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An Investigation into the Ecological Status of Metalliferous Mine Tailings Sites in Counties Galway, Sligo and Tipperary.

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by

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Muna bhfuil ach Pocaide Gabhair agat bí í lár an aonaigh leis.

(Irish Saying)

DEDICATION

To

Mum and Dad,

Adrienne, Nicola and Jarlath.

and to the memories of

Lorraine Gunning and Shane McGrath

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ABSTRACT

Metalliferous mining in Ireland is a multi-million pound industry and its operations are a "far-cry" from the first Bronze Age workings. With the modern industry however, comes the production of large quantities of mine tailings. These are composed of waste rock containing residual heavy metals, uneconomic minerals, water and chemicals and must be managed in a way that will not pose a threat to the environment.

The conventional management process involves pumping the mine tailings, in slurry form, into a constructed pond where, over time the water is decanted leaving a material high in metals but devoid of the elements necessary for its stabilisation. Rehabilitation of this material is necessary to prevent pollution but also to convert it to an aesthetically pleasing state.

This study investigated the existing status of five metalliferous mine tailings sites in Ireland, to determine the degree of rehabilitation at each. These sites are located at Tynagh, County Galway, Abbeytown, County Sligo and Gortdrum, Shallee and Silvermines, County Tipperary. Abbeytown and Shallee underwent natural colonisation while managed rehabilitation took place at the other sites.

Results from studies undertaken between 1990 and 1994 indicate that natural or managed rehabilitation of the five mine tailings sites was taking place. Abbeytown mine tailings site, which was naturally rehabilitated, appeared to be the most successfully rehabilitated site. It was felt that no assistance was required to enhance the rehabilitation process there. In relation to the other sites it was felt that further assistance may be required to ensure long term stabilisation.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

1:1 Introduction

Mine tailings from ore extraction are composed of waste rock, containing residual heavy metals, uneconomic minerals, water and chemicals. These must be disposed of in a manner that will not adversely effect the environment. The various methods of disposal include discharge to lentic systems, lotic systems, the sea, underground disposal and land impoundment (Williamson, Johnson and Bradshaw, 1982).

The two general classes of impoundment in the surface disposal of mine tailings are water-retention type dams and raised embankments (Vick, 1983). Following extraction of metalliferous ore, the mine tailings which is a liquid slurry is pumped to these impoundment's where, over time, the water is decanted leaving a thixotrophic material similar in appearance to wet cement. This material is initially devoid of the constituents necessary for successful stabilisation and in this state has the potential to create many forms of pollution, including surface, groundwater and land pollution attributed to wind-blow.

Prendergast (1991) states there was little emphasis on the need to rehabilitate mine tailings sites in Ireland up to the 1960's and as a result there are many sites with no record of rehabilitation. Rehabilitation of mine tailings is of vital importance to prevent pollution but also to convert these sites to a state that is aesthetically pleasing. Once rehabilitation is complete these sites have the potential to be used for a wide variety of purposes including agriculture, sylviculture, wetland habitats and amenity areas.

This study which was undertaken between 1990 and 1994 involved examining the physical, chemical, microbiological and botanical characteristics of five mine tailings sites in Counties Galway, Sligo and Tipperary.

1:2 The objectives of the study are:

1. To ascertain what degree of managed or natural rehabilitation has taken place at each mine tailings site. This objective includes the assessment of the progress of colonisation by indigenous plant species on the rehabilitated mine tailings.

2. To investigate what factors are responsible for the success or failure of mine tailings rehabilitation and if these factors are interrelated.

3. To determine if there is a point in the mine tailings rehabilitation process after which assistance is no longer necessary and the system is self-sustaining.

1:3 Literature Review

1:3.1 The importance of promoting revegetation on mine tailings and mine land

The objective of mine land reclamation should be the establishment of a landscape that is stable and aesthetically and environmentally compatible with surrounding undisturbed land. The revegetation of this land should use plant species that will contribute most to the stability of the system.

Tober, Jacobson and Haas carried out work in 1975 at the Center and Indian Head mine sites in North Dakota, USA to evaluate plant species for surface mined lands in the Northern Great Plains. Mine spoil at these sites was levelled, topsoil was spread on the surface and soil analyses were undertaken prior to planting. No fertiliser was applied to the Center plots however it was applied to the Indian Head plots.

This study involved planting cool-season grasses, legumes and one shrub species in the spring and fall of 1975 respectively. Warm-season native grasses were planted on the Center site.

Panicum virgatum L. NDG-965-98 had the highest five-year average forage yield and the best percentage basal cover of the tall warm-season

native grasses. 'Pierre' and 'Killdeer' varieties of *Bouteloua curtipendula* (Michx.) Torr. were quick to establish, had excellent seedling vigour and had the highest percentage basal cover of all the grasses tested.

The native cool-season grasses showed good establishment e.g. *Agropryon trachycaulum* (Link) Malte had high seeding vigour and quick stand establishment.

Cultivars of *Agropyron smithii* Rydb. provided good basal cover and forage production. *Stipa viridula* Trin. was well adapted to both sites.

In relation to some of the introduced cool-season grasses *Agropyron intermedium* (Host) Beauv. var. intermedium, *Agropyron trichophorum* (Link) Richt and *Agropyron elongatum* (Host.) Beauv. had the highest five-year average forage yield. *Festuca longifolia* Thuill provided very good ground cover.

In relation to the legumes *Medicago falcata* L. was the highest forage producer of the legume species.

The growth of the shrub *Atriplex canescens* (Pursh) Nutt. proved good to excellent on the Center plots but poor to fair on the Indian Head plots. This species if included in a range seeding mixture has the potential to provide high quality browse and an improved wildlife habitat.

1:3.2 Factors affecting the revegetation of mine tailings and mine waste

1:3.2.1 Nutrients

Nicholson studied abandoned mine lands in the Northern Great Plains of the USA and noted that nitrogen and phosphorus limited revegetation. Studies showed enhanced plant growth with nitrogen, phosphorus and potassium fertilisation under well watered conditions. Nicholson reported that strongly acidic or alkaline conditions significantly limited the uptake of nutrients, in general, by plant species.

Williamson and Johnson (1984) state that low background levels of essential nutrients are a constraint to plant growth. These levels reflect severe deficiencies or an absence of organic matter and clay minerals.

These provide the nutrient store and cation-exchange capacity of normal soils.

1:3.2.2 Metals

Down (1975) noted that at minimal levels many metals are required by plant species for healthy growth. However there is often a very sharp division between the levels required for growth and the levels responsible for toxicity.

Different species have different levels of susceptibility to a metal. This susceptibility varies according to the chemical format in which the metal exists. This format in turn may control the availability of the metal to the plant.

Kuja and Hutchinson (1979) carried out a screening study of plant species on mine tailings from different regions of Canada. The species used were *Arctagrostis latifolia*, *Artemisia tilesii*, *Carex bigelowii*, *Hierochloe alpina* clones, *Deschampsia caespitosa* and *Hordeum jubatum* seedlings.

The screening experiment examined the performance of each species on the mine tailings and indicated that they had evolved some metal tolerance. *Artemisia tilesii* was the only species that grew on all mine tailings. No growth of *Arctagrostis latifolia* and *Deschampsia caespitosa* occurred on mine tailings having a pH of 3.0 or less. These species must have evolved some degree of tolerance to acidic conditions as they grew on mine tailings having a pH 3.3.

Carex bigelowii and *Hierochloe alpina* did not grow as vigorously as other species and did not survive on very acidic mine tailings. *Hordeum jubatum* grew vigorously on neutral or alkaline mine tailings but didn't grow on acidic material.

Results from field trials on mine tailings sites indicated that *Arctagrostis latifolia*, *Artemisia tilesii*, *Carex bigelowii* and *Hierochloe alpina* were surviving after three years at Nickel Rim site.

Percentage germination and survival of *Deschampsia caespitosa* were good on plots whose pH was amended to above 5.0. Best growth on the Nickel Rim site was attributed to the addition of organic and inorganic fertilisers and to the addition of limestone.

All plots failed at Cyprus Anvil site in the Yukon. High sulphur, lead, zinc and cadmium levels were toxic to all species.

At Arctic Gold and Silver sites *Arctagrostis latifolia* was the only species from the clonal group which survived two summers on plots whose pH was amended to above 5.0. Poor results were obtained for one summers planting of *Deschampsia caespitosa* and *Hordeum jubatum* on these sites. However a significantly better response was obtained following an autumn reseeding. In general seedlings of both species survived only on limed plots. The addition of peat and fertiliser improved the response of *Deschampsia caespitosa*.

At Venus site the clonal group of species did not respond well but *Arctagrostis latifolia* grew best. A lack of available moisture limited growth. The *Deschampsia caespitosa* and *Hordeum jubatum* results supported this finding.

At Whitehorse Copper site *Arctagrostis latifolia* grew best followed by *Artemisia tilesii*, the former surviving on all treatments.

The most vigorous growth occurred on untreated plots which was attributed to their accidental flooding by mine tailings. On non-flooded plots the best response was attributed to the application of phosphate fertiliser and peat.

The best performance of *Deschampsia caespitosa* and *Hordeum jubatum* appeared to have occurred with peat and organic fertiliser or peat and phosphate fertiliser treatments.

Williamson and Johnson (1984) noted that metal levels in excess of 0.1% (w/w) were phytotoxic. This depended on the metallic species, release characteristics and the nature of the accessory minerals. These metal levels may frequently be found in mine wastes.

Gregory and Bradshaw (1965) collected populations of *Agrostis tenuis* from a range of mine habitats in Britain and Germany. They compared the tolerance of each population to copper, nickel, zinc and lead with corresponding metal levels in soils from which they were taken. Results for tolerance indices showed a marked difference between them in tolerance to individual metals with these tolerances being specific.

Results showed a significant correlation (0.84, $P < 0.01$) between the index of tolerance to zinc and the soil zinc level. The correlation coefficient was similar (0.64, $P < 0.05$) for copper. However they were not significant for lead (0.60) and nickel (-0.20).

According to the authors tolerance to a particular metal didn't automatically confer tolerance to another, with the exception of zinc and nickel. However it is possible for plants to be tolerant to two metals if these metals are present in toxic quantities in the soil.

Wong (1982) carried out work in Britain to investigate metal co-tolerance to copper, lead and zinc in *Festuca rubra*. Results showed that populations from copper mine spoil in Staffordshire had a high index of tolerance to copper, zinc and lead.

Medium to high levels of tolerance to copper and zinc were obtained for *Festuca rubra* populations from copper mine spoil at Great Orme Clwyd.

Festuca rubra S59, the control, was collected from the campus of Liverpool University. It had the lowest level of tolerance to copper, zinc and lead.

Results from Duncans new multiple range test showed that the indices of tolerance of copper and zinc of the control were significantly different at a 1% level from plants collected from contaminated sites. No significant differences were found regarding the index of tolerance of lead between the control and plants from other sites.

Henriques and Fernandes (1991) studied *Juncus conglomeratus* L. growing on pyrite mine tailings in Lousal, Portugal and examined the heavy metal content of roots and shoots of this species and of soil within which it grew. The average total levels of iron, zinc, copper and lead within the soil and roots and shoots of *Juncus conglomeratus* were higher than in the control soil and plants.

Within the mining area of Lousal, the patterns of metal accumulation differed between sites A and B. For example the iron level in plant roots from site B was 3.5 to 7 times higher than in roots from site A despite the soil level being 3 to 4 times lower at site B. The different root iron levels in *Juncus conglomeratus* at both sites were probably attributed to different waterlogging conditions that resulted in different degrees of ferric iron plaque formation on root surfaces. The root levels of the other metals did not differ significantly between sites, with the possible exception of lead.

The reductions in copper and lead in the shoots of *Juncus conglomeratus* compared to the roots were significant. The authors reported that both metals displayed poor translocation. A large proportion of the total copper and lead absorbed by the plants is retained within the roots. Manganese levels in the shoots were higher than in the roots.

Iron, copper and lead present in excess in the contaminated soil did not reach toxic levels in the shoots of *Juncus conglomeratus*. However this species did absorb manganese from the substrate which was deficient in this metal and accumulated it within the shoot. This suggested that it had developed a high selectivity with regards the uptake of metals and their translocation.

Eltrop, Brown, Joachim and Brinkmann (1991) studied *Betula pendula* and *Salix caprea* in the former lead-mining area of Mechernich, Germany. The objectives of the study were to investigate if these species were growing on soils containing significant levels of plant-available lead, if soil conditions exerted an influence on their distribution and on lead levels in plant tissues

and if high soil lead levels led to the development of heavy metal tolerant strains of *Betula*.

Results indicated that average total lead levels in *Salix* and *Betula* soils were 6,425mg/kg and 12,467mg/kg respectively.

Root lead levels for *Salix* and *Betula* were 8,467mg/kg and 20,969mg/kg dry weight (dw) respectively. The lead accumulation index for these species indicated that *Betula* accumulated more lead within its roots.

Correlation between root lead and NH_4-ac soil lead levels indicated the presence of two groups of *Betula* in the contaminated site.

A significant negative correlation was obtained for *Betula* ($r = 0.73$) but not for *Salix* ($r = 0.18$) in relation to soluble soil phosphate and root lead levels. This indicated a negative relationship between phosphate and the uptake of lead in *Betula*. Soil calcium did not influence lead tolerance in *Betula*.

Results indicated that roots of ecotype plants of *Betula pendula* growing on lead contaminated soil contained up to 64% more lead than normal type plants from the non-contaminated area. These plants also transferred more lead to their shoots. Results also showed that the difference in root lead content between the ecotype and normal type populations of *Betula* could be attributed to acid soluble lead. The authors believed that the higher tolerance to lead in the ecotype population must be genetically determined.

Obbard and Jones (1993) determined if effective strains of *Rhizobium leguminosarum* biovar. *trifolii* which are capable of symbiotic nitrogen fixation with *Trifolium repens* were present in metal contaminated soils. This study involved comparing sewage amended sites, which included experimental, pasture grassland and arable sites, with abandoned metalliferous mine sites.

Results indicated that when *Trifolium repens* was indigenous to a sward rhizobia were present in nodules and in the soil rhizosphere of all tested sites. They were capable of effective symbiosis and nitrogen fixation (Acetylene reduction activity (ARA) was the method used to screen for

effective nitrogen fixation) though metal levels in some situations exceeded soil metal limits. Nodulation didn't occur in some cases where *Trifolium repens* was not indigenous to metal-contaminated soils. This indicated the presence of an ineffective rhizobial population or the absence of effective cells from the soil.

The influence of individual metals on ARA was not determined conclusively. However cadmium levels appeared to be important in determining the presence of effective ARA in soils having no indigenous clover.

1:3.2.3 pH

Down (1975) states that acidity may be generated in waste tips and mine tailings, from sulphide areas, due to bacterial oxidation. Wastes with a pH of less than 4 may be inhibiting because of the acidity itself or because of the resulting mobility and availability of metal ions.

1:3.2.4 Physical and Chemical Factors

Nicholson studied abandoned mine lands in the Northern Great Plains of the USA and noted that site age was an artificial factor in affecting revegetation. It did not limit revegetation but did in the sense that factors affecting revegetation varied with time.

Plants require suitable sites for seeds to lodge, survive and germinate. Abandoned mine sites with steep slopes and sodic induced crusts are not conducive to seed importation. Where seeds do land the absence of a suitable cover may prevent germination or seedling survival if germination does occur.

A suitable rooting medium is required for the survival and growth of plants. However, in general, abandoned mines provide a poor rooting medium.

Down (1975) noted that physical and chemical factors can act as severe barriers to revegetation and may seriously limit the nature of the plants which may be used. These factors include temperature extremes which in

turn are affected by climatic regimes. These regimes together with tip slope angle, tip orientation and waste colour control precise extremes at the waste surface. Large temperature fluctuations are responsible for the death of newly established seedlings. Wind scouring may cause abrasion to plant stems and their subsequent death, particularly on mine tailings sites. Excessive or inadequate drainage results in water stress or waterlogging respectively. Compaction may inhibit root penetration. Slope instability and in particular surface slumping results in the transport of established plants and root breakage's.

1:3.2.5 Salinity

Nicholson states that salinity inhibits the promotion of plant growth and survival. Elevated sodium may give rise to crusting. High salinity reduces water availability by elevating the osmotic pressure of the soil solution and also leads to ion toxicity in plants.

Williamson and Johnson (1984) state that high salinity is a common feature of modern mine tailings sites. Conductivity levels in excess of 16µS/cm, the levels at which crops don't survive, have been reported.

Hayward and Wadleigh (1949) state that saline soils may affect plant growth in two distinct ways: (1). The increased osmotic pressure of the soil solution effects an accompanying decrease in the physiological availability of water to the plant and (2). The concentrated soil solution may be conducive to the accumulation of toxic levels of ions within the plant.

Most evidence indicates that the accumulation of neutral salts in the substrate inhibits plant growth primarily as a consequence of the increase in osmotic pressure of the soil solution and the accompanying decrease in the physiological availability of water.

Hayward and Wadleigh (1949) reported that germination together with seedling growth, under saline soil conditions, is critical since the ability of a given variety to germinate and establish the seedling is frequently the

limiting factor in crop production. Two ways in which saline soils may effect germination are: (1). There may be enough soluble salt in the seed bed to build up the osmotic pressure of the soil solution to a point which will retard or prevent intake of necessary water and (2). Certain constituent salts or ions may be toxic to the embryo and seedling.

The first effect of increasing salt levels on vegetative development is usually a reduction in growth rate which may be unaccompanied by visible symptoms of injury. The first physiological reaction to increased salt levels is reduced water entry to roots.

As a rule forage plants, grasses and legumes exhibit the highest degree of salt tolerance on saline lands. However there are marked specific differences. Grasses are more salt resistant than legumes the outstanding species being *Sporobolus airoides*, *Distichlis spicata*, *Puccinellia nutalliana*, *Cynodon dactylon*, *Chloris gayana* and *Agropyron smithii*.

Among leguminous forage plants, alfalfa, white and yellow sweet clovers, *Lotus corniculatus*, *Trifolium fragiferum* and hubum clover are moderately salt tolerant while *Lotus corniculatus* var. *Tenuifolius* has a high salt tolerance.

Bernstein and Hayward (1958) reported that the effects of salinity on a plant may vary depending on its stage of development. During the germination stage sensitivity may be quite different than at later stages and fruiting in some crops may be affected differently from vegetative growth. The first effective increments of salinity, for a given crop, generally retard germination with little or no effect on the ultimate number of seedlings which emerge.

Higher levels of salinity aggravate the delay in emergence and decrease final germination percentages. The top inch of soil is usually more saline due to evaporation and capillary rise of saline waters. Seeds therefore are generally in a more saline environment than established plants whose roots can utilise less saline portions of the soil profile. In addition to germination

being inhibited early seedling growth stages may also be quite sensitive to salinity.

Plants growing in nonsaline soils may become more sensitive to an abrupt rise in salinity as they increase in size.

Tiku and Snaydon (1971) investigated the response of natural populations of *Agrostis stolonifera*, from different habitats, to sodium chloride in nutrient solutions. After 18 days growth of four populations total root length was greatest in full nutrient solution and least in distilled water at three sodium levels of 0mg/L, 200mg/L and 1,000mg/L. In the case of the latter sodium level, calcium nitrate solution produced a greater root length. There was no significant difference between *Agrostis* populations in the effect of sodium chloride upon root elongation ($P > 0.1$).

Six populations of *Agrostis stolonifera* were grown in a Long Ashton nutrient solution at sodium levels of 0mg/L, 1,500mg/L and 5,000mg/L. In the absence of sodium, populations from three non-saline inland habitats produced the greatest number of roots, the longest single root, the greatest total root length and the greatest dry matter yield. Two populations from the saline maritime habitat and one from the non-saline maritime habitat ranked lowest in these measures.

Dry weight yield of *Agrostis* populations from inland and non-saline maritime sites was more effected by sodium chloride in culture solution than were populations from saline maritime sites.

Rozema and Blom (1977) measured the responses of maritime populations of *Juncus gerardii* and *Agrostis stolonifera* to salinity and inundation.

Inundated *Agrostis stolonifera* plants had higher maximum and mean stolon lengths, mean internode lengths and shoot fresh weights at three inundation levels (water table 5cm above the soil surface, water table at the soil surface and capillary water only) at a soil salt level of 0%. With regards to *Juncus gerardii*, inundation depressed mean shoot height, number of shoots per plant, mean leaf number per shoot, rhizome length

and root length. This applied to the same inundation levels and soil salt level as for *Agrostis stolonifera*.

With regards to salinity and *Agrostis stolonifera* the addition of salt did not appear to be favourable for the morphological characters measured. Maximum stolon length, mean stolon length, mean internode length and shoot fresh weight were in general lower at the three inundation levels and at a soil salt level of 50%. In *Juncus gerardii*, seawater caused an overall reduction in most morphological characters. The characters measured were mean shoot height, number of shoots per plant, mean leaf number per shoot, rhizome length and root length. The same inundation levels and soil salt level applied as for *Agrostis stolonifera*.

High salinity was responsible for increased sodium levels in the roots and shoots of *Agrostis stolonifera* and *Juncus gerardii*. Potassium levels, especially in *Juncus gerardii*, were less influenced by salinity.

Inundation caused an increased iron and manganese content in the root material of both species. Results also showed that inundation and salinity had a significant effect on the phosphorus content of the root material of *Juncus gerardii*.

Parker, Page and Thomason (1991) investigated plant management as a critical component of a remediation strategy to reduce soil or sediment selenium levels to safe levels in an area of the San Joaquin Valley, California, USA. Soil salinity was one of the parameters that posed limitations to the use of plant species.

A number of cultivars or lines of species from *Astragalus, Leucaena, Medicago, Trifolium, Elymus, Elytrigia, Festuca, Leymus, Oryzopsis, Psathyrostachys, Puccinellia* and *Sporobolus* were screened for tolerance to salinity. During seed germination variation in tolerance to salinity, occurred within and across species. Electrical conductivity's required to produce a 50% reduction in germination ranged from 5 to 30dS/m.

The most promising genotypes, which represented 15 plant species, were tested for salinity during the seedling growth stage. Lines of the five

species *Astragalus bisulcatus, Astragalus. racemosus, Elytrigia pontica, Puccinellia distans* and *Sporobolus airoides* appeared to be the most promising with each having electrical conductivity's greater than 20dS/m.

1:3.2.6 Micro-organisms

Nicholson states that micro-organisms affect plants in many ways. These include promoting nutrient availability and aiding nutrient uptake. However characteristics of mine spoils such as the lack of organic matter, acidity, aridity and coarse texture may limit bacteria.

1:3.3 The role of leguminous plants in normal and metal contaminated soils

Martin (1960) states that the presence of leguminous plants in a sward is valuable because they fix atmospheric nitrogen by the agency of associated root nodule bacteria thus causing an increase in the potential nitrogen production from the sward. Martin (1960) reported the following observations relating to leguminous plants: *Trifolium repens* is valuable for grazing because it is capable of surviving under conditions of intensive defoliation and increases the palatability and protein level of most swards. The production of a grass clover sward is equivalent to the production of a pure grass sward receiving 91kg to 113kg of fertiliser per acre. A significant linear correlation exists, in most cases, between the percentage of clover and yield of crude protein in grass production trials. The herbage yield and quality (in terms of protein content) are greatest when there is a high percentage of clover in the sward. For the maintenance of sward productivity a ratio of grass to clover of 2:1 is most ideal. Short time periods beneath a grass/clover sward will improve a soils physical structure.

Cowling and Lockyer (1967) sowed plots with seven grasses and one mixture in spring 1959. These plots were split and received four levels of nitrogen fertiliser. S100 *Trifolium repens* was sown with grass in a fifth sub-plot which did not receive nitrogen. Annual nitrogen applications were

made in mid-March and after every cut except the last. These cuts took place from 1960 to 1962 inclusive.

Agrostis had the highest percentage nitrogen in dry matter in all year's and at all nitrogen levels, with one exception, while S24 *Lolium perenne* had the lowest. In general *Dactylis glomerata* produced the highest nitrogen yield while *Agrostis* and the ryegrasses produced the lowest.

In relation to the grass/clover swards, *Trifolium repens* made up a high proportion of the dry matter yield. The percentage nitrogen in dry matter of the mixed herbage exceeded that of grass at the highest nitrogen level.

There were significant differences ($P < 0.01$) between annual nitrogen yields for each grass/clover mixture in 1960 only. The *Agrostis* mixture, which had a very high clover content, gave a higher total yield than all other grass/clover mixtures.

Masterson (1973) states that *Trifolium repens* is indigenous to Ireland. This plant species is richer in minerals and proteins and maintains a higher digestibility level throughout the season than grasses. It forms a symbiotic relationship with a soil bacterium *Rhizobium* to fix atmospheric nitrogen which in turn is converted to plant protein.

The annual pattern of nitrogen fixation by *Trifolium repens* was examined in a grazed sward and a number of conclusions were made: During the winter low levels of fixation were detected. This was followed by a rapid increase in activity in spring. Grazing of the sward resulted in the defoliation of clover plants. This led to an interruption in the flow of photosynthate to the nodule system and reduced nitrogen fixation temporarily. Flowering of clover caused a large decrease in activity.

Fertiliser nitrogen applied in spring resulted in a prolonged reduction in fixation with the effect lasting until after flowering. This reduction was greater when nitrogen was applied later in the season.

Rother, Millbank and Thornton (1983) studied sites contaminated with metals from shallow or open-cast zinc mines in Somerset and lead mines in

Derbyshire, England. The aim of this study was to assess the effects of heavy metals in the soil on nitrogen fixation under natural conditions and with the minimum of disturbance to plants while under incubation conditions.

Most sites at Somerset and Derbyshire contained a mixture of grasses, mainly *Lolium, Phleum, Dactylis* and *Agrostis* and *Trifolium repens*. The remaining sites contained a greater variety of plants. These included *Trifolium arvense*, *Lotus corniculatus*, *Festuca*, *Holcus* and several herb species. However the plants at these sites were considerably smaller.

In relation to the effect of soil contamination, by heavy metals, on nitrogenase activity differences were observed between contaminated and control sites. These could not be simply or consistently correlated with differences in the levels of heavy metals in various soils. During spring especially the potential quantity of nitrogen fixed was appreciable, even in heavily contaminated sites.

1:3.4 Distribution and activity of soil micro-organisms in normal and metal contaminated soils

Went and DeJong (1966) studied the breakdown of cellulose in the litter of two forests and in two orchard soils in the Netherlands.

Soil results found that cellophane disappeared quicker in the calcareous mull than mor part of one forest soil. Climatic conditions appeared to have been influencing cellulose breakdown.

On investigating the breakdown of cellophane in different forest-floor types a sequence of rate of attack was discovered. Here a dry period resulted in such a large delay in cellophane breakdown that total decomposition had not been reached after 60 to 80 weeks. In orchard soils cellophane decomposed very quickly.

On investigating successive cellulose-decomposing organisms foci of attack by fungi, eubacteria and cytophaga's were identified in cellophane within 4 weeks after soil insertion. In the first few weeks cellophane from orchard

soils showed more foci of attack by bacteria than cellophane from forest soils where fungi dominated from the beginning.

Analyses of forest soil and litter yielded mainly bacteria, myxobacteria and actinomycetes.

The majority of fungi isolated from cellophane, that was left in forest and orchard soils for one to three weeks, belonged to the genera *Penicillium*, *Trichoderma*, *Pachybasium*, *Mucor* and *Fusarium*.

Pancholy and Rice (1973) hypothesised that amylase, cellulase, invertase, urease and dehydrogenase activities in soil would change markedly during old field succession. Experiments tested this in two old-field successional stages and a climax stand in three plant types: Tall grass prairie, post oak-blackjack forest (*Quercus stellata*, *Quercus marilandica*) and oak-pine (*Quercus*, *Pinus*) forest.

The first successional stage (P_1) was in the lst year after abandonment from cultivation in the oak-pine and tall grass prairie areas and in the 2nd year in the post oak-blackjack area. Three P_1 plots were placed in the pioneer weed stage of succession. The second successional stage (P_2) was in the 6th year after abandonment in the tall grass prairie area. It was placed in the annual grass stage of succession. The P_2 plot in the post oak-blackjack area was in the 8th year after abandonment while in the oak-pine area this plot was abandoned from cultivation for 25 years.

Amylase, cellulase and invertase activity were highest generally in P_1, intermediate in P_2 and lowest in P_3 (climax stand) under all three plant types throughout the year. Low cellulase activity in P_2 of the post oak-blackjack area was the exception. Amylase activity was highest in spring and summer with highest activity consistently occurring in the tall grass prairie area. Cellulase activity generally showed similar trends to amylase activity in all plots. Invertase activity generally showed similar trends to amylase and cellulase activity and was consistently high throughout spring, summer and fall in most plots.

Urease activity was generally lowest in P_1, intermediate in P_2 and highest in P_3. Dehydrogenase activity demonstrated a similar trend to urease activity under all plant types with activity being lowest in P_1, intermediate in P_2 and highest in P_3, however there were exceptions.

The plant type and type of organic matter added to soil during succession appeared to be the chief determiners of the activity gradients of the enzymes studied.

Walker (1975) states that soil nitrification is predominantly affected by autotrophic nitrifying bacteria. The two genera of bacteria commonly regarded as playing an important role in this biochemical process are *Nitrosomonas* and *Nitrobacter*. Nitrifying bacterial numbers in most soils are not very high with populations in fertile arable soils usually in the range of thousands per gram. This may be due to their slow growth rate and to their requirement for considerable quantities of ammonium or nitrite.

Under favourable conditions numbers are largely dependent on the quantity of ammonium present.

Certain plants, particularly grasses, may inhibit nitrifiers near their roots. This may be due to the dense network of fine roots, which characterises many grasses, interfering with oxygen access to the soil and in so doing decreasing the aeration capacity needed for nitrifiers.

Conditions that favour nitrifying bacteria are largely those that favour plant growth, especially good aeration, neutral pH and nitrogen supply. This has led to suggestions that the presence of an active nitrifying regime in soil may be a useful indicator of soil fertility but chemical methods for assessing fertility are probably preferable.

Cundell (1977) examined the role that micro-organisms played in reclaiming spent shale wastes and overburden from lignite strip-mining in the western USA.

Factors including low organic matter, salinity, fine texture, lack of nitrogen and phosphorus together with a slow rate of soil formation were

responsible for limiting revegetation of the wastes. Microbial processes however are responsible for the accretion of organic matter, fixation of nitrogen and modification of adverse soil properties with the spoil.

Fresquez, Aldon and Lindemann (1986) determined microbial populations, diversity and composition of fungi and enzyme activities in an undisturbed soil and in reclaimed non-topsoiled and topsoiled areas of varying age. Populations of bacteria, ammonium oxidisers, *Azotobacter*, *Streptomyces* together with fungal propagules were present in soils three months after topsoiling and revegetation. The activities of most enzymes with the exception of dehydrogenase equalled those in the undisturbed soil. Most populations and activities peaked one or two years after reclamation with topsoiling and generally declined thereafter. The oldest topsoiled area was found to be more stable than the older non-topsoiled area as the former had soil physical and chemical properties together with a biological component similar to the undisturbed soil.

Bhuiya and Cornfield (1974) studied the effects of adding 1,000mg/L PbO and ZnO to a sandy soil, containing moderate levels of these elements. In soils which did not receive PbO or ZnO nitrification and nitrogen mineralisation increased with pH. Neither Pb nor Zn had a significant effect on these processes at pH 6.0 when compared with the control. At pH 7.0 Pb and Zn slightly decreased nitrification while nitrogen mineralisation was decreased by Zn. Nitrification and nitrogen mineralisation were slightly decreased by Pb and decreased to a fair extent by Zn at pH 7.7.
The slightly increasing toxicity of Pb to nitrogen mineralisation and nitrification was roughly correlated with increasing Morgan-Pb but not with EDTA-Pb. The increasing toxicity of Zn to both processes with increasing pH was poorly correlated with either extractable form of Zn.

Bruna, Borges, Fernandes, Barros, Muchovej and Della-Bruna (1991) investigated microbial activity in a dystrophic red-yellow latosol soil which was amended with Eucalyptus litter, phosphorus, nitrogen and lime. This soil was collected from virgin and Eucalyptus forests.

Microbial activity, determined by carbon dioxide release, was found to be higher in the virgin forest. Lower activity in the Eucalyptus forest appeared to have been attributed to a lower base saturation and pH together with a higher exchangeable aluminium and C:N ratio in this soil.

The addition of phosphorus, nitrogen and lime to the soil increased the amount of carbon dioxide released from both forests.

Ebregt and Boldewijn (1977) carried out a study to measure soil amylase activity in the surroundings of a brass foundry in Sweden. Here large quantities of heavy metals, in particular Cu and Zn, were emitted to the atmosphere and were deposited in the surrounding areas.

High negative correlation values were found between heavy metal concentration and amylase activity. Ca and Mn were positively correlated with amylase activity. Little or no correlation was shown by Mg, K, Na and Fe.

The relationship between log Σ(Cu+Zn+Pb+Cd) concentration and soil respiration ($r = -0.693$) and decomposition of starch ($r = -0.459$) was investigated and found to be significant ($p < 0.001$).

Positive correlation values were obtained with Ca and Mn. Values obtained were 0.318 (starch decomposition) and 0.505 (soil respiration) and 0.256 (starch decomposition) and 0.310 (soil respiration) respectively.

Doelman and Haanstra (1979) determined the effect of lead on soil respiration and dehydrogenase activity in the Netherlands. This involved sampling soils to a depth of 10cm and mixing each with different quantities of $PbCl_2$. These soils underwent further treatment prior to tests being carried out.

Results indicated that at 7,500µg Pb/g soil respiration was seriously inhibited in sandy soils. The respiration rate, as a percentage of untreated soil, was 19% and 4% respectively while in clay and peat soil it was 44% and 108% respectively.

The long term effects of lead were investigated using an "Eng" sandy soil. This involved measuring the respiration of samples to which four different levels of Pb were added. These were returned to the field and after different time periods subsamples were taken and respiration rates were determined.

Soil respiration was considerably retarded after more than 36 months. The respiration rates, as a percentage of untreated soil, for 0µg Pb/g and 1,500µg Pb/g treatments were 100% and 70% respectively after 40 months.

Inhibition of dehydrogenase activity was similar in both sandy soils with none occurring in clay and peat soils. In clay soil the fact that the respiration rate was seriously retarded at Pb levels at which there was no enzyme inhibition suggested that respiration rate was a more sensitive parameter in characterising inhibitory effects of heavy metals.

Rother, Millbank and Thornton (1982) studied the effects of heavy-metal additions on ammonification and nitrification in soils contaminated with cadmium, lead and zinc in Britain.

Ammonification of peptone showed little correlation between treatments with cadmium, zinc (1,000µg/g and 5,000µg/g) and lead (10,000µg/g and 20,000µg/g) and soil origin. Nitrification was found to be more sensitive to heavy metals than ammonification.

The soils studied had active and often large populations of ammonifying and nitrifying organisms. Tolerant populations of nitrifying organisms were present in contaminated soils with tolerance eventually acquired by non-contaminated soil populations.

Hemida, Omar and Abdel-Mallek (1997) studied the effects of adding 200µg/g and 2,000µg/g copper and zinc as sulphates to a clay or sandy soil. These effects specifically related to total fungi, bacteria and actinomycete numbers and urease, nitrate reductase and amidase activities. According to the results a reduction in microbial numbers followed the application of copper and zinc to the clay soil. Although neither of these metals showed any significant increasing effect on numbers in clay soil, stimulatory effects were noted in the sandy soil.
Urease and nitrate reductase activity was inhibited by heavy metal application to both soils. However, amidase activity was inhibited only at the higher application rate after some experimental periods.

Westerman and Tucker (1974) determined the effects of different levels of salts (sodium, copper and calcium chloride) and $^{15}NH_4^+$-N on mineralisation of soil nitrogen, nitrification and immobilisation.
Dilute levels of salt, $^{15}NH_4Cl$ and dilute salts plus $^{15}NH_4Cl$ were responsible for stimulating the mineralisation of nitrogen in a Pima clay loam. Nitrification of indigenous ammonium nitrogen and ^{15}N-labelled ammonium decreased as the concentrations of salt increased. High concentrations of copper and calcium chloride salts inhibited nitrification of ^{15}N-labelled ammonium more than did sodium salts. Immobilisation of $^{15}NH_4^+$-N was decreased significantly by high concentrations of salt.

Badran (1994) studied the effects of soil salinity on the decomposition of sugar cane straw by the cellulolytic fungi *Aspergillus flavus*, *Aspergillus niger*, *Chaetomium globosum* and *Penicillium chrysogenum*.
In saline soils carbon dioxide evolution was inhibited but in control soils it increased. The activity of cellulase decreased with increasing soil salinity and the carbon content in saline soils increased while their nitrogen content decreased.

Lindemann, Lindsey and Fresquez (1984) determined the effects of amendments on microbial numbers, the distribution of fungi, the activity of dehydrogenase and on the formation of mycorrhizae in mine spoil in the field.

This spoil was amended with hay, sludge or topsoil inoculum or was covered with 30cm of topsoil. The specific parameters measured in both the rhizosphere and non-rhizosphere were bacterial numbers, ammonium oxidisers, *Azotobacter*, *Streptomyces*, fungal distribution and dehydrogenase activity. Mycorrhizal inoculum was applied and plants were examined for percentage mycorrhizal roots.

The addition of sludge, hay or topsoiling increased the number of micro-organisms, enzyme activity and fungal genera distribution in the non-rhizosphere spoil. Topsoil added as an inoculum had little or no effect on these factors. The number of *Azotobacter* was significantly increased in the rhizosphere by amendment. Providing an available carbon source was more critical in stimulating an active and varied microflora than was a topsoil inoculum. Mycorrhizal infection was poor in all treatments with amendments having little or no effect on percentage mycorrhizal roots. Covering the spoil with 30cm of topsoil provided the greatest amount of mycorrhizal infection.

Bardgett, James and Leemans (1995) examined the impact of different application rates of silage effluent on the biomass and activity of micro-organisms in a typical grassland soil.

A significant trend of increasing microbial biomass C, microbial respiration and dehydrogenase activity with increasing rates of silage effluent application was observed after 2 and 4 days incubation. These parameters declined thereafter and were not significantly different from the unamended control.

A significant positive linear relationship (r^2 = 0.98; $P<0.001$) existed between silage effluent application rates up to 30L/m^2 and microbial respiration. Dehydrogenase activity increased up to an application of

15L/m^2 and declined thereafter. This may have been due to high levels of certain chemical compounds within the effluent having an adverse effect on the enzyme assay.

1:3.5 Case studies of revegetation programmes on mine sites

Ashby reported that natural invasion processes on strip-mines were similar to those on old fields. Early invaders are typically weedy or pioneers, both herbaceous and woody. The plants involved are those which can be effectively dispersed over long distances, have high seed production rates and/or are available locally.

Dense establishment of herbaceous or shrub cover causes a delay in tree invasion. This invasion may still be delayed by soil conditions even if this cover is not established. The main invading herbs belong to the Gramineae, Compositae and Leguminosae families, but this depends largely on soil conditions. Forest-type herbs may replace these as a canopy develops and as propagules are available for invasion. The types of invading trees are probably chiefly related to soil conditions, seed dispersal and herbaceous competition. *Salix* species invades areas around water-bodies. *Platanus occidentalis* is a likely primary invader on medium to strongly acidic mine spoils. Such a waste will have mature trees in a matrix of developing herb, shrub or young-tree cover.

On strongly acidic mine spoils *Betula nigra* will probably be the primary tree invader. While *Platanus occidentalis* and *Populus deltoides* seedlings may occur, they only become established in pockets of mine-soil at a higher pH.

Populus deltoides readily invades neutral to alkaline newly-available spoil.

With the advent of initial tree cover other tree species come into the stand in response to change in site conditions and/or in animals which contribute to seed dispersal. Examples of the former appear to be *Ulmus* species and *Acer negundo* with *Sassafras albidum*, *Prunus serotina*, *Diospyros virginiana*, *Juniperus virginiana*, *Quercus palustris* and *Quercus imbricaria* being examples of both.

Tree plantings influence herbaceous and tree invasion. Ashby reported that *Robinia pseudo-acacia* stands develop a dense ground cover of forest herbs.

Ashby reviewed a study of a natural vegetation chronosequence on a surface-mined site in southern Illinois, USA. He noted that of nineteen families present after 43 years the most common were the Gramineae, Compositae (sunflower), Leguminosae and Rosaceae families. Between 22 and 43 years after mining, annuals decreased, perennials increased and the six species of canopy trees had risen to sixteen. Invasion by trees appeared to be limited by the presence of herbaceous layers and dense shrub. The main overstory trees included *Populus deltoides, Platanus occidentalis, Ulmus americana, Acer negundo* and *Prunus* serotina while a minor part of the overstory after 43 years was *Quercus palustris, Quercus rubra* and *Quercus imbricaria.*

Ashby reviewed a study which evaluated four areas in southern Illinois, USA for plant and soil features. He noted that in 1970-1971 these areas were characterised as problem areas due to their pH being less than 5.0 and/or their plant density being less than 25%. However they were at or close to early hardwood development stage in 1980. Plant density was more related to the chemical characteristics of the waste than to the duration since mining. The Compositae, Gramineae, Leguminosae and Rosaceae families were best represented in terms of species numbers. Overstory *Populus deltoides* and *Robinia pseudo-acacia* as well as immature *Quercus* species, *Prunus serotina*, *Diospyros virginiana* and *Sassafras albidum* were present. Interspersed within these areas, relatively barren and vegetated areas were found.

Skousen, Johnson and Garbutt (1994) studied fifteen sites on abandoned mine-land in West Virginia, USA to investigate plant invasion and

establishment. These sites were chosen from three surface-mined coal beds at Pittsburgh, Freeport and Kittanning.

Total tree cover was significantly different among sites on Pittsburgh and Kittanning coal mine sites. Among coal beds, Kittanning sites had the lowest tree cover of 33%, Pittsburgh had 67% cover and Freeport sites had a multilayered tree cover averaging greater than 100%. In total 29 tree species were present on these sites. No tree species occurred on all 15 sites, however *Prunus serotina* and *Acer rubrum* were recorded on 13 sites.

