116	124	47	8	55
30	1	Tailings	Flax	2	51	96	128	45	32	77
31	1	Tailings	Flax	3	73	105	153	32	48	80
32	1	Tailings	Flax	4	67	117	125	50	8	58
33	2	Compost	Kanuka	1	64	102	107	38	5	43
34	2	Compost	Kanuka	2	72	97	116	25	19	44
35	2	Compost	Kanuka	3	54	115	122	61	7	68
36	2	Compost	Kanuka	4	82	137	144	55	7	62
37	2	Compost	Pittospo	1	35	94	102	59	8	67

38	2	Compost	Pittospo	2	62	117	180	55	63	118
39	2	Compost	Pittospo	3	38	82	92	44	10	54
40	2	Compost	Pittospo	4	36	86	99	50	13	63
41	2	Compost	Cabbage	1	45	62	77	17	15	32
42	2	Compost	Cabbage	2	45	83	107	38	24	62
43	2	Compost	Cabbage	3	39	74	80	35	6	41
44	2	Compost	Cabbage	4	35	53	97	18	44	62
45	2	Compost	Flax	1	78	42	104	-36	62	26
46	2	Compost	Flax	2	79	95	110	16	15	31
47	2	Compost	Flax	3	85	131	165	46	34	80
48	2	Compost	Flax	4	80	100	112	20	12	32
49	2	Tailings	Kanuka	1	55	119	113	64	-6	58
50	2	Tailings	Kanuka	2	70	114	131	44	17	61
51	2	Tailings	Kanuka	3	87	92	105	5	13	18
52	2	Tailings	Kanuka	4	49	74	89	25	15	40
53	2	Tailings	Pittospo	1	63	117	138	54	21	75
54	2	Tailings	Pittospo	2	38	70	133	32	63	95
55	2	Tailings	Pittospo	3	41	78	120	37	42	79
56	2	Tailings	Pittospo	4	50	116	155	66	39	105
57	2	Tailings	Cabbage	1	24	46	50	22	4	26
58	2	Tailings	Cabbage	2	39	47	48	8	1	9
59	2	Tailings	Cabbage	3	38	38	98	0	60	60
60	2	Tailings	Cabbage	4	40	57	72	17	15	32
61	2	Tailings	Flax	1	74	72	104	-2	32	30
62	2	Tailings	Flax	2	60	85	125	25	40	65
63	2	Tailings	Flax	3	70	107	128	37	21	58
64	2	Tailings	Flax	4	61	84	127	23	43	66
65	3	Tailings	Kanuka	1	75	142	145	67	3	70
66	3	Tailings	Kanuka	2	47	83	99	36	16	52
67	3	Tailings	Kanuka	3	56	115	128	59	13	72
68	3	Tailings	Kanuka	4	54	88	120	34	32	66
69	3	Tailings	Pittospo	1	61	128	161	67	33	100
70	3	Tailings	Pittospo	2	51	103	132	52	29	81
71	3	Tailings	Pittospo	3	44	81	99	37	18	55
72	3	Tailings	Pittospo	4	37	80	90	43	10	53
73	3	Tailings	Cabbage	1	37	52	79	15	27	42
74	3	Tailings	Cabbage	2	33	51	68	18	17	35
75	3	Tailings	Cabbage	3	45	81	85	36	4	40
76	3	Tailings	Cabbage	4	35	81	75	46	-6	40
77	3	Tailings	Flax	1	78	92	129	14	37	51
78	3	Tailings	Flax	2	73	95	127	22	32	54
79	3	Tailings	Flax	3	64	93	126	29	33	62