Clustering produced a herbaceous community, an *Acer rubrum* dominated community and a tree community consisting mainly of *Betula lenta*. Herbaceous communities were recorded on sites with a soil pH greater than 5.0 while tree communities occurred on sites with a pH less than 5.0. Herbaceous plants rapidly invaded and formed an almost complete cover on disturbed sites with a high soil pH. On low pH sites invasion of plant species from adjacent undisturbed sites was initiated in favourable microsites where mine-soil or environmental conditions were ameliorated.

CHAPTER 2

DESCRIPTIONS OF METALLIFEROUS MINES AND MINE TAILINGS SITES IN COUNTIES GALWAY, SLIGO AND TIPPERARY

2:1 ABBEYTOWN

2:1.1 Metalliferous mine

Abbeytown zinc/lead mine (Map 2.1, Plate 2.1 and Satellite Image 2.1) is located approximately 500m west of Ballisodare village (Grid Reference: G 668 290) in County Sligo (Hitzman, 1986).

The Ballisodare orebody was originally developed by monks called the Black Cannons in the 7th and 8th Centuries. They built an Abbey on the shore near this mine, the ruins of which still exist. The metal originally extracted is believed to have been silver although the quantity mined is thought to have been small. Following the raiding and looting of the Abbey by the Danes *circa* 831 AD there is no further reference to the monks. It is reported that these monks produced a wide range of silver work including cups and chalices and a "Silver Pig". Tradition says that when the Danes raided the monastery the monks escaped across the channel, it was stormy, the boat capsized and the "Silver Pig" was lost.

During the 16th, 17th and 18th Centuries the mines were not exploited until exploration by Thornton commenced about 1930 (Gilligan, *circa* 1974).

Between the 1700's and the late 1950's the mines eastern orebody was exploited. A western orebody was discovered by a mining company, named Johannesburg Consolidated Investments, in the latter half of the 1950's.

Mining operations ceased in 1961 due to the exhaustion of ore reserves and low base metal prices.

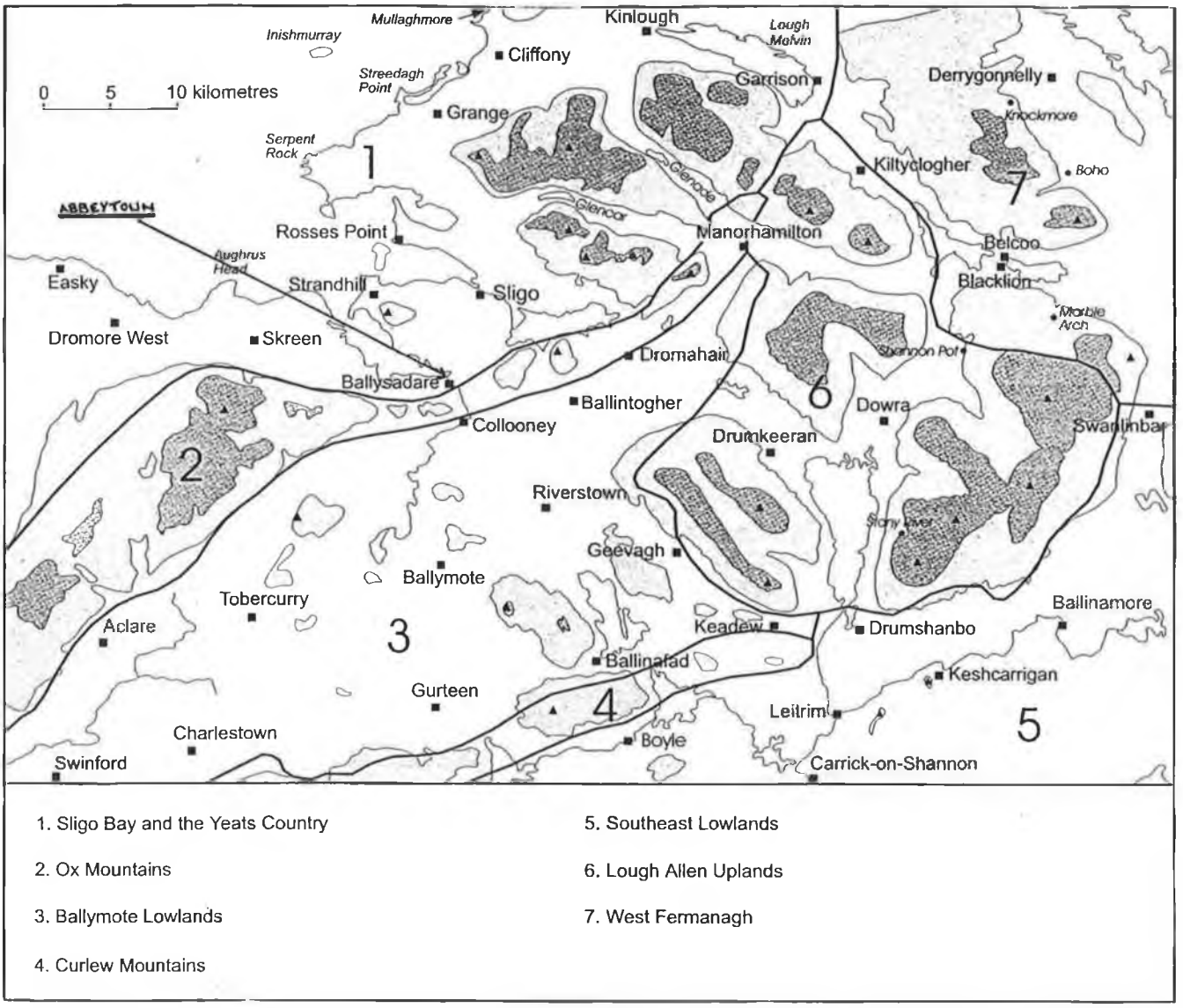
The total production for the Abbeytown area was approximately 1.1 million tonnes. This comprised approximately 3.8% zinc, 1.5% lead and 40 to 45g per tonne silver (Hitzman, 1986).

The mine at present is being worked as a limestone quarry by Harrington Concrete.

2:1.2 Mine tailings site

During the operational period of Abbeytown mine, mine tailings were discharged to a mine tailings pond (Map 2.2 and Plate 2.2) situated in close proximity to the estuary of Ballisodare River. This pond has since dried out and at present is being used as a storage area by Harrington Concrete. During this operational period the dam wall surrounding this tailings pond failed to contain the entire tailings load. This resulted in a significant quantity of it entering the estuary. This spillage area covering 6.1Ha (Prendergast, 1991) (Maps 2.3, 2.4 and 2.5, Plates 2.3 and 2.4 and Satellite Image 2.1) was originally covered with a soil layer (Gilligan, *circa* 1974) and underwent natural colonisation to produce a diverse population of plants (Plates 2.5 to 2.10). These plants appeared to be tolerant to lead and zinc and to high salt concentrations within the mine tailings (Prendergast, 1991).

Map 2.1 Site location map of Abbeytown mine, Ballisodare, County Sligo.



1. Sligo Bay and the Yeats Country
2. Ox Mountains
3. Ballymote Lowlands
4. Curlew Mountains
5. Southeast Lowlands
6. Lough Allen Uplands
7. West Fermanagh

(MacDermot, Long and Harney, 1996)

Plate 2.1 Aerial view of Harringtons limestone quarry, Abbeytown, Ballisodare, County Sligo in December 1992 (Quarry was originally Abbeytown zinc/lead mine).

Satellite Image of Ballisodare Estuary.
County Sligo.

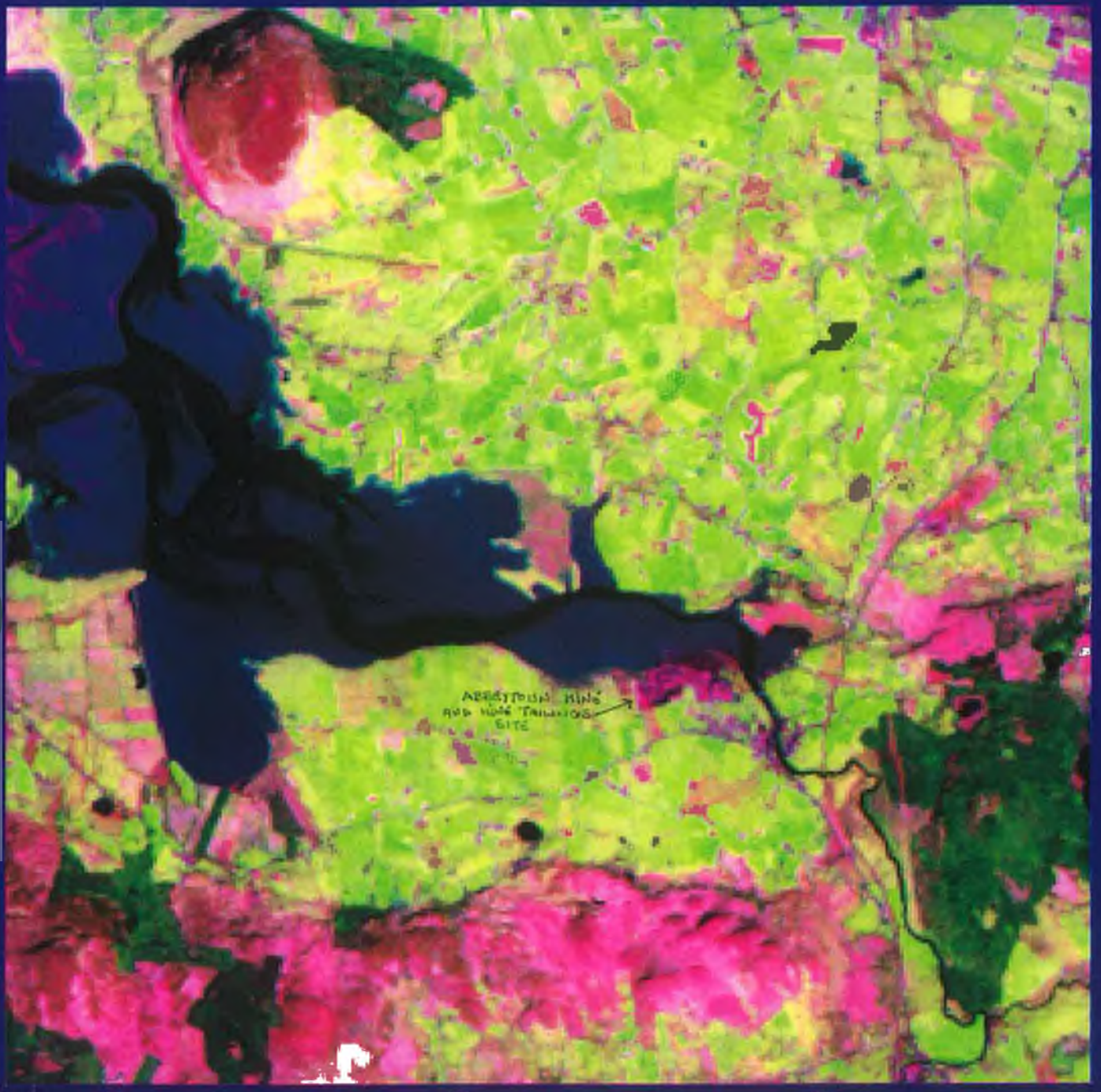
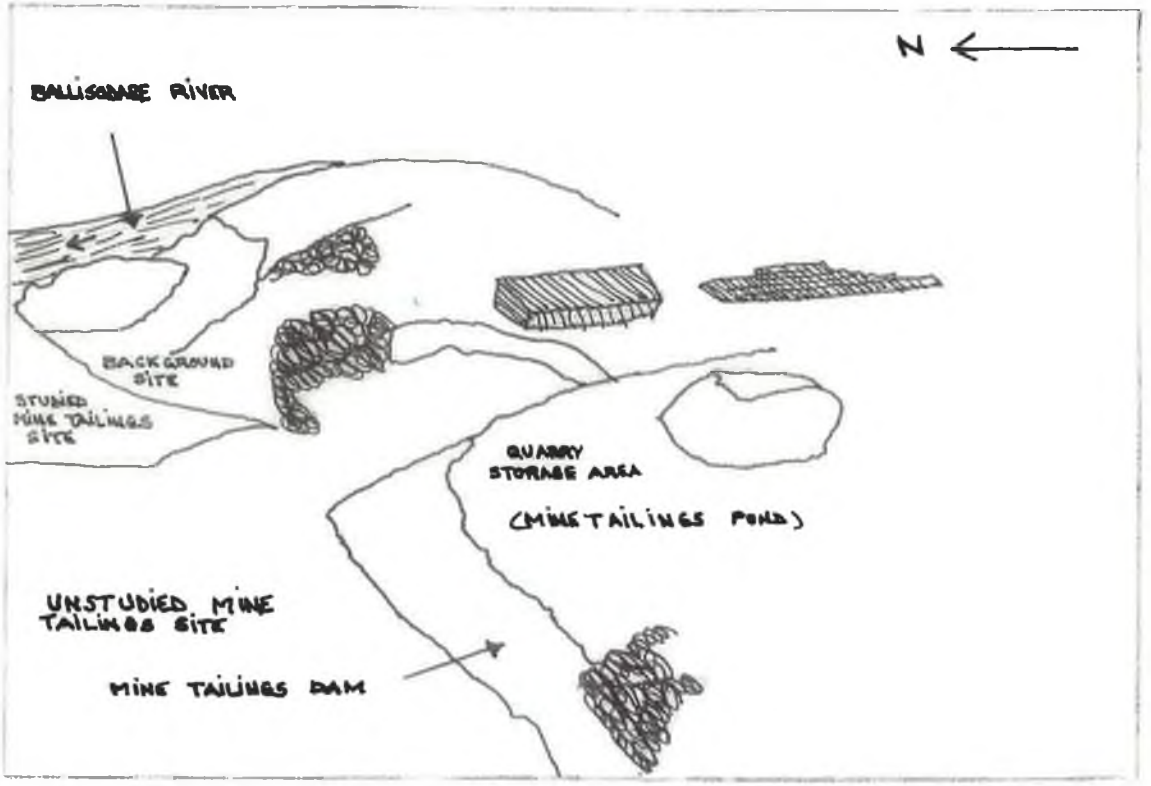


Plate 2.2 Aerial view of Abbeytown mine tailings pond, Ballisodare, County Sligo in December 1992 (the dam wall of the mine tailings pond begins in the centre foreground and follows a north-westerly direction before turning north-easterly).

Map 2.2 Map of Abbeytown features in Plate 2.2.



Map 2.3 Site location map of Abbeytown mine tailings site, Ballisodare, County Sligo.

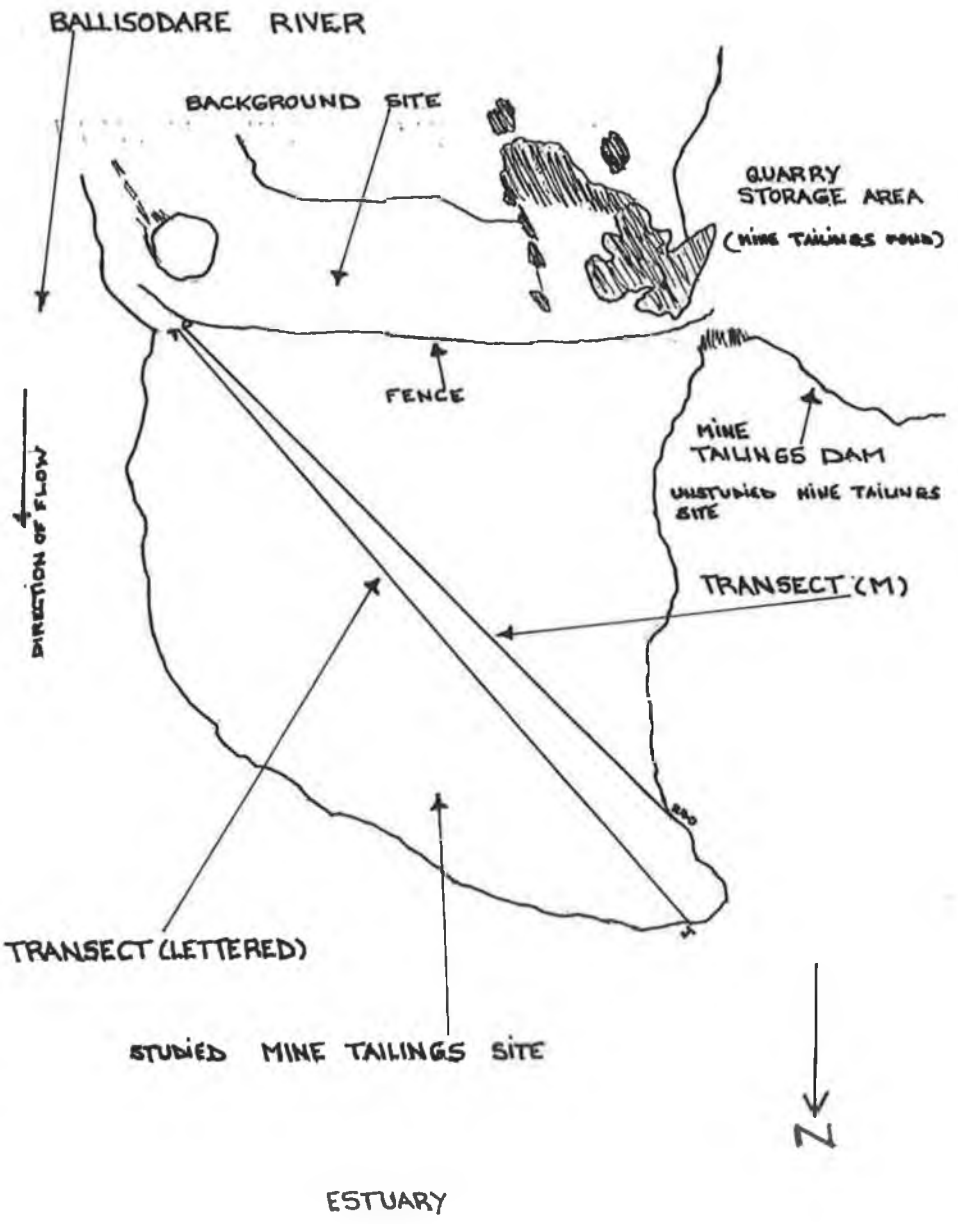


Plate 2.3 Aerial view of studied section of Abbeytown mine tailings site, Ballisodare, County Sligo in December 1992.

Map 2.4 Map of Abbeytown features in Plate 2.3.

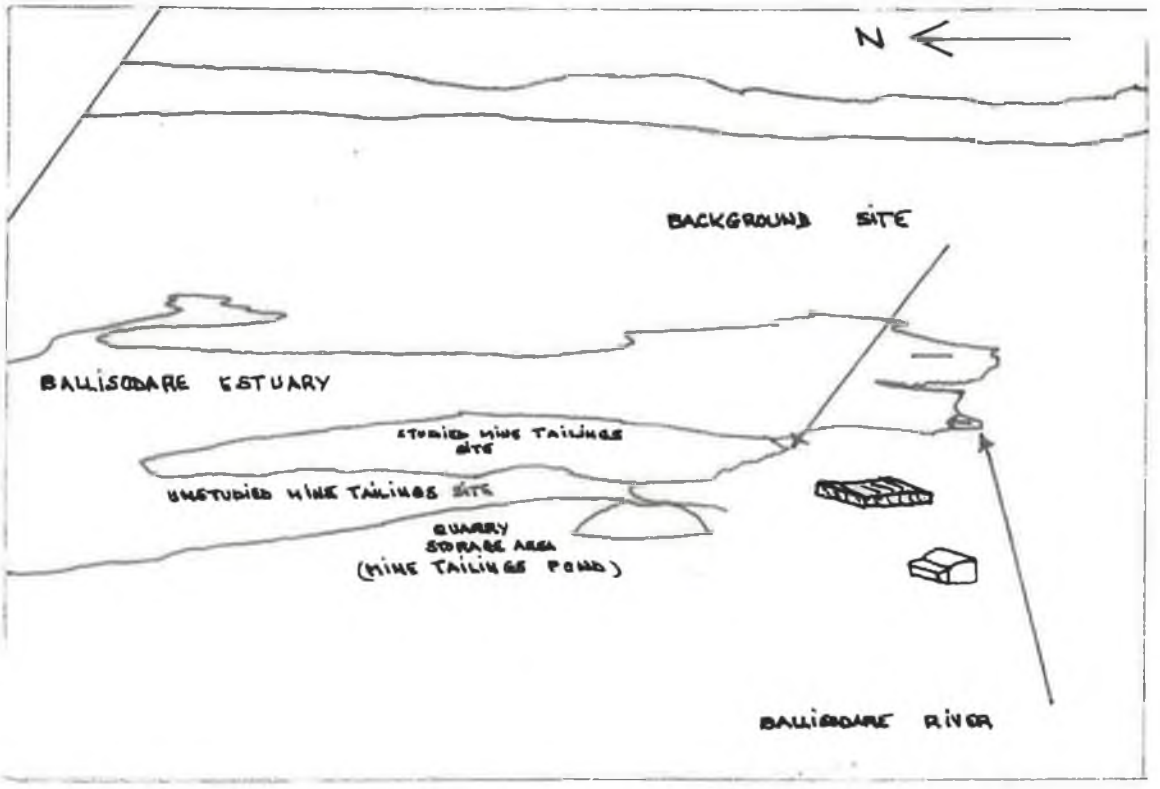


Plate 2.4 Aerial view of studied section of Abbeytown mine tailings site, Ballisodare, County Sligo in December 1992.

Map 2.5 Map of Abbeytown features in Plate 2.4.

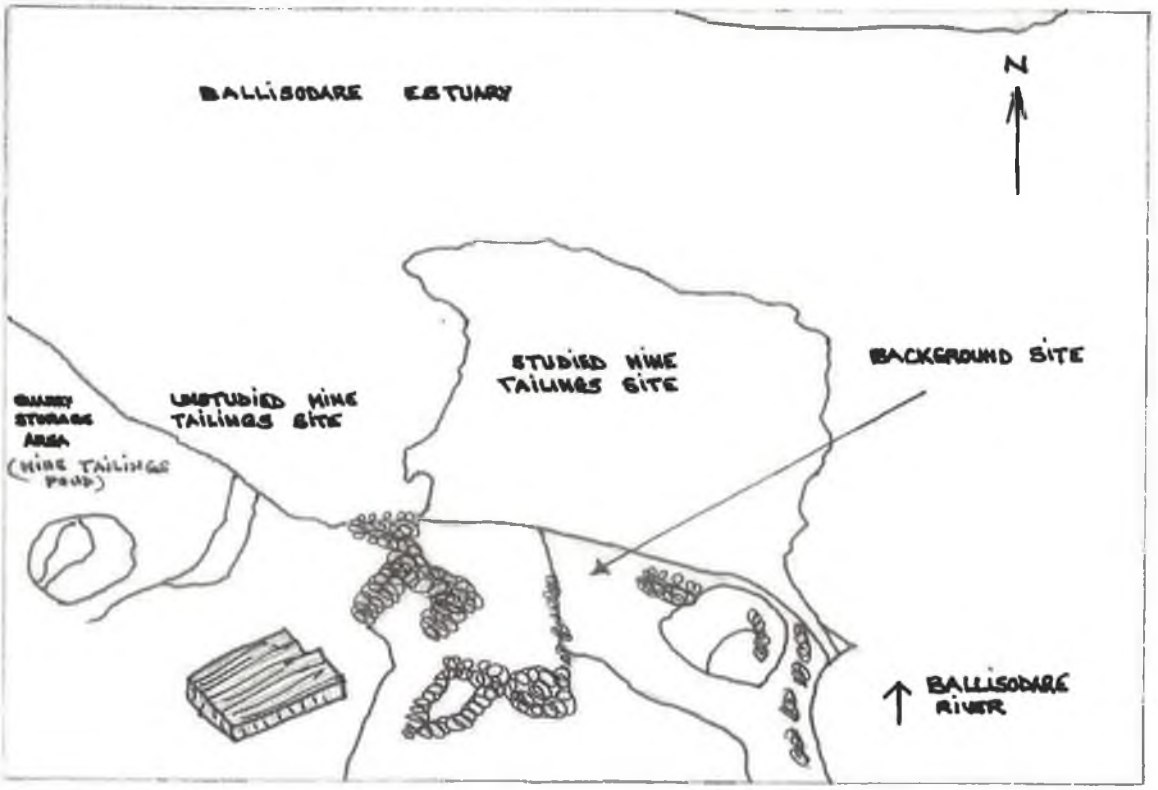


Plate 2.5 Plant species growing on Abbeytown mine tailings site, Ballisodare, County Sligo in early 1993 (Marren, 1993).

Plate 2.6 Plant species growing on Abbeytown mine tailings site, Ballisodare, County Sligo.

Plate 2.7 Plant species growing on Abbeytown mine tailings site, Ballisodare, County Sligo in August 1992 (Furey, 1992).

Plate 2.8 Plant species growing on Abbeytown mine tailings site, Ballisodare, County Sligo in August 1992 (Furey, 1992).

Plate 2.9 Plant species growing on Abbeytown mine tailings site, Ballisodare, County Sligo in August 1992 (Furey, 1992).

Plate 2.10 Plant species growing on Abbeytown mine tailings site, Ballisodare, County Sligo in August 1992 (Furey, 1992).

2:2 GORTDRUM

2:2.1 Metalliferous mine

Gortdrum copper/silver/mercury mine (Map 2.6) is located 1.9km from Tipperary town (Grid Reference: Easting 189,000; Northing 135,500) in County Tipperary (Holland, 1973).

In 1962 and 1963 an extensive geological survey was carried out in the area (Holland, 1973) by a mining exploration syndicate (Tyler, 1979). This led to the discovery of a substantial copper deposit. A drilling programme initiated by Gortdrum Mines Ltd. in October 1964 discovered a metal ore deposit comprising of an estimated 4,191,000 short tonnes and containing 1.19% copper and 0.75oz of silver per tonne.

Gortdrum mine started production in 1967. It was early 1968 before it reached full capacity (Holland, 1973). Extraction was by an open-pit method (Timpson, 1998). During early 1968 mercury was discovered to be associated with the copper deposit.

Most of the ore extracted was exported to Spain for smelting (Holland, 1973).

Mining operations ceased at Gortdrum in mid 1975 at which time the ore reserves had been depleted (Prendergast, 1991).

During its operational period the mine produced 34,737 tonnes of copper, 82,878kg of silver and 16,975kg of mercury (Tyler, 1979). This represented 76.6% and 92.8% of the original reserve estimate for copper and silver respectively (Steed, 1986).

2:2.2 Mine tailings site

Overburden from the mining process at Gortdrum was used, where suitable, in the construction of the main core of the dam surrounding the 56Ha mine tailings pond. The walls of this dam were composed of a clay core with rock facing (Holland, 1973).

The mine tailings pond (Map 2.7), after drying out, was seeded during 1981, 1982 and 1984 and received annual applications of cattle slurry and

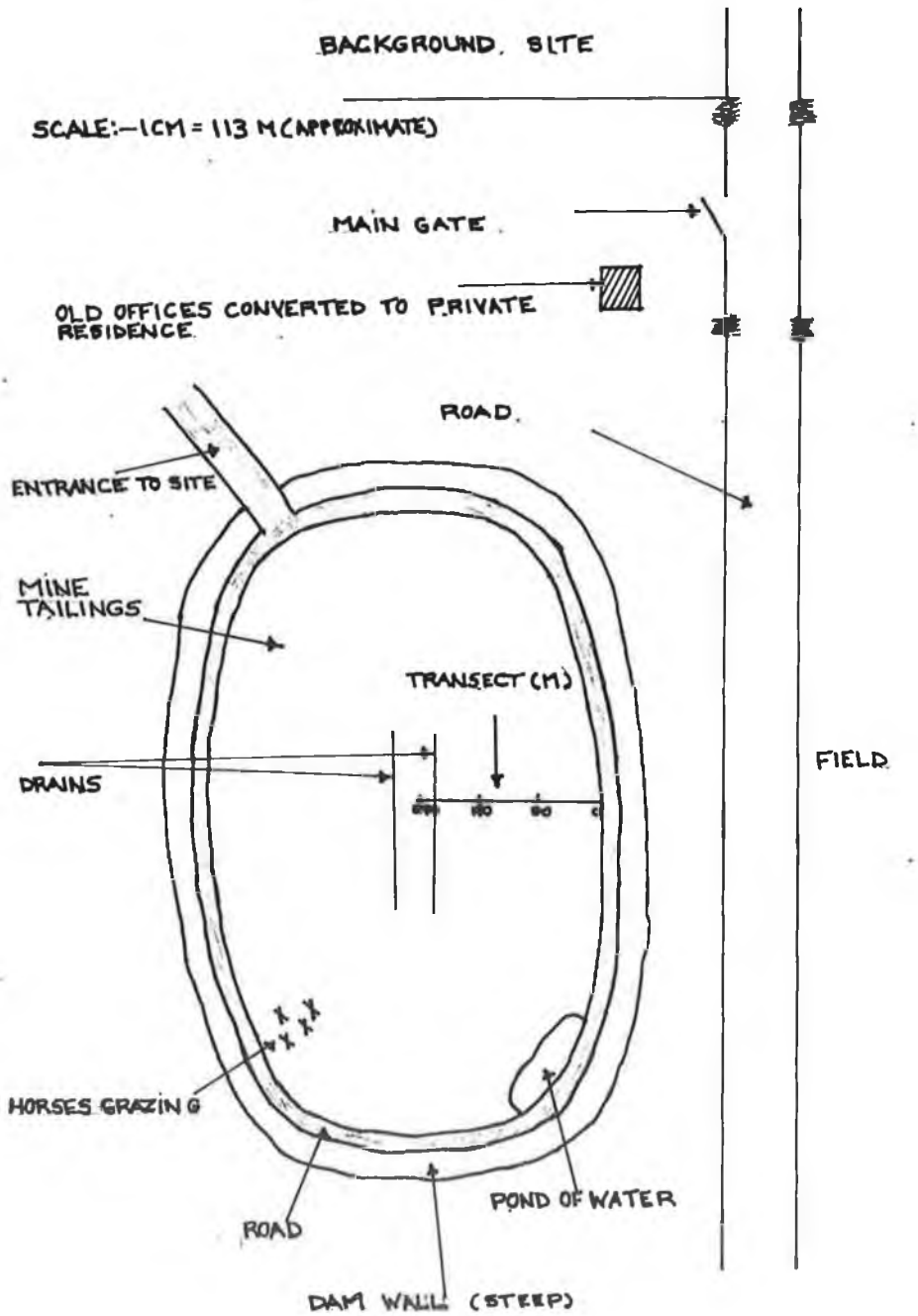
fertiliser (Prendergast, 1991). In the late 1980's the site was sold by Ennex International (Timpson, 1998) and sheep were placed on it for rough grazing (Prendergast, 1991).

The mine tailings site was revegetated using a method of harrow and direct planting. The seed mixture used contained 70% *Agrostis tenuis* Parys, 15% *Festuca rubra* Dawson, 10% *Lolium perenne* Pennline and 5% *Trifolium repens* S184. Inorganic fertiliser in the form of 10N:10P:20K was applied to the mine tailings site at a rate of 250kg/Ha (Timpson, 1988 and 1991) and (Timpson and Fitzgerald, 1997).

Map 2.6 Site location map of Gortdrum mine, County Tipperary.

(Archer, Sleeman and Smith, 1996)

Map 2.7 Site location map of Gortdrum mine tailings site, County Tipperary.



2:3 SHALLEE

2:3.1 Metalliferous mine

Shallee lead/zinc/silver mine (Map 2.8) is located in close proximity to Silvermines village (Grid Reference: Easting 184,000; Northing 171,400) in County Tipperary.

Metalliferous mining in the Shallee area dates back to 900 AD when lead deposits were believed to have been mined by the Danes (Atkinson, 1968). Shallee was mentioned in "Irelands Natural History" by Boate *circa* 1643 (Donelan, 1985).

The General Mining Company of Ireland mined Shallee site from 1862 to 1874.

The Irish Exploration Company produced lead sulphide concentrates from extracted ore at this mine from 1949 to 1953 and from 1955 to 1958 (Taylor, 1979).

2:3.2 Mine tailings site

Shallee mine tailings were deposited in a tailings pond. Here coarse particles settled towards the perimeter of the pond while fine particles settled towards the centre (Prendergast, 1991). This deposition ceased in 1959 (Grennan, 1998).

Rehabilitation of the mine tailings site (Plates 2.11 to 2.14) is believed to have been natural. Quite a diversity of plant species have colonised this site (Prendergast, 1991).

Map 2.8 Site location map of Shallee mine, County Tipperary.

(Archer, Sleeman and Smith, 1996)

Plate 2.11 Shallee mine tailings site, County Tipperary in May 1992 (damage to plants by motorbike scrambling can be seen).

Plate 2.12 Shallee mine tailings site, County Tipperary in May 1992 (*Riparia riparia* (sand martin) nests located within a bank of the mine tailings).

Plate 2.13 Plant species growing on Shallee mine tailings site, County Tipperary in May 1992.

Plate 2.14 Plant species growing on Shallee mine tailings site, County Tipperary in May 1992.

2:4 SILVERMINES

2:4.1 Metalliferous mine

Silvermines zinc/lead mine (Map 2.9) is located in close proximity to Silvermines village (Grid Reference: Easting 184,000; Northing 171,400) in County Tipperary.

Mining in this area of County Tipperary dates back to the early 9th Century when mining of argentiferous galena was carried out by the Danes (Andrew, 1986).

At the beginning of the 1600's a lead deposit in Devonian quartzites, outcropping on the Silvermines fault trace, was extracted.

Initial mining activity in the 17th and 18th Centuries was concentrated in the Ballygowan South and Knockanroe (K zone) area of County Tipperary, south of Silvermines village. Here lead-silver residual sulphide ore was extracted. The name "Silvermines" was derived from these areas (Boland, Clifford, Meldrum and Poustie, 1992).

Between 1862 and 1874 ore was extracted at Gortnadyne, County Tipperary by the General Mining Company of Ireland.

The British Non-Ferrous Mining Corporation re-opened old mine workings in the K zone at Silvermines between 1929 and 1930. This project was abandoned due to metallurgical problems.

Mining was restarted in 1949 by the Irish Exploration Company which produced zinc oxides from calamine ore. This project was abandoned in 1952 (Taylor, 1979).

Boland, Clifford, Meldrum and Poustie (1992) indicated that between 1968 and 1982 the Silvermines area was mined for base metals by Mogul of Ireland Ltd. The authors reported that this mine, which exploited two orebodies, extracted 10.7 million tonnes of ore grading 2.70% lead and 7.36% zinc.

Andrew (1986) states that the Silvermines area is being explored by Ennex International PLC. This company purchased Mogul of Ireland Ltd. in 1983 (Boland, Clifford, Meldrum and Poustie, 1992). Ennex hope to add to the

known remaining base metal ore reserves of 6,894,929 tonnes containing 2.26% lead and 4.98% zinc (Andrew, 1986).

2:4.2 Mine tailings site

Mine tailings, from operations at Silvermines, were discharged in slurry form to a mine tailings pond where segregation of particles occurred. Following the drying of these tailings this segregation facilitated a major tailings blow which had undesirable effects on the surrounding area (Prendergast, 1991).

Ennex International, who had recently acquired the property, immediately initiated trials (Timpson, 1998) to revegetate this 60.7Ha site (Plates 2.15 to 2.17). The process was carried out over a four year period between 1985 and 1988 using a method of harrow and direct planting. The seed mixture used contained 30% *Agrostis stolonifera* Seaside, 20% *Festuca rubra* Waldorf, 10% *Lolium perenne* Wendy, 20% *Lolium perenne* Vigor, 10% *Pucinellia distans* and 10% *Trifolium repens* S184.

Organic and inorganic fertilisers were added during and following planting of these plant species. Inorganic fertilisers in the form of 16N:5P:20K, 11% phosphorus (P) and murate of potash were applied at rates of 375kg/Ha, 125kg/Ha and 125kg/Ha respectively. Organic fertiliser, in the form of cattle slurry, was applied at a rate of $11m^3$/Ha (Timpson, *circa* 1991).

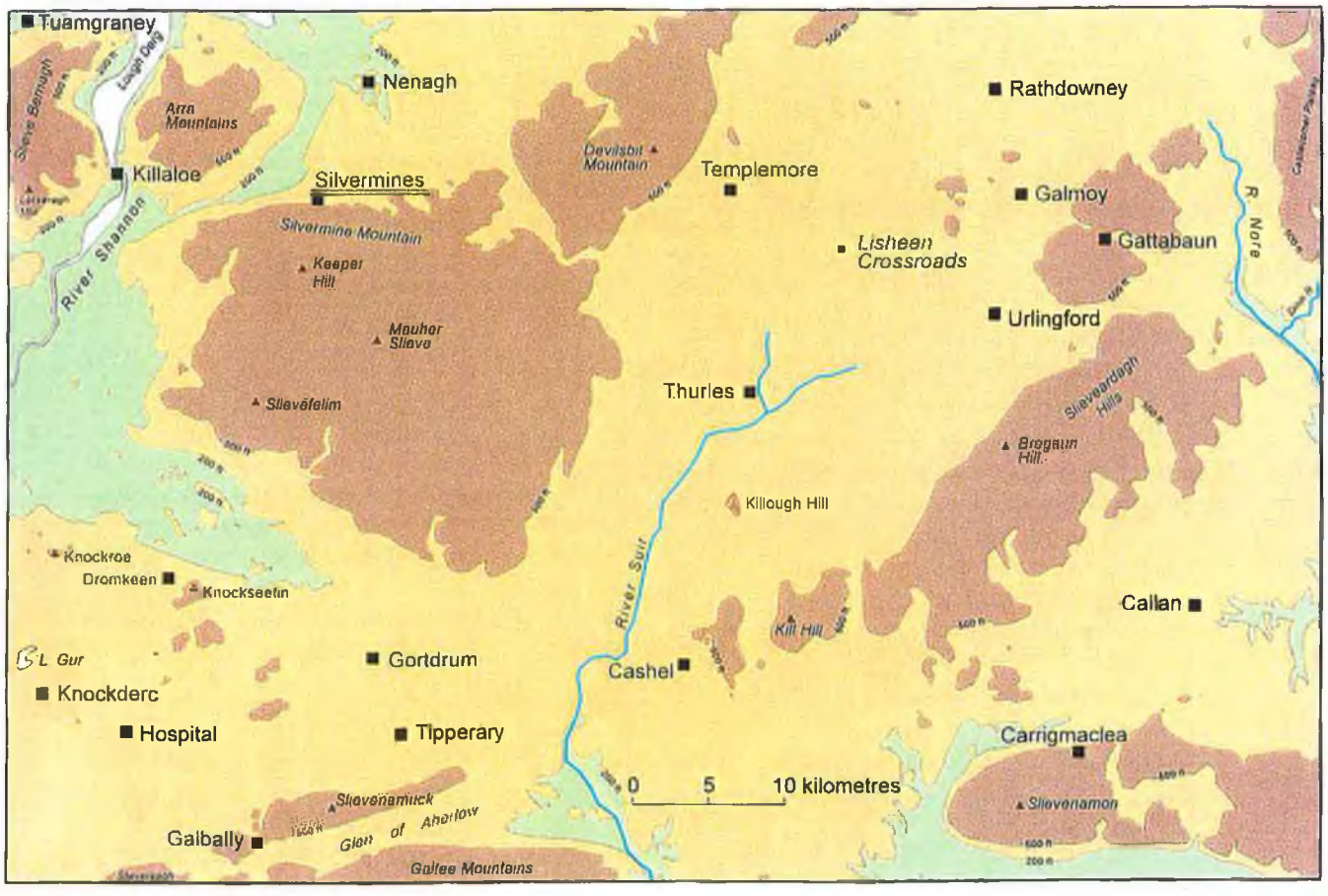
Timpson (1990) reported that this mine tailings site contained significant levels of lead, zinc and copper having concentrations of 5,700mg/kg, 8,400mg/kg and 80mg/kg respectively with pyrite levels varying between 2% and 21%.

Prendergast (1991), on surveying the rehabilitated surface, indicated that there was a dense mat of roots and shoots growing on the surface of the mine tailings site. *Rubia*, a shrub species and nitrogen fixer, which was originally planted on a trial basis was doing well. *Rubus* (bramble) species, which indicate a change from pioneer to higher plants, were also present. Secondary seeding by *Agrostis stolonifera* Seaside had occurred in certain

areas. *Phragmites* which was introduced to wetter areas was growing well. Areas to which slurry had been applied had a greater diversity of plant species. No species were observed in areas where an iron pan had developed, although dense plant species did appear to exist there immediately following rehabilitation.

Certain areas of the mine tailings were waterlogged, with the water level in some cases been as high as 75cm.

Map 2.9 Site location map of Silvermines mine, County Tipperary.



(Archer, Sleeman and Smith, 1996)

Plate 2.15 Changes in plant cover and colour at different locations on Silvermines mine tailings site, County Tipperary.

Plate 2.16 Rope transect laid down along Silvermines mine tailings site, County Tipperary. Samples were taken at sites which corresponded with the areas rehabilitated in 1985, 1986, 1987 and 1988.

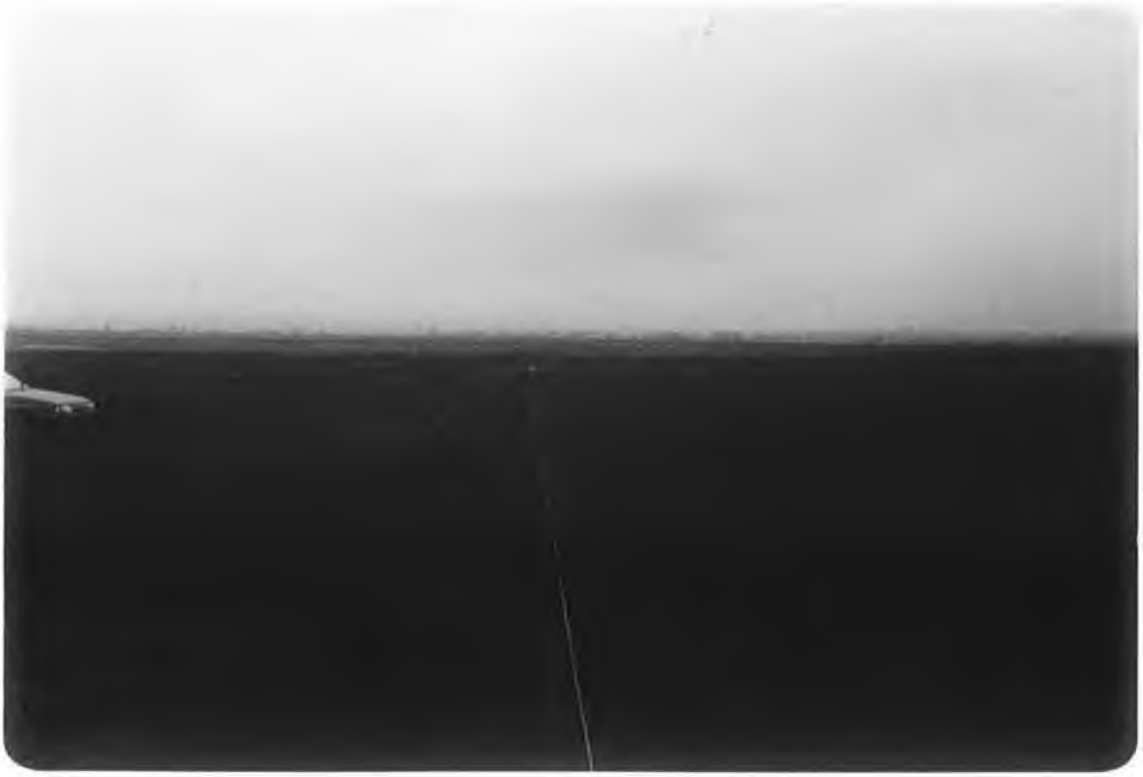


Plate 2.17 The effect of 'acid burn', attributed to the oxidation of pyrites, on plant species growing on Silvermines mine tailings site, County Tipperary.

2:5 TYNAGH

2:5.1 Metalliferous mine

Tynagh lead/zinc/copper/silver/barite mine (Map 2.10) is located in close proximity to Tynagh village (Grid Reference: Easting 175,000; Northing 211,000) in County Galway.

O'Cleirigh *et al.* reported Tynagh as an area of mineral deposits in "The Annals of the Four Masters" in 1632 (Clifford, Ryan and Kucha, 1986).

In 1865 the Geological Survey of Ireland made the first recording of a mines existence in the Tynagh area.

Mineralisation was confirmed by the Irish Geological Survey following tests in 1953 and 1956 (Hutchings, 1979).

In September 1961 metal analyses of soil samples taken close to the old Tynagh mine revealed greater than 1,000mg/L lead and 8,000mg/L zinc.

In November 1961 following drilling within the vicinity of Tynagh, one of the richest base metal deposits ever found in Ireland was discovered.

Mining at Tynagh began on October 22 1965 (Clifford, Ryan and Kucha, 1986). Initially open-cast production was employed (Sevastopulo, 1979), this being undertaken by Irish Base Metals Ltd. (Holland, 1973). It was planned that this method would account for the extraction of 4.93 million tonnes of ore while 2.77 million tonnes would be extracted by underground mining.

The ore reserve underground was re-estimated at 5 million tonnes in 1967 but this figure dropped to 4.4 million tonnes following the cessation of investigatory studies in 1970. This reserve had lead, zinc, copper and silver concentrations estimated at 4.28%, 3.12%, 0.35% and 1.4oz per tonne respectively.

In 1967 2.6 million tonnes of mineralised ground was delimited to the east of the mines main orebody. This figure was reduced to 1.85 million tonnes five years later and was found to contain lead, zinc, copper and silver concentrations of 3.4%, 4.6%, 0.28% and 0.64oz per tonne respectively (Hutchings, 1979).

At the time the mine opened in 1965 it was believed that a final ore reserve (economic grade) approaching 9.9 million tonnes would be obtained. A further 1.9 million tonnes were outlined between February 1967 and March 1968 (Clifford, Ryan and Kucha, 1986).

Underground mining at Tynagh began in 1972 (Sevastopulo, 1979).

No further mineral deposits of economic grade were discovered in the area between March 1968 and 1980. The mine closed in 1981 due to the exhaustion of the orebody (Clifford, Ryan and Kucha, 1986).

During its operational period Tynagh mine produced lead and zinc concentrate and bulk lead-zinc concentrate from sulphide ore. It produced lead concentrate containing copper from oxide ores. In some of these concentrates payable silver was extracted.

Concentrates were exported to the European continent and USA for smelting (Holland, 1973).

2:5.2 Mine tailings site

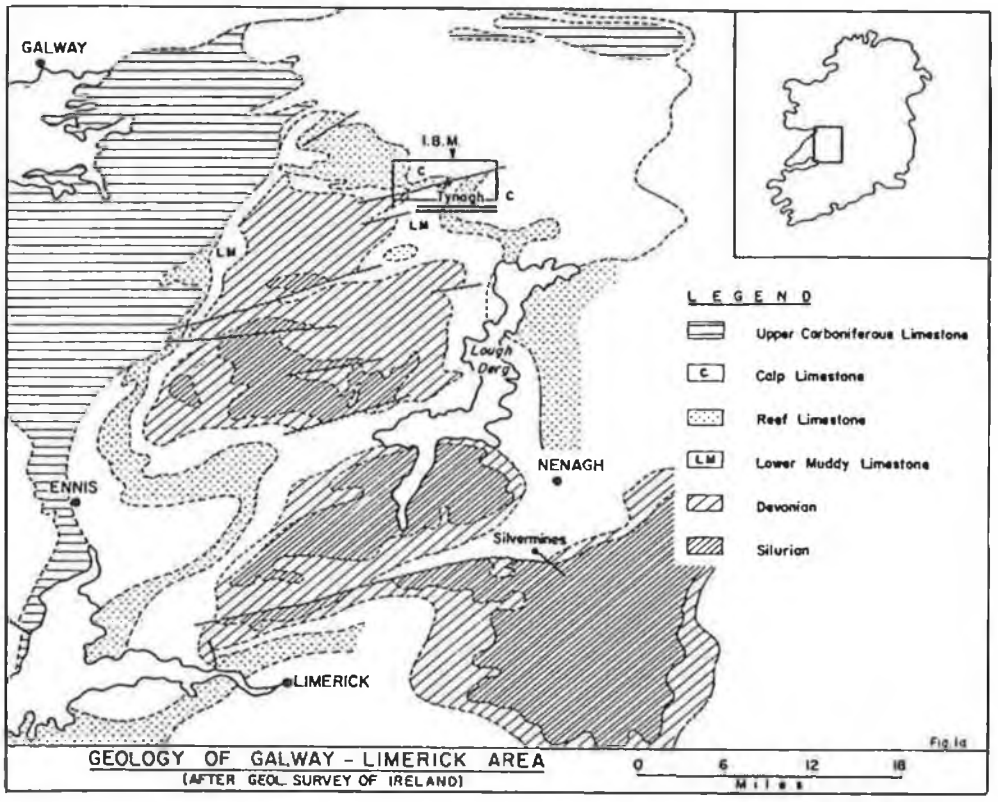
Tynagh mine tailings site (Map 2.11 and Plates 2.18 and 2.19) was operated in two sections and covered a total area of 54Ha.

An area of 21Ha underwent revegetation by hydroseeding in 1983 while the remainder, which retained mine tailings water, was not rehabilitated. The exposed mine tailings now has a moss covering. Reeds colonised the submerged non-rehabilitated mine tailings and took root in the original substratum in certain areas (Prendergast, 1991).

The seed mixture used in the hydroseeding technique contained 5% *Agrostis stolonifera* Emerald, 70% *Festuca rubra* Merlin, 10% *Festuca rubra* Dawson, 10% *Lolium perenne* S23 and 5% *Trifolium repens* Huia.

Inorganic fertilisers in the form of slow release NPK and 17N:17P:17K were applied to the mine tailings site at a rate of 125kg/Ha and 250kg/Ha respectively (Timpson, 1997).

Map 2.10 Site location map of Tynagh mine, County Galway.



(Derry, Clark and Gillatt, 1965)

Map 2.11 Site location map of Tynagh mine tailings site, County Galway.

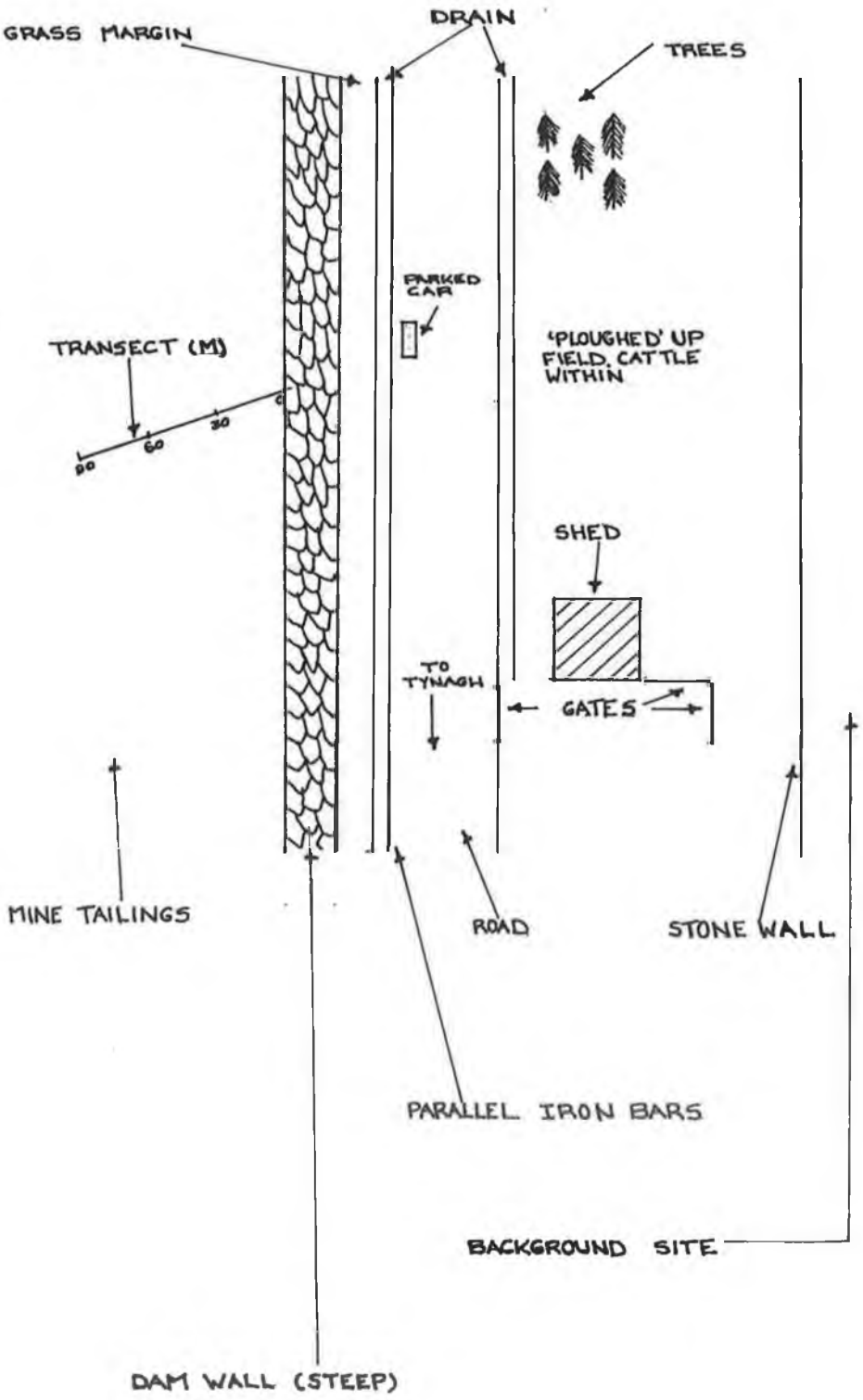


Plate 2.18 A 90m rope transect laid down along Tynagh mine tailings site, County Galway in February 1993. Samples were taken at 30m intervals from the perimeter of the mine tailings site.

Plate 2.19 Changes in plant cover and colour at different locations on Tynagh mine tailings site, County Galway in February 1993.

CHAPTER 3
MATERIALS AND METHODS

3:1 Physical, chemical, textural, microbiological, botanical and statistical determinations

3:1.1 Sampling method

3:1.1.1 1990/1991

Method

Physical, chemical and textural samples were collected at Gortdrum, Shallee, Silvermines and Tynagh in 1990/1991, microbiological samples were collected at Silvermines and Tynagh in April 1991 and plant samples were collected at Gortdrum, Shallee and Silvermines in 1990/1991 (Prendergast, 1991).

3:1.1.2 1992, 1993 and 1994

3:1.1.2.1 ABBEYTOWN

Method

Abbeytown mine tailings site (Map 2.3) was sampled for plants in August 1992, for physical and chemical analyses in November 1992 and May 1994 and for microbiological analyses in February and March/April 1992.

For physical, chemical and microbiological analyses most sample cores were taken along a 240m line transect at 30m intervals from the upper end of the mine tailings site. Sample cores were also taken along a second line transect at specific sites, originating at the upper end of the mine tailings site, where particular plant species were dominant. The condition of the sampling sites in November 1992 and May 1994 is summarised in Tables 3.1 to 3.3. Background samples were taken in proximity to the 0m site.
Plant samples were collected, by hand, in an approximate 1m area around each peg laid down along the transects.

Table 3.1

Condition of 30m interval sampling sites on Abbeytown mine tailings site, County Sligo in November 1992.

Distance (m)	Condition of sampling sites
0	X
	Raised above other sites.
30	XXXXX
High Spring Tide	
60	XXXXX
90	XXXXX
120	XXX
Average High Tide	
150	XXX
180	XX
210	XX
240	X

Legend

X	Dry
XX	Slightly Wet
XXX	Wet
XXXX	Very Wet
XXXXX	Submerged

Table 3.2

Condition of specific sites where particular plant species were dominant on Abbeytown mine tailings site, County Sligo in November 1992.

Site	Condition of sampling sites
A	X
B	XXX
C	XXX
D	XXXX
E	XXXX
F	XXX
G	XXX
H	XXX
I	XX
J	XX
Background	XXX

Legend

X	Dry
XX	Slightly Wet
XXX	Wet
XXXX	Very Wet
XXXXX	Submerged

Table 3.3

Condition of sampling sites on Abbeytown mine tailings site, County Sligo in May 1994.

Distance (m)	Condition of sampling sites
0	X
30	XXXX
High Spring Tide	
60	XXXX
90	XXX
120	XXX
Average High Tide	
150	XXX
180	XXX
210	XXX
240	Site on the edge of the mine tailings site.
Background	X Site grazed by cattle, located on the quarry side of the fence at the top of the mine tailings site.

Legend

X	Dry
XX	Slightly Wet
XXX	Wet
XXXX	Very Wet
XXXXX	Submerged

3:1.1.2.2 GORTDRUM

Method

Gortdrum mine tailings site (Map 2.7) was sampled for microbiological, physical and chemical analyses in February 1993.

Duplicate sample cores were taken along a 270m transect at 90m intervals from the perimeter of the mine tailings site. At the background site duplicate sample cores were taken from a field located approximately 100m to 200m from the mine tailings site. These cores were taken for microbiological analyses. An individual sample core was taken there for physical and chemical analyses. The condition of these sampling sites is summarised in Table 3.4.

Table 3.4

Condition of 90m interval sampling sites on Gortdrum mine tailings site, County Tipperary in February 1993.

Distance (m)	Condition of sampling sites
90	The general area of this site was swampy. Good grass cover, moss and animal excrement present.
180	Damp but not wet, despite high water table. Good grass cover, other plants such as moss and thistles present.
270	Damp but not wet, despite high water table. Good grass cover, moss and other plants present.
Background	Site adjacent to Gortdrum mine and grazed by cattle.

3:1.1.2.3 SHALLEE

Method

Shallee mine tailings site was sampled for microbiological, physical and chemical analyses and for plants in May 1992.

Sample cores and plant samples were taken at two different areas on the mine tailings site which corresponded with the dominance of vetch or willow species. Duplicate and individual sample cores were taken for microbiological and physical and chemical analyses respectively.

3:1.1.2.4 SILVERMINES

Method

Silvermines mine tailings site was sampled for microbiological, physical and chemical analyses and for plants in May 1992.

Sample cores for analyses and plant samples were taken along a line transect (Plate 2.16) at approximately 15m, 60m, 145m and 240m intervals from the perimeter of the mine tailings site. These sites corresponded with the areas rehabilitated in 1985, 1986, 1987 and 1988. Background samples were taken from a field located approximately 100m from the mine tailings wall. Duplicate and individual sample cores were taken for microbiological and physical and chemical analyses respectively.

3:1.1.2.5 TYNAGH

Method

Tynagh mine tailings site (Map 2.11) was sampled for microbiological, physical and chemical analyses in February 1993.

Duplicate sample cores were taken along a 90m transect (Plate 2.18) at 30m intervals from the perimeter of the mine tailings site. Background samples were taken from a field located approximately 100m from the mine tailings site. Individual and duplicate sample cores were taken at this site for microbiological and physical and chemical analyses respectively. The condition of the sampling sites is summarised in Table 3.5.

Table 3.5

Condition of 30m interval sampling sites on Tynagh mine tailings site, County Galway in February 1993.

Distance (m)	Condition of sampling sites
30	An extensive grass cover in the immediate sampling area and all around.
60	The immediate sampling area was quite bare with little plant cover. In general the overall area had an extensive grass cover with little moss observed.
90	In the immediate sampling area a bare patch existed. Very little grass was evident with moss being the predominant species. What was believed to be animal excrement was also observed.
Background	Grassland site located approximately 100m from the mine tailings site.

3:1.2 Microbiological determinations

3:1.2.1 1991

Determination	Method
Total bacteria	Pour plate using soil extract agar
Total fungi	Pour plate using rose bengal streptomycin agar
Actinomycetes	Spread plate using dextrose-nitrate agar

(Prendergast, 1991)

3:1.2.2 1992 and 1993

Microbiological determinations were carried out under aseptic conditions

3:1.2.2.1 Preparation of sample cores prior to microbiological determinations

Method

A sample core was placed on a white tray. The grass/root cover was removed and the core was cut with a scalpel 4cm from the top. An internal core was taken from this 4cm core by inserting a metal corer (10.5cm long x 3cm wide) vertically into it. The internal core was placed in a Petri dish, thoroughly mixed and large roots removed.

A quantity of sample weighing 5g was used for the microbiological determinations. The remainder of the sample was refrigerated until its dry weight could be determined.

3:1.2.2.2 Serial dilution preparation of sample cores

Method

A quantity of sample weighing 5g was added to 45cm^3 of quarter-strength Ringer solution to make a 10^{-1} dilution. This suspension was shaken by hand for 10 minutes afterwhich large particles were allowed to settle. An aliquot of 1cm^3 of the resulting supernatant was added to 9cm^3 of quarter-strength Ringer solution and was thoroughly mixed to make a 10^{-2} dilution. These serial dilution's were continued to 10^{-6}.

3:1.2.2.3 Total bacteria determination (Black *et al.*, 1965)

Method

Soil extract agar plates were dried in a 30°C to 45°C drying oven. An aliquot of $0.1cm^3$ of each serial dilution was plated, after thorough mixing, in duplicate or triplicate on to corresponding plates. The 10^{-1} dilution was not mixed prior to plating. With the aid of a bent glass rod the $0.1cm^3$ aliquots were spread across the surface of the plates to ensure even distribution of colonial growth.

The plates were allowed to dry and were incubated at approximately 30°C for 7 to 14 days. The total bacteria in each sample core, expressed as Colony Forming Units (CFU) per g dry weight of soil, were calculated (Appendices 1h and 1i).

3:1.2.2.4 Aerobic spore forming bacteria determination (Black *et al.*, 1965)

Method

An aliquot of the 10^{-1} dilution was added to a sterile test-tube which in turn was placed in a water bath. Once the temperature in an accompanying test-tube, containing water and a thermometer, reached 80°C to 85°C the heat treatment was continued for 15 minutes. The contents of the test-tube were mixed during this period to keep them suspended and to enable complete eradication of non-spore forming micro-organisms to take place. The test-tube was removed from the water bath, its contents cooled and further serial dilution's prepared.

The same method and calculation applied as for the total bacteria determination from here on except that nutrient agar plates were used and the conditions of incubation were approximately 30°C for 1 to 4 days.

3:1.2.2.5 Actinomycete determination (Black *et al.*, 1965 and Page *et al.*, 1982)

Method

The same method and calculation applied as for the total bacteria determination from here on except that dextrose-nitrate agar plates containing 1μg/cm^3 benzyl penicillin and 5μg/cm^3 polmyxin B sulphate were used and the conditions of incubation were approximately 30°C for at least 10 days.

3:1.2.2.6 Total fungi determination (Black *et al.*, 1965)

Method

The same method and calculation applied as for the total bacteria determination from here on except that rose bengal agar plates containing 30μg/cm^3 streptomycin sulphate BP were used and the conditions of incubation were approximately 30°C for 7 days.

3:1.2.2.7 Dry weight determination of sample cores

Method

Two aluminium trays were initially dried between 103°C and 105°C and placed in a dessicator to cool. These trays were weighed to four decimal places, zeroed and samples weighed into them. The samples were placed in a 103°C to 105°C oven and dried for approximately 24 hours. The samples were removed, placed in a dessicator to cool and reweighed to four decimal places. The dry weights of the sample cores were calculated (Appendix 1h).

3:1.3 Physical, chemical and textural determinations

3:1.3.1 1990/1991

3:1.3.1.1 Preparation of sample cores prior to physical and chemical determinations

Method

A sample core was divided into a top and bottom 3.5cm layer. It was broken up, dried for 1 to 2 weeks and passed through a 2mm sieve. Analyses were carried out on both layers (Prendergast, 1991).

3:1.3.1.2 Determinations

Determination	Method
pH	Electrometric
Organic matter	Loss on ignition
Organic carbon	Walkley-Black
Kjeldahl nitrogen	Kjeldahl digestion and Markham still
Available phosphorus	Ultraviolet-visible spectrophotometer
Exchangeable potassium	Flame photometer
Particle size distribution	Sieving for coarse particles (greater than 0.05mm) and sedimentation for fine particles (less than 0.05mm)

(Prendergast, 1991)

3:1.3.2 1992 and 1993

3:1.3.2.1 Preparation of sample cores prior to physical and chemical determinations

Method

The grass/root cover of a sample core was removed. The core was cut 4cm from the top and was air dried for 1 to 2 weeks. The resulting air dried sample was stored until being analysed. Prior to carrying out physical and chemical analyses the sample was passed through a laboratory test sieve having an aperture of 2.00mm.

3:1.3.2.2 pH determination - Electrode method (Black *et al.*, 1965)

Note

Sample weights and distilled water volumes did not exceed 20g and 20cm^3 respectively.

3:1.3.2.3 Organic matter determination - Loss on ignition method (Black *et al.*, 1965)

Method

Samples of between 1g and 10g were weighed to 4 decimal places into pre-weighed porcelain crucibles. The crucibles were placed in a muffle furnace set between 695°C and 700°C and ignited for 15 to 30 minutes. On being removed they were relabelled and placed in a 103°C to 105°C oven to remove any moisture which may have accumulated during relabelling. The crucibles were placed in a dessicator to cool and reweighed. The level of organic matter in the sample cores was determined (Appendix 1a).

3:1.3.2.4 Organic carbon determination - Walkley-Black method (Black *et al.*, 1965)

Note

The calculation used in determining the level of organic carbon in the sample cores can be seen in Appendix 1c.

Ferrous ammonium sulphate was standardised by carrying out the Walkley-Black method without a sample (Appendix 1b).

3:1.3.2.5 Kjeldahl nitrogen determination - Kjeldahl method (Black *et al.*, 1965)

Method

Ground samples, not exceeding 11g, were weighed to two decimal places and added to kjeldahl digestion tubes. An aliquot of 25cm^3 of redistilled water was added followed by 2 kjeltab catalyst tablets and the contents mixed. An aliquot of 30cm^3 of concentrated sulphuric acid was added slowly. The digestion tubes were placed in a kjeldahl digestion block and

the samples were digested until they turned white or grey/white. At this stage the digestion period was continued for a further 30 minutes.

The digestion tubes were removed and cooled. A blank digestion was carried out in the same manner as previous using an equivalent volume of redistilled water instead of sample.

Digested samples were transferred to 'Buchi' digestion tubes. In many cases redistilled water aliquots of between $50cm^3$ and $100cm^3$ were required to resuspend and transfer these samples to the digestion tubes. Each digestion tube was attached, in turn, to a 'Buchi' distillation unit. Approximately $90cm^3$ of 32% or 40% sodium hydroxide were dispensed into each tube in a ratio of 3 parts sodium hydroxide to 1 part sulphuric acid. A distillation time was set and the samples were distilled into between $15cm^3$ and $50cm^3$ of boric acid containing bromocresol green/methyl red indicator. The distillate was titrated with standardised 0.02N hydrochloric acid until there was a colour change from green to pink.

A blank distillation was carried out in the same manner as previous using redistilled water. The level of kjeldahl nitrogen in the sample cores was determined (Appendix 1e).

3:1.3.2.5.1 Standardisation of 0.02N hydrochloric acid

Method

An aliquot of $25cm^3$ of hydrochloric acid was added to an Erlenmeyer flask followed by 2 to 3 drops of bromothymol blue indicator. The solution was titrated with 0.02N sodium hydroxide until there was a colour change from yellow to blue and the normality of hydrochloric acid was determined (Appendix 1d).

3:1.3.2.6 Available phosphorus determination - 'Ag' method

Method

Samples of between 2g and 6g were weighed to two decimal places into 200cm^3 or 250cm^3 Erlenmeyer flasks. Morgan's extracting reagent was added to make a dilution of 1 in 5 or 1 in 10 with the sample. The Erlenmeyer flasks were placed on a mechanical shaker for approximately 30 minutes. The contents were filtered and the filtrate was refrigerated until it could be analysed. Aliquots of 'Ag' reagent were added to aliquots of filtrate in a ratio of 2 parts reagent to 1 part filtrate. The contents were mixed thoroughly and allowed to stand on the bench for at least 10 minutes to enable full colour development to occur.

A series of standards between 0mg/L and 4mg/L phosphorus were prepared from a 100mg/L phosphorus stock solution in Morgan's extracting reagent. These standards were treated in the same manner as the samples with regards the addition of 'Ag' reagent.

The absorbance of each standard and sample was read at 880nm, using a path length of 1cm. A calibration curve was plotted and from it the levels of available phosphorus in the filtrate were extrapolated. In order to determine the actual levels of available phosphorus in the sample cores the dilution factor of sample to Morgan's extracting reagent together with the dilution, if any, of filtrate to Morgan's extracting reagent was taken into account (Appendix 1f).

3:1.3.2.7 Exchangeable potassium determination

Flame photometer method

Method

Samples were prepared as per the available phosphorus determination up to and including refrigeration. Aliquots of 109.58mg/L lithium were added to aliquots of filtrate to make a dilution of 1 in 20 with the filtrate and the contents were mixed thoroughly. Lithium reagent was originally added as

an internal standard. However it was not measured in the determination and therefore served no purpose.

A series of standards between 0mg/L and 20mg/L potassium were prepared from a 100mg/L potassium working solution in Morgan's extracting reagent. These standards were treated in the same manner as the samples with regards the addition of lithium solution.

The emission readings of each standard and sample were read on a flame photometer. A calibration curve was plotted and from it the levels of exchangeable potassium in the filtrate were extrapolated. In order to determine the actual levels of exchangeable potassium in the sample cores the dilution factor of sample to Morgan's extracting reagent together with the dilution factor, if any, of filtrate to Morgan's extracting reagent and dilution factor of filtrate to lithium solution was taken into account (Appendix 1g).

3:1.3.2.8 Chloride determination - Argentometric method

Method

Air dried samples were passed through a 180 micron mesh sieve.

The sample-to-water extraction ratio was 5:1.

The dried samples were weighed and placed in chloride free plastic bottles which had been rinsed with nitric acid. Deionised water was added at a rate of 100cm^3 of water per 20g of sample. The mixture was placed on a mechanical shaker for 1 hour after which it was filtered. The filtrate was titrated with silver nitrate which was standardised against 0.0141N sodium chloride.

A series of standards containing 5mg/L, 20mg/L and 40mg/L chloride were prepared from a 100mg/L chloride solution. Three 0mg/L chloride standards (blanks) containing deionised water were prepared (Furey, 1994).

3:1.4 Botanical determination

3:1.4.1 1992

Method

Plant specimens were refrigerated until pressed. Each pressed specimen was mounted on light A4 cardboard with paper glue or on A4 Xerox paper with thin strips of masking tape. The mounted specimens were placed in transparent sleeves. The specimens were identified using a low power stereo microscope, dichotomous keys and other identification books (Chapter 7). Confirmation of these identifications was made by professionals (Acknowledgements) experienced in the botanical field.

3:1.5 Statistical determination

Method

The relationship between physical, chemical, textural and microbiological parameters (Y variable) and corresponding sites or corresponding physical and chemical parameters (X variable) was determined using a statistical method called correlation. This involved plotting scatter graphs of Y or Log Y against X and fitting simple or exponential curves to these graphs from which a correlation coefficient (r) was determined.

This correlation coefficient measured how close the relationship between these variables was to linearity with a perfect relationship indicated by an r value of +1 or -1. The positive figure indicated that both variables increased together while the negative figure indicated that one increased while the other decreased (Barrington and Willis, 1969).

When Log Y versus X was plotted, with X beginning with 0, the 0 data point had to be converted to 0.1 to enable the graph to be plotted.

The significance of the correlation coefficient (r) was tested at 1% and 5% levels (Appendix 3a). The number of degrees of freedom were N-2 because there were N pairs of variables X and Y. Calculated r from the graph had to be at least as large as the value in Appendix 3a before it was regarded as significant (Barrington and Willis, 1969).

CHAPTER 4

RESULTS

Explanations for abbreviations used in Chapter 4:

A = Top 3.5cm of sample core

Aer. Spore Form. Bact. = Aerobic Spore Forming Bacteria

Avail. P = Available Phosphorus

B = Bottom 3.5cm of sample core

CFU = Colony Forming Units

Cl = Chloride

Exch. K = Exchangeable Potassium

Kjel. N = Kjeldahl Nitrogen

Org. C = Organic Carbon

Org. M = Organic Matter

r = Correlation Coefficient

r^2 = Coefficient of Determination

Vetch and Willow A and B = A and B are separate sample cores

W/V = Weight/Volume

Year* = Year of Rehabilitation

1985, 1986, 1987 and 1988 A and B = A and B are separate sample cores

4:1 ABBEYTOWN

4:1.1 Introduction

Section 4:1 presents physical, chemical, microbiological and botanical results obtained along two transects on Abbeytown mine tailings site in 1992 and 1994. The physical, chemical and microbiological results are presented in graphic form with the corresponding data in Appendix 2. The botanical results are presented in tabular form with some data in graphic form.

Figures 4.1 to 4.4 show the physical and chemical distribution of five parameters at 30m intervals from the upper end of the mine tailings site in 1992 and 1994. Figure 4.5 shows the microbiological distribution of four parameters along this same area and at the same sampling intervals in 1992. Table 4.3 presents a breakdown of the plants occurring at 30m intervals from the upper end of the mine tailings site in 1992 with Figure 4.6 showing the distribution of genera at these sites. Statistical results are presented in Tables 4.1 and 4.2.

Figures 4.7 to 4.9 show the physical and chemical distribution of four parameters at specific sites, originating at the upper end of the mine tailings site, where particular plant species were dominant in 1992. Figure 4.10 shows the microbiological distribution of four parameters along this same area and at the same sampling intervals in 1992. Table 4.6 presents a breakdown of the plants occurring at these specific sites along the mine tailings site in 1992 while Figure 4.11 shows the distribution of genera at these sites. Statistical results are presented in Tables 4.4 and 4.5.

Figure 4.1
pH distribution at 30m intervals from the upper end of Abbeytown mine tailings site, County Sligo in November 1992.

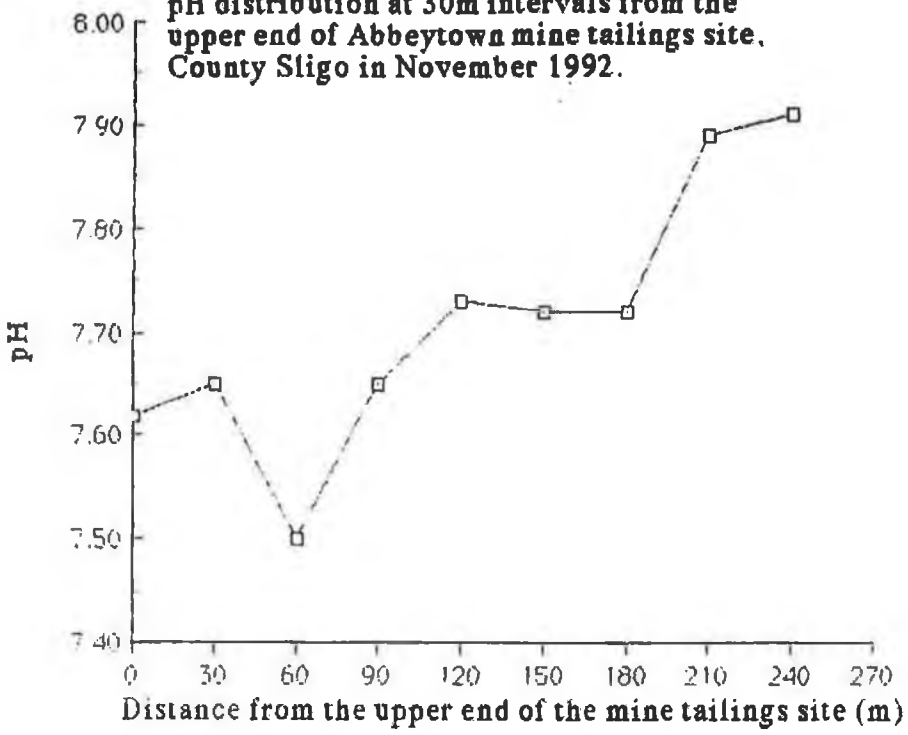


Figure 4.2
Organic matter and organic carbon distribution at 30m intervals from the upper end of Abbeytown mine tailings site, County Sligo in November 1992.

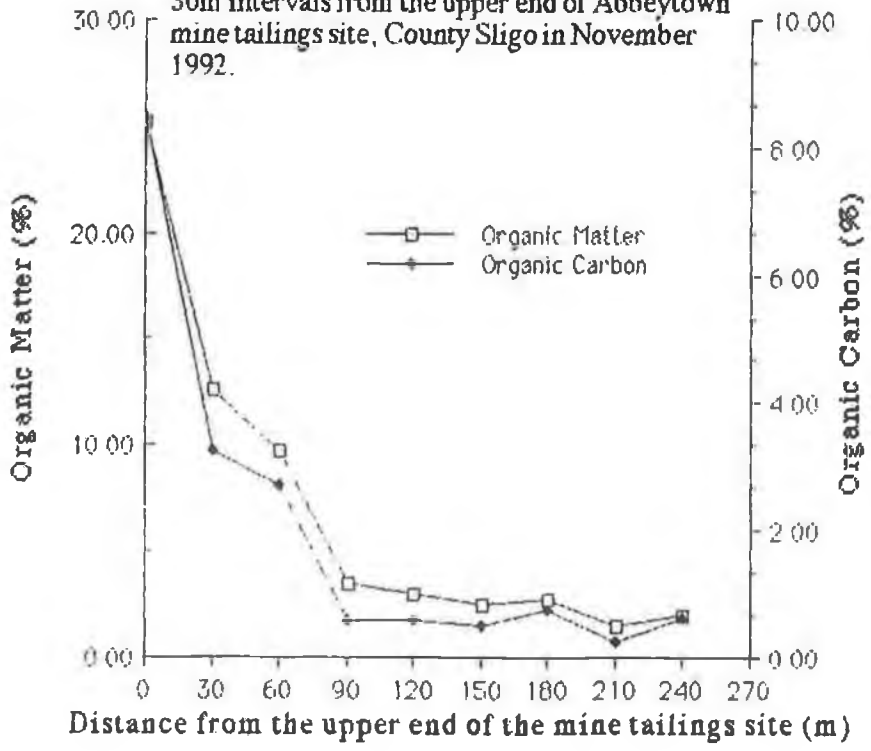


Figure 4.3
Exchangeable potassium distribution at 30m intervals from the upper end of Abbeytown mine tailings site, County Sligo in November 1992.

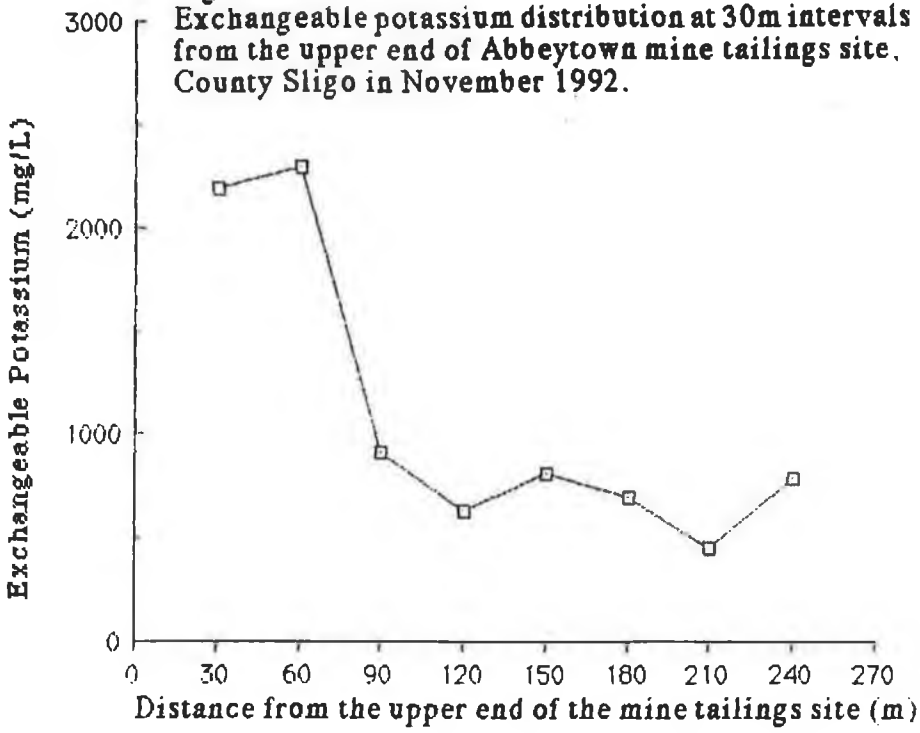


Figure 4.4
Chloride distribution at intervals from the upper end of Abbeytown mine tailings site, County Sligo in May 1994.

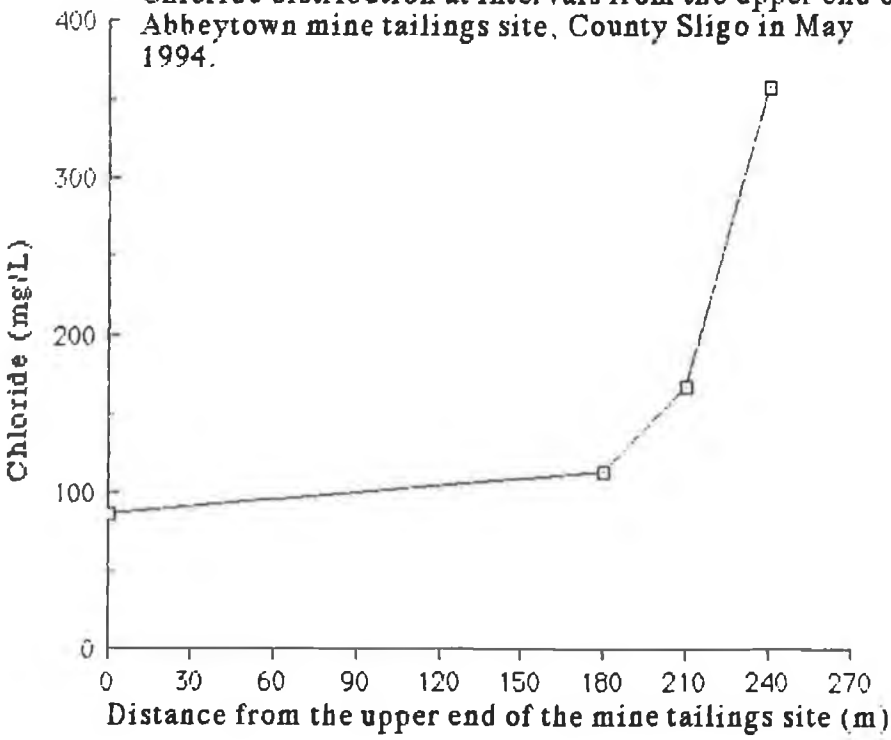


Table 4.1

Statistical results assessing the relationship between physical and chemical parameters and their corresponding sites at 30m intervals from the upper end of Abbeytown mine tailings site, County Sligo in November 1992 and May 1994.

				Significance Level	
Parameters Compared	**Curve Fit**	**r**	**r^2**	**1%**	**5%**
pH V's Distance	Simple	0.848	0.719	+	+
Log Org. M V's Distance	Exponential	-0.925	0.855	+	+
Log Org. C V's Distance	Exponential	-0.847	0.718	+	+
Log Exch. K V's Distance	Exponential	-0.798	0.636	-	+
Log Cl V's Distance	Exponential	0.790	0.624	-	-

Note

Positive (+) = The correlation coefficient is significant at the stated significance level.

Negative (-) = The correlation coefficient is not significant at the stated significance level.

Figure 4.5
Microbiological distribution at 30m intervals from the upper end of Abbeytown mine tailings site, County Sligo in February 1992.