80	3	Tailings	Flax	4	78	104	108	26	4	30
81	3	Compost	Kanuka	1	66	102	104	36	2	38
82	3	Compost	Kanuka	2	55	104	126	49	22	71
83	3	Compost	Kanuka	3	89	149	152	60	3	63
84	3	Compost	Kanuka	4	60	127	138	67	11	78
85	3	Compost	Pittospo	1	57	103	155	46	52	98
86	3	Compost	Pittospo	2	47	113	150	66	37	103
87	3	Compost	Pittospo	3	50	103	103	53	0	53
88	3	Compost	Pittospo	4	50	82	99	32	17	49
89	3	Compost	Cabbage	1	44	71	92	27	21	48
90	3	Compost	Cabbage	2	40	84	80	44	-4	40
91	3	Compost	Cabbage	3	46	97	130	51	33	84
92	3	Compost	Cabbage	4	43	67	85	24	18	42
93	3	Compost	Flax	1	65	108	150	43	42	85
94	3	Compost	Flax	2	72	93	110	21	17	38
95	3	Compost	Flax	3	53	83	104	:30	21	51
96	3	Compost	Flax	4	96	131	153	3.9	22	57
97	4	Tailings	Kanuka	1	87	146	153	59	7	66
98	4	Tailings	Kanuka	2	76	125	15'/	49	32	81
99	4	Tailings	Kanuka	3	71	109	122	38	13	51
100	4	Tailings	Kanuka	4	52	93	100	41	7	48
101	4	Tailings	pittospo	1	31	71	81	40	10	50
102	4	Tailings	Pittospo	2	41	81	120	40	39	79
103	4	Tailings	Pittospo	3	44	78	102	34	24	58
104	4	Tailings	Pittospo	4	41	94	108	53	14	67
105	4	Tailinqs	Cabbage	1	40	69	92	29	23	52
106	4	Tailings	Cabbage	2	30	74	76	44	2	46
107	4	Tailings	Cabbage	3	43	59	135	16	76	92
108	4	Tailings	cabbage	4	31	58	30	27	-28	-1
109	4	Tailings	Flax	1	95	99	99	4	0	4
110	4	Tailings	Flax	2	78	86	70	8	-16	-8
111	4	Tailings	Flax	:3	70	41	100	-29	59	30
112	4	Tailings	Flax	4	82	102	125	20	23	43
113	4	Compost	Kanuka	1	65	105	129	40	24	64
114	4	Compost	Kanuka	2	74	123	178	49	5.5	104
115	4	Compost	Kanuka	3	60	66	73	6	7	13
116	4	Compost	Kanuka	4	81	137	172	56	35	91
117	4	Compost	Pittospo	1	63	100	111	37	11	48
118	4	Compost	Pittospo	2	44	113	133	69	20	89
119	4	Compost	Pittospo	3	33	113	129	80	16	96
120	4	Compost	Pittospo	4	52	107	162	55	55	110
121	4	Compost	Cabbage	1	41	60	65	19	5	24

122	4	Compost	Cabbage	2	35	56	102	21	46	67
123	4	Compost	Cabbage	3	45	65	85	20	20	40
124	4	Compost	Cabbage	4	26	44	53	18	9	27
125	4	Compost	Flax	1	45	87	106	42	19	61
126	4	Compost	Flax	2	54	92	165	38	73	111
127	4	Compost	Flax	3	81	98	120	17	22	39
128	4	Compost	Flax	4	88	102	132	14	30	44

Appendix 4.1 - Example of Four Pages of the Model

REHABILITATION PREDICTIVE MODEL

The model predicts costs for tailings rehabilitation given that various options exist.

The model is based on the following scenario:

1. Once tailings deposition ceases, the existing decant pond is retained as the low point collecting water from the surrounding tailings surface. The size of this lake can be modified in the constants sheet.
2. The model allows for water treatment costs arising from the tailings to be calculated. It assumes that the lake initially has a one metre freeboard. Water would spill from the lak and either flow by gravitation to the water treatment plant if treatment is required, or to the Ohinemuri River if treatment is not required. Meteorological data can be added for wet, dry, and mean years to determine water treatment costs and these three regimes and the optimum theoretical lake size could be calculated.
3. The lake would initially have the purpose of containing contaminated water prior to treatment and allowing evaporative loss. Hence the water level of the lake would not need to remain constant. Once water quality is such that water can be discharged, the lake could be planted with wetland species. For this a constant water level would be required.
4. It is assumed that the surrounding waste bund is restored to pasture and all runoff water from the tailings surface is directed to the lake. The bund is assumed to be graze by light stock, hence it is feasible to assume that the stock could graze tailings restored to pasture.
5. It is assumed that it is possible to grow native tree and shrub species within the tailings. The model gives the option of planting colonizing plants in the first year, and then interplanting with longer-living trees such as totara at year five, as is standard practice. Any other crop could be substituted for natives, with space allowed in the model to put in the revenue expected from a crop.

Constants Sheet.
The model allows the user to investigate various ways in which the area could be restored by allowing the following settings to be changed.