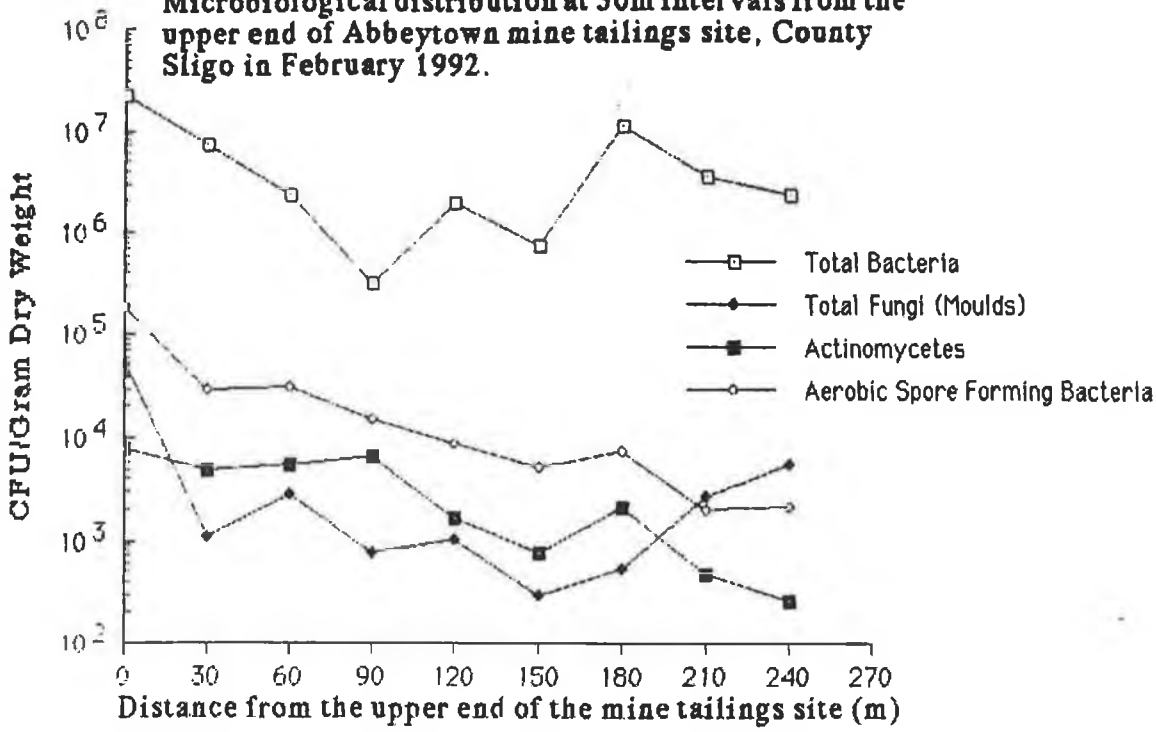


Table 4.2

Statistical results assessing the relationship between microbiological parameters and their corresponding sites and physical and chemical parameters at 30m intervals from the upper end of Abbeytown mine tailings site, County Sligo.

				Significance Level	
Parameters Compared	**Curve Fit**	**r**	**r^2**	**1%**	**5%**
Total Bacteria V's Distance	Simple	-0.467	0.218	-	-
Total Fungi V's Distance	Simple	-0.507	0.257	-	-
Log Actinomycetes V's Distance	Exponential	-0.910	0.828	+	+
Log Aerobic Spore Forming Bacteria V's Distance	Exponential	-0.949	0.901	+	+
Total Bacteria V's pH	Simple	-0.228	0.052	-	-
Total Bacteria V's Org. M	Simple	0.818	0.669	+	+
Total Bacteria V's Org. C	Simple	0.854	0.730	+	+
Log Total Bacteria V's Exch. K	Exponential	0.187	0.035	-	-
Log Total Bacteria V's Cl	Exponential	-0.851	0.724	-	-
Total Fungi V's pH	Simple	-0.219	0.048	-	-
Total Fungi V's Org. M	Simple	0.863	0.745	+	+
Total Fungi V's Org. C	Simple	0.912	0.832	+	+
Log Total Fungi V's Exch. K	Exponential	0.170	0.029	-	-
Total Fungi V's Cl	Simple	-0.446	0.199	-	-
Log Actinomycetes V's pH	Exponential	-0.890	0.792	+	+
Actinomycetes V's Org. M	Simple	0.779	0.606	-	+
Actinomycetes V's Org. C	Simple	0.742	0.551	-	+
Actinomycetes V's Exch. K	Simple	0.660	0.436	-	-
Log Actinomycetes V's Cl	Exponential	-0.836	0.698	-	-
Log Aerobic Spore Forming Bacteria V's pH	Exponential	-0.812	0.660	+	+
Aerobic Spore Forming Bacteria V's Org. M	Simple	0.941	0.886	+	+
Aerobic Spore Forming Bacteria V's Org. C	Simple	0.969	0.939	+	+
Aerobic Spore Forming Bacteria V's Exch. K	Simple	0.959	0.920	+	+
Log Aerobic Spore Forming Bacteria V's Cl	Exponential	-0.643	0.414	-	-

Note

Positive (+) = The correlation coefficient is significant at the stated significance level.

Negative (-) = The correlation coefficient is not significant at the stated significance level.

Table 4.3

Plant distribution at 30m intervals from the upper end of Abbeytown mine tailings site, County Sligo in August 1992.

Distance (m)	Family	Genus/Species	Common Name
0	Gramineae	*Agrostis* species	Bent species
	Gramineae	*Holcus lanatus*	Yorkshire Fog
	Gramineae	*Dactylis glomerata*	Cocksfoot
	Leguminosae	*Vicia sepium*	Bush Vetch
	Leguminosae	*Vicia* species	Vetch species
	Leguminosae	*Lathyrus pratensis*	Meadow Vetchling
	Compositae	*Sonchus* species	Sow-Thistle species
	Rosaceae	*Potentilla anserina*	Silverweed
	Plantaginaceae	*Plantago lanceolata*	Ribwort Plantain
30	Leguminosae	*Trifolium repens*	White Clover
	Labiatae	*Mentha aquatica*	Water Mint
	Equisetaceae	*Equisetum palustre*	Marsh Horsetail
	Juncaginaceae	*Triglochin* species	Arrow-Grass species
	Cruciferae	*Cardamine* species	Bittercress species
	Umbelliferae	*Angelica* species	Angelica species
	Ranunculaceae	*Ranunculus flammula*	Lesser Spearwort
	Cyperaceae	*Carex dioica*	Dioecious Sedge
	Cyperaceae	*Carex otrubae*	False Fox Sedge
	Juncaceae	*Juncus articulatus*	Jointed Rush
	Juncaceae	*Juncus* species	Rush species
	Unknown	*Eurynchium praelongum*	Moss species
60	Gramineae	*Agrostis stolonifera*	Creeping Bent
	Gramineae	*Festuca rubra*	Creeping Red Fescue
	Gramineae	*Holcus lanatus*	Yorkshire Fog
	Leguminosae	*Trifolium repens*	White Clover
	Labiatae	*Mentha aquatica*	Water Mint
	Plantaginaceae	*Plantago lanceolata*	Ribwort Plantain
	Equisetaceae	*Equisetum arvense*	Common Horsetail
	Umbelliferae	*Angelica* species	Angelica species
	Onagraceae	*Epilobium palustre*	Marsh Willowherb
	Onagraceae	*Epilobium* species	Willowherb species
	Ranunculaceae	*Ranunculus flammula*	Lesser Spearwort
	Ranunculaceae	*Ranunculus repens*	Creeping Buttercup
	Cyperaceae	*Carex otrubae*	False Fox Sedge
	Cyperaceae	*Carex* species	Sedge species

Distance (m)	Family	Genus/Species	Common Name
60	Juncaceae	*Juncus articulatus*	Jointed Rush
	Juncaceae	*Juncus effusus*	Soft Rush
90	Gramineae	*Agrostis stolonifera*	Creeping Bent
	Labiatae	*Mentha aquatica*	Water Mint
	Equisetaceae	*Equisetum arvense*	Common Horsetail
	Equisetaceae	*Equisetum palustre*	Marsh Horsetail
	Onagraceae	*Epilobium palustre*	Marsh Willowherb
	Onagraceae	*Epilobium parviflorum*	Hoary Willowherb
	Onagraceae	*Epilobium* species	Willowherb species
	Cruciferae	*Cardamine* species	Bittercress species
	Cyperaceae	*Carex nigra*	Common Sedge
	Cyperaceae	*Carex* species	Sedge species
	Juncaceae	*Juncus* species	Rush species
	Unknown	*Cratoneuron filicinum*	Moss species
120	Equisetaceae	*Equisetum arvense*	Common Horsetail
	Equisetaceae	*Equisetum palustre*	Marsh Horsetail
	Labiatae	*Mentha aquatica*	Water Mint
	Onagraceae	*Epilobium parviflorum*	Hoary Willowherb
	Onagraceae	*Epilobium* species	Willowherb species
	Cruciferae	*Cardamine* species	Bittercress species
	Salicaceae	*Salix fragilis*	Crack Willow
	Juncaceae	*Juncus articulatus*	Jointed Rush
	Juncaceae	*Juncus effusus*	Soft Rush
	Juncaceae	*Juncus inflexus*	Hard Rush
	Unknown	*Cratoneuron filicinum*	Moss species
150	Gramineae	*Holcus lanatus*	Yorkshire Fog
	Labiatae	*Mentha aquatica*	Water Mint
	Equisetaceae	*Equisetum arvense*	Common Horsetail
	Onagraceae	*Epilobium palustre*	Marsh Willowherb
	Juncaginaceae	*Triglochin* species	Arrow-Grass species
	Caryophyllaceae	*Cerastium glomeratum*	Sticky Mouse-Ear
	Cyperaceae	*Carex flacca*	Glaucous Sedge
	Juncaceae	*Juncus articulatus*	Jointed Rush
	Juncaceae	*Juncus effusus*	Soft Rush
	Juncaceae	*Juncus inflexus*	Hard Rush
	Juncaceae	*Juncus* species	Rush species
	Unknown	*Cratoneuron filicinum*	Moss species

Distance (m)	Family	Genus/Species	Common Name
180	Equisetaceae	*Equisetum fluviatile*	Water Horsetail
	Onagraceae	*Epilobium palustre*	Marsh Willowherb
	Onagraceae	*Epilobium* species	Willowherb species
	Juncaginaceae	*Triglochin* species	Arrow-Grass species
	Cruciferae	*Cardamine* species	Bittercress species
	Umbelliferae	*Oenanthe* species	Water Dropwort species
	Caryophyllaceae	*Cerastium glomeratum*	Sticky Mouse-Ear
	Juncaceae	*Juncus articulatus*	Jointed Rush
	Juncaceae	*Juncus effusus*	Soft Rush
	Juncaceae	*Juncus* species	Rush species
	Unknown	*Barbula* species	Moss species
210	Gramineae	*Agrostis stolonifera*	Creeping Bent
	Juncaginaceae	*Triglochin* species	Arrow-Grass species
	Cyperaceae	*Scirpus maritimus*	Sea Club-Rush
	Juncaceae	*Juncus articulatus*	Jointed Rush
	Juncaceae	*Juncus effusus*	Soft Rush
	Unknown	*Barbula* species	Moss species
240	Juncaginaceae	*Triglochin* species	Arrow-Grass species
	Cyperaceae	*Scirpus maritimus*	Sea Club-Rush
	Juncaceae	*Juncus articulatus*	Jointed Rush

Figure 4.6
Plant genera at 30m intervals from the upper end of Abbeytown mine tailings site, County Sligo in August 1992.

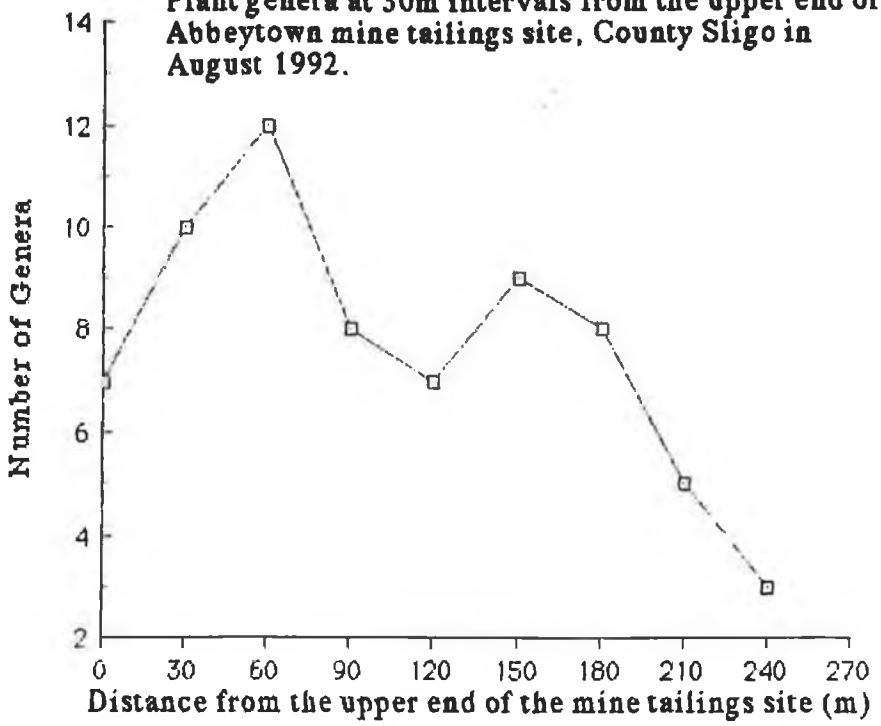


Figure 4.7
pH distribution at specific sites where particular plant species were dominant along Abbeytown mine tailings site, County Sligo in November 1992.

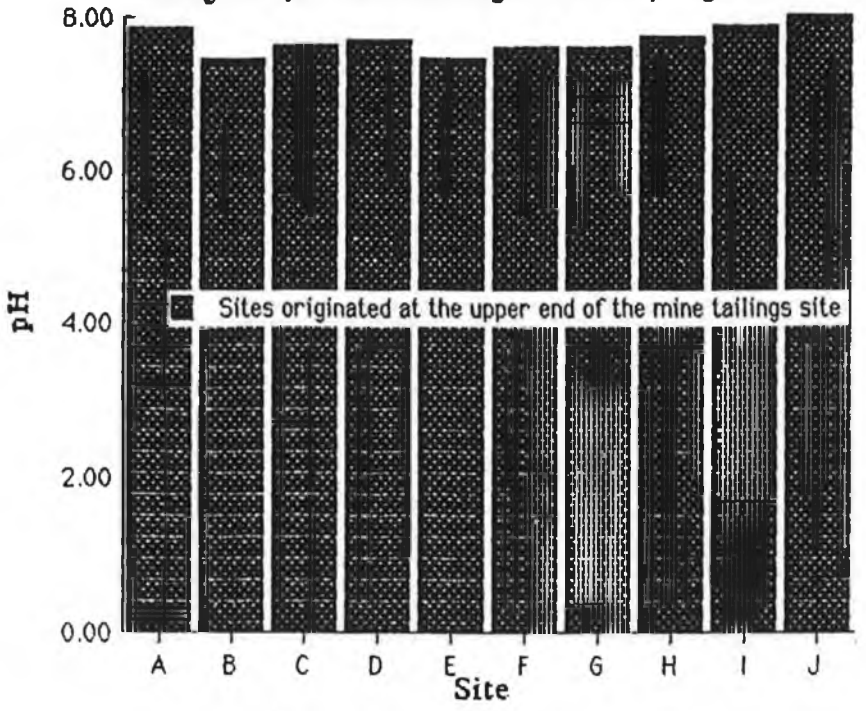
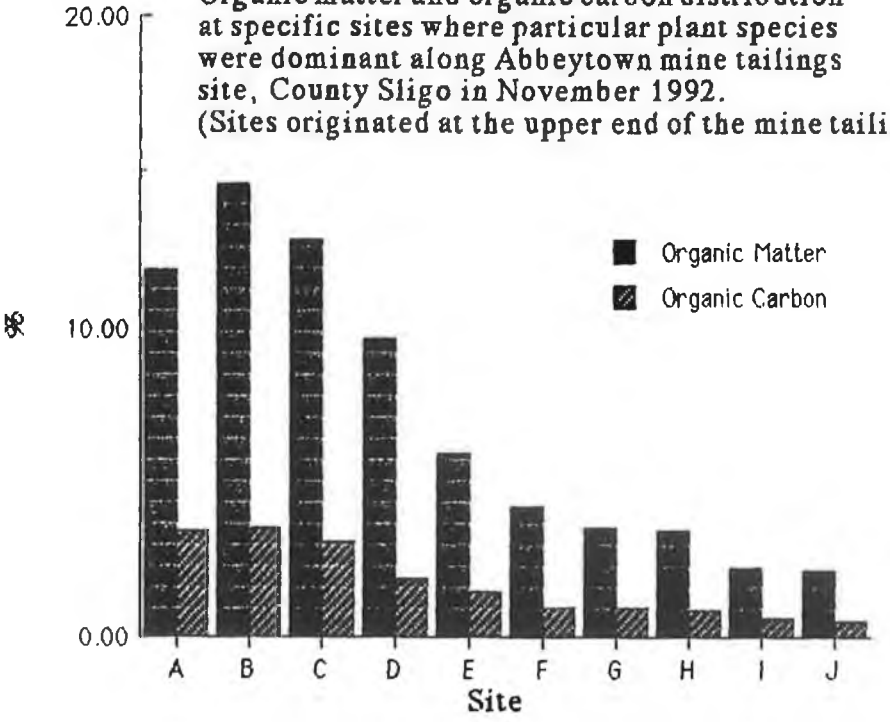


Figure 4.8
Organic matter and organic carbon distribution at specific sites where particular plant species were dominant along Abbeytown mine tailings site, County Sligo in November 1992.
(Sites originated at the upper end of the mine tailings site)



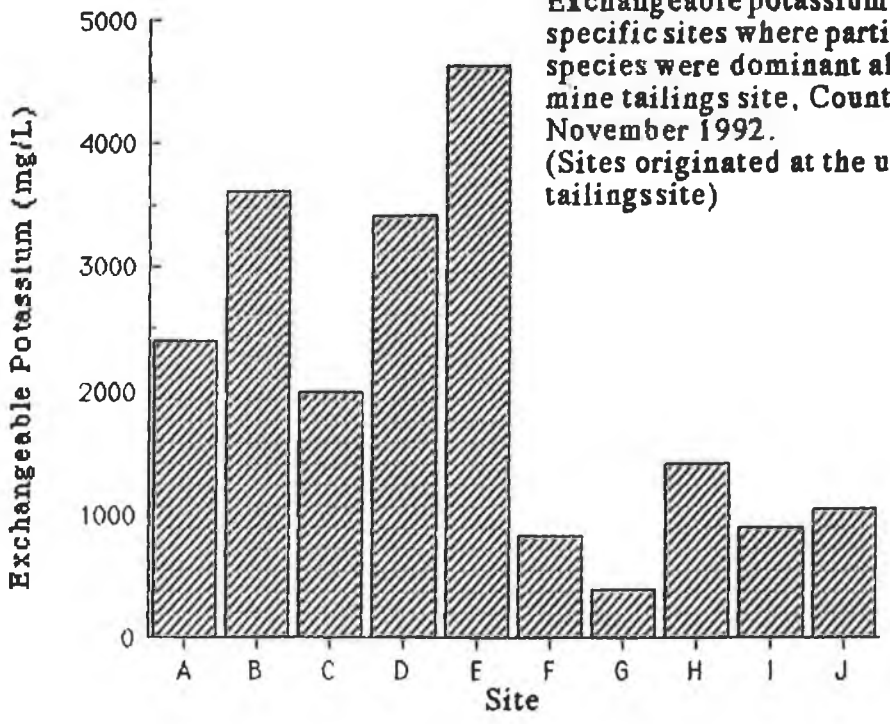


Figure 4.9
Exchangeable potassium distribution at specific sites where particular plant species were dominant along Abbeytown mine tailings site, County Sligo in November 1992.
(Sites originated at the upper end of the mine tailingssite)

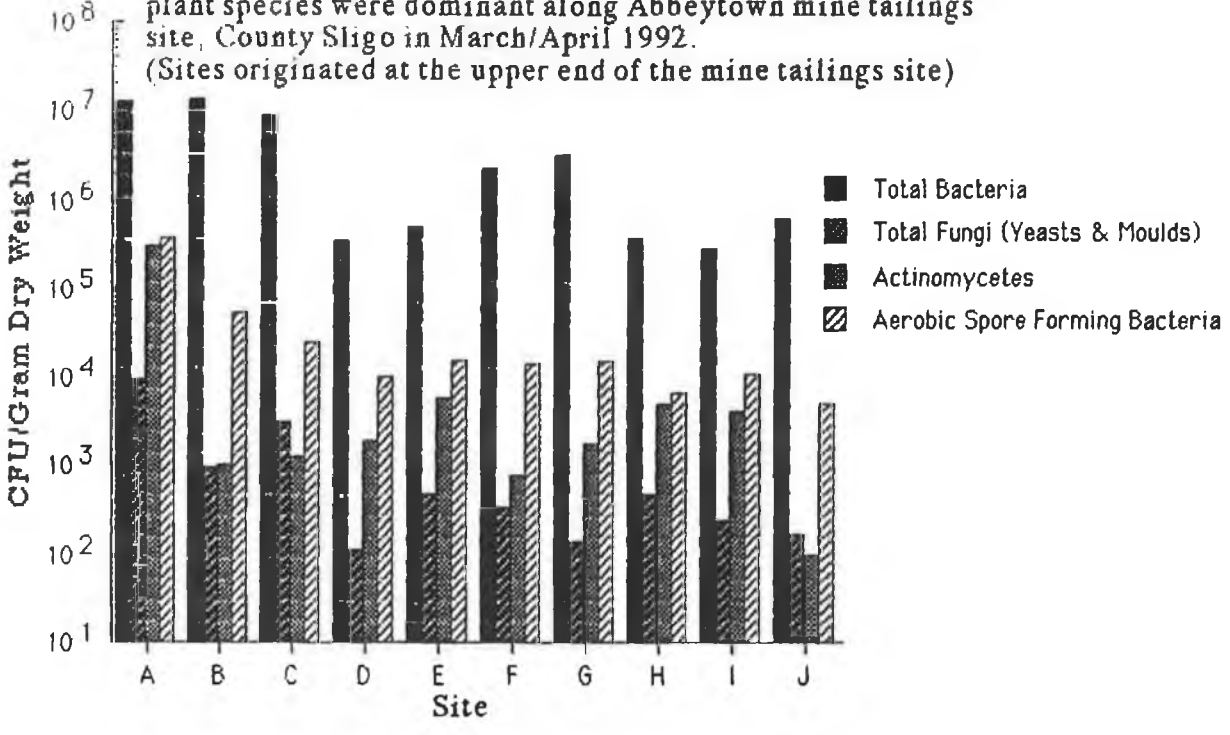


Figure 4.10
Microbiological distribution at specific sites where particular plant species were dominant along Abbeytown mine tailings site, County Sligo in March/April 1992.
(Sites originated at the upper end of the mine tailings site)

Table 4.4

Statistical results assessing the relationship between physical and chemical parameters and specific sites where particular plant species were dominant along Abbeytown mine tailings site, County Sligo in November 1992. (Sites originated at the upper end of the mine tailings site)

				Significance Level	
Parameters Compared	**Curve Fit**	**r**	**r^2**	**1%**	**5%**
pH V's Site	Simple	0.431	0.186	-	-
Log Org. M V's Site	Exponential	-0.971	0.942	+	+
Log Org. C V's Site	Exponential	-0.980	0.960	+	+
Log Exch. K V's Site	Exponential	-0.639	0.408	-	+

Note

Positive (+) = The correlation coefficient is significant at the stated significance level.

Negative (-) = The correlation coefficient is not significant at the stated significance level.

Table 4.5

Statistical results assessing the relationship between microbiological parameters and their corresponding sites and physical and chemical parameters at specific sites where particular plant species were dominant along Abbeytown mine tailings site, County Sligo. (Sites originated at the upper end of the mine tailings site)

				Significance Level	
Parameters Compared	**Curve Fit**	**r**	**r^2**	**1%**	**5%**
Total Bacteria V's Site	Simple	-0.804	0.646	+	+
Log Total Fungi V's Site	Exponential	-0.704	0.496	-	+
Log Actinomycetes V's Site	Exponential	-0.520	0.270	-	-
Log Aerobic Spore Forming Bacteria V's Site	Exponential	-0.819	0.671	+	+
Log Total Bacteria V's pH	Exponential	-0.281	0.079	-	-
Total Bacteria V's Org. M	Simple	0.841	0.708	+	+
Total Bacteria V's Org. C	Simple	0.909	0.827	+	+
Total Bacteria V's Exch. K	Simple	0.249	0.062	-	-
Total Fungi V's pH	Simple	0.265	0.070	-	-
Log Total Fungi V's Org. M	Exponential	0.665	0.442	-	+
Log Total Fungi V's Org. C	Exponential	0.773	0.598	+	+
Log Total Fungi V's Exch. K	Exponential	0.239	0.057	-	-
Actinomycetes V's pH	Simple	0.341	0.116	-	-
Actinomycetes V's Org. M	Simple	0.352	0.124	-	-
Actinomycetes V's Org. C	Simple	0.494	0.244	-	-
Log Actinomycetes V's Exch. K	Exponential	0.243	0.059	-	-
Aerobic Spore Forming Bacteria V's pH	Simple	0.272	0.074	-	-
Log Aerobic Spore Forming Bacteria V's Org. M	Exponential	0.696	0.485	-	+
Log Aerobic Spore Forming Bacteria V's Org. C	Exponential	0.808	0.652	+	+
Log Aerobic Spore Forming Bacteria V's Exch. K	Exponential	0.288	0.083	-	-

Note

Positive (+) = The correlation coefficient is significant at the stated significance level.

Negative (-) = The correlation coefficient is not significant at the stated significance level.

Table 4.6

Plant distribution at specific sites where particular plant species were dominant along Abbeytown mine tailings site, County Sligo in August 1992. (Sites originated at the upper end of the mine tailings site)

Site	Family	Genus/Species	Common Name
A	Gramineae**	*Festuca* species	Fescue species
	Gramineae	*Poa* species	Meadow-Grass species
	Gramineae	*Agrostis stolonifera*	Creeping Bent
	Gramineae	*Holcus lanatus*	Yorkshire Fog
	Leguminosae	*Trifolium pratense*	Red Clover
	Leguminosae	*Vicia sepium*	Bush Vetch
	Leguminosae	*Lathyrus pratensis*	Meadow Vetchling
	Plantaginaceae	*Plantago lanceolata*	Ribwort Plantain
	Rosaceae	*Potentilla anserina*	Silverweed*
	Rosaceae	*Rubus* species	Bramble species
	Compositae	*Sonchus* species	Sow-Thistle species
	Compositae	*Taraxacum* species	Dandelion species
	Compositae	*Carduus* species	Thistle species
	Betulaceae	*Alnus* species	Alder species
B	Gramineae	*Festuca arundinacea*	Tall Fescue
	Leguminosae	*Trifolium repens*	White Clover
	Plantaginaceae	*Plantago lanceolata*	Ribwort Plantain
	Labiatae	*Mentha aquatica*	Water Mint
	Equisetaceae	*Equisetum palustre*	Marsh Horsetail
	Juncaginaceae	*Triglochin* species	Arrow-Grass species
	Cruciferae	*Rorippa* species	Yellowcress species
	Compositae	*Senecio aquaticus*	Marsh Ragwort
C	Gramineae	*Agrostis stolonifera*	Creeping Bent
	Leguminosae	*Trifolium repens*	White Clover*
	Compositae	*Sonchus* species	Sow-Thistle species
	Labiatae	*Mentha aquatica*	Water Mint
	Equisetaceae	*Equisetum arvense*	Common Horsetail*
	Equisetaceae	*Equisetum palustre*	Marsh Horsetail
	Juncaginaceae	*Triglochin* species	Arrow-Grass species
	Ranunculaceae	*Caltha palustris*	Marsh Marigold
	Onagraceae	*Epilobium palustre*	Marsh Willowherb
	Onagraceae	*Epilobium* species	Willowherb species
	Umbelliferae	*Angelica* species	Angelica species
	Umbelliferae	*Oenanthe* species	Water Dropwort species
	Cruciferae	*Cardamine* species	Bittercress species

Site	Family	Genus/Species	Common Name
C	Cyperaceae	*Carex dioica*	Dioecious Sedge*
	Cyperaceae	*Carex otrubae*	False Fox Sedge
	Cyperaceae	*Carex* species	Sedge species
	Juncaceae	*Juncus articulatus*	Jointed Rush*
	Juncaceae	*Juncus gerardii*	Mud Rush*
	Unknown	*Cratoneuron filicinum*	Moss species
D	Gramineae	*Arrhenatherum elatius*	Tall or False Oat-Grass
	Leguminosae	*Trifolium repens*	White Clover
	Labiatae	*Mentha aquatica*	Water Mint
	Equisetaceae	*Equisetum palustre*	Marsh Horsetail
	Cruciferae	*Cardamine* species	Bittercress species
	Ranunculaceae	*Ranunculus repens*	Creeping Buttercup
	Cyperaceae	*Carex dioica*	Dioecious Sedge
	Juncaceae	*Juncus articulatus*	Jointed Rush
	Juncaceae	*Juncus effusus*	Soft Rush
	Unknown	*Calliergon cuspidatum*	Moss species
E	Onagaceae	*Epilobium hirsutum*	Great Willowherb
	Polygonaceae	*Rumex* species	Dock species
	Equisetaceae**	*Equisetum fluviatile*	Water Horsetail
F	Rubiaceae	*Galium palustre*	Marsh Bedstraw
	Labiatae	*Mentha aquatica*	Water Mint
	Equisetaceae	*Equisetum palustre*	Marsh Horsetail
	Equisetaceae	*Equisetum fluviatile*	Water Horsetail
	Equisetaceae	*Equisetum arvense*	Common Horsetail*
	Onagraceae	*Epilobium palustre*	Marsh Willowherb
	Onagraceae	*Epilobium* species	Willowherb species
	Betulaceae	*Alnus* species	Alder species
	Iridaceae	*Iris* species	Iris species
	Juncaceae	*Juncus articulatus*	Jointed Rush****
	Juncaceae	*Juncus effusus*	Soft Rush***
	Juncaceae	*Juncus* species	Rush species
	Unknown	*Cratoneuron filicinum*	Moss species
G	Gramineae	*Agrostis stolonifera*	Creeping Bent
	Labiatae	*Mentha aquatica*	Water Mint
	Equisetaceae**	*Equisetum pratense*	Shade Horsetail
	Onagraceae	*Epilobium* species	Willowherb species

Site	Family	Genus/Species	Common Name
G	Cruciferae	*Cardamine pratensis*	Cuckoo Flower
	Compositae	*Senecio jacobaea*	Ragwort
	Umbelliferae	*Heracleum sphondylium*	Hogweed
	Umbelliferae	*Conopodium majus*	Pignut
	Cyperaceae	*Carex* species	Sedge species
	Juncaceae**	*Juncus articulatus*	Jointed Rush
	Juncaceae	*Juncus conglomeratus*	Compact Rush
	Juncaceae	*Juncus effusus*	Soft Rush
	Unknown	*Cratoneuron filicinum*	Moss species
	Unknown	*Calliergon cuspidatum*	Moss species
H	Gramineae	*Agrostis stolonifera*	Creeping Bent
	Gramineae	*Festuca rubra*	Creeping Red Fescue
	Juncaginaceae	*Triglochin palustris*	Marsh Arrow-Grass
	Onagraceae	*Epilobium palustre*	Marsh Willowherb
	Cruciferae	*Cardamine* species	Bittercress species
	Cruciferae	*Rorippa* species	Yellowcress species
	Juncaceae	*Juncus acutiflorus*	Sharp-Flowered Rush****
	Juncaceae	*Juncus articulatus*	Jointed Rush****
	Juncaceae	*Juncus effusus*	Soft Rush
	Juncaceae	*Juncus maritimus*	Sea Rush
	Unknown	*Calliergon cuspidatum*	Moss species
I	Gramineae	*Agrostis stolonifera*	Creeping Bent
	Leguminosae	*Trifolium repens*	White Clover
	Labiatae	*Mentha aquatica*	Water Mint
	Compositae	*Sonchus* species	Sow-Thistle species
	Compositae	*Taraxacum* species	Dandelion species
	Onagraceae	*Epilobium* species	Willowherb species
	Plantaginaceae	*Plantago* species	Plantain species
	Cyperaceae	*Carex* species	Sedge species
	Juncaceae	*Juncus articulatus*	Jointed Rush
	Juncaceae	*Juncus gerardii*	Mud Rush
J	Gramineae**	*Agrostis stolonifera*	Creeping Bent
	Juncaginaceae	*Triglochin* species	Arrow-Grass species
	Cyperaceae**	*Scirpus maritimus*	Sea Club-Rush
	Unknown	*Cratoneuron filicinum*	Moss species

Key

* = Plant species dominant.

** = Plant species dominant. Member of family.

*** = Plant species dominant, may be *Juncus effusus*.

**** = Plant species dominant, may be *Juncus articulatus* or *Juncus acutiflorus*.

Note

The identities of some dominant species at sites A and C were unknown.

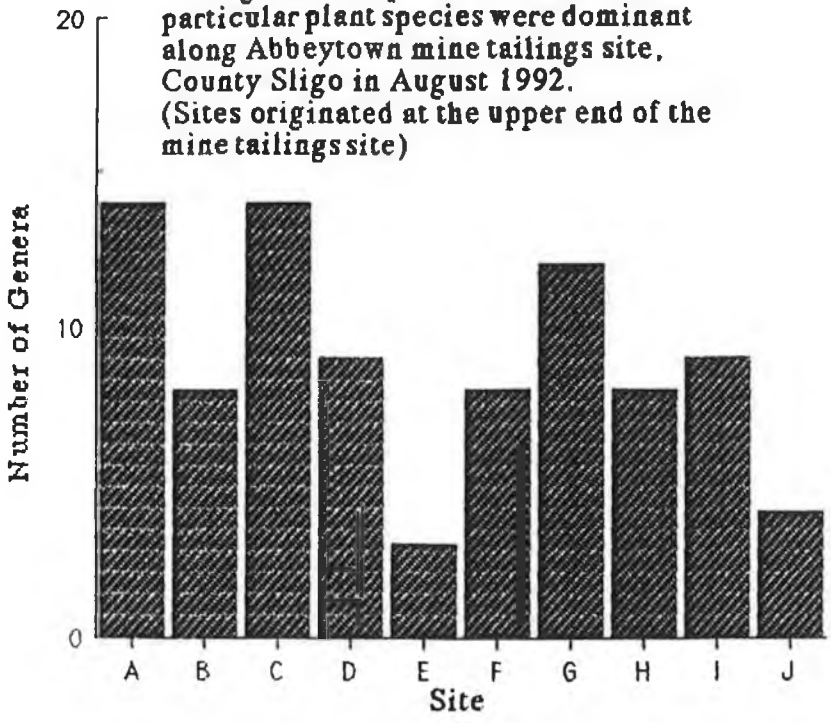
The dominant species at sites B, D and I were not identified.

At site G the identity of the member of the Juncaceae family is uncertain.

At site H *Scirpus* species may have also been dominant.

At site J two genera of the Gramineae family may have been dominant.

Figure 4.11
Plant genera at specific sites where particular plant species were dominant along Abbeytown mine tailings site, County Sligo in August 1992.
(Sites originated at the upper end of the mine tailings site)



4:2 GORTDRUM

4:2.1 Introduction

Section 4:2 presents physical, chemical, textural and botanical results obtained from sites on Gortdrum mine tailings site in 1990/1991 and physical, chemical and microbiological results obtained along a transect on this mine tailings site in 1993. The physical, chemical, textural and microbiological results are presented in graphic form with the corresponding data in Appendix 2. The botanical results are presented in tabular form.

Figures 4.12 to 4.16 show the physical and chemical distribution of five parameters at sites corresponding with seven locations (Table 4.7) on the mine tailings site in 1990/1991. Figure 4.17 shows the distribution of clay and silt at two of these sites in 1990/1991. Table 4.8 presents a breakdown of plants occurring on the mine tailings site in 1990/1991.

Figures 4.18 to 4.20 show the physical and chemical distribution of five parameters at 90m intervals from the perimeter of the mine tailings site in 1993. Figure 4.21 shows the microbiological distribution of four parameters along this same area and at the same sampling intervals in 1993. Statistical results are presented in Tables 4.9 and 4.10.

Table 4.7
Sampling site locations at Gortdrum mine tailings site, County Tipperary in 1990/1991.

Site	Description	Rehabilitation
1	100m below drain	1981/1982
2	Midway	1981/1982
3	Mid tailings, initial planting clover	1981/1982
4	Mid tailings, new section	1984
5	Moss core	1984
6	Wet area	1984
7	Slurry area	1984

Figure 4.12
pH distribution at sites on Gortdrum mine tailings site, County Tipperary in 1990/1991.

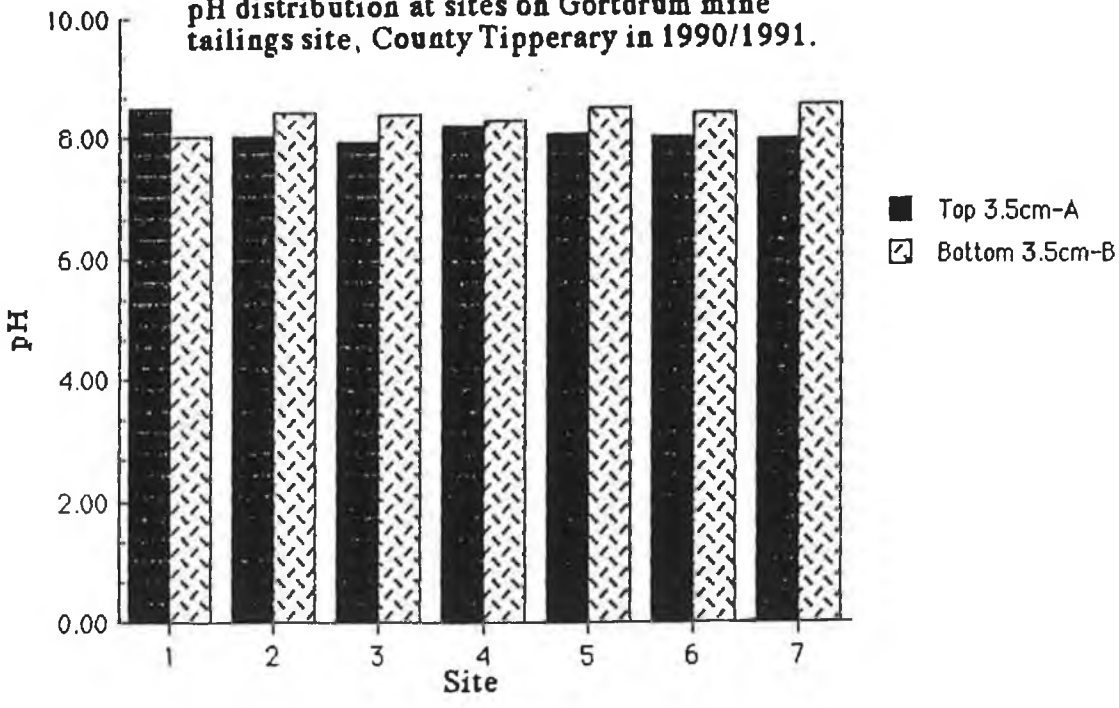


Figure 4.13
Organic matter distribution at sites on Gortdrum mine tailings site, County Tipperary in 1990/1991.

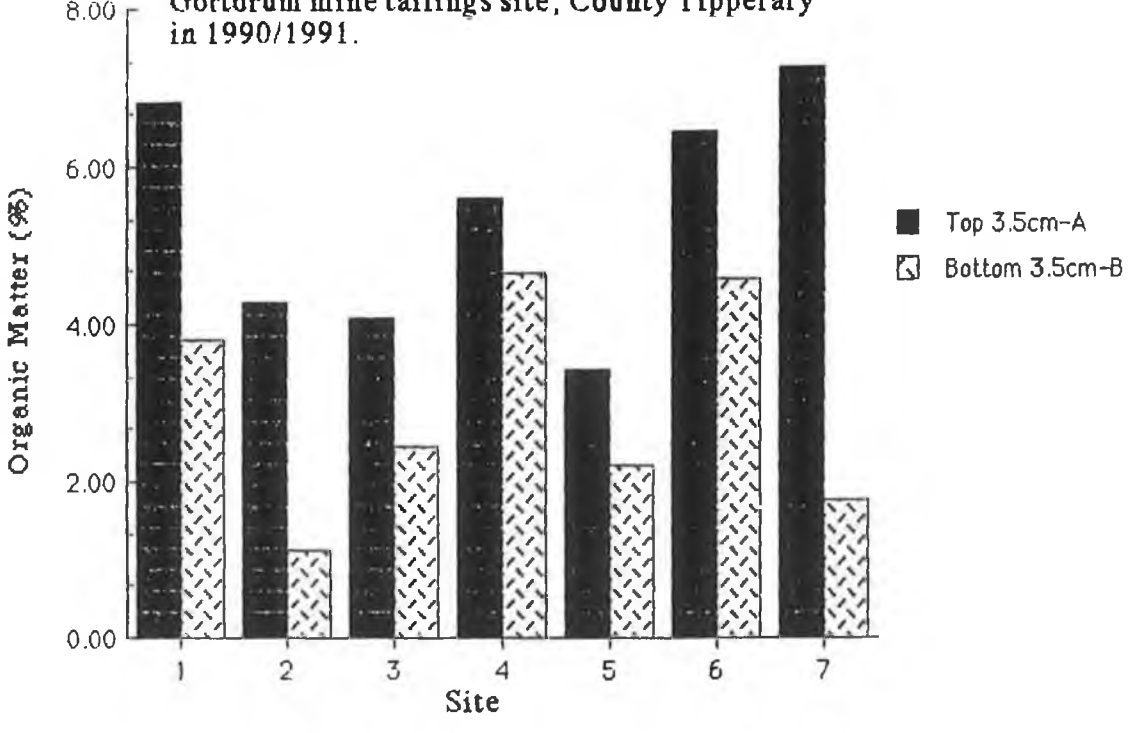


Figure 4.14
Kjeldahl nitrogen distribution at sites on Gortdrum mine tailings site, County Tipperary in 1990/1991.

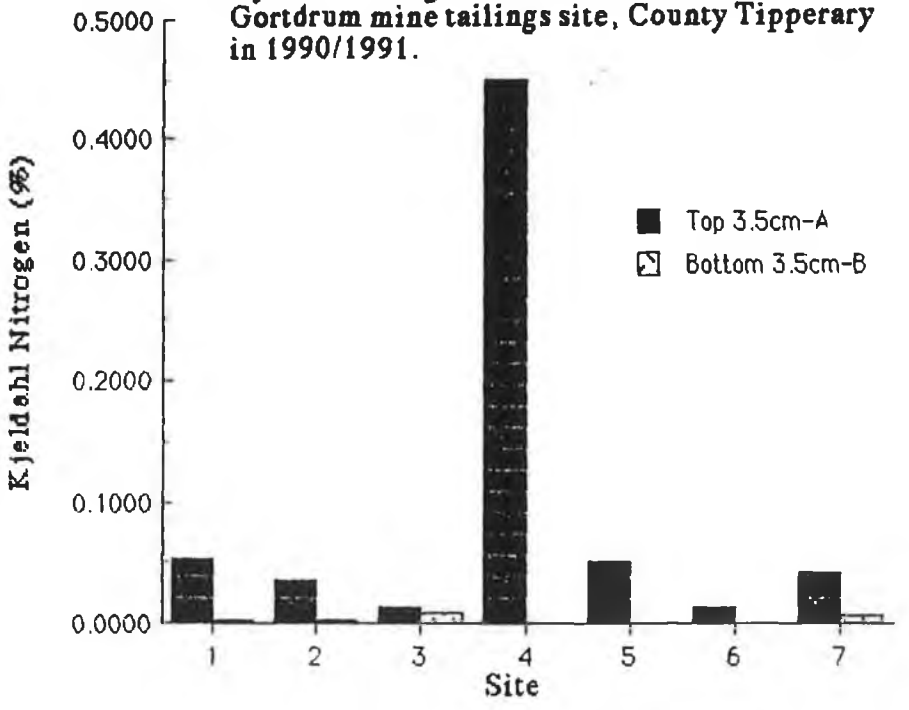


Figure 4.15
Available phosphorus distribution at sites on Gortdrum mine tailings site, County Tipperary in 1990/1991.

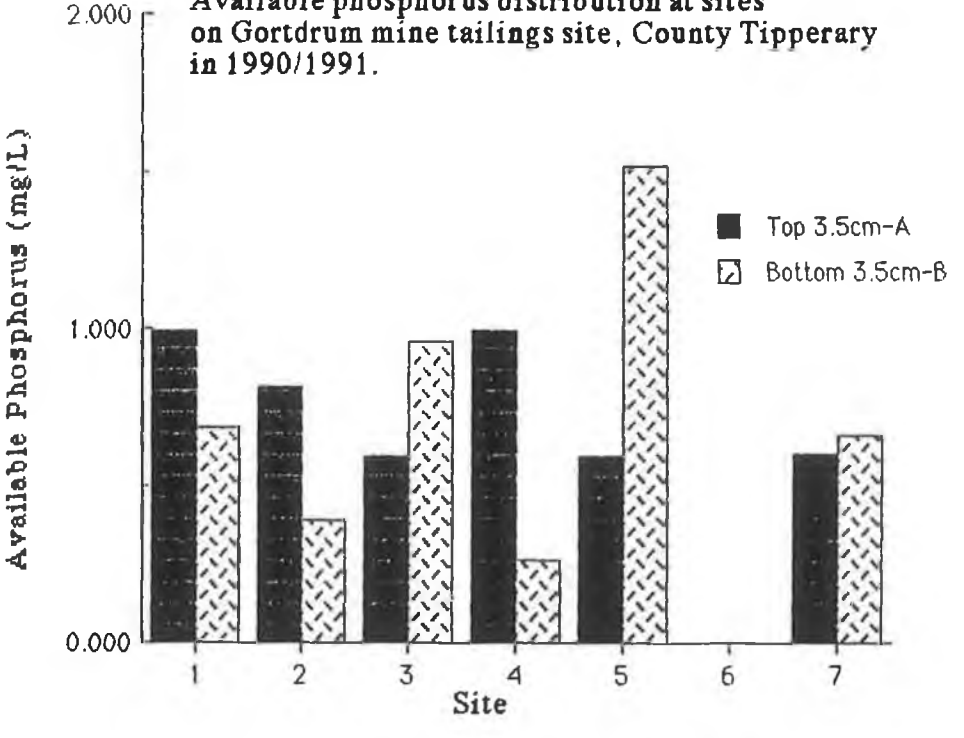


Figure 4.16
Exchangeable potassium distribution at sites on Gortdrum mine tailings site, County Tipperary in 1990/1991.

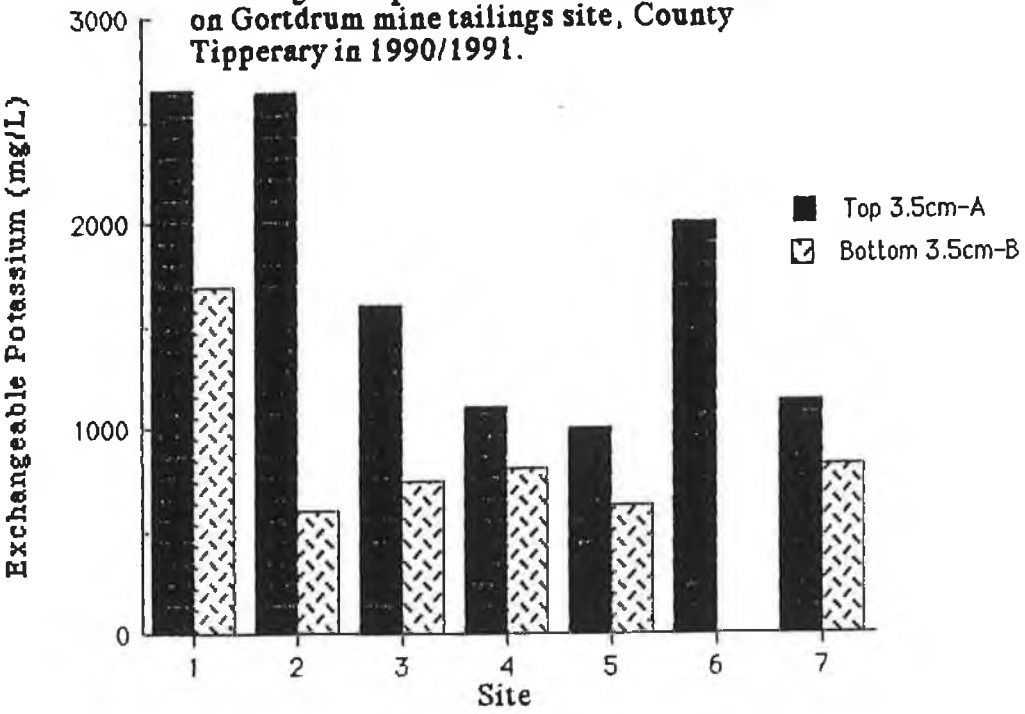


Figure 4.17
Clay and silt distribution at sites on Gortdrum mine tailings site, County Tipperary in 1990/1991.

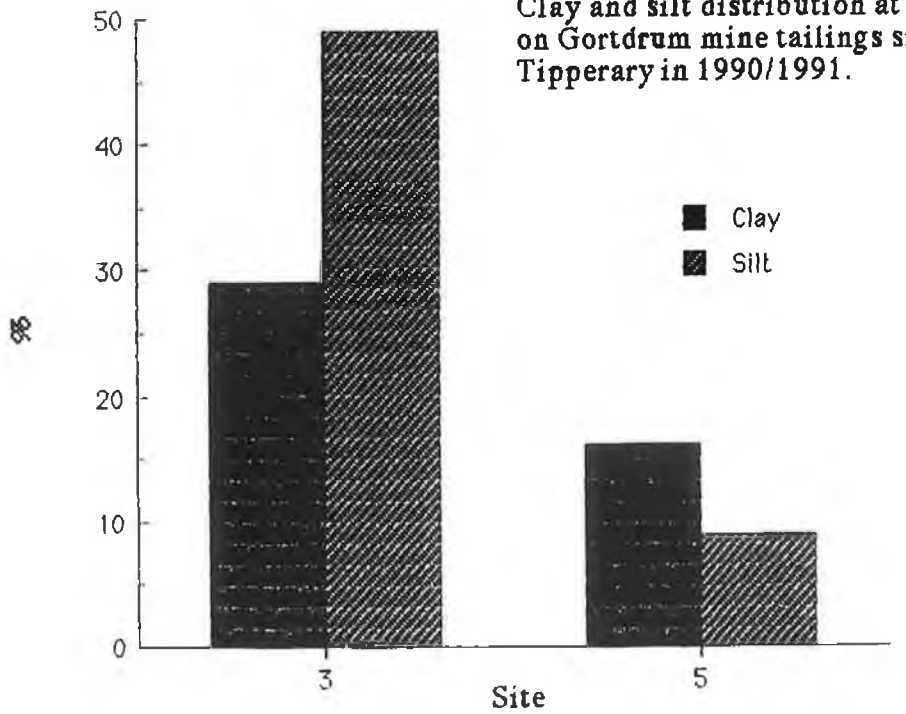


Table 4.8
Plant distribution at Gortdrum mine tailings site, County Tipperary in 1990/1991.

Family	Genus/Species	Common Name
Leguminosae	*Trifolium repens*	White Clover
Ericaceae	*Vaccinium myrtillus*	Bilberry
Unknown	*Pseudoscleropodium purum*	Moss species
Unknown	*Rhytidiadelphus squarrosus*	Moss species

Figure 4.18
pH distribution at 90m intervals from the perimeter of Gortdrum mine tailings site, County Tipperary in February 1993.

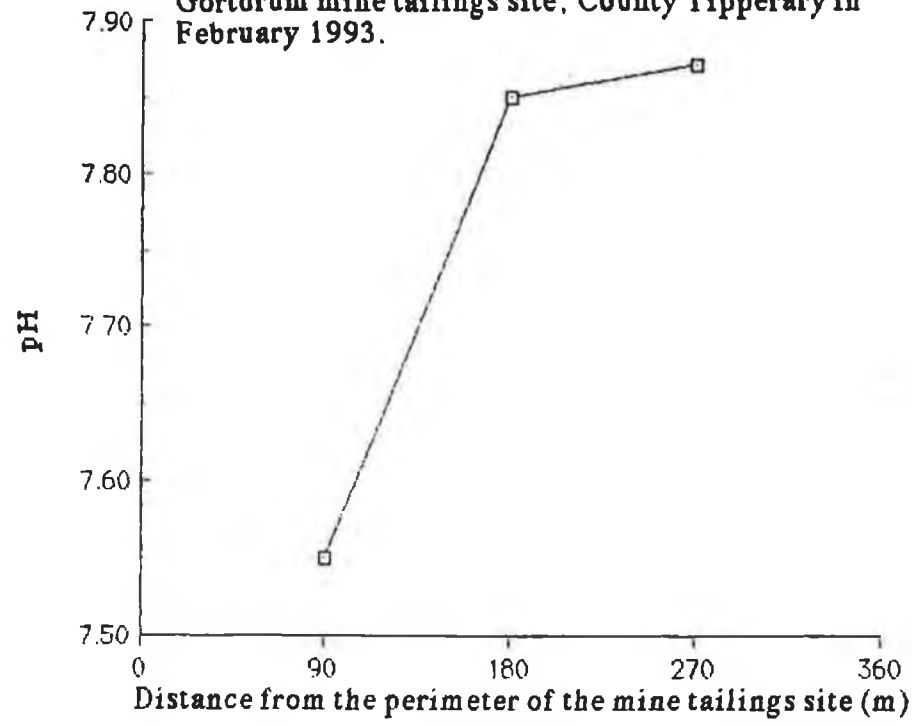


Figure 4.19
Organic matter and organic carbon distribution at 90m intervals from the perimeter of Gortdrum mine tailings site, County Tipperary in February 1993.

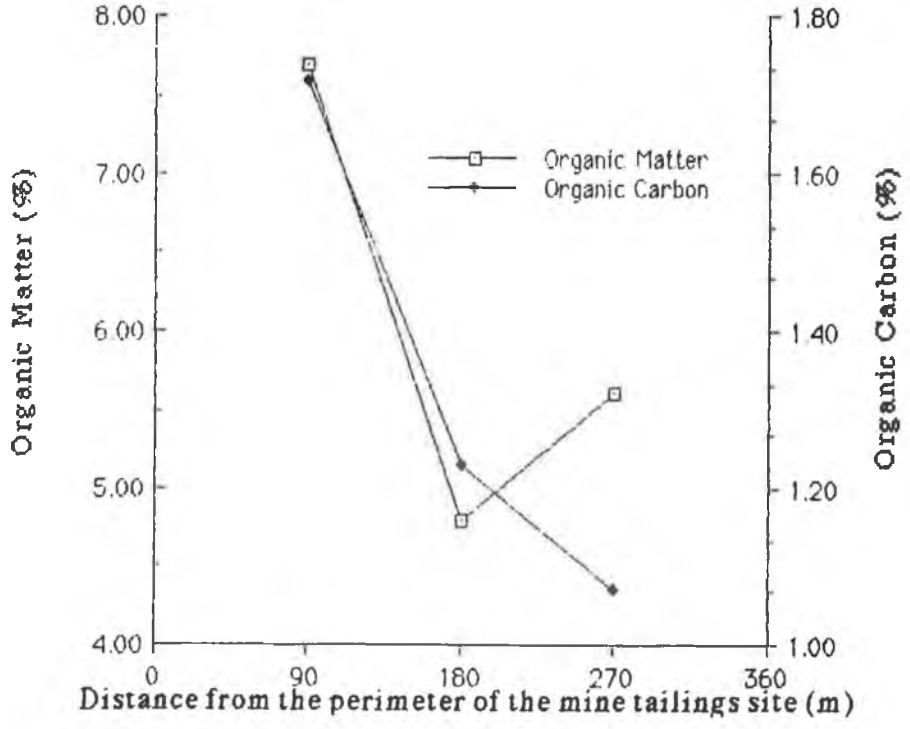


Figure 4.20
Available phosphorus and exchangeable potassium distribution at 90m intervals from the perimeter of Gortdrum mine tailings site, County Tipperary in February 1993.

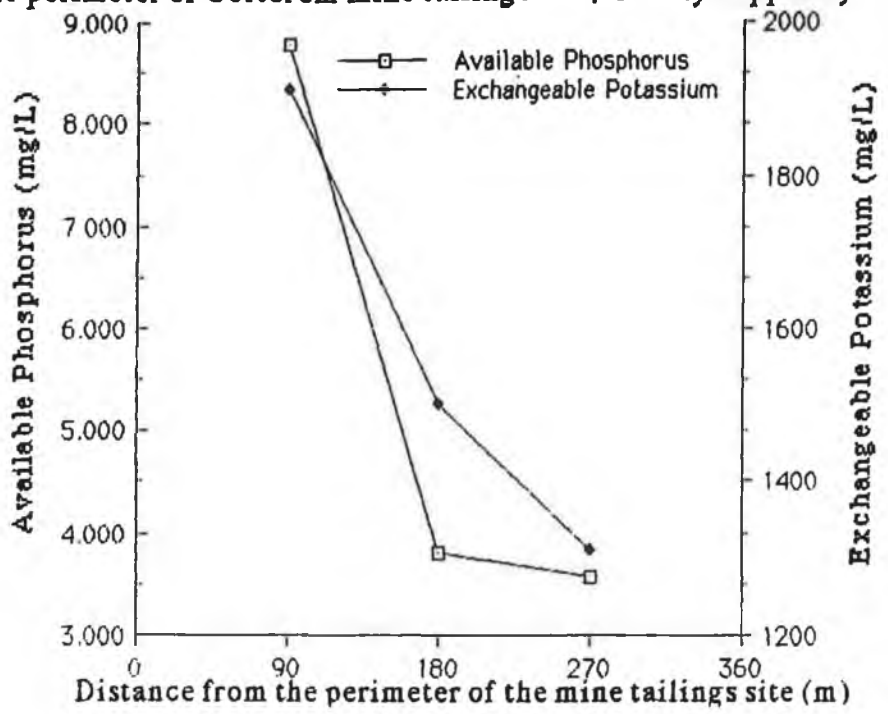


Figure 4.21
Microbiological distribution at 90m intervals from the perimeter of Gortdrum mine tailings site, County Tipperary in February 1993. (Duplicate sample results presented)

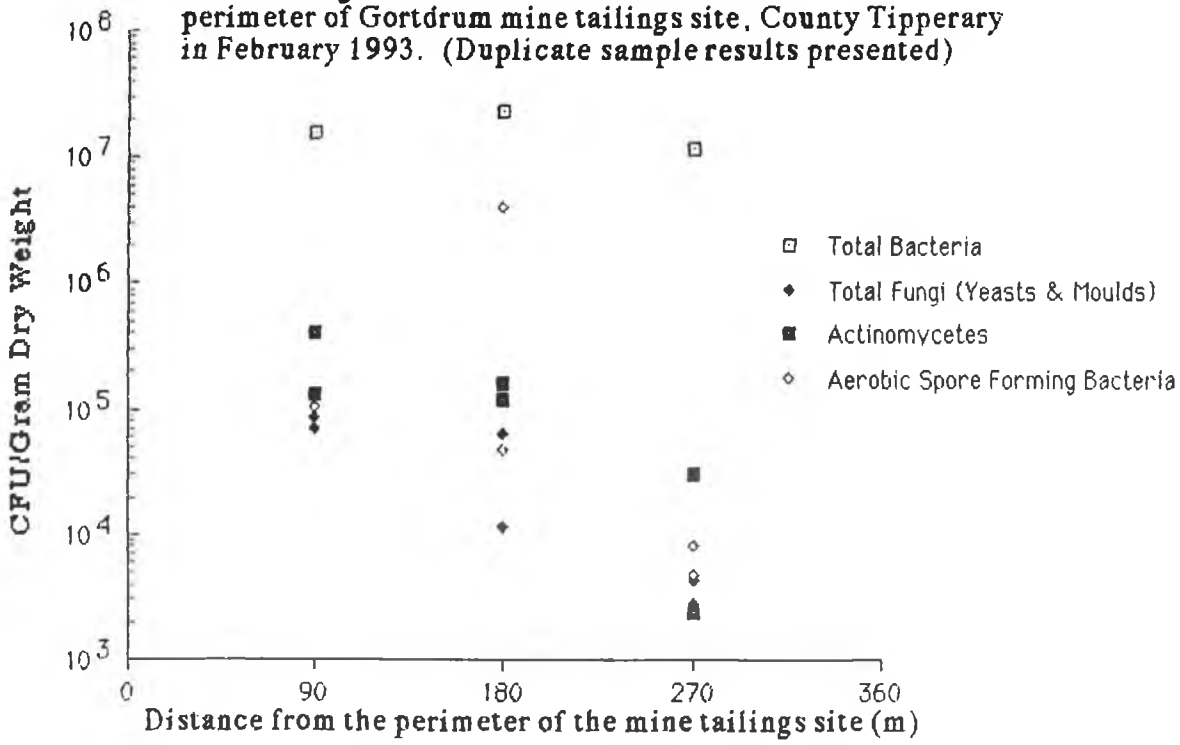


Table 4.9

Statistical results assessing the relationship between physical and chemical parameters and their corresponding sites at 90m intervals from the perimeter of Gortdrum mine tailings site, County Tipperary in February 1993.

				Significance Level	
Parameters Compared	**Curve Fit**	**r**	**r^2**	**1%**	**5%**
pH V's Distance	Simple	0.893	0.797	-	-
Org. M V's Distance	Simple	-0.696	0.484	-	-
Log Org. C V's Distance	Exponential	-0.973	0.946	-	-
Log Avail. P V's Distance	Exponential	-0.895	0.801	-	-
Log Exch. K V's Distance	Exponential	-0.987	0.975	-	-

Table 4.10

Statistical results assessing the relationship between microbiological parameters and their corresponding sites at 90m intervals from the perimeter of Gortdrum mine tailings site, County Tipperary in February 1993.

				Significance Level	
Parameters Compared	**Curve Fit**	**r**	**r^2**	**1%**	**5%**
Log Total Bacteria V's Distance	Exponential	-0.398	0.158	-	-
Log Total Fungi V's Distance	Exponential	-0.914	0.835	-	+
Log Actinomycetes V's Distance	Exponential	-0.814	0.663	-	+
Log Aerobic Spore Forming Bacteria V's Distance	Exponential	-0.566	0.320	-	-

Note

Positive (+) = The correlation coefficient is significant at the stated significance level.

Negative (-) = The correlation coefficient is not significant at the stated significance level.

4:3 SHALLEE

4:3.1 Introduction

Section 4:3 presents physical, chemical, textural and botanical results obtained along a transect on Shallee mine tailings site in 1990/1991 and physical, chemical, microbiological and botanical results obtained from sites on this mine tailings site in 1992. The physical, chemical, textural and microbiological results are presented in graphic form with the corresponding data in Appendix 2. The botanical results are presented in tabular form with some data in graphic form.

Figures 4.22 to 4.26 show the physical and chemical distribution of five parameters at sites along a transect on this mine tailings site in 1990/1991. These sites may have originated at the perimeter of the mine tailings site. Figure 4.27 shows the distribution of clay and silt at six of these sites in 1990/1991. Table 4.12 presents a breakdown of the plants occurring at five of these sites in 1990/1991 with Figure 4.28 showing the distribution of genera. Statistical results are presented in Table 4.11.

Figures 4.29 to 4.32 show the physical and chemical distribution of five parameters at sites corresponding with the dominance of vetch and willow species on the mine tailings site in 1992. Figure 4.33 shows the microbiological distribution of four parameters at these sites in 1992. Table 4.13 presents a breakdown of the plants occurring at these sites in 1992 with Figure 4.34 showing the distribution of genera.

Figure 4.22
pH distribution at sites along Shallee mine tailings site, County Tipperary in 1990/1991. (Sites may have originated at the perimeter of the mine tailings site)

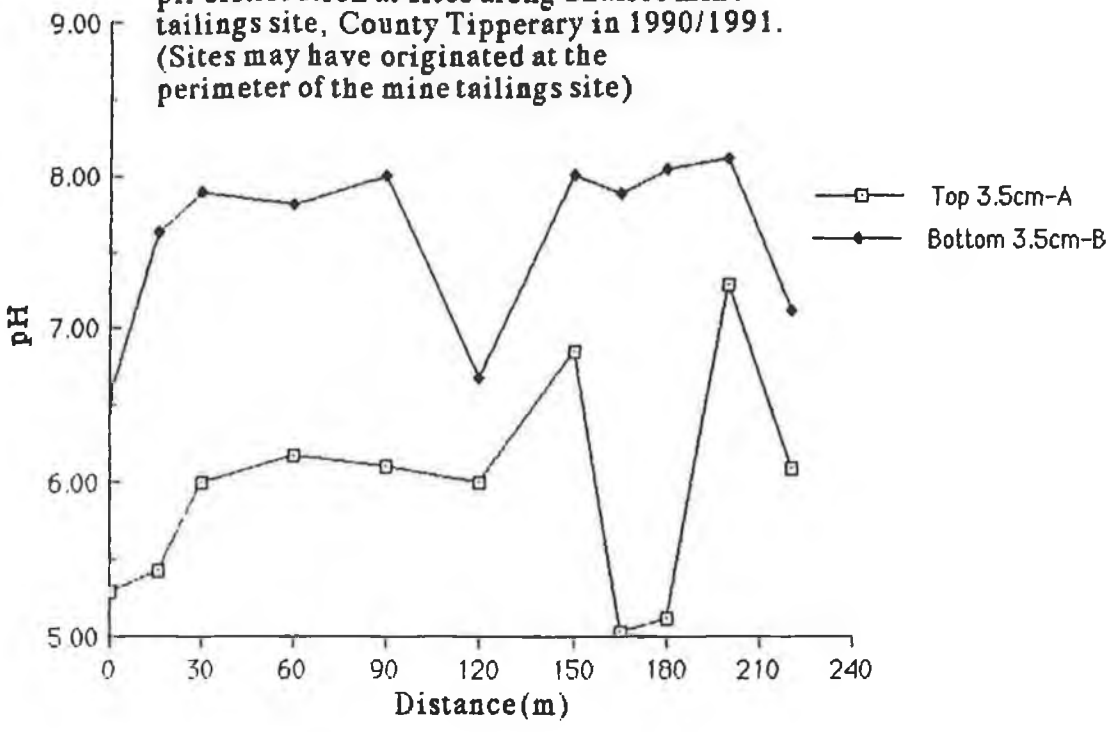


Figure 4.23
Organic matter distribution at sites along Shallee mine tailings site, County Tipperary in 1990/1991. (Sites may have originated at the perimeter of the mine tailings site)

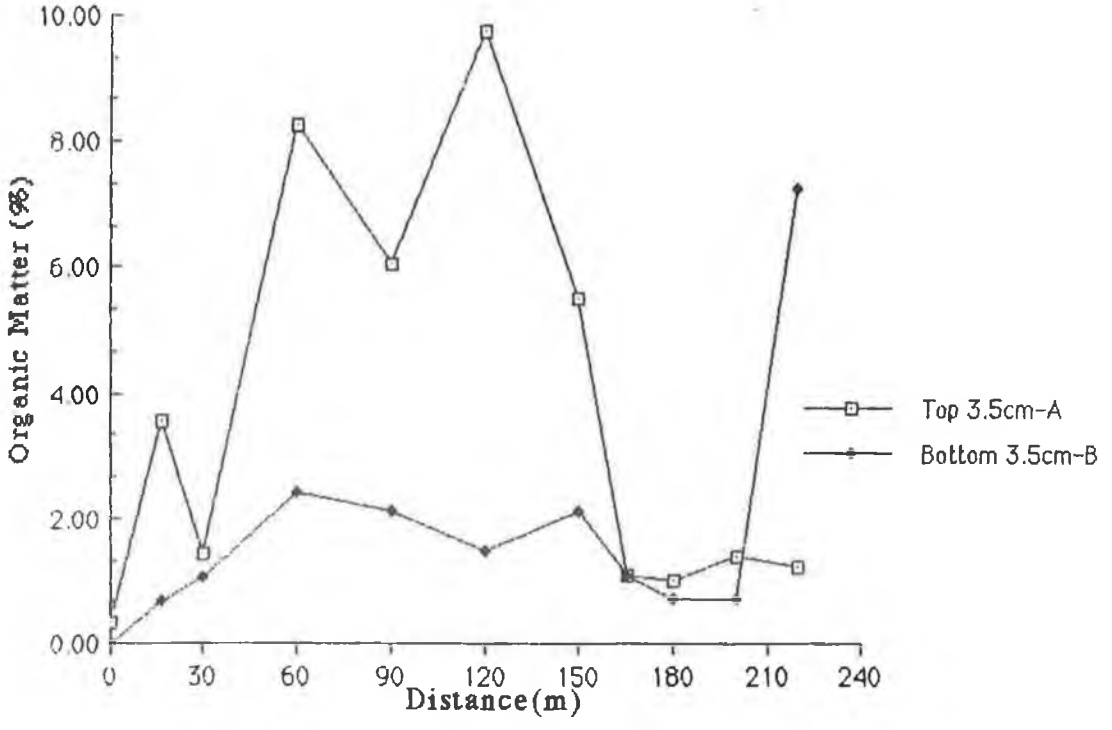


Figure 4.24
Kjeldahl nitrogen distribution at sites along Shallee mine tailings site, County Tipperary in 1990/1991. (Sites may have originated at the perimeter of the mine tailings site)

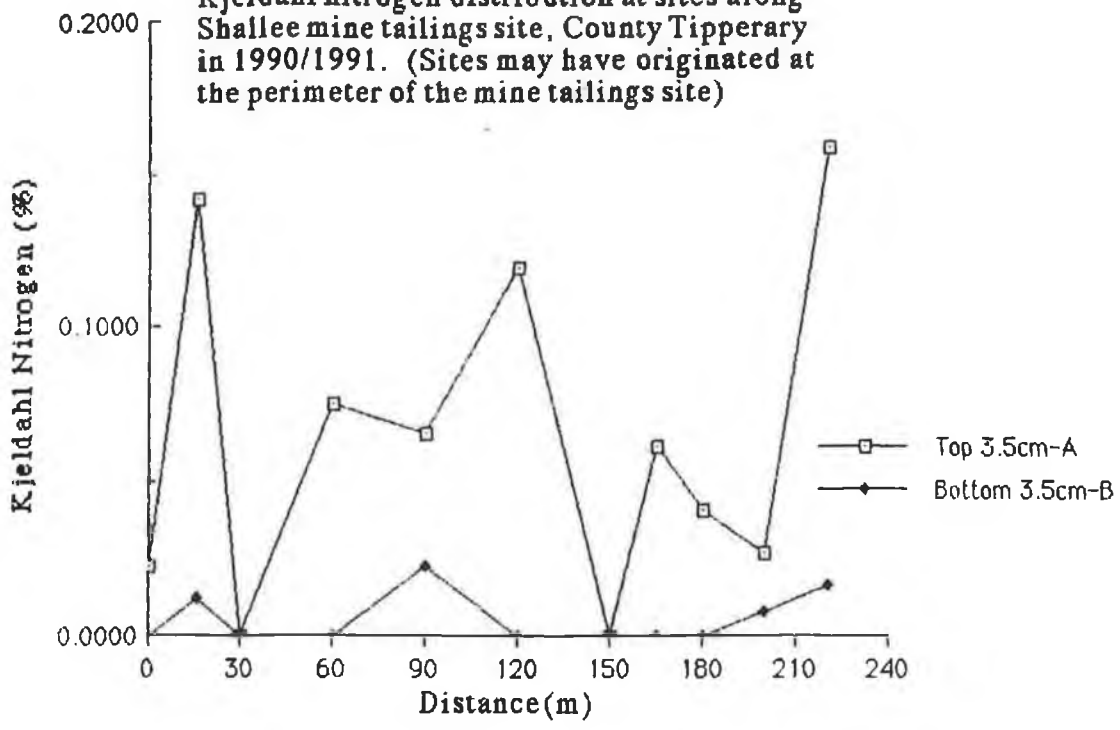


Figure 4.25
Available phosphorus distribution at sites along Shallee mine tailings site, County Tipperary in 1990/1991. (Sites may have originated at the perimeter of the mine tailings site)

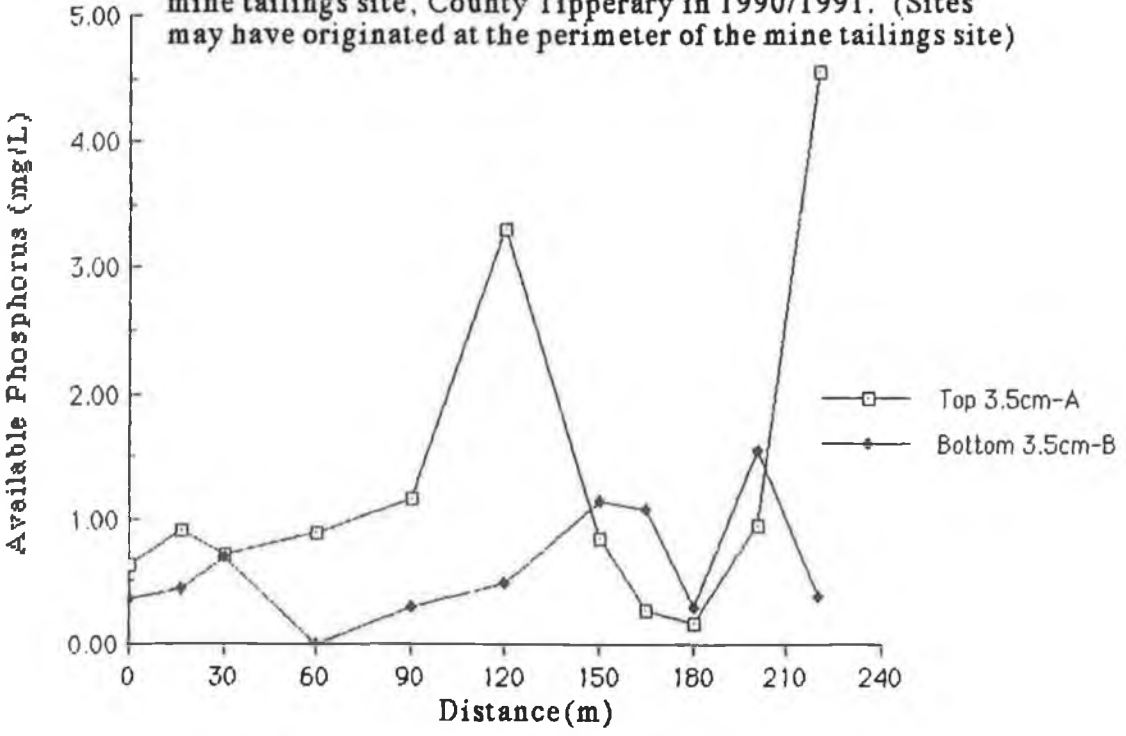


Figure 4.26
Exchangeable potassium distribution at sites along Shallee mine tailings site, County Tipperary in 1990/1991. (Sites may have originated at the perimeter of the mine tailings site)

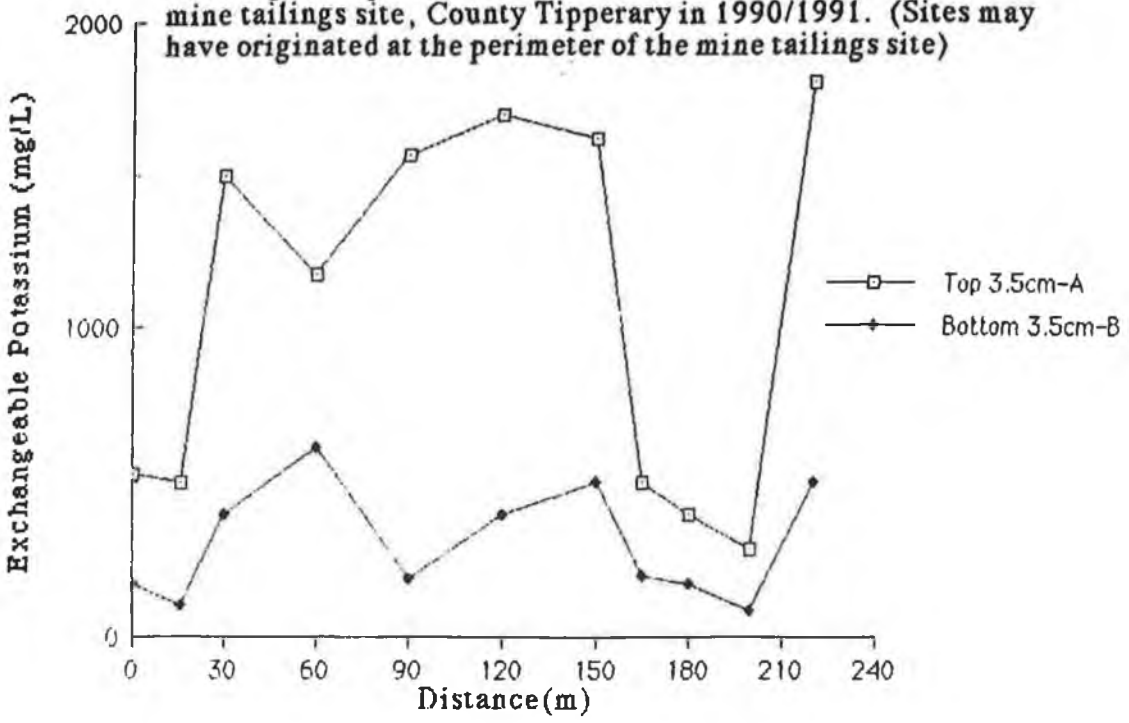


Figure 4.27
Clay and silt distribution at sites along Shallee mine tailings site, County Tipperary in 1990/1991. (Sites may have originated at the perimeter of the mine tailings site)

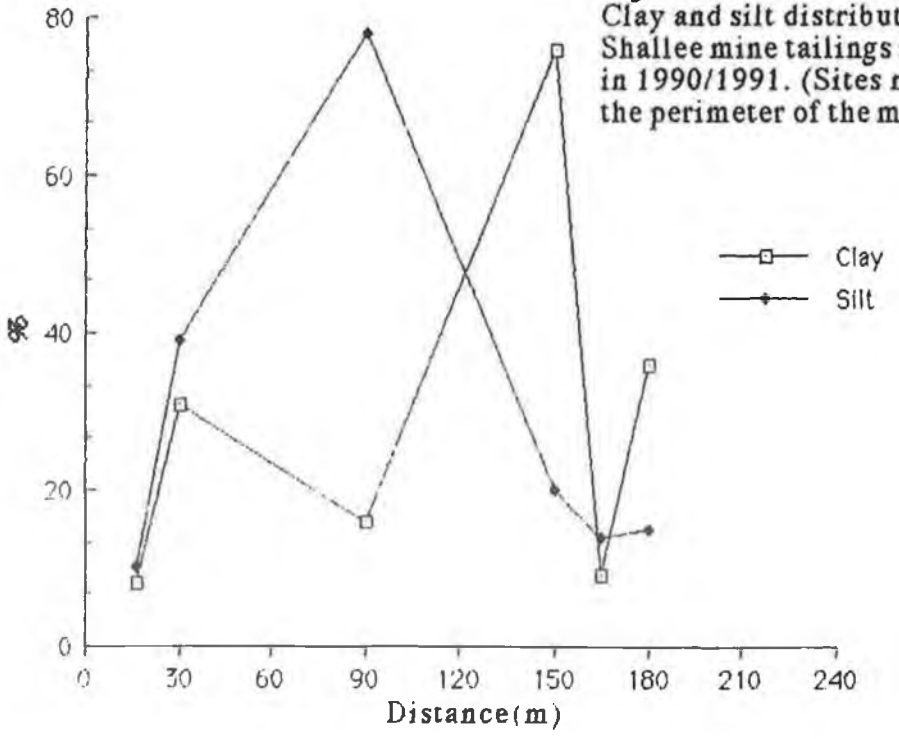


Table 4.11

Statistical results assessing the relationship between physical and chemical parameters and their corresponding sites along Shallee mine tailings site, County Tipperary in 1990/1991.

(Sites may have originated at the perimeter of the mine tailings site)

				Significance Level	
Parameters Compared	**Curve Fit**	**r**	**r^2**	**1%**	**5%**
pH-A V's Distance	Simple	0.305	0.093	-	-
pH-B V's Distance	Simple	0.257	0.066	-	-
Org. M-A V's Distance	Simple	-0.152	0.023	-	-
Org. M-B V's Distance	Simple	0.479	0.229	-	-
Kjel. N-A V's Distance	Simple	0.118	0.014	-	-
Kjel. N-B V's Distance	Simple	0.127	0.016	-	-
Avail. P-A V's Distance	Simple	0.354	0.125	-	-
Avail. P-B V's Distance	Simple	0.443	0.196	-	-
Log Exch. K-A V's Distance	Exponential	-0.063	0.004	-	-
Exch.K-B V's Distance	Simple	0.063	0.004	-	-

Note

Positive (+) = The correlation coefficient is significant at the stated significance level.

Negative (-) = The correlation coefficient is not significant at the stated significance level.

Table 4.12

Plant distribution at sites along Shallee mine tailings site, County Tipperary in 1990/1991.

(Sites may have originated at the perimeter of the mine tailings site)

Distance (m)	Family	Genus/Species	Common Name
16	Caryophyllaceae	*Cerastium holosteoides*	Mouse-Ear species
	Ericaceae	*Calluna vulgaris*	Heather
	Ericaceae	*Erica cinerea*	Bell Heather
	Unknown	*Rhytidiadelphus squarrosus*	Moss species
	Unknown	*Hypnum cupressiforme*	Moss species
	Unknown	*Climacium splendens*	Moss species
30	Ericaceae	*Calluna vulgaris*	Heather
	Ericaceae	*Erica cinerea*	Bell Heather
	Ericaceae	*Erica tetralix*	Cross-Leaved Heath
	Leguminosae	*Ulex europaeus*	Gorse
	Corylaceae	*Corylus avellana*	Common Hazel
	Unknown	*Rhytidiadelphus squarrosus*	Moss species
	Unknown	*Pseudoscleropodium purum*	Moss species
	Unknown	*Thuidium tamariscinum*	Moss species
	Unknown	*Hylocomium splendens*	Moss species
60	Leguminosae	*Trifolium ornithopodioides*	Fenugreek
	Compositae	*Hieracium alpinum*	Alpine Hawkweed
	Unknown	*Pseudoscleropodium splendens*	Moss species
	Unknown	*Rhytidiadelphus squarrosus*	Moss species
120	Ericaceae	*Erica cinerea*	Bell Heather
	Ericaceae	*Erica tetralix*	Cross-Leaved Heath
	Leguminosae	*Trifolium repens*	White Clover
	Leguminosae	*Trifolium ornithopodiodes*	Fenugreek
	Compositae	*Hieracium alpinum*	Alpine Hawkweed
	Unknown	*Rhytidiadelphus squarrosus*	Moss species
	Unknown	*Hylocomium splendens*	Moss species
220	Ericaceae	*Calluna vulgaris*	Heather
	Equisetaceae	*Equisetum sylvaticum*	Wood Horsetail
	Unknown	*Pseudoscleropodium purum*	Moss species
	Unknown	*Rhytidiadelphus squarrosus*	Moss species
	Unknown	*Hypnum cupressiforme*	Moss species

Figure 4.28
Plant genera at sites along Shallee mine tailings site, County Tipperary in 1990/1991. (Sites may have originated at the perimeter of the mine tailings site)

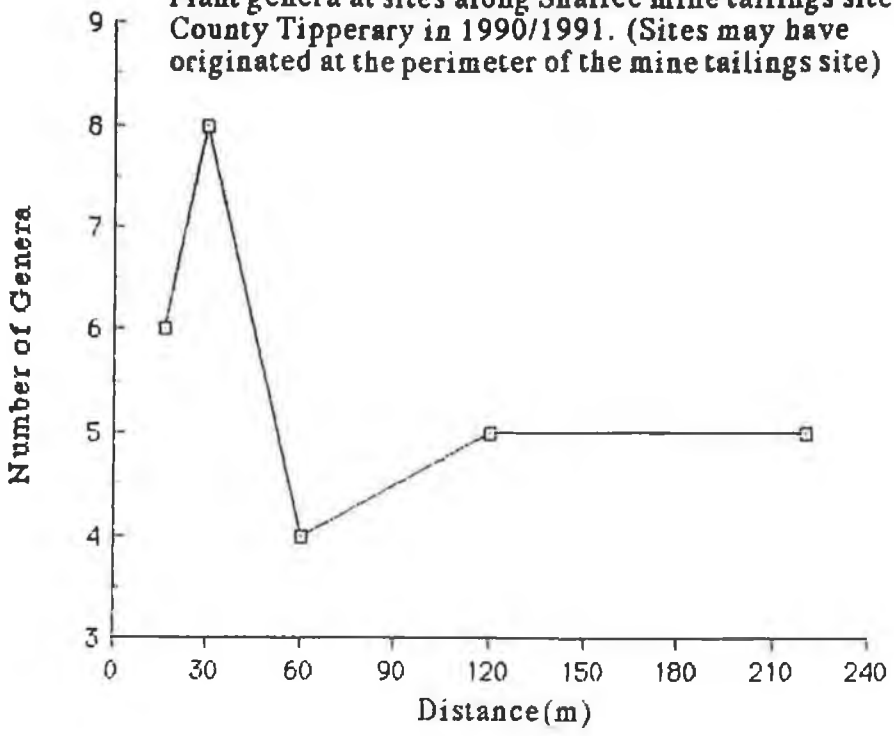


Figure 4.29
pH distribution at sites on Shallee mine tailings site, County Tipperary in May 1992.