1. Lake Size. Lake size can be changed to increase evaporative loss and reduce water treatment costs, or reduce lake level fluctuations..
2. Size of areas restored to pasture or native species. The model allows the user to investigate several combinations of lake size, and size of the areas restored to pasture or native species. It also allows flexibility to schedule rehabilitation over a 10 year period.
3. The model allows the user to specify the timing of and size of areas to be drained. It assumes that drainage is required before clay covers are spread or restoration to native trees and/or pasture commences.
4. The model allows the user to specify what area requires a clay cover, and what depth of cover is required. In the same way, it allows the user to specify whether any amendment of topsoil or compost is required and the depths needed. Note that 1000m3 of topsoil or compost covers 1 ha to a depth of 100 mm. The model also allows the user to sow pasture or plant natives directly into tailings without a soil or compost amendment but assumes that fertiliser costs and maintenance costs will be similar for all three scenarios.

Water Sheet.
The water sheet allows calculation of the amount of water discharging from the lake using average rainfall evaporation and rainfall data entered over fifteen years. It is possible to cut and paste wet and dry years if required. A table summarizes the quantities discharged from the lake and graphs the lake level.

Costs Sheet.
Calculates costs for each scenario. It is assumed that pasture returns some revenue but requires more maintenance costs than natives, and that the natives return no revenue. There is some opportunity to add revenue for the natives if it is expected one could be returned. The costs sheet also provides a schedule of materials required for each option selected to allow different scenarios to be compared with what is practically and economically available to cover and amend the tailings.

Table 1: Constants.

Enter data where the numbers are black.

The model expects all draining, clay covering, topsoil amending, compost amending, pasture sowing and native planting to be carried out within the first nine years. This allows changes in costs and revenue which occur five years after planting/sowing to be picked up by year 14.

It is assumed that restoration would commence on the drier tailings beach and progress towards the lake as areas became available following drainage.

Catchment Characteristics.	
Tailings dam area ha	36.5
Runoff coefficient from unvegetated area	1
Runoff coefficient from vegetated area up to yr 3	0.8
Runoff coefficient from vegetated area yr 3 onwards	0.7
Lake RL at start mRL	138.5
Lake Free board, m	1
Drainage & Cover Costs:	
Drainage Costs/ha	3000
Clay cover per m3 supplied & spread (includes Zone H subsoil	3
Topsoil /m3 (0 if available on site)	0
Compost/m3	38
Spreading cost of topsoil or compost/m3	3
Pasture Costs:	
Harrowing + Seeding + Fert/ha	6500
Maintenance/ha (incl spraying & fert)	200
Earthworm seeding/ha	100
Fencing + water/ha (assume one year after sowing)	1400
Pasture Returns, Yr 1 to 5,ha/yr	478
Pasture Returns, Yr 5 onwards/ha/yr	957
Native Planting Costs:	
Natives - includ tree costs, planting costs, fert/ha	14000
Maintenance/ha yr 1 to 5	10063
Maintenance/ha yr 5 onwards	1463
Supplementary planting, yr 5/ha	7875
Returns on natives, year 1 to 5, $/ha	0
Returns on natives, year 5 onwards	0

REHABILITATION OPTIONS.	Yr 1	Yr 2
Area Drained, ha/yr	26	0
Area clay covered, ha	0	0
Depth of cover, mm	0	0
Area topsoiled, ha	0	0
Topsoil depth required, mm	0	0
Area with compost applied, ha	0	26
Compost depth required, mm	0	50
Lake area, ha	10.5	10.5
Area restored to natives, ha	0	0
Area restored to pasture, ha	0	26
Unrestored Area, ha	26	0
Area earthworm seeded & fenced, ha (1 yr after sowing).	0	0
Area Supplementary Planted With Natives, ha (5yrs after planti	0	0
Water Treatment Costs per m3.	0.9	0.9

SUMMARY - YEAR 14.	
Total Area of Tailings Surface ha	36.5
Total Area Drained	26
Total Area Clay Covered	0
Total Area Topsoiled	0
Total Area Compost Amended	26
Total Area Unrestored	0
Total Lake Area	10.5
Total Area Restored To Pasture	26
Total Area Restored To Natives	0
	36.5
Total Area Earthworm Seeded.	26
Total Native Area Supplementary Planted	0

WATER BALANCE CALCULATIONS.	Yr 1	Yr 2
Total Area Unrestored	26	0
Area Restored (natives & pasture) < 3 yrs old	0	26
Area Restored (natives & pasture) > 3 yrs old	0	0

COSTS CALCULATIONS		
Total Area Natives < 5 yrs old	0	0
Total Area Natives 5 to 10 yrs old	0	0
Total Pasture < 5 yrs old	0	26
Total Pasture > 5 yrs old	0	0