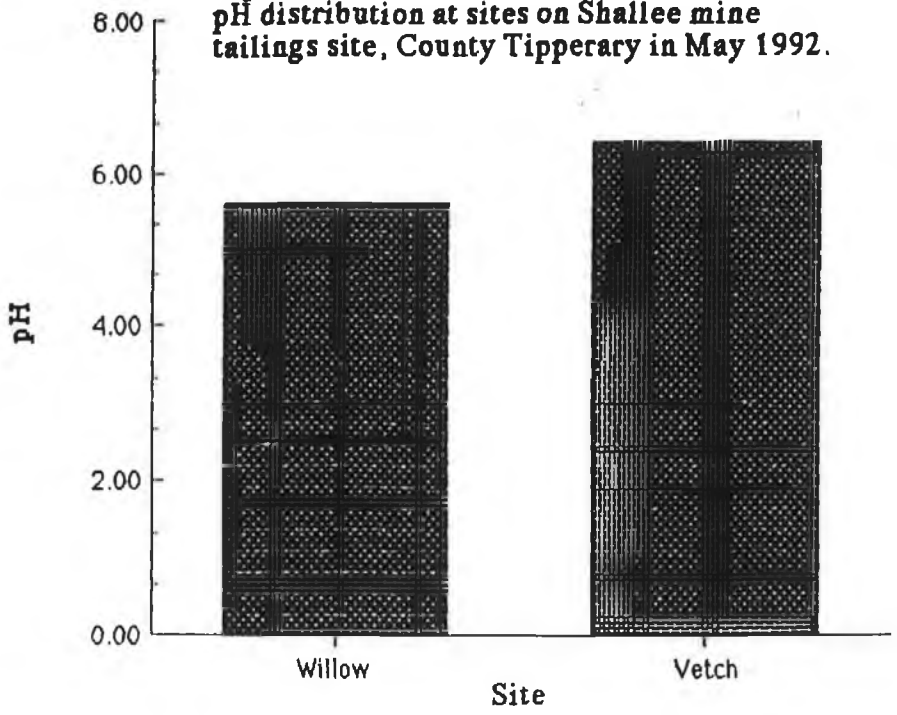


Figure 4.30
Organic matter and organic carbon distribution at sites on Shallee mine tailings site, County Tipperary in May 1992.

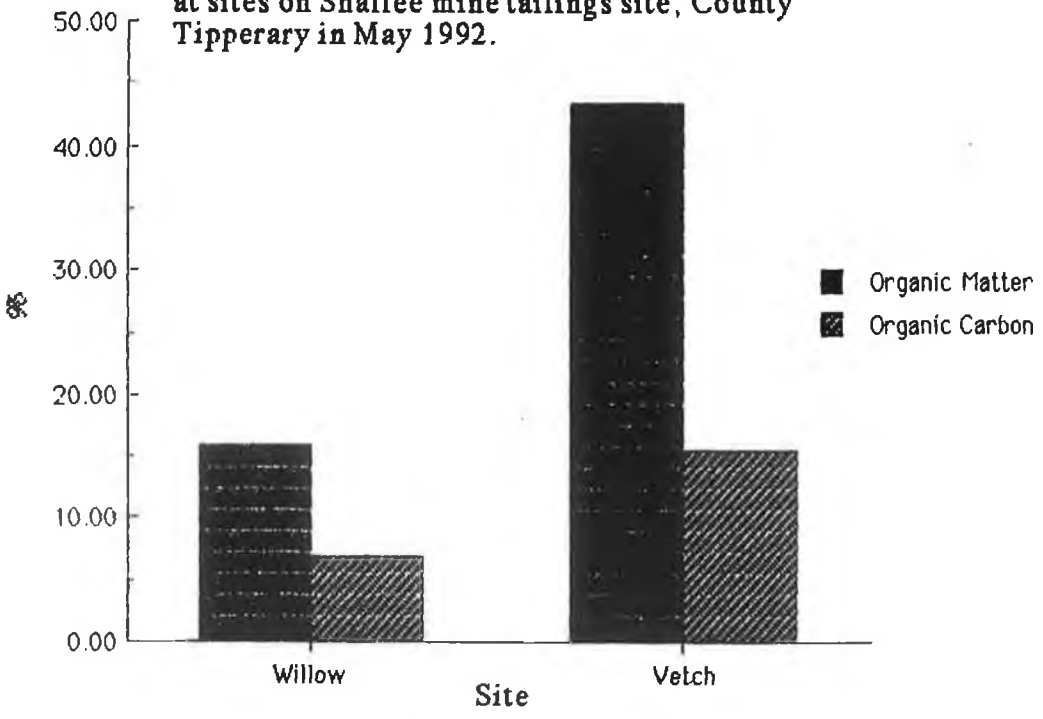


Figure 4.31
Available phosphorus distribution at sites on Shallee mine tailings site, County Tipperary in May 1992.

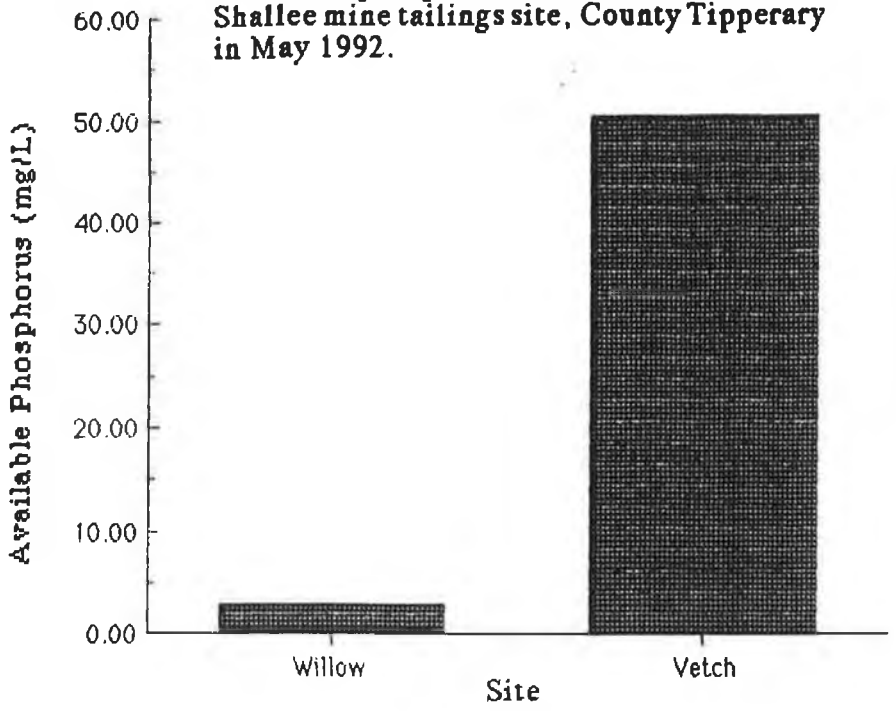


Figure 4.32
Exchangeable potassium distribution at sites on Shallee mine tailings site, County Tipperary in May 1992.

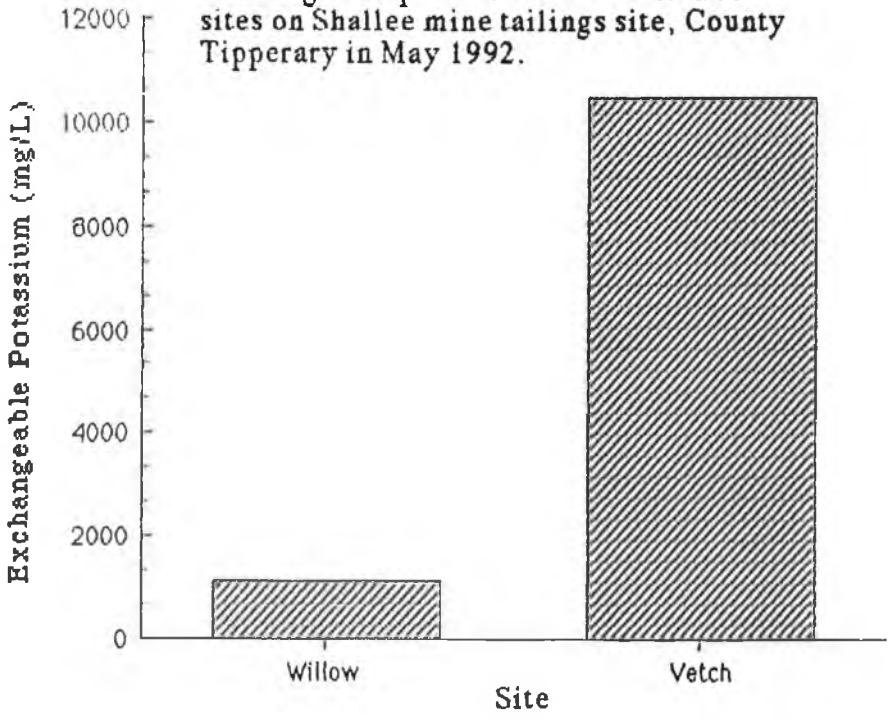


Figure 4.33
Microbiological distribution at sites on Shallee mine tailings site, County Tipperary in May 1992. (Duplicate sample results presented)

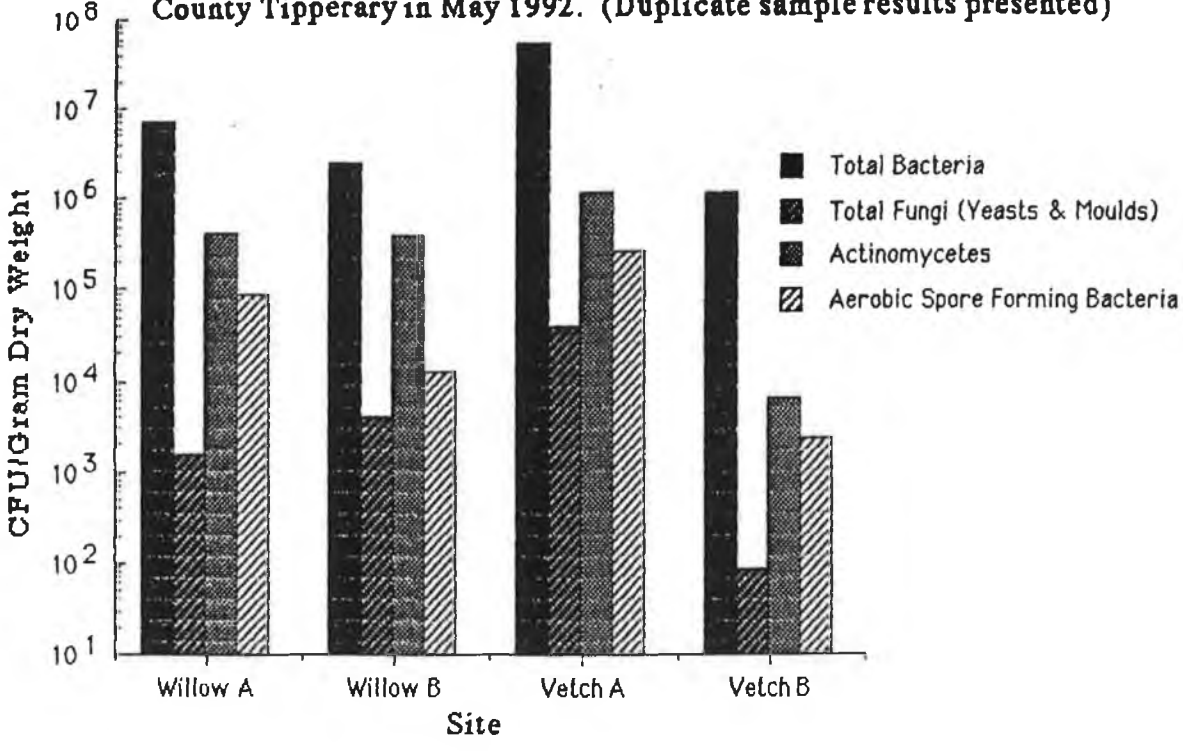
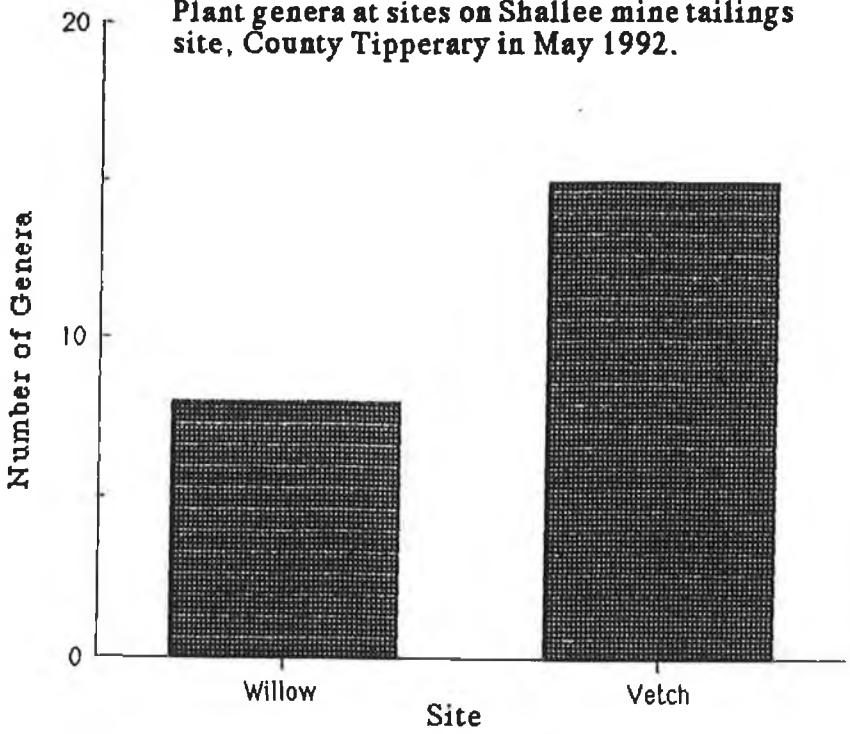


Table 4.13
Plant distribution at sites on Shallee mine tailings site, County Tipperary in May 1992.

Site	Family	Genus/Species	Common Name
Willow	Leguminosae	*Vicia sepium*	Bush Vetch
	Ericaceae	*Calluna vulgaris*	Heather
	Ericaceae	*Erica tetralix*	Cross-Leaved Heath
	Rosaceae	*Potentilla erecta*	Tormentil
	Scrophulariaceae	*Veronica officinalis*	Heath Speedwell
	Equisetaceae	*Equisetum palustre*	Marsh Horsetail
	Salicaceae	*Salix aurita*	Eared Willow
	Unknown	Unknown	Moss species
Vetch	Gramineae	*Dactylis glomerata*	Cocksfoot
	Gramineae	*Holcus lanatus*	Yorkshire Fog
	Leguminosae	*Lotus corniculatus*	Birdsfoot Trefoil
	Ericaceae	*Calluna vulgaris*	Heather
	Ericaceae	*Erica cinerea*	Bell Heather
	Rosaceae	*Rosa* species	Rose species
	Linaceae	*Linum catharticum*	Purging Flax
	Caryophyllaceae	*Cerastium fontanum*	Common Mouse-Ear
	Caryophyllaceae	*Cerastium* species	Mouse-Ear species
	Plantaginaceae	*Plantago media*	Hoary Plantain
	Ranunculaceae	*Ranunculus acris*	Meadow Buttercup
	Guttiferae	*Hypericum perforatum*	Perforate St. John's Wort
	Salicaceae	*Salix aurita*	Eared Willow
	Unknown	*Pseudoscleropodium purum*	Moss species
	Unknown	*Thuidium tamariscinum*	Moss species
	Unknown	*Pleurozium schreberi*	Moss species
	Unknown	Unknown	Moss species

Figure 4.34
Plant genera at sites on Shallee mine tailings site, County Tipperary in May 1992.



4:4 SILVERMINES

4:4.1 Introduction

Section 4:4 presents physical, chemical, textural, microbiological and botanical results obtained from sites along Silvermines mine tailings site in 1990/1991 and physical, chemical, microbiological and botanical results obtained from sites along this mine tailings site in 1992. The physical, chemical, textural and microbiological results are presented in graphic form with the corresponding data in Appendix 2. The botanical results are presented in tabular form with some data in graphic form.

Figures 4.35 to 4.39 show the physical and chemical distribution of five parameters at sites rehabilitated on the mine tailings site in 1985, 1986, 1987 and 1988 and sampled in 1990/1991. Figure 4.40 shows the distribution of clay and silt at three of these sites in 1990/1991. Figures 4.41 and 4.42 show the bulk density distribution at sites along good and poorly rehabilitated sections of the mine tailings site in 1990/1991. These sites may have originated at the perimeter of the mine tailings site. Figure 4.43 shows the microbiological distribution of two parameters at sites rehabilitated in 1985, 1986, 1987 and 1988 and sampled in 1991. Table 4.16 presents a breakdown of the plants occurring at sites along the mine tailings site in 1991 with Figure 4.44 showing the distribution of genera at them. These sites originated at the perimeter of the mine tailings site and may have differed in location from the previous parameters sites. Statistical results are presented in Tables 4.14 and 4.15.

Figures 4.45 to 4.49 show the physical and chemical distribution of six parameters at sites rehabilitated on the mine tailings site in 1985, 1986, 1987 and 1988 and sampled in 1992. Figures 4.50 and 4.51 show the microbiological distribution of four parameters at these sites in 1992. Table 4.19 presents a breakdown of the plants occurring at these sites in 1992 while Figure 4.52 shows the distribution of genera. These sites may have differed in location from those sampled in 1990/1991. Statistical results are presented in Tables 4.17 and 4.18.

Figure 4.35
pH distribution at rehabilitated sites on Silvermines mine tailings site, County Tipperary in 1990/1991.

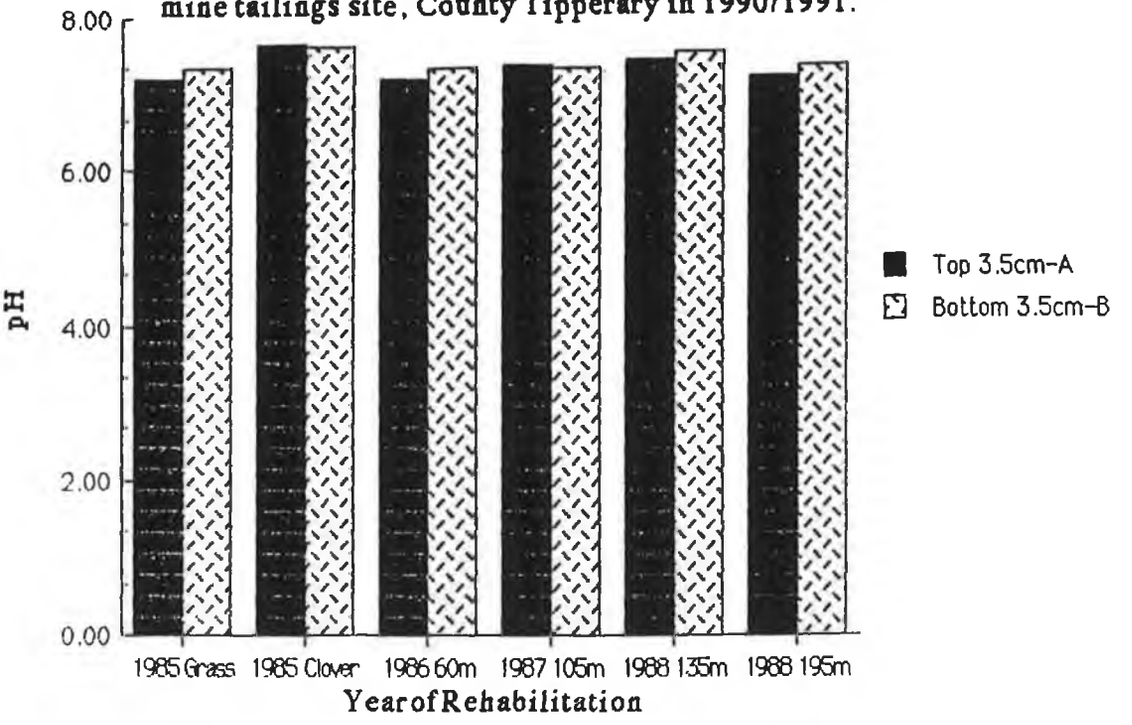


Figure 4.36
Organic matter distribution at rehabilitated sites on Silvermines mine tailings site, County Tipperary in 1990/1991.

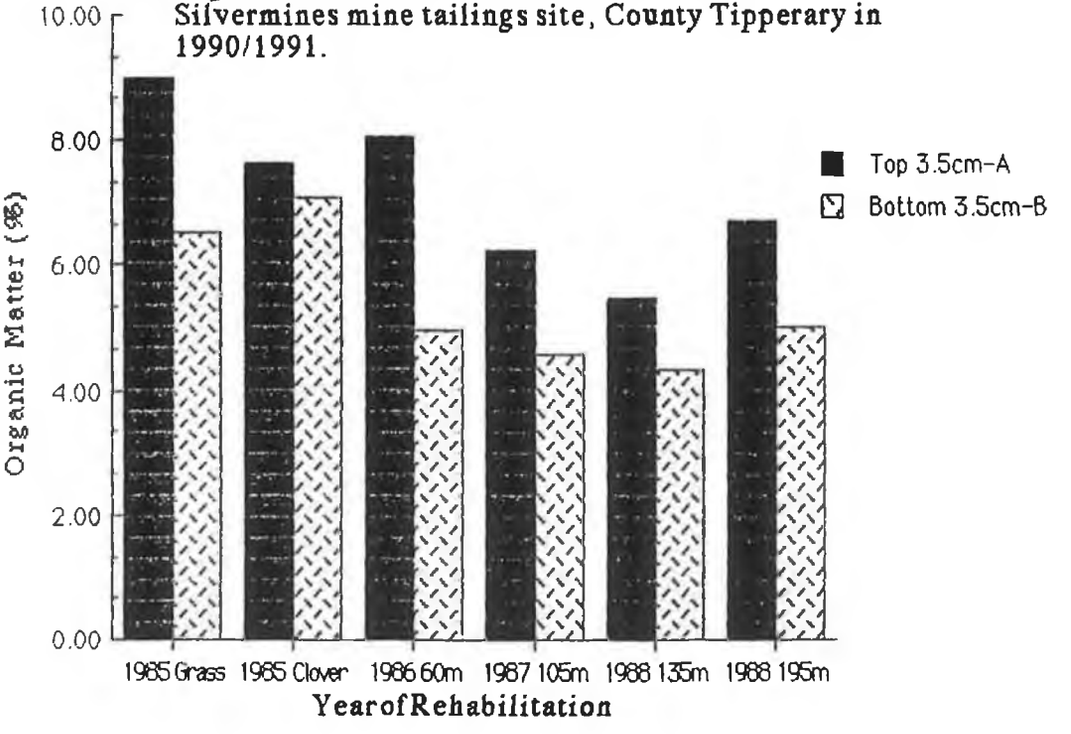


Figure 4.37
Kjeldahl nitrogen distribution at rehabilitated sites on Silvermines mine tailings site, County Tipperary in 1990/1991.

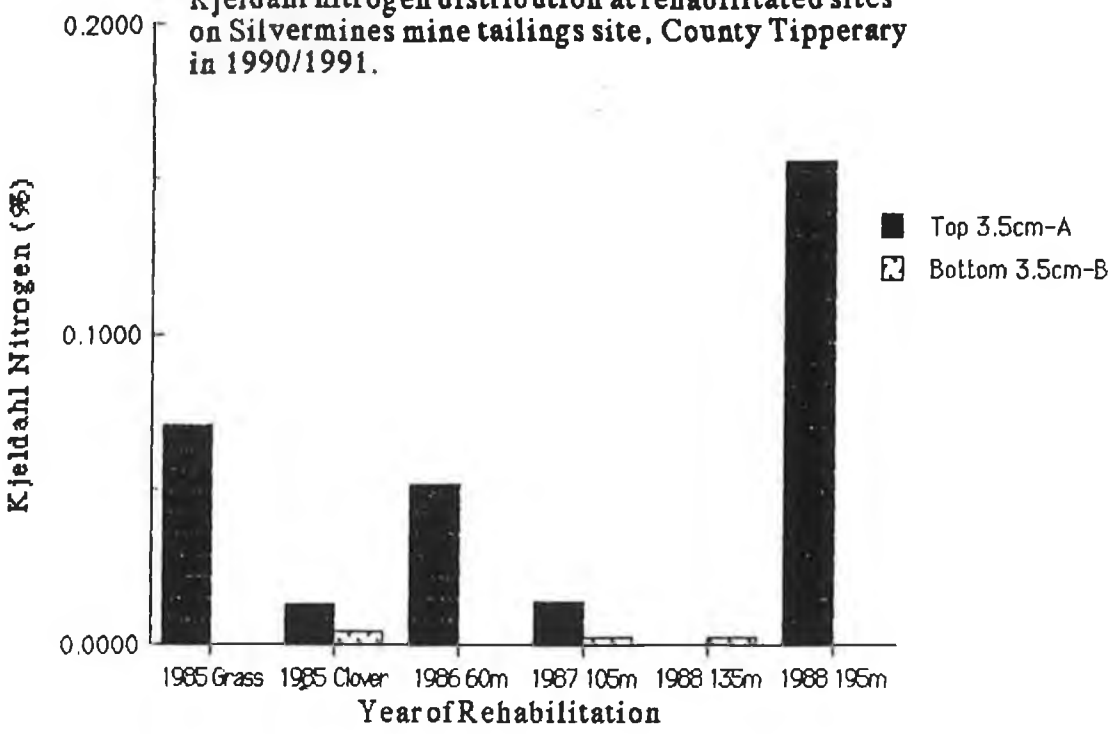


Figure 4.38
Available phosphorus distribution at rehabilitated sites on Silvermines mine tailings site, County Tipperary in 1990/1991.

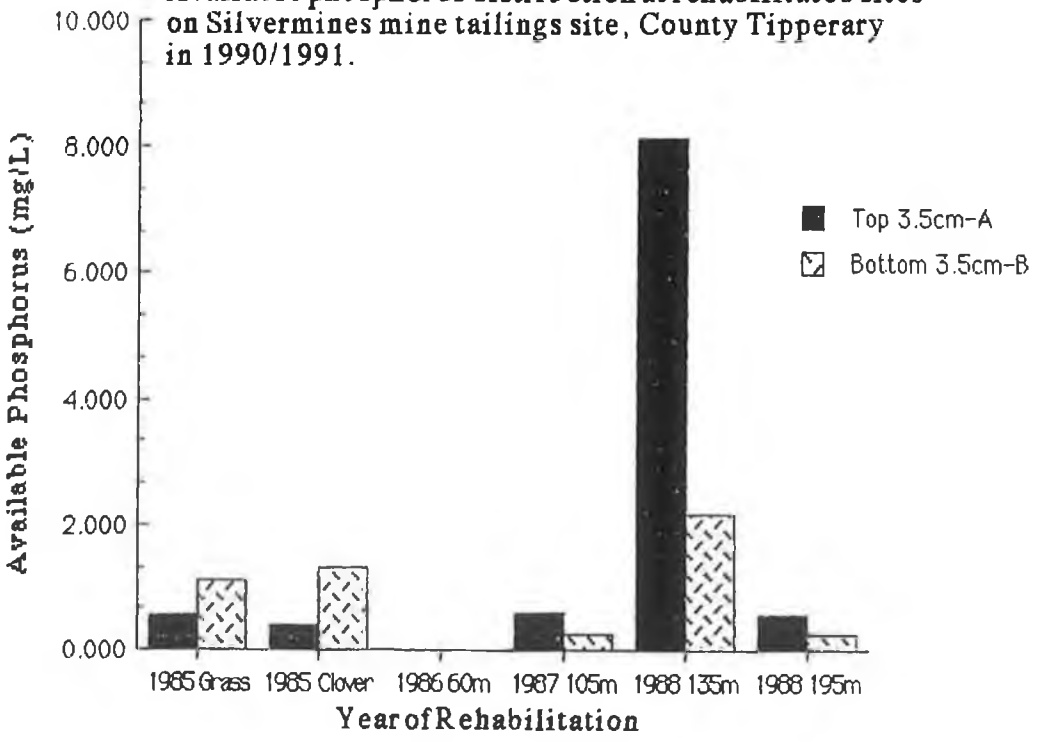


Figure 4.39
Exchangeable potassium distribution at rehabilitated sites on Silvermines mine tailings site, County Tipperary in 1990/1991.

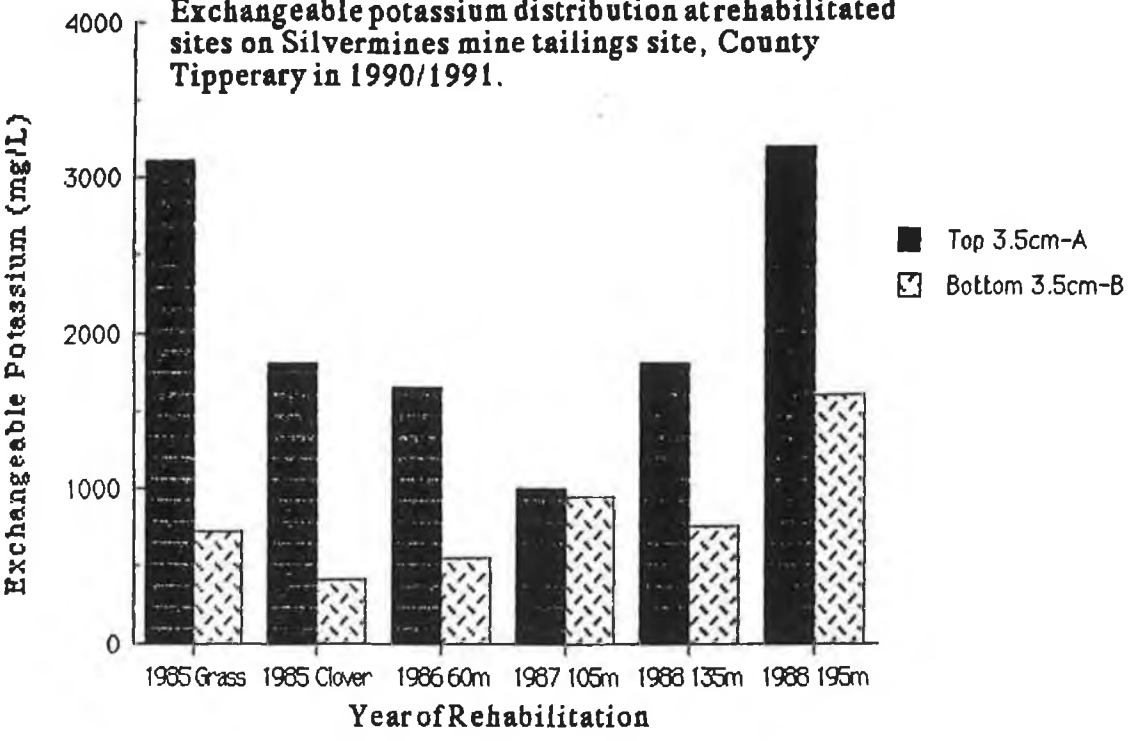


Figure 4.40
Clay and silt distribution at rehabilitated sites on Silvermines mine tailings site, County Tipperary in 1990/1991.

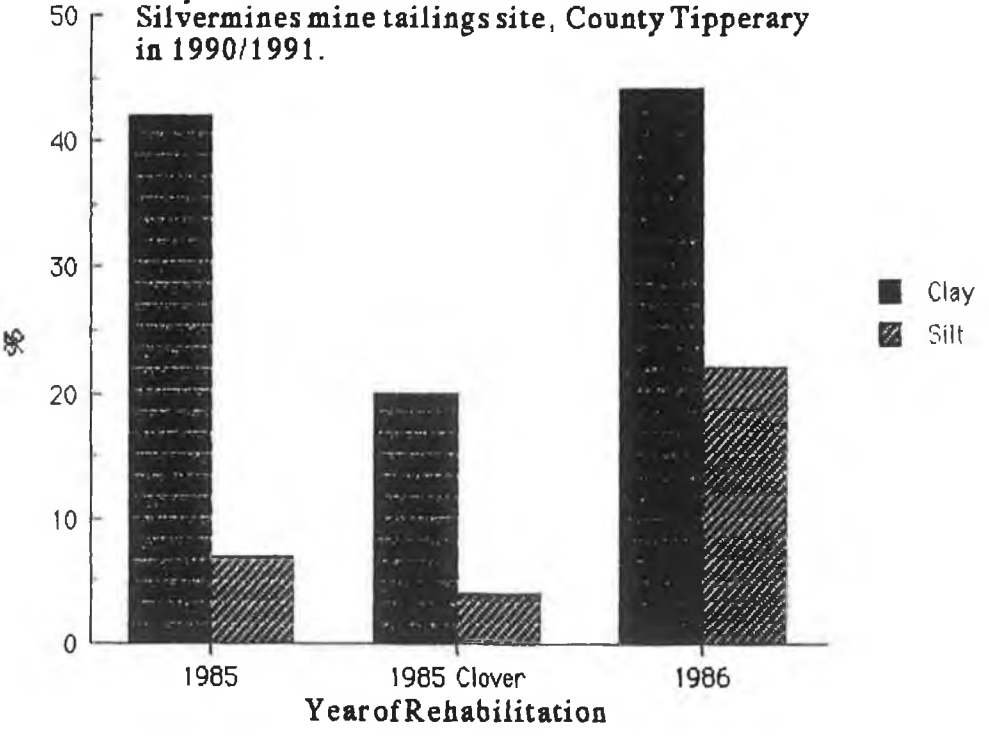


Figure 4.41
Bulk density distribution at 20m intervals along a good section of Silvermines mine tailings site, County Tipperary in 1990/1991. (Sites may have originated at the perimeter of the mine tailings site)

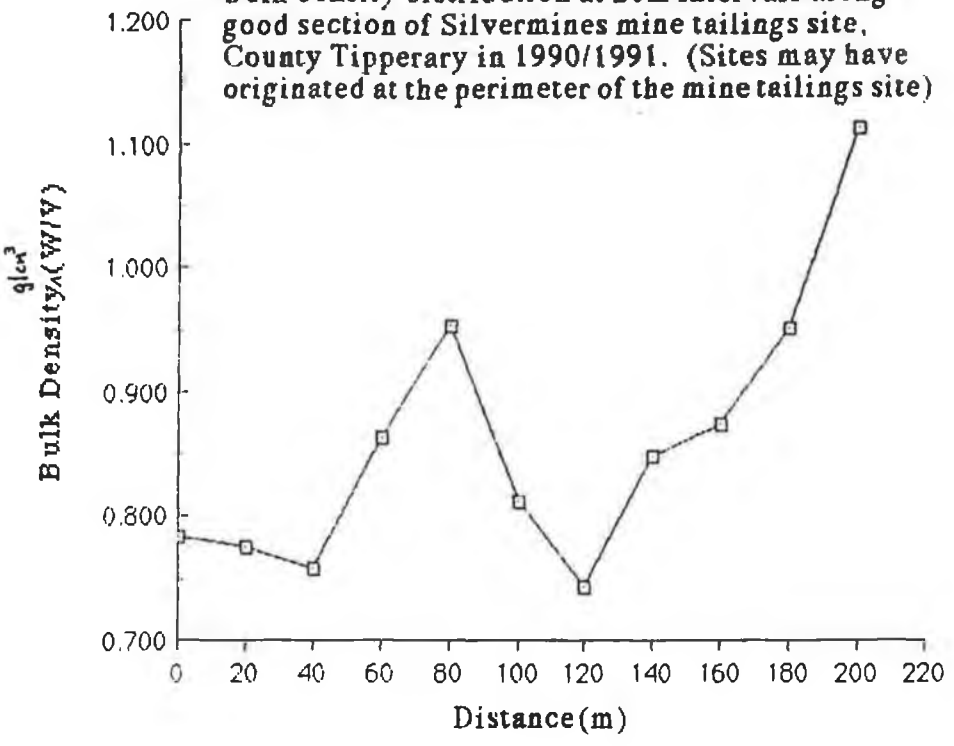


Figure 4.42
Bulk density distribution at 30m intervals along a poorly rehabilitated section of Silvermines mine tailings site, County Tipperary in 1990/1991. (Sites may have originated at the perimeter of the mine tailings site)

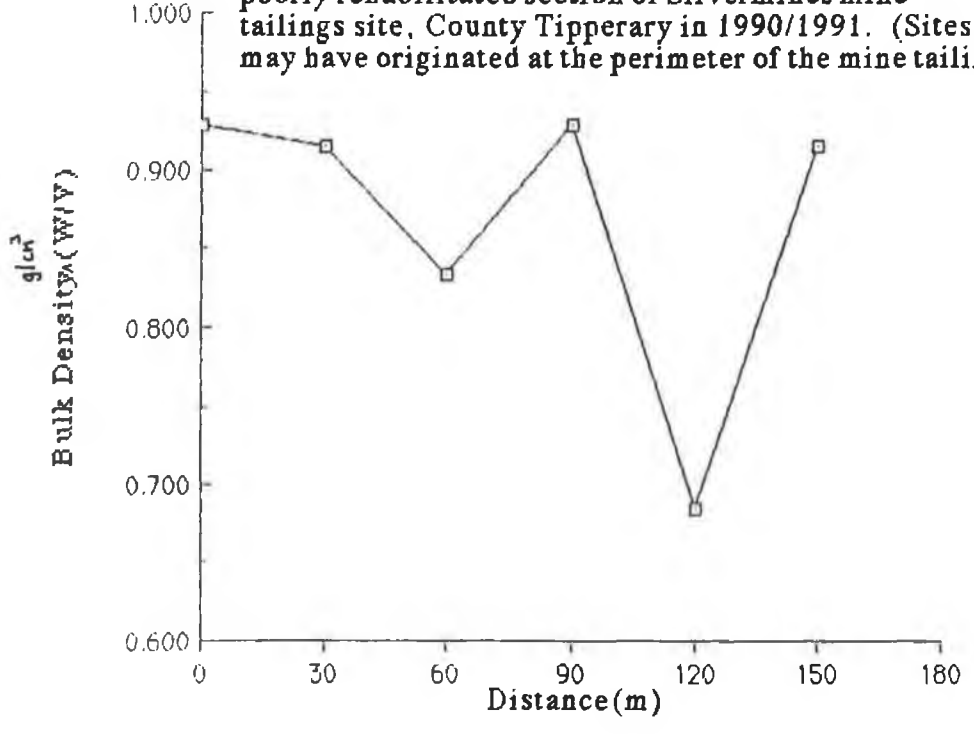


Figure 4.43
Microbiological distribution at rehabilitated sites on Silvermines mine tailings site, County Tipperary in April 1991.

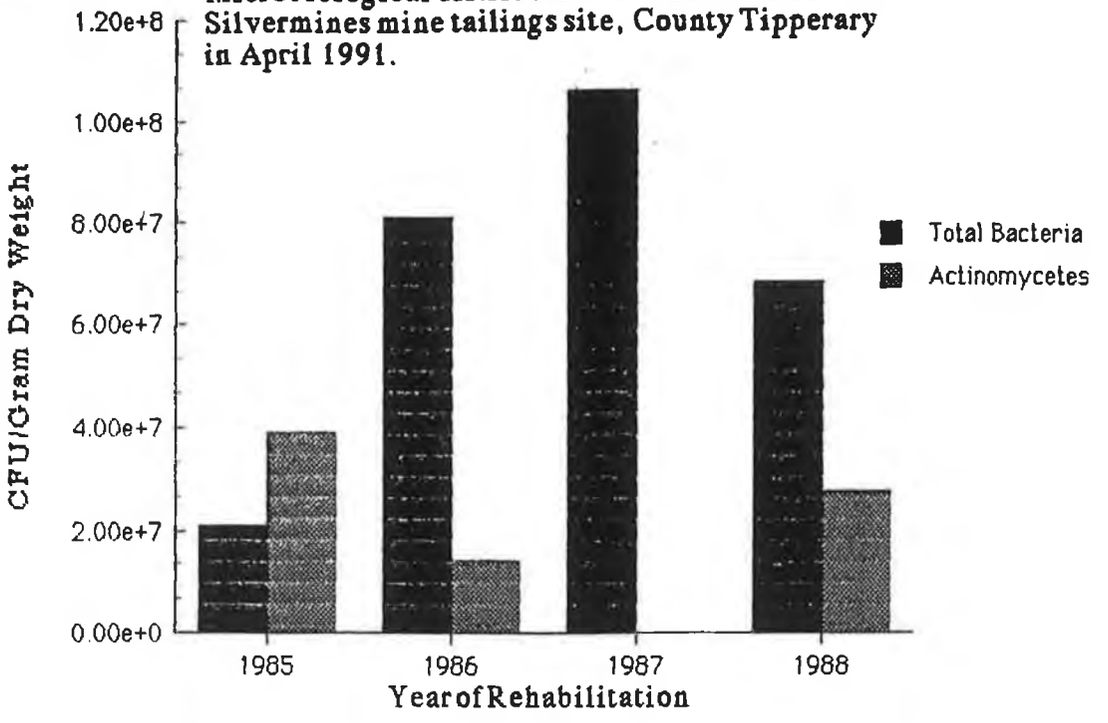


Table 4.14

Statistical results assessing the relationship between bulk density and their corresponding sites at 20m and 30m intervals along good* and poorly rehabilitated* sections respectively of Silvermines mine tailings site, County Tipperary in 1990/1991.
(Sites may have originated at the perimeter of the mine tailings site)

				Significance Level	
Parameters Compared	**Curve Fit**	**r**	**r^2**	**1%**	**5%**
Bulk Density V's Distance-Good Section*	Simple	0.675	0.455	-	+
Log Bulk Density V's Distance-Poor Section*	Exponential	-0.373	0.139	-	-

Table 4.15

Statistical results assessing the relationship between microbiological parameters and their corresponding rehabilitated sites along Silvermines mine tailings site, County Tipperary in April 1991.

				Significance Level	
Parameters Compared	**Curve Fit**	**r**	**r^2**	**1%**	**5%**
Log Total Bacteria V's Year of Rehabilitation	Exponential	0.691	0.477	-	-
Actinomycetes V's Year of Rehabilitation	Simple	-0.290	0.084	-	-

Note

Positive (+) = The correlation coefficient is significant at the stated significance level.

Negative (-) = The correlation coefficient is not significant at the stated significance level.

Table 4.16

Plant distribution at sites originating at the perimeter of Silvermines mine tailings site, County Tipperary *circa* September/October 1991.

Distance (m)	Family	Genus/Species	Common Name
0	Gramineae	*Festuca rubra*	Creeping Red Fescue
30	Gramineae	*Festuca rubra*	Creeping Red Fescue
	Gramineae	*Poa* species	Meadow-Grass species
	Leguminosae	*Trifolium repens*	White Clover
60	Gramineae	*Festuca rubra*	Creeping Red Fescue
	Gramineae	*Agrostis stolonifera*	Creeping Bent
	Leguminosae	*Trifolium repens*	White Clover
90	Gramineae	*Festuca rubra*	Creeping Red Fescue
	Gramineae	*Agrostis stolonifera*	Creeping Bent
	Leguminosae	*Trifolium repens*	White Clover
120	Gramineae	*Festuca rubra*	Creeping Red Fescue
	Gramineae	*Poa* species	Meadow-Grass species
	Leguminosae	*Trifolium repens*	White Clover
180	Gramineae	*Festuca* species	Fescue species
	Gramineae	*Agrostis stolonifera*	Creeping Bent
	Leguminosae	*Trifolium repens*	White Clover
240	Gramineae	*Agrostis stolonifera*	Creeping Bent
300	Gramineae	*Agrostis stolonifera*	Creeping Bent

Figure 4.44
Plant genera at sites originating at the perimeter of Silvermines mine tailings site, County Tipperary circa September/October 1991.

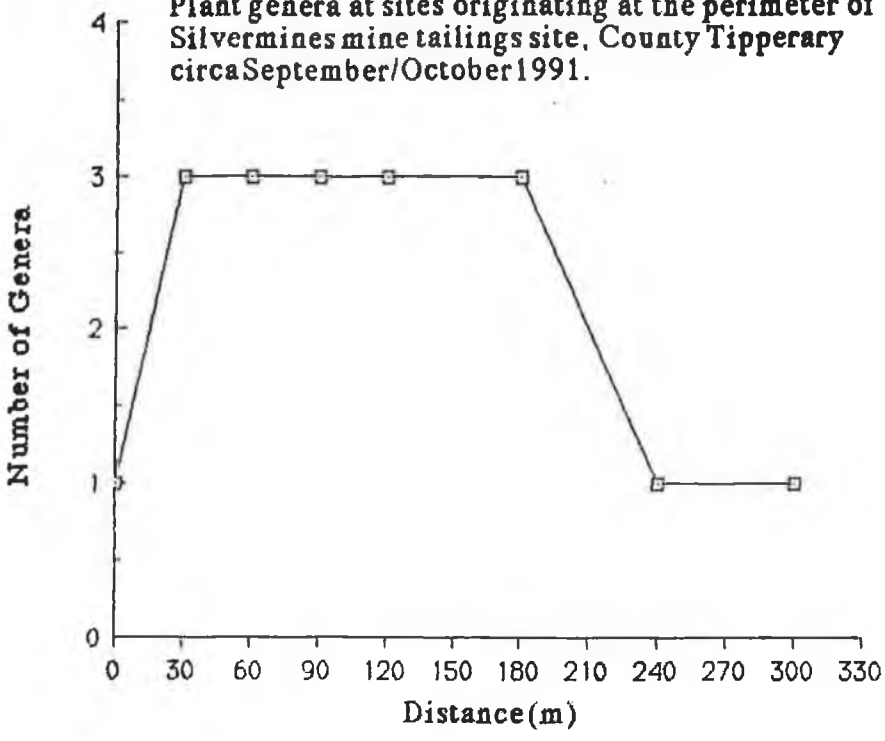


Figure 4.45
pH distribution at rehabilitated sites on Silvermines mine tailings site, County Tipperary in May 1992.

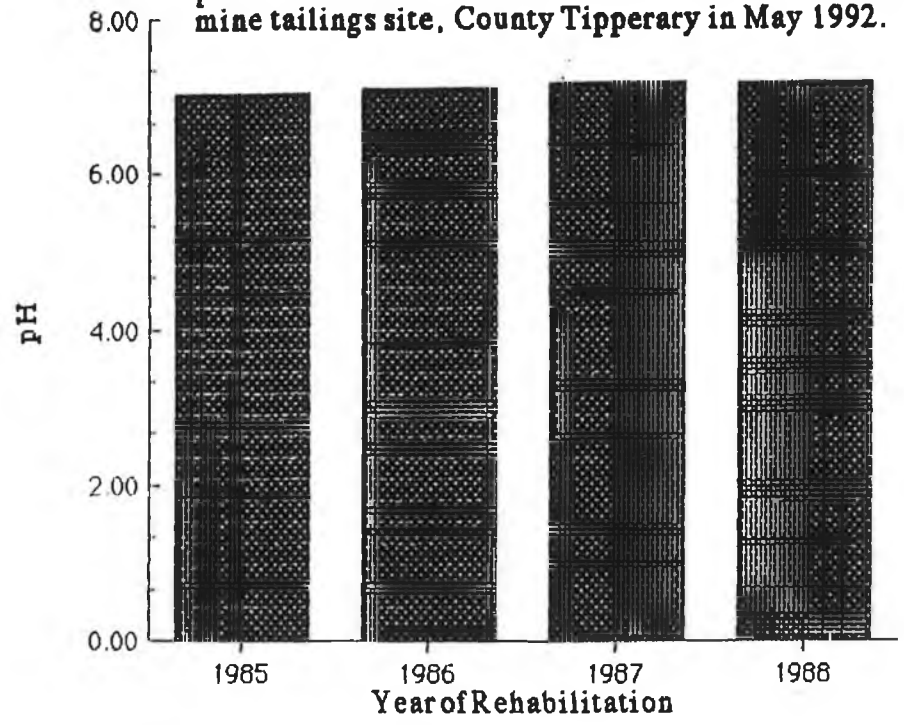


Figure 4.46
Organic matter and organic carbon distribution at rehabilitated sites on Silvermines mine tailings site, County Tipperary in May 1992.

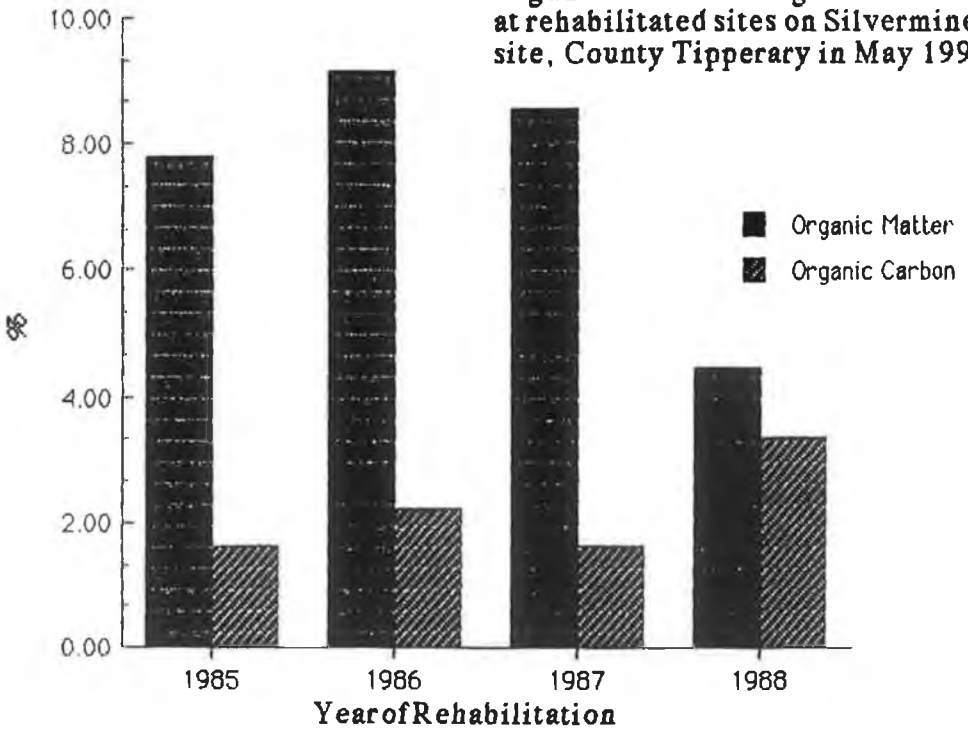


Figure 4.47
Kjeldahl nitrogen distribution at rehabilitated sites on Silvermines mine tailings site, County Tipperary in May 1992.

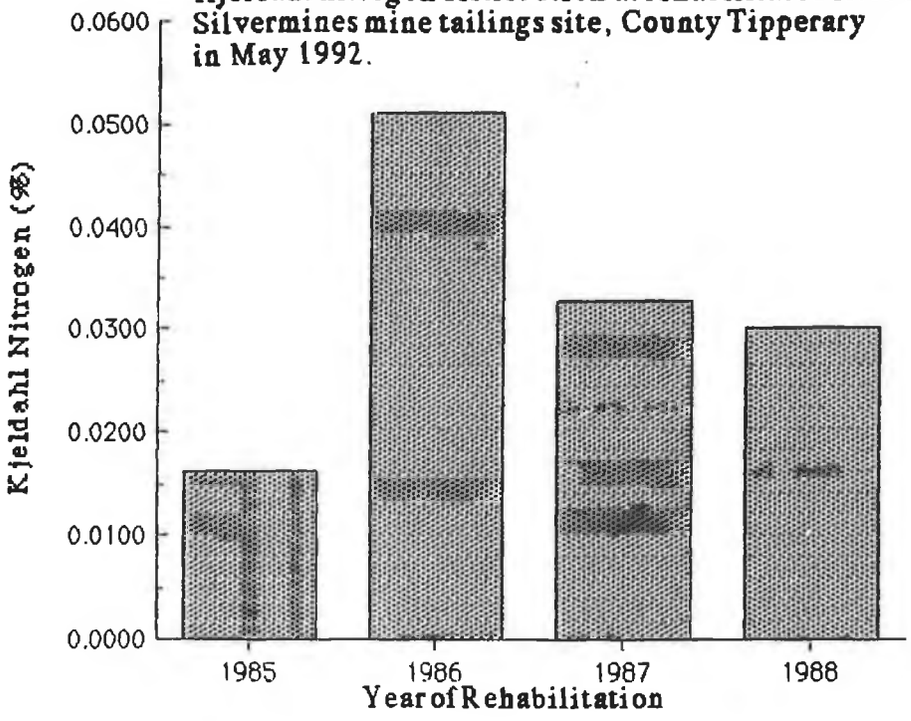
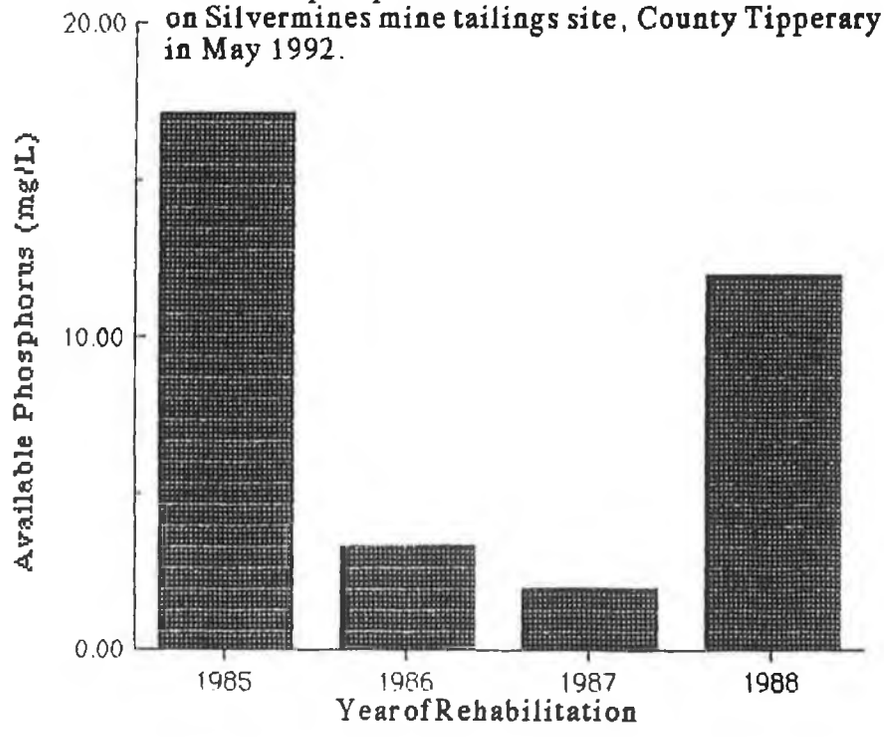


Figure 4.48
Available phosphorus distribution at rehabilitated sites on Silvermines mine tailings site, County Tipperary in May 1992.



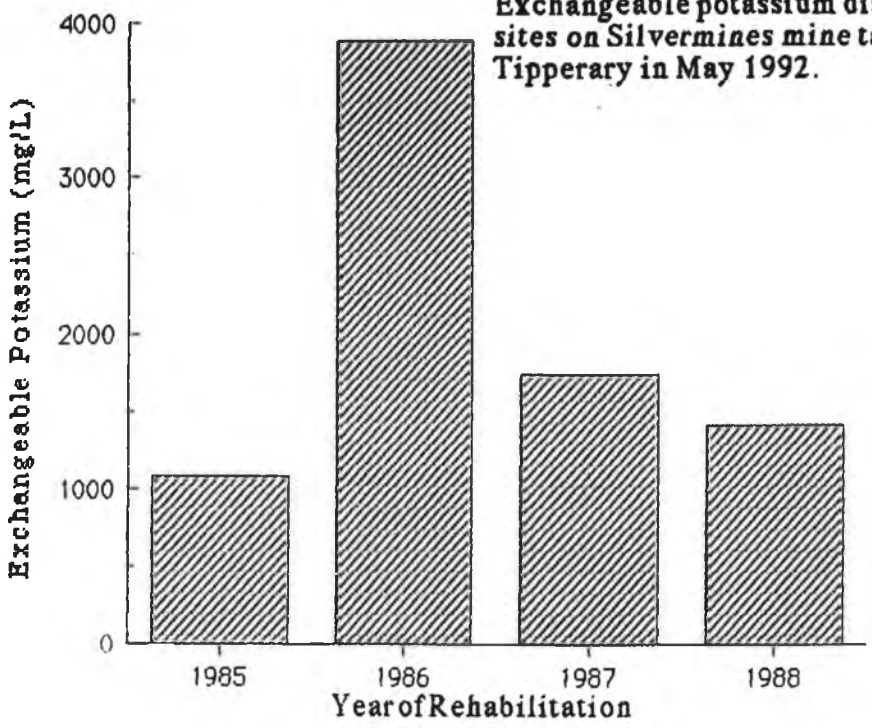


Figure 4.49
Exchangeable potassium distribution at rehabilitated sites on Silvermines mine tailings site, County Tipperary in May 1992.

Figure 4.50
Microbiological distribution at rehabilitated sites on Silvermines mine tailings site, County Tipperary in May 1992. (Duplicate sample results presented)

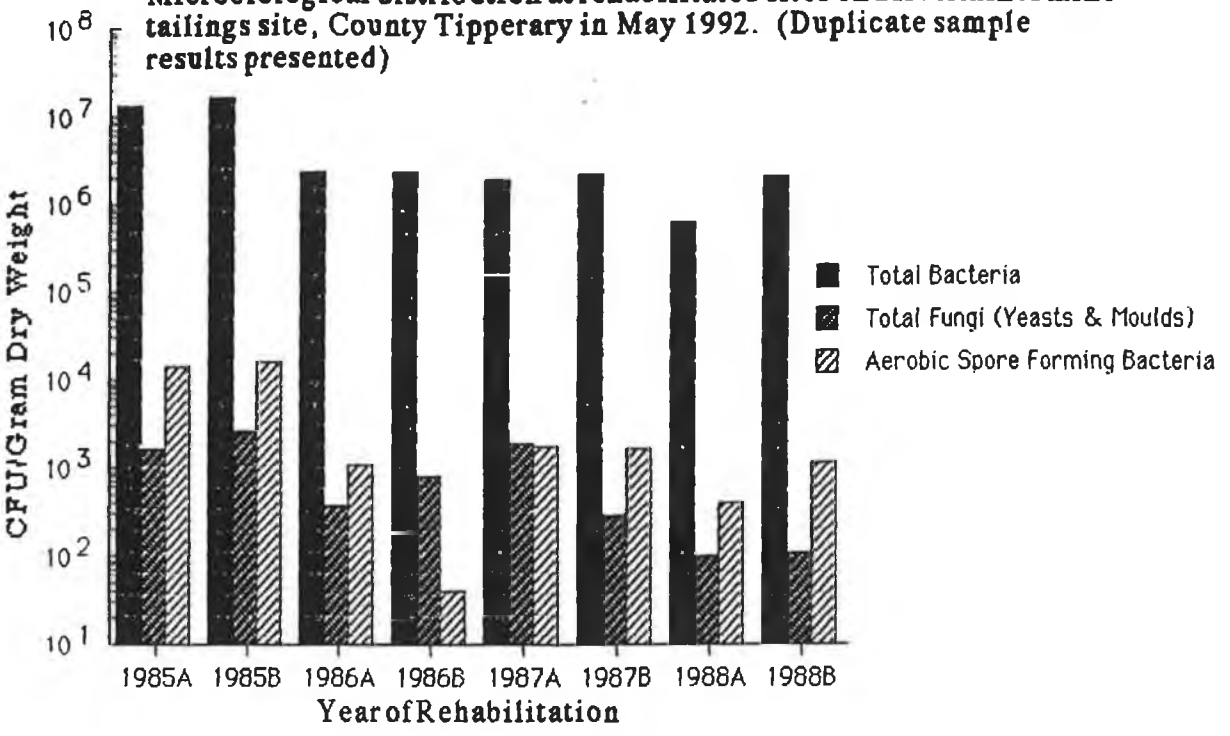


Figure 4.51
Microbiological distribution at rehabilitated sites on Silvermines mine tailings site, County Tipperary in May 1992. (Duplicate sample results presented)

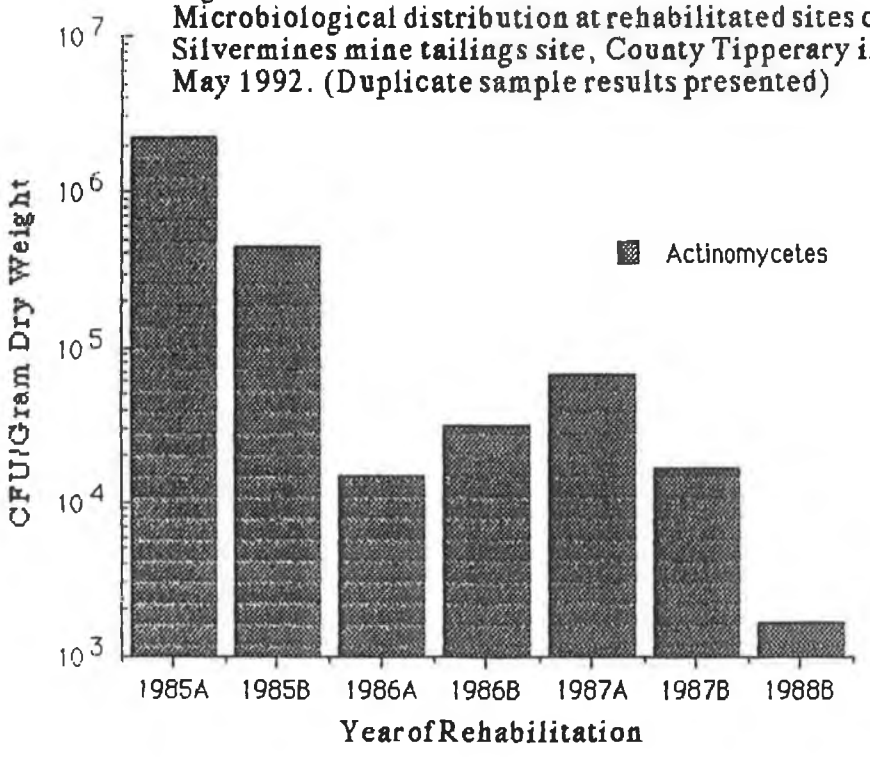


Table 4.17

Statistical results assessing the relationship between physical and chemical parameters and their corresponding rehabilitated sites along Silvermines mine tailings site, County Tipperary in May 1992.

				Significance Level	
Parameters Compared	**Curve Fit**	**r**	**r^2**	**1%**	**5%**
pH V's Year of Rehabilitation	Simple	0.921	0.848	-	-
Log Org. M V's Year of Rehabilitation	Exponential	-0.683	0.467	-	-
Org. C V's Year of Rehabilitation	Simple	0.728	0.530	-	-
Log Kjel. N V's Year of Rehabilitation	Exponential	0.385	0.148	-	-
Avail. P V's Year of Rehabilitation	Simple	-0.303	0.092	-	-
Exch. K V's Year of Rehabilitation	Simple	-0.118	0.014	-	-

Table 4.18

Statistical results assessing the relationship between microbiological parameters and their corresponding rehabilitated sites along Silvermines mine tailings site, County Tipperary in May 1992.

				Significance Level	
Parameters Compared	**Curve Fit**	**r**	**r^2**	**1%**	**5%**
Log Total Bacteria V's Year of Rehabilitation	Exponential	-0.872	0.760	+	+
Log Total Fungi V's Year of Rehabilitation	Exponential	-0.819	0.670	-	+
Actinomycetes V's Year of Rehabilitation	Simple	-0.616	0.379	-	-
Aer. Spore Form. Bact. V's Year of Rehabilitation	Simple	-0.762	0.581	-	+

Note

Positive (+) = The correlation coefficient is significant at the stated significance level.

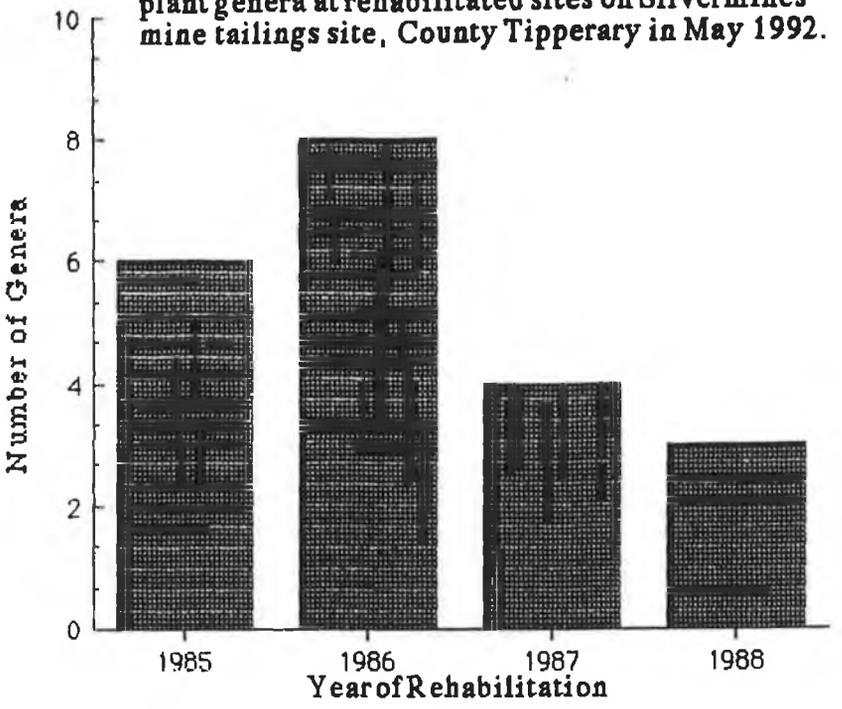
Negative (-) = The correlation coefficient is not significant at the stated significance level.

Table 4.19

Plant distribution at rehabilitated sites on Silvermines mine tailings site, County Tipperary in May 1992.

Year*	Family	Genus/Species	Common Name
1985	Gramineae	*Festuca rubra*	Creeping Red Fescue
	Gramineae	*Festuca arundinacea*	Tall Fescue
	Gramineae	*Agrostis* species	Bent species
	Gramineae	*Poa pratensis*	Smooth Meadow-Grass
	Gramineae	*Poa trivialis*	Rough Meadow-Grass
	Gramineae	*Poa* species	Meadow-Grass species
	Gramineae	*Dactylis glomerata*	Cocksfoot
	Ranunculaceae	*Ranunculus acris*	Meadow Buttercup
	Rosaceae	*Sorbus aucuparia*	Rowan or Mountain Ash
1986	Gramineae	*Festuca rubra*	Creeping Red Fescue
	Gramineae	*Festuca arundinacea*	Tall Fescue
	Gramineae	*Agrostis stolonifera*	Creeping Bent
	Gramineae	*Poa palustris*	Swamp Meadow-Grass
	Gramineae	*Dactylis glomerata*	Cocksfoot
	Leguminosae	*Trifolium repens*	White Clover
	Leguminosae	*Trifolium pratense*	Red Clover
	Leguminosae	*Trifolium* species	Clover species
	Leguminosae	*Trifolium campestre* or *Medicago lupulina*	Hop Trefoil or Black Medick
	Ranunculaceae	*Ranunculus acris*	Meadow Buttercup
	Salicaceae	*Salix atrocinerea*	Grey Willow
	Brassicaceae	Unknown	Unknown
1987	Gramineae	*Festuca rubra*	Creeping Red Fescue
	Gramineae	*Festuca arundinacea*	Tall Fescue
	Gramineae	*Poa trivialis*	Rough Meadow-Grass
	Leguminosae	*Trifolium repens*	White Clover
	Unknown	*Funaria hygrometrica*	Moss species
1988	Gramineae	*Festuca rubra*	Creeping Red Fescue
	Gramineae	*Festuca arundinacea*	Tall Fescue
	Gramineae	*Poa trivialis*	Rough Meadow-Grass
	Leguminosae	*Trifolium* species	Clover species

Figure 4.52
plant genera at rehabilitated sites on Silvermines mine tailings site, County Tipperary in May 1992.



4:5 TYNAGH

4:5.1 Introduction

Section 4:5 presents physical, chemical, textural and microbiological results obtained from sites along Tynagh mine tailings site in 1990/1991 and physical, chemical and microbiological results obtained along a transect on this mine tailings site in 1993. The physical, chemical, textural and microbiological results are presented in graphic form with the corresponding data in Appendix 2.

Figures 4.53 to 4.57 show the physical and chemical distribution of five parameters at sites along a transect on this mine tailings site in 1990/1991. These sites may have originated at the perimeter of the mine tailings site. Figure 4.58 shows the distribution of clay and silt at five sites in 1990/1991. Figure 4.59 shows the microbiological distribution of two parameters at four sites on this mine tailings site in 1991. Statistical results are presented in Table 4.20.

Figures 4.60 to 4.64 show the physical and chemical distribution of six parameters at 30m intervals from the perimeter of the mine tailings site in 1993. Figure 4.65 shows the microbiological distribution of four parameters along this same area and at the same sampling intervals in 1993. Statistical results are presented in Tables 4.21 and 4.22.

Figure 4.53
pH distribution at sites along Tynagh mine tailings site, County Galway in 1990/1991. (Sites may have originated at the perimeter of the mine tailings site)

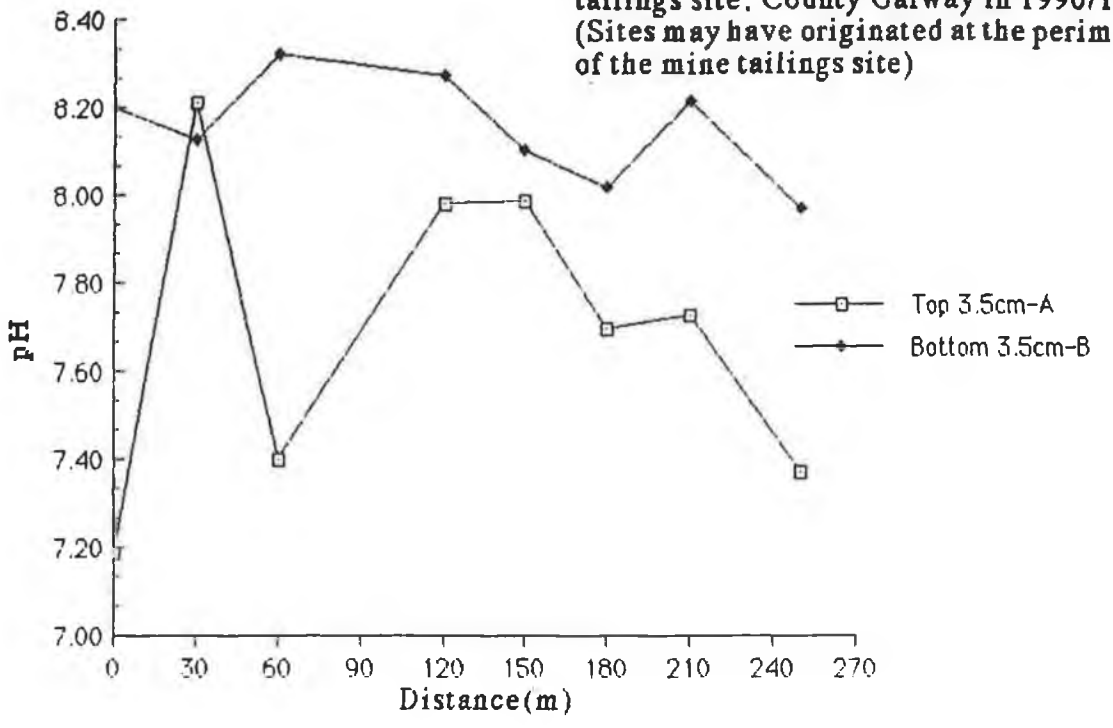
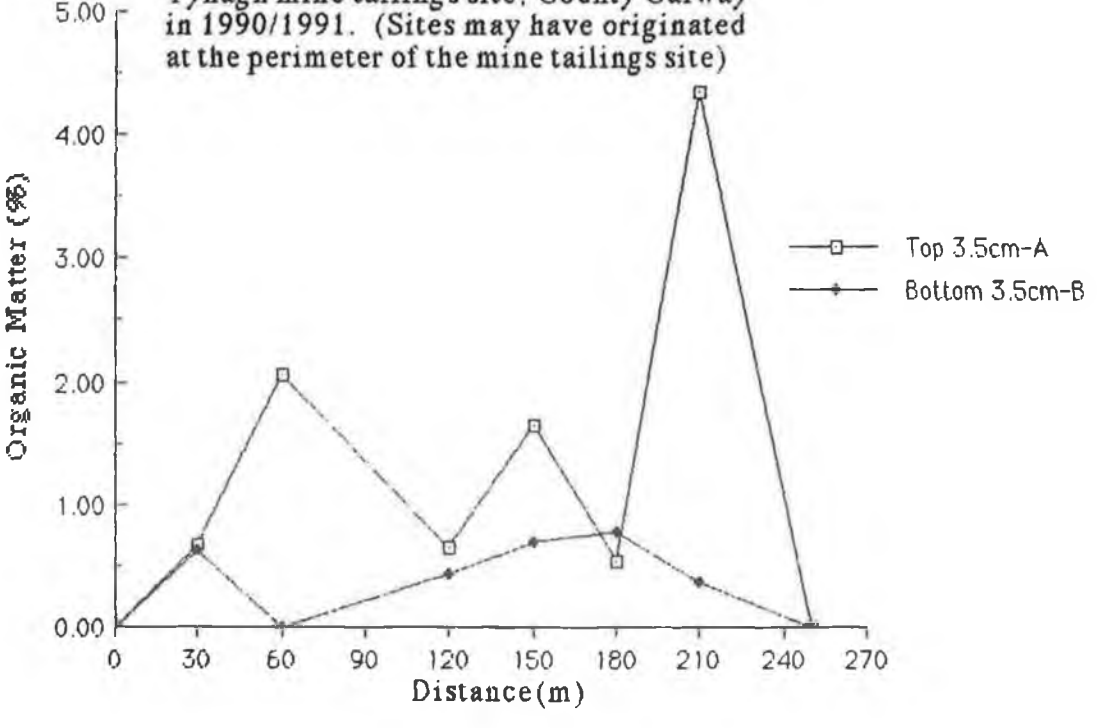


Figure 4.54
Organic matter distribution at sites along Tynagh mine tailings site, County Galway in 1990/1991. (Sites may have originated at the perimeter of the mine tailings site)



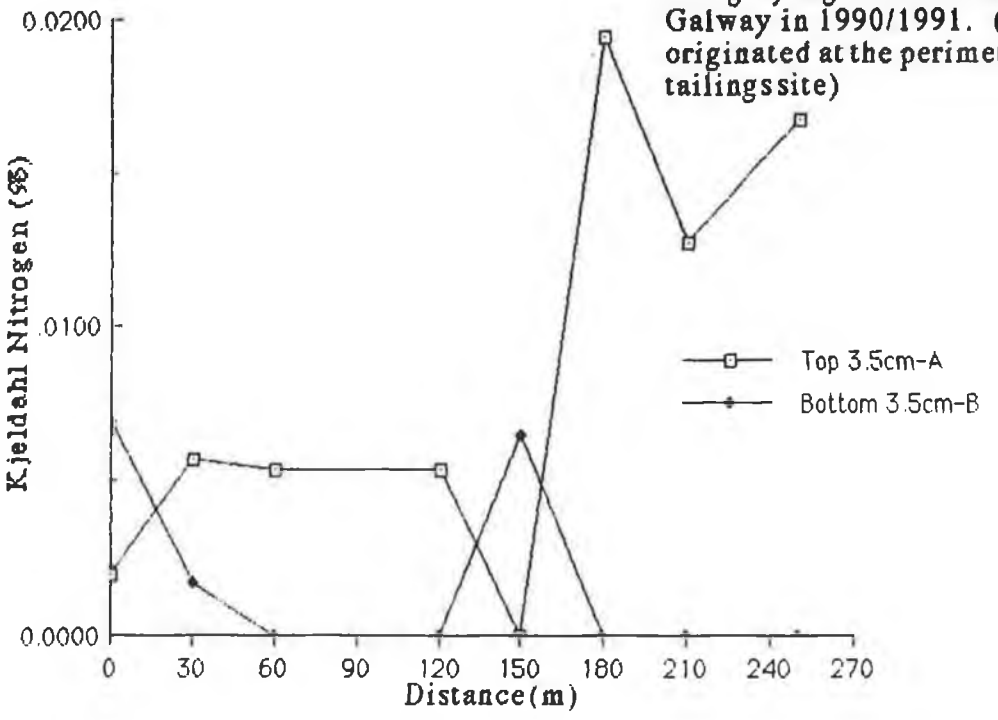


Figure 4.55
Kjeldahl nitrogen distribution at sites along Tynagh mine tailings site, County Galway in 1990/1991. (Sites may have originated at the perimeter of the mine tailings site)

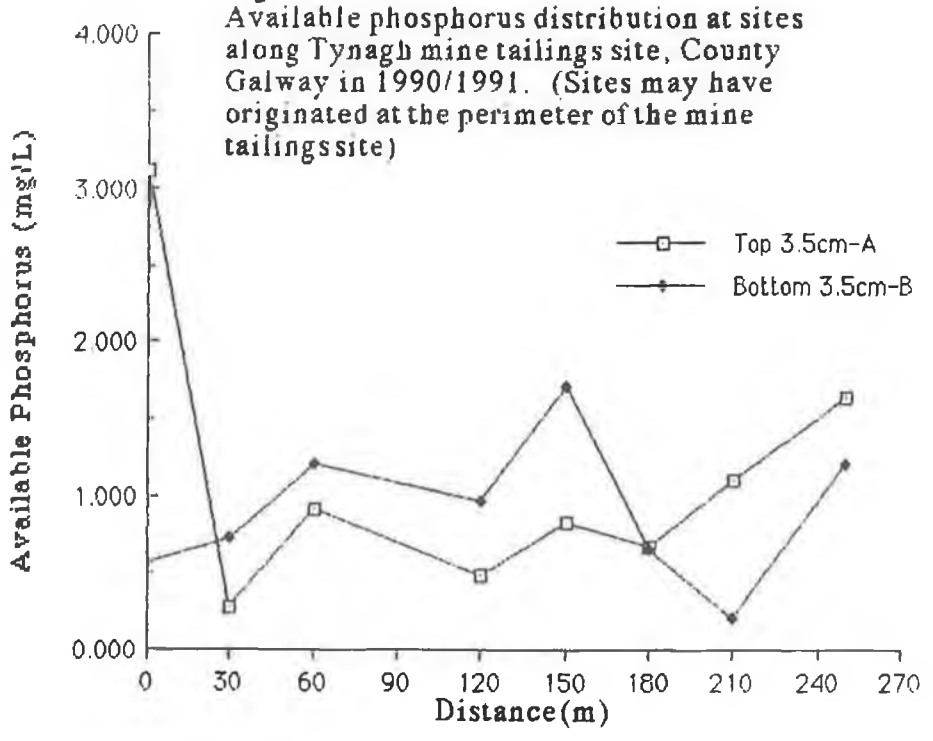


Figure 4.56
Available phosphorus distribution at sites along Tynagh mine tailings site, County Galway in 1990/1991. (Sites may have originated at the perimeter of the mine tailings site)

Figure 4.57
Exchangeable potassium distribution at sites along Tynagh mine tailings site, County Galway in 1990/1991. (Sites may have originated at the perimeter of the mine tailings site)

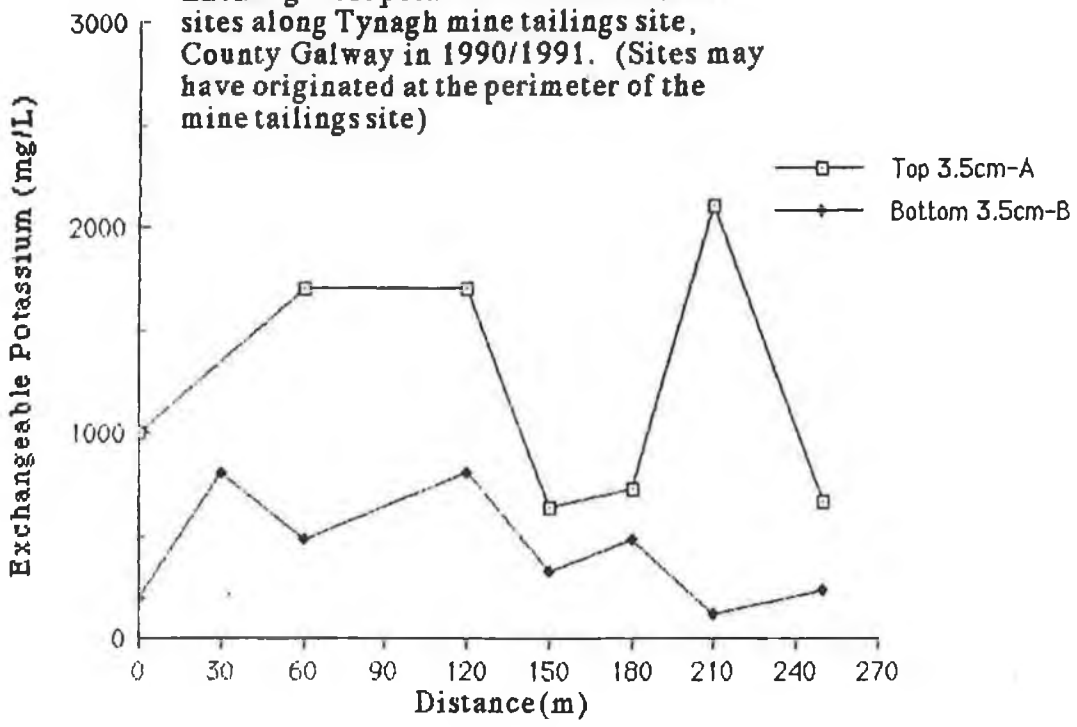


Figure 4.58
Clay and silt distribution at sites on Tynagh mine tailings site, County Galway in 1990/1991. (Sites may have originated at the perimeter of the mine tailings site)

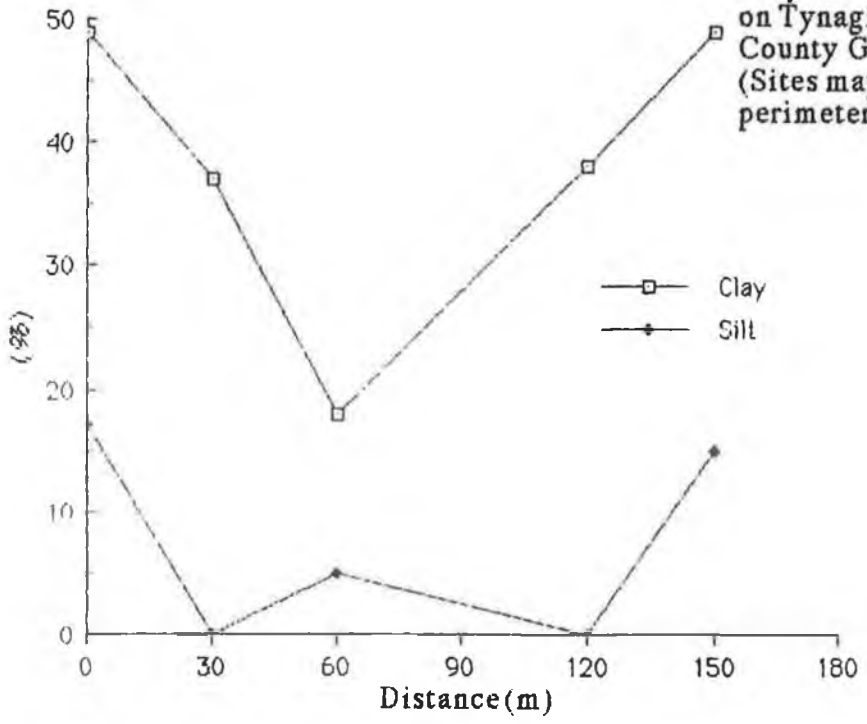


Table 4.20

Statistical results assessing the relationship between physical and chemical parameters and their corresponding sites along Tynagh mine tailings site, County Galway in 1990/1991.