Table 2. Water Balance

		Rainfall mm	Evapn mm	Rainfall - Evap mm	Rf - Evap input to lake, m3	Runoff from unrestore areas	Runoff from restored areas < 3 yrs	Runoff from restore areas > 3 yrs	Total input m3	Rise/fall in lake m	Actual Lake level	Discharge
Year 1	01-Jan	0	5.8	-5.8	-609	0	0	0	-609	-0.0058	138.4942	0
	02-Jan	0	5.8	-5.8	-609	0	0	0	-609	-0.0058	138.4884	0
	03-Jan	11	5.8	5.2	546	1352	0	0	1898	0.018076	138.5065	0
	04-Jan	0	5.8	-5.8	-609	0	0	0	-609	-0.0058	138.5007	0
	05-Jan	1	5.8	-4.8	-504	0	0	0	-504	-0.0048	138.4959	0
	06-Jan	0	5.8	-5.8	-609	0	0	0	-609	-0.0058	138.4901	0
	07-Jan	0	5.8	-5.8	-609	0	0	0	-609	-0.0058	138.4843	0
	08-Jan	0	5.8	-5.8	-609	0	0	0	-609	-0.0058	138.4785	0
	09-Jan	0	5.8	-5.8	-609	0	0	0	-609	-0.0058	138.4727	0
	10-Jan	0	5.8	-5.8	-609	0	0	0	-609	-0.0058	138.4669	0
	11-Jan	0	5.8	-5.8	-609	0	0	0	-609	-0.0058	138.4611	0
	12-Jan	0	5.8	-5.8	-609	0	0	0	-609	-0.0058	138.4553	0
	13-Jan	0	5.8	-5.8	-609	0	0	0	-609	-0.0058	138.4495	0
	14-Jan	0	5.8	-5.8	-609	0	0	0	-609	-0.0058	138.4437	0
	15-Jan	0	5.8	-5.8	-609	0	0	0	-609	-0.0058	138.4379	0

Summary of Quantities Discharged.

	m3
Yr 1	552821
Yr 2	552359.8
Yr 3	552359.8
Yr 4	552359.8
Yr 5	499629.2
Yr 6	499629.2
Yr 7	499629.2
Yr 8	499629.2
Yr 9	499629.2
Yr 10	499629.2
Yr 11	499629.2
Yr 12	499629.2
Yr 13	499629.2
Yr 14	499629.2

Table 1 - Materials Required.

	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	Yr 8	Yr 9	Yr 10	Yr11	Yr 12	Yr 13	Yr 14	
Clay For Cover m3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Topsoil, m3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Compost, m3	0	13000	0	0	0	0	0	0	0	0	0	0	0	0	13000

Table 2 - Costs & Revenues.

FIXED COSTS

Resurfacing																
Drainage Costs	78000	0	0	0	0	0	0	0	0	0	0	0	0	0	78000	
Clay Cover Costs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Topsoil Costs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Compost Costs	0	494000	0	0	0	0	0	0	0	0	0	0	0	0	494000	
Spreading costs for topsoil & compo	0	39000	0	0	0	0	0	0	0	0	0	0	0	0	39000	
															0	
Pasture															0	
Harrowing, fert, seed sowing	0	169000	0	0	0	0	0	0	0	0	0	0	0	0	169000	
Earthworms	0	0	2600	0	0	0	0	0	0	0	0	0	0	0	2600	
Fencing + water	0	0	36400	0	0	0	0	0	0	0	0	0	0	0	36400	
															0	
Natives															0	
Initial planting (incl plants, labour, fer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Supplementary Planting (after 5 yrs)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
															819000	Total Fixed Costs
MAINTENANCE COSTS																
Pasture	0	5200	5200	5200	5200	5200	5200	5200	5200	5200	5200	5200	5200	5200	67600	
Natives less than 5 yrs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Natives more than 5 yrs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
															67600	Total Variable Costs
WATER TREATMENT COSTS	497538.9	497123.8	0	0	0	0	0	0	0	0	0	0	0	0	994662.7	Total Water Tr Costs
TOTAL COSTS	575538.9	1204323.8	44200	5200	5200	5200	5200	5200	5200	5200	5200	5200	5200	5200	1881263	Total Costs
REVENUE																
Pasture < 5yrs old	0	12428	12428	12428	12428	12428	0	0	0	0	0	0	0	0	62140	
Pasture > 5yrs old	0	0	0	0	0	0	24882	24882	24882	24882	24882	24882	24882	24882	199056	
Natives < 5yrs old	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Natives > 5yrs old	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
TOTAL REVENUE	0	12428	12428	12428	12428	12428	24882	24882	24882	24882	24882	24882	24882	24882	261196	Total Revenue
NET COSTS (-ve = profit from pastur	575538.9	1191896	31772	-7228	-7228	-7228	-19682	-19682	-19682	-19682	-19682	-19682	-19682	-19682		

Appendix 6.2 - Breakdown of Scheduled Operations, Costs and Returns For Scenarios 1 to 5.