(Sites may have originated at the perimeter of the mine tailings site)

				Significance Level	
Parameters Compared	**Curve Fit**	**r**	**r^2**	**1%**	**5%**
Log pH-A V's Distance	Exponential	-0.032	0.001	-	-
Log pH-B V's Distance	Exponential	-0.560	0.313	-	-
Org. M-A V's Distance	Simple	0.267	0.071	-	-
Org. M-B V's Distance	Simple	0.141	0.020	-	-
Kjel. N-A V's Distance	Simple	0.701	0.491	-	-
Kjel. N-B V's Distance	Simple	-0.456	0.208	-	-
Avail. P-A V's Distance	Simple	-0.215	0.046	-	-
Avail. P-B V's Distance	Simple	0.084	0.007	-	-
Log Exch. K-A V's Distance	Exponential	-0.241	0.058	-	-
Exch. K-B V's Distance	Simple	-0.377	0.142	-	-

Note

Positive (+) = The correlation coefficient is significant at the stated significance level.

Negative (-) = The correlation coefficient is not significant at the stated significance level.

Figure 4.59
Microbiological distribution at sites on Tynagh mine tailings site, County Galway in April 1991.

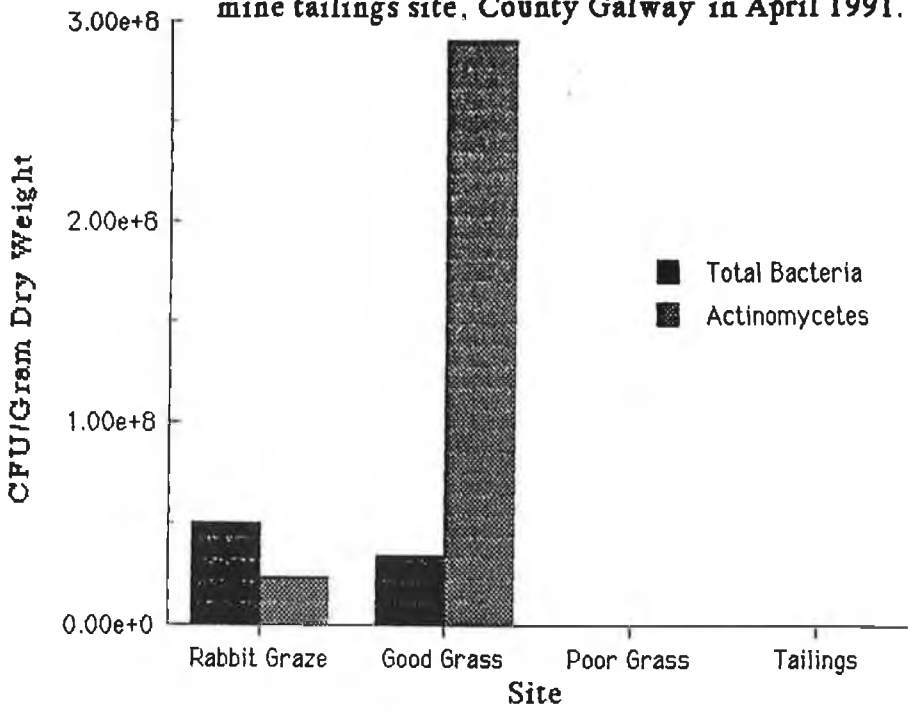


Figure 4.60
pH distribution at 30m intervals from the perimeter of Tynagh mine tailings site, County Galway in February 1993. (Duplicate sample results presented)

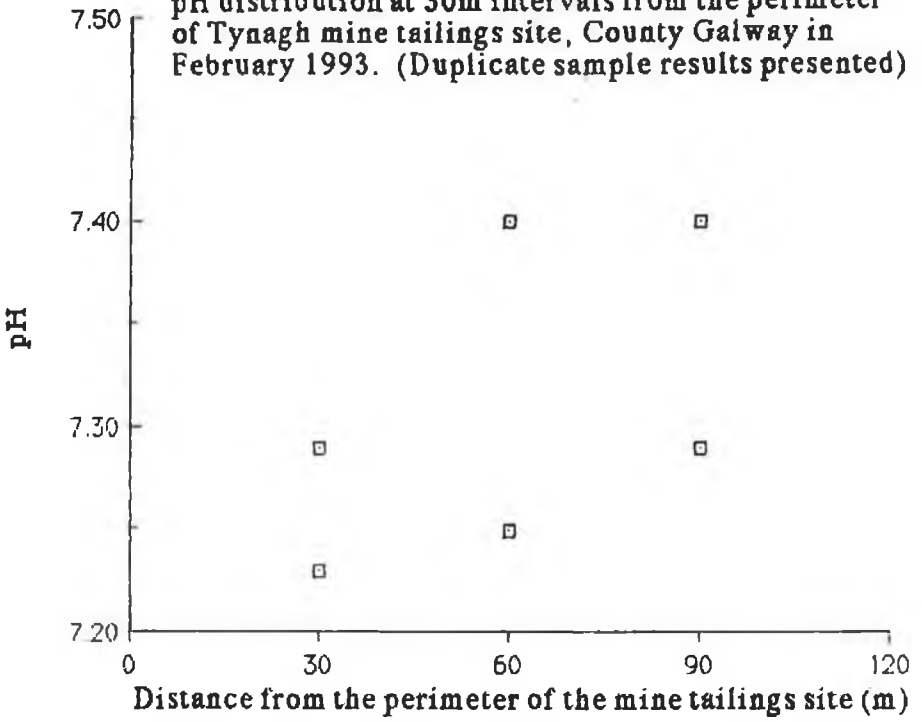


Figure 4.61
Organic matter and organic carbon distribution at 30m intervals from the perimeter of Tynagh mine tailings site, County Galway in February 1993. (Duplicate sample results presented)

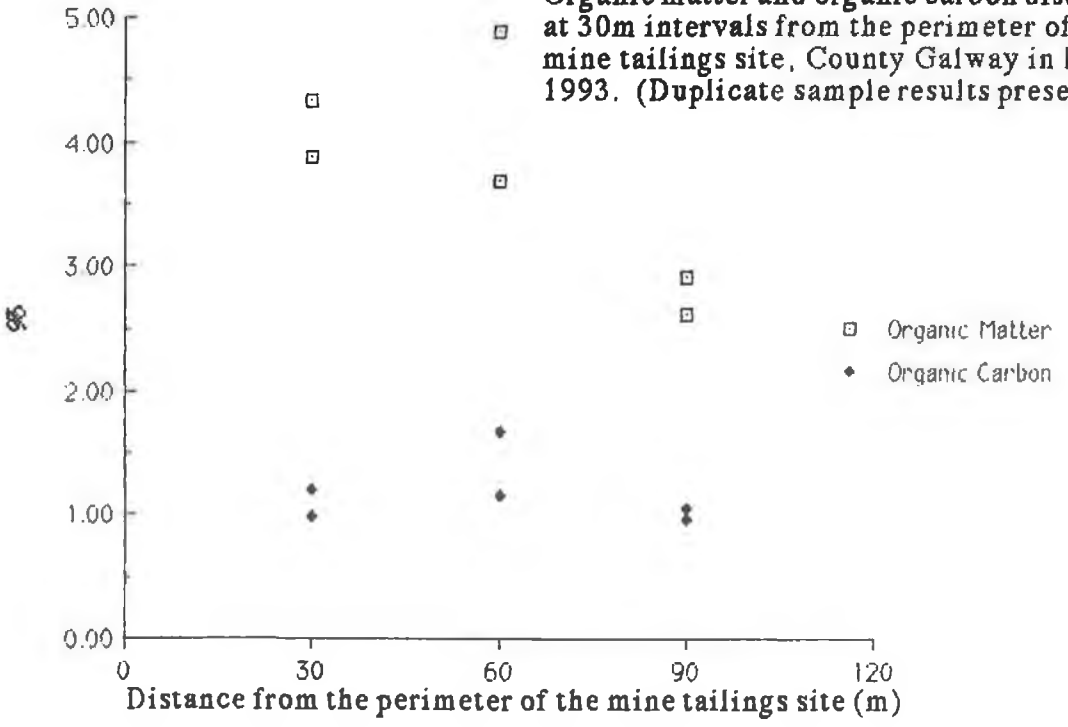


Figure 4.62
Kjeldahl nitrogen distribution at 30m intervals from the perimeter of Tynagh mine tailings site, County Galway in February 1993. (Duplicate sample results presented)

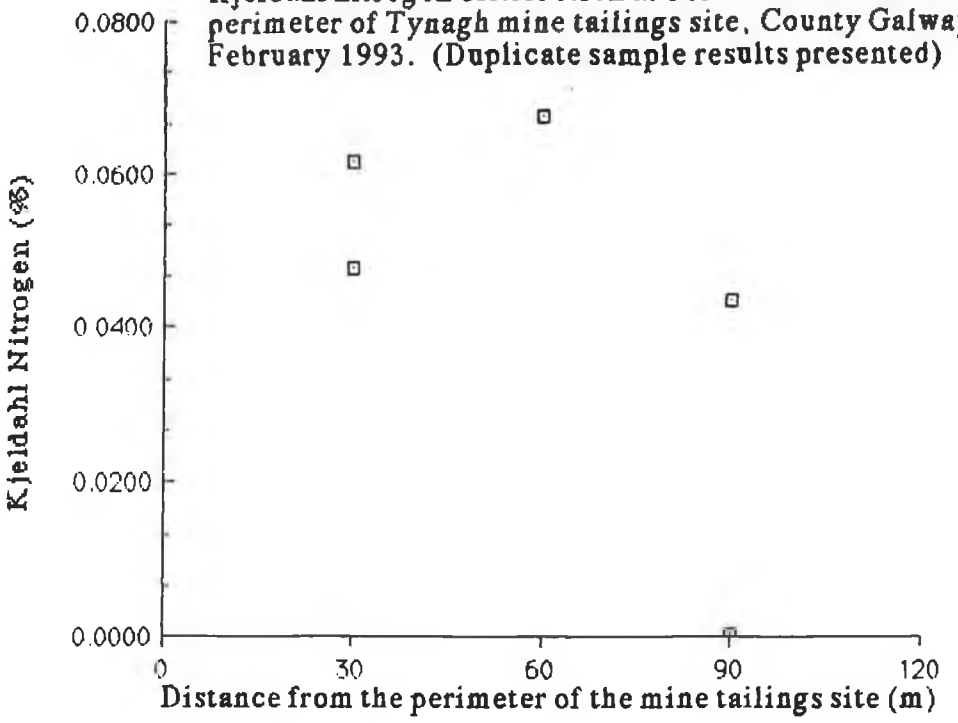


Figure 4.63
Available phosphorus distribution at 30m intervals from the perimeter of Tynagh mine tailings site, County Galway in February 1993. (Duplicate sample results presented)

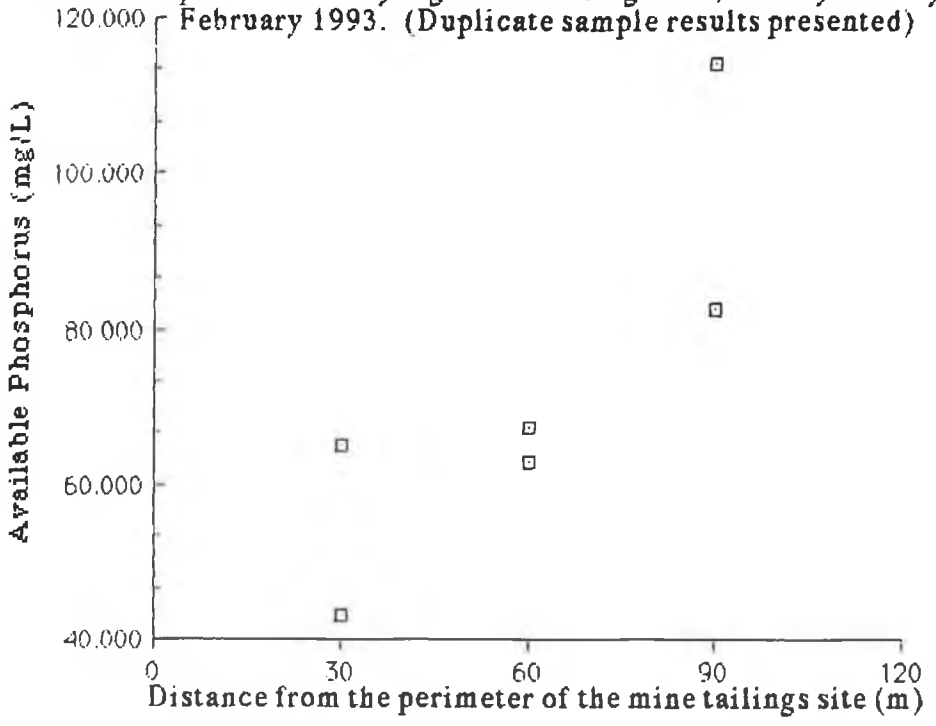


Figure 4.64
Exchangeable potassium distribution at 30m intervals from the perimeter of Tynagh mine tailings site, County Galway in February 1993. (Duplicate sample results presented)

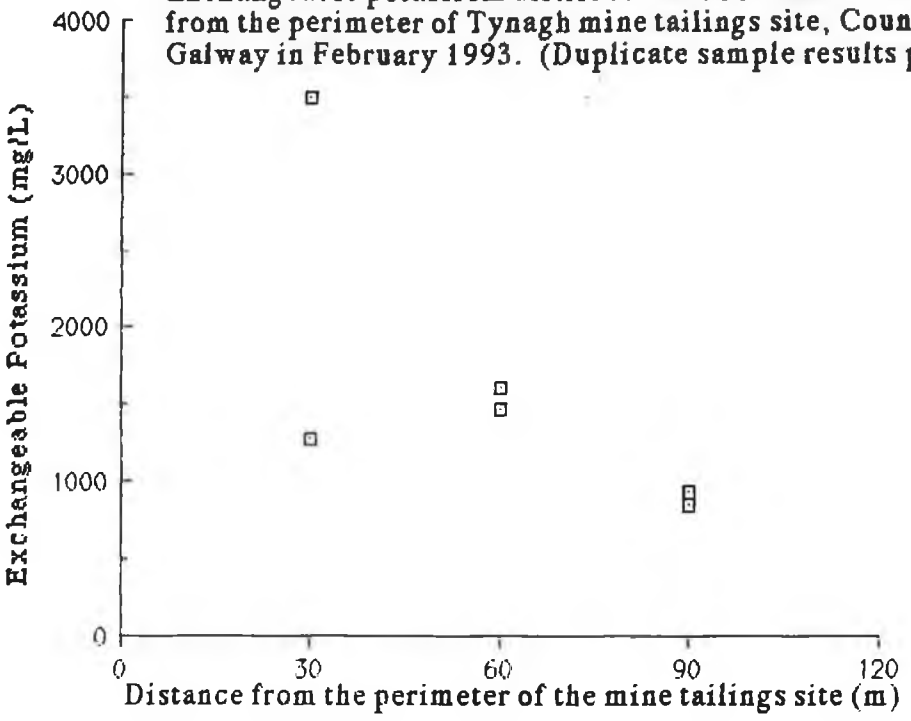


Figure 4.65
Microbiological distribution at 30m intervals from the perimeter of Tynagh mine tailings site, County Galway in February 1993. (Duplicate sample results presented)

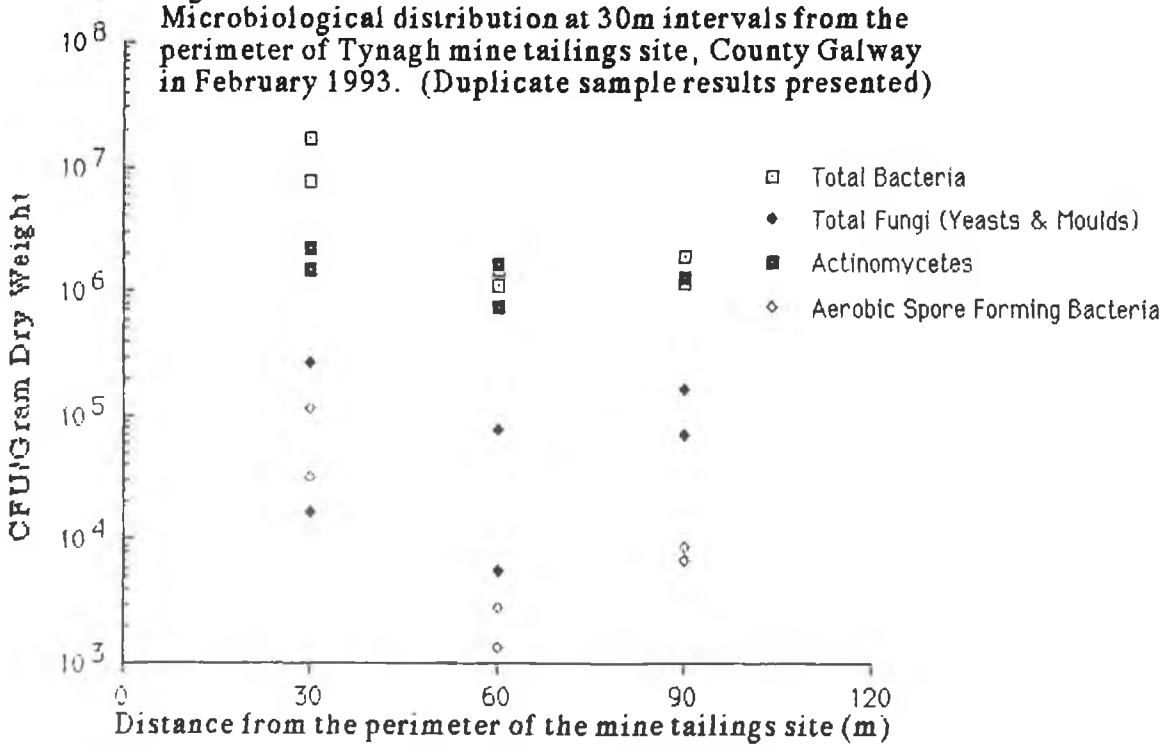


Table 4.21

Statistical results assessing the relationship between physical and chemical parameters and their corresponding sites at 30m intervals from the perimeter of Tynagh mine tailings site, County Galway in February 1993.

Parameters Compared	Curve Fit	r	r^2	Significance Level 1%	Significance Level 5%
pH V's Distance	Simple	0.518	0.268	-	-
Log Org. M V's Distance	Exponential	-0.744	0.554	-	-
Log Org. C V's Distance	Exponential	-0.148	0.022	-	-
Kjel. N V's Distance	Simple	-0.618	0.382	-	-
Log Avail. P V's Distance	Exponential	0.842	0.709	-	+
Log Exch. K V's Distance	Exponential	-0.762	0.581	-	-

Table 4.22

Statistical results assessing the relationship between microbiological parameters and their corresponding sites at 30m intervals from the perimeter of Tynagh mine tailings site, County Galway in February 1993.

Parameters Compared	Curve Fit	r	r^2	Significance Level 1%	Significance Level 5%
Log Total Bacteria V's Distance	Exponential	-0.806	0.650	-	-
Log Total Fungi V's Distance	Exponential	0.145	0.021	-	-
Actinomycetes V's Distance	Simple	-0.531	0.282	-	-
Aerobic Spore Forming Bacteria V's Distance	Simple	-0.663	0.439	-	-

Note

Positive (+) = The correlation coefficient is significant at the stated significance level.

Negative (-) = The correlation coefficient is not significant at the stated significance level.

CHAPTER 5
DISCUSSION AND CONCLUSIONS

5:1 Discussion

5:1.1 Physical and Chemical Parameters

pH levels (Figures 4.1, 4.7, 4.12, 4.18, 4.22, 4.29, 4.35, 4.45, 4.53 and 4.60) ranged from 5.03 at Shallee to 8.53 at Gortdrum. These fell within the normal soil pH range of 3 to 9 (FitzPatrick, 1980). Williamson, Johnson and Bradshaw (1982) stated that normal plant growth could be achieved in a pH range from 5 to 7 and at levels of less than 3 and greater than 9 problems are encountered in establishing and maintaining plants. Despite some pH's being less than 5.5, this may not have inhibited plant growth. Martin (1960) reported the optimum pH for the growth of Trifolium repens to be 5.5.

Microbial activity may have been affected by these low pH's. Brady (1974) stated that bacterial and fungal activity in mineral soils declined when the pH dropped to below 5.5. At a pH of less than 5.5 toxic salts and metal ions enter solution, microbial activity is restricted and shortages of available calcium and phosphate are induced. Bacterial and fungal activity are best at intermediate and high pH's in mineral soils. The optimum pH for actinomycete growth is between 6 and 7.5.

Williamson, Johnson and Bradshaw (1982) state that alkalinity may lead to deficiencies in iron, manganese, boron and magnesium. Phosphates may be removed from solution and nitrogen may be lost as ammonia. At high pH's toxicity occurs due to increased solubility of aluminium and zinc.

Organic matter levels (Figures 4.2, 4.8, 4.13, 4.19, 4.23, 4.30, 4.36, 4.46, 4.54 and 4.61) ranged from 0.00% at Shallee and Tynagh to 43.36% at Shallee. Many of these levels were in agreement with typical soil figures (FitzPatrick, 1980). He indicated that the upper horizons of most soils contained less than 15% organic matter. Many levels were in agreement with Williamson, Johnson and Bradshaw (1982) who stated that soils contained between 2% and 5% organic matter. They also stated that the importance of organic matter in a developing ecosystem lay in the fact that, apart from other functions, it supplied nutrients and contributed to a soil's

physical properties. Wild (1993) stated that organic matter increased water supply to crops, gave greater flexibility for cultivation's, released nitrogen, phosphorus and sulphur on mineralisation, reduced the hazard from heavy metals, acted as a pH buffer, retained nutrient cations against leaching loss and may support organisms which help control root diseases.
Organic matter in the bottom section of certain mine tailings sites may have been attributed to the possible presence of earthworms. Wild (1993) stated that *Lumbricus terrestris* could travel from near the soil surface to an approximate 2m depth in order to escape desiccation. In the process of doing so it may have carried organic matter with it, thus contributing to the levels there.

Organic carbon levels (Figures 4.2, 4.8, 4.19, 4.30, 4.46 and 4.61) ranged from 0.26% at Abbeytown to 15.64% at Shallee. There was a data contradiction between this parameter and organic matter. A figure of 0.26% was stated here with an organic matter level of 0.00% being recorded. Prendergast (1991) determined organic matter only in 1990/1991, where 0% levels were obtained. Organic matter and organic carbon were determined in 1992 and 1993, where organic carbon levels were obtained at all sites. Hence the ranges given for organic matter spanned from 1990/1991 to 1993 while those for organic carbon spanned from 1992 to 1993. Stevenson (1986) stated that absolute levels of carbon varied between soils. The carbon content in coarse-textured soils could be 1% or less, in prairie grassland soils the figure could be as high as 3.5% while in poorly drained soils, levels approaching 10% have been reported.
The presence of organic carbon is essential in a developing ecosystem. Thorn (*circa* 1990) stated that a high proportion of the energy acquired by soil fauna came from the oxidation of this compound.

Kjeldahl nitrogen levels (Figures 4.14, 4.24, 4.37, 4.47, 4.55 and 4.62 and Appendices 2a, 2g and 2k) ranged from 0.0000% to 0.6528%, with the latter occurring at Abbeytown. Some of these levels are in conformity with

soil figures (FitzPatrick, 1980). He indicated that soil total nitrogen (assumed to be kjeldahl nitrogen) ranged from approximately 0.05% to 2%. Many of these levels fell below the lower end of this range while some were in agreement with subsoil figures (Black *et al.*, 1965). He indicated that total nitrogen levels of less than 0.02% occurred within the subsoil.

The fact that no kjeldahl nitrogen was detected at many sites may have been attributed to the following reasons: Levels may have been below the detection limit of the analytical method, no kjeldahl nitrogen may have been present and finally any organic nitrogen present may have been ammonified. In relation to the latter, the resulting ammonia may have been lost from the system through volatilisation or leaching. Ammonia may have been utilised by plants or it may have been nitrified with the resulting nitrate being utilised by plant species and soil organisms. If nitrification, instead of volatilisation, took place following ammonification the resulting nitrate may have been leached from the system.

Williamson, Johnson and Bradshaw (1982) stated that nitrogen was the nutrient exhausted most rapidly in normal soils and mine wastes. This too may explain the absence or low levels of kjeldahl nitrogen at many sites.

Stevenson (1986) stated that nitrogen was significant in nature because after carbon, hydrogen and oxygen it was the element most closely associated with microbiological reactions. Organic nitrogen makes up the largest nitrogen reservoir potentially available in soil. Brady (1974) stated that 2% to 3% of this nitrogen was mineralised annually under normal conditions. Stevenson (1986) reported that approximately 95% of the nitrogen that cycles per annum within the pedosphere interacts solely within the soil-microbial-plant system.

Carbon to nitrogen (C:N) ratio's (Appendices 2a, 2b, 2g, 2k, 2q and 2v) ranged from 12.3:1 at Gortdrum to 3233.3:1 at Tynagh. Figures at Abbeytown, Gortdrum and Tynagh compared closely with the 8:1 to 15:1 range quoted for cultivated soils (Brady, 1974). As these ratio's were not wide there may have been little or no competition between carbon

degrading organisms and plant species for available nitrogen. The very wide ratio's at Shallee, Silvermines and Tynagh may give rise to problems, relating to nitrogen availability. These problems may be overcome through supplementing these sites with adequate quantities of nitrogen.

Available phosphorus levels (Figures 4.15, 4.20, 4.25, 4.31, 4.38, 4.48, 4.56 and 4.63) ranged from 0.000mg/L at Gortdrum, Shallee and Silvermines to 114.03mg/L at Tynagh. No results were obtained for Abbeytown. The application of fertilisers to most sites during the initial stages of rehabilitation may have been responsible for providing them with phosphorus. As soil profile development evolved and nutrient cycling took place this element may have been continuously recycled within the system. The possible presence of apatite in mine tailings may also have contributed to the phosphorus levels here. Stevenson (1986) stated that the phosphorus constituent of apatite was released during weathering and soil development processes.

On comparing the levels obtained with corresponding pH's it was believed that maximum availability of phosphorus to plant species was not taking place. According to Brady (1974) maximum availability of phosphorus is believed to occur in the pH range 6.0 to 7.0. The pH ranges at many sites were greater than 7.0.

The typical range for soil phosphorus is from 500µg/g (dry weight) to 800µg/g (dry weight). Total phosphorus levels are highest in the upper A horizon of soils but lowest in the lower A and upper B horizons due to plant utilisation. In general phosphorus distribution in a soil profile may be altered through the upward transport of this element by plants and retention in the surface soil (Stevenson, 1986).

The presence of phosphorus in a mine tailings site is essential for the establishment of plant species. Stevenson (1986) stated that phosphorus was required for seed formation, root development and crop maturity. Martin (1960) stated that phosphate stimulated the growth of clover roots and was essential for nodulation and active fixation of nitrogen in these

leguminous species. Williamson, Johnson and Bradshaw (1982) stated that phosphorus levels greater than 20µg/g were acceptable for grasses while extreme deficiency was indicated by levels of less than 5µg/g. According to Stevenson (1986) phosphorus deficiency in plants may lead to stunted growth and delayed maturity.

Exchangeable potassium levels (Figures 4.3, 4.9, 4.16, 4.20, 4.26, 4.32, 4.39, 4.49, 4.57 and 4.64) ranged from 0mg/L at Gortdrum to 10,473mg/L at Shallee. The application of fertilisers to most sites during the initial stages of rehabilitation may have been responsible for providing them with potassium. The possible presence of feldspars and micas in the mine tailings may have also been responsible for the potassium levels here. Brady (1974) stated that approximately 90% to 98% of potassium in mineral soils is unavailable and mostly originates from these rocks. However it is converted gradually to more available forms by solvents.
Williamson, Johnson and Bradshaw (1982) stated that potassium levels greater than 100µg/g were acceptable for grasses. However they reported that extreme deficiency was indicated by levels of less than 40µg/g.
According to Brady (1974) potassium is necessary for chlorophyll development and is an essential element for photosynthesis, starch formation and translocation of sugars. It tends to prevent "lodging" of plant species and counteracts damage created by excessive nitrogen by increasing resistance to certain crop diseases and encouraging strong root systems.

Chloride (Figure 4.4) was determined along the 240m line transect at Abbeytown and ranged from less than 28mg/L to 358mg/L. This parameter increased, in general, with increasing distance along the transect. This trend may have been responsible for the general decrease in physical and chemical parameters and plant genera numbers along this transect. High levels towards the estuarine end of the mine tailings site may have been an indication that they were saline in nature. FitzPatrick (1980) stated

that chloride was one of the principle anions associated with salinity. These saline conditions may have been attributed to a high tide covering this area of the mine tailings site. FitzPatrick (1980) stated that land under tidal influences may be affected by salinity.

Textural analyses (Figures 4.17, 4.27, 4.40 and 4.58) were carried out at Gortdrum, Shallee, Silvermines and Tynagh.

At Gortdrum, sites 3 and 5, which were rehabilitated in 1981/1982 and 1984, contained 29% clay and 49% silt and 16% clay and 9% silt respectively. Williamson, Johnson and Bradshaw (1982) reported that the silt and clay compositions of Canadian mine tailings ranged from 0% to 96% and from 0% to 40% respectively. Both sites fell within these ranges. On the basis of results for site 3 and on the literature (Brady, 1974) this site may have contained a fine-textured soil, assuming a soil had developed. Brady (1974) stated that such a soil was composed largely of silt and clay and that the plasticity and stickiness of it indicated the likelihood of it being difficult to till or cultivate. This soil would be expected to have slow water and air movement through it. Site 5 contained lower levels of silt and clay and therefore may have contained a high level of larger sized particles. This in turn may have resulted in it having good drainage and being well aerated.

Stevenson (1986) stated that for any climatic zone, provided plants and topography were constant, the levels of carbon and nitrogen depended on textural properties. Williamson, Johnson and Bradshaw (1982) stated that most of a soil's physical and chemical properties were influenced by texture.

At Shallee, Prendergast (1991) stated that coarse particles settled towards the perimeter of the mine tailings pond while fine particles settled towards the centre. The sites studied may have originated at the perimeter of this pond and ended in the centre. On the basis of this, it was expected that on moving along the transect there would have been a distinct decrease in particle size.

At the 16m site, clay and silt levels of 8% and 10% were obtained respectively. These levels were expected here as these fractions were quite fine and not expected to settle out until further along the transect. Larger fractions however may have settled out. If this was the case such a site may have had good air and water movement through it. At 30m, clay and silt levels increased considerably to 31% and 39% respectively. At 90m, 78% silt and 16% clay were detected while at 150m the figures were 76% clay and 20% silt. The levels at the 90m and 150m sites may have indicated that these were the sites at which most of the clay and silt sized fractions settled out. The presence of these fractions may result in slow water and air movement through the sites. Prendergast (1991) stated that silty soils had a great capacity to hold available water for plant growth. She also indicated that waterlogging may occur in mine tailings if too high a percentage of it was silty in composition.

Clay and silt levels comparable to those found at the 16m site were detected at 165m. These were 9% and 14% respectively. At 180m silt and clay levels of 15% and 36% were obtained respectively.

Brady (1974) stated that silt and especially the presence of clay in a soil gave it a fine texture and resulted in slow water and air movement through it.

At Silvermines, the 1985-Clover site had the lowest clay and silt content with levels of 20% and 4% respectively. These levels may have indicated the presence of a high level of a larger sized fraction of particles. Such particles may have imparted good air and water movement throughout the site. The 1985 site had a high clay content of 42% while the silt content was 7%. A similar clay level of 44% was obtained at the 1986 site with the silt content here being 22%. In comparing the 1985 and 1986 sites the latter may have been likely to retain more water and be less oxygenated.

The different levels of clay and silt at each site suggested to Prendergast (1991) that particle size distribution throughout the mine tailings was not uniform. She stated that problems may arise, when developing a plant cover on mine tailings, if there is no uniformity.

At Tynagh, clay and silt distributions were not the same at each site. According to Prendergast (1991) this may have suggested that particle size distribution throughout these sites was not uniform. She indicated that a tailings blow, following deposition, may have been responsible for the non-uniformity of particles across this area.

Bulk density distribution was carried out on two sections of Silvermines mine tailings site. Levels along a good section (Figure 4.41) ranged from 0.742 to 1.112g/cm^3.

Prendergast (1991) stated that bulk densities greater than 1g/cm^3 restricted root penetration. With the exception of one site, the levels here may not give rise to this problem. Williamson, Johnson and Bradshaw (1982) stated that the bulk density of mine tailings often occurred within the range 1.0g/cm^3 to 1.5g/cm^3 for normal soils. A figure of less than 1.0g/cm^3 could be obtained in a well-structured soil having a high level of organic matter. Williamson, Johnson and Bradshaw (1982) reported that the mean bulk density of Canadian mine tailings was 1.5g/cm^3 with a range from 0.2g/cm^3 to 3.1g/cm^3. The levels obtained here fell within this range.

Williamson, Johnson and Bradshaw (1982) stated that bulk density increased when a material was compacted. The trend in this parameter along the transect may have indicated that these sites were being more compacted.

Williamson, Johnson and Bradshaw (1982) stated that aeration and infiltration decreased and mechanical impedance and moisture retention increased when a material was compacted. Wild (1993) stated that mechanical impedance restricted root growth.

Bulk density levels along a poorly rehabilitated section (Figure 4.42) of the mine tailings site ranged from 0.684g/cm^3 to 0.928g/cm^3.

The statistical results assessing the relationships between the physical and chemical parameters and their corresponding sites are presented in Tables 4.1, 4.4, 4.9, 4.11, 4.14, 4.17, 4.20 and 4.21.

5:1.2 Microbiological Parameters

Microbiological levels (Figures 4.5, 4.10, 4.21, 4.33, 4.43, 4.50, 4.51, 4.59 and 4.65) ranged from 0 CFU/g dry weight to $1.06x10^8$ CFU/g dry weight, from $8.66x10^1$ CFU/g dry weight to $2.65x10^5$ CFU/g dry weight, from 0 CFU/g dry weight to $2.90x10^8$ CFU/g dry weight and from $4.08x10^1$ CFU/g dry weight to $4.05x10^6$ CFU/g dry weight for total bacteria, total fungi, actinomycetes and aerobic spore forming bacteria respectively.

On comparing these levels with estimated soil numbers (based on plate counts) reported by Stevenson (1986) it was discovered that the typical soil figures occurred within a narrower range. The ranges reported by Stevenson (1986) were $3x10^6$/g to $5x10^8$/g (assumed to be CFU/g) for bacteria, $6x10^3$/g to $1x10^6$/g (assumed to be yeast and mould estimated numbers combined) for fungi and $1x10^6$/g to $2x10^7$/g for actinomycetes. Some microbiological levels did fall within these ranges.

While broader ranges were obtained along the mine tailings sites, it must be remembered that these sites may not have been characteristic of the soils referred to by Stevenson (1986). According to him the reported soil numbers should be regarded as conservative because they were based on plate counts.

The microbial groups investigated play important roles in soil processes and therefore are important in developing ecosystems such as mine tailings sites. Brady (1974) stated that bacteria monopolised nitrification, nitrogen fixation and sulphur oxidation while fungal moulds played the most important role in the soil. According to Stevenson (1986) they together with spore forming bacteria are especially active in consuming proteins, starches and cellulose.

Alexander (1961) stated that fungi could use many carbon sources. These included hexoses, pentoses, organic acids, disaccharide's, starch, pectin, cellulose and lignin. Lignin is resistant to bacterial decomposition. Brady (1974) indicated that fungal moulds were responsible for soil decomposition processes continuing after the roles by bacteria and actinomycetes had ceased. He also said that when it came to aggregate

stabilisation and humus formation fungal moulds played a more important role than bacteria.

Alexander (1961) stated that soil fungi were actively involved in the synthesis of ammonium and simple nitrogen compounds. He also indicated that many strains of actinomycetes could synthesise *in vitro* the aromatic molecules assumed to play an important role in the humus fraction of mineral soils. These micro-organisms were also involved in the decomposition of the resistant compounds cellulose, chitin and phospholipids and in humus formation.

The statistical results assessing the relationships between the microbiological parameters and their corresponding sites and physical and chemical parameters are presented in Tables 4.2, 4.5, 4.10, 4.15, 4.18 and 4.22.

5:1.3 Botanical Parameters

Due to the considerable plant diversity between the five mine tailings sites this section of the discussion will be presented on a site by site basis.

A wide diversity of plant species occurred at sites investigated on Abbeytown (Figures 4.6 and 4.11 and Tables 4.3 and 4.6). This diversity, reflected in numbers of genera, declined in general on moving towards the estuarine end of the mine tailings site. This trend was apparent along one transect. The decline in diversity may have been attributed to the levels of physical and chemical parameters at these sites, to elevated chloride levels or to variations in sampling technique.

Previous work has been carried out on species identified at Abbeytown. Williamson, Johnson and Bradshaw (1982) stated that *Dactylis glomerata* was an agricultural forage species in Britain. These species require large quantities of nutrients and long-term management and have been useful in waste stabilisation world-wide. *Dactylis glomerata* can grow over a wide pH range provided adequate quantities of nutrients are present. Martin

(1960) stated that this species was considered to inhibit clover development.

The presence of the leguminous species *Vicia sepium*, *Lathyrus pratensis*, *Trifolium repens* and *Trifolium pratense* was an encouraging sign on this developing ecosystem. The symbiotic relationship between the bacterium *Rhizobium* and leguminous plants has had a long and comprehensive development. *Vicia* and *Lathyrus* are hosts for *Rhizobium leguminosarum* while *Trifolium* is a host for *Rhizobium trifolii*. The main source of fixed nitrogen for a large quantity of the world's soil is leguminous plants. One of the factors leading to the more extensive use of these or other nitrogen-fixing plants is the need to reclaim disturbed lands. It was reported that *Trifolium repens* was estimated to fix between 128kg Nitrogen/Ha and 268kg Nitrogen/Ha (Stevenson, 1986). Martin (1960) reported that *Trifolium repens* was valuable for grazing because it was capable of surviving under conditions of intensive defoliation and increased the palatability and protein level of host swards. Stevenson (1986) stated that *Medicago pratense* (believed to be *Trifolium pratense*) was estimated to fix between 17kg Nitrogen/Ha and 154kg Nitrogen/Ha. He also reported that *Vicia villosa* was estimated to fix 184kg Nitrogen/Ha while *Vicia faba* was estimated to fix between 121kg Nitrogen/Ha and 171kg Nitrogen/Ha.

Alnus a non-leguminous plant was identified at Abbeytown. This plant forms a symbiotic relationship with micro-organisms and is involved in nitrogen fixation. There was little information about the endophyte responsible for nitrogen fixation. However an actinomycete identified as *Frankia* was mentioned. An estimated yearly gain of 62kg Nitrogen/Ha by *Alnus crispa*, during colonisation of recessional moraines of Alaskan glaciers, was reported by Stevenson (1986).

No scientific reason could explain the dominance of particular plant species along one transect. The main factor governing dominance at many sites may have been their wet condition.

Plant species identified by Prendergast (1991) at Gortdrum (Table 4.8) were *Trifolium repens*, *Vaccinium myrtillus* and two moss species *Pseudoscleropodium purum* and *Rhytidiadelphus squarrosus*. She stated that *Trifolium repens* was an important pasture legume and was sown mostly with a companion grass. *Pseudoscleropodium purum* grows in close association with flowering plants and is tolerant to soil reaction while *Rhytidiadelphus squarrosus* was indifferent to this parameter. It grows equally well on chalk grassland, in acid heaths and among grass on lawns.

A diverse range of plant species were identified at sites on Shallee (Figures 4.28 and 4.34 and Tables 4.12 and 4.13). Many of these species belonged to the Ericaceae, Leguminosae and moss families.

The moss species *Rhytidiadelphus squarrosus* and *Pseudoscleropodium purum* were present. *Pseudoscleropodium purum* was found growing in association with flowering plants at two sites.

The leguminous species *Ulex europaeus*, *Trifolium ornithopodioides*, *Trifolium repens*, *Vicia sepium* and *Lotus corniculatus* were identified. Stevenson (1986) stated that wild species of legumes are important for nitrogen fixation in natural ecosystems. Williamson, Johnson and Bradshaw (1982) reported that *Ulex europaeus* could be found in acidic, neutral and calcareous soils with *Trifolium repens* preferring neutral and calcareous soils.

The grass species *Dactylis glomerata* and *Holcus lanatus* were identified at one site. Williamson, Johnson and Bradshaw (1982) stated that *Dactylis glomerata*, in general, has a high fertility demand, is tolerant to neutral and calcareous pH's and has a medium drought tolerance. This species is also known as an agricultural forage species. They have been useful in waste stabilisation world-wide.

On the basis of some of the plant species identified at Shallee the stages of plant succession reported by Ashby in 1:3.5 may have been in the early stages of development on this site.

At Silvermines a number of observations were made on examining the five sites 1985, 1986, 1987 and 1988 in 1991 (Figure 4.44 and Table 4.16): In general the same number and diversity of plant species occurred at each site. Some of the species that formed part of the original seed mixture had disappeared. At the 1985 and 1987 sites three species were present *Festuca