1. COSTS.

a. Costs Provided by Jeff Ruddock, Development Site Engineer, Waihi Gold Company.
(All prices ex GST).

- **Drainage.** Assuming the tailings have been sufficiently drained to allow vehicle access, approximate costs for providing hump and hollow drainage, like on the Hauraki Plains is estimated to be $3000/ha.

- **Clay Cover.** The cost to spread a clay cover, from on site materials is estimated at $3/m^3$.

- **Topsoil/Compost Application.** The cost to spread these materials, assuming they are already on site is estimated at $3/m^3$.

- **Fertilising/Seeding/Harrowing the Final Surface.** Based on current costs for the waste embankment rehabilitation, this is estimated at $6,500/ha.

- **Farm Race**. Assuming a 3m wide race, constructed of metal, similar to that existing on the south end of the waste embankment, the cost is estimated at $15 per linear metre. (Note - this cost was not included in the model because it was assumed it would already be available as part of the existing farming operation).

b. Costs Provided by Duncan Smeaton, Agricultural Consultant.

- **Fencing.**
  7 wire fence = $7 to $10 per metre erected including labour (excl GST).
  2 wire electric fence = $2 per metre including labour (excl GST).
  Pipe gates = $110 each incl fittings (incl GST).

- **Water.**
  Concrete Troughs $250 to $300 each including fittings and GST.
  Water Pipe, 95c/m including GST.
  Headworks, ie pump, reservoir tank and main line lead out pipe will be approximately $7,000 to $10,000 if required. (Note - this cost was not included in the model because it was assumed it would already be available as part of the existing farming operation. In the same way, the costs of animal health, wages to manage stock, feed, eg hay, silage, freight, vehicle expenses, electricity, repairs and maintenance and administration have not been calculated, as it is assumed they would be included in other farm costs previously existing).

- **Fertiliser.**
  Maintenance Application, including cartage and spreading, $130/ha/yr ex GST.

- **Weed Control.**
  Depends on severity of weed infestation and types of weeds - estimated at $50 to $75/ha/yr including labour, chemicals and GST.

c. Costs Provided by Wayne Allan, Allanscapes Nurseries, Hamilton. (All costs calculated on planting one hectare at a density of one plant per 1.5 m^2, based on a clean site with no brush weed removal).

All prices are for a per one m^2 rate exclusive of GST. Basic planting 5,000 plants 70% PB2 and 30% RT4s.

Planting. Includes plant supply, planting, fertiliser, pre-planting spot spray, one application Tree-pel = $1.60/m^2.

Maintenance - First five years = $1.15/m^2, and over five years, 15c/m^2.

Supplementary Planting. Assuming an initial cover has been achieved and assuming 1000 plants/ha, cost = 90c/m^2 including plant supply and labour.

2. RETURNS FROM PASTURE. (Supplied by Duncan Smeaton, Agricultural Consultant).

In theory, a dairy heifer being charged $4.50 to $5.00/head/week for grazing eats 2,000 kg dry matter in one year. Typically, dairy heifers are stocked at up to five heifers/ha.

In practice, the Farm Manager for Waihi Gold Mining Co Ltd runs 3.5 heifers/ha on pastures over all of the land owned by the Company. This includes good and mediocre land. An appropriate stocking rate for the first five years, assuming a dry matter production of 11,000 kg DM/ha from tailings, might be 2 heifers/ha, with severe constraints on when the area can be grazed, and it is assumed that an overflow area exists where heifers can be grazed in wet weather.

Assuming that pasture production after the first five years averages 12,000 kg DM/ha, and assuming no grazing constraints in wet weather, a stocking rate of 4+ heifers/ha should be feasible.

To summarise, gross returns (ex GST) from pasture will be:

	Heifers/ha	Return/ha/week	Return/ha/year
Period 1, yrs 1 to 5	2	$4.60	$478.40
Period 2, yrs 6+	4	$4.60	$956.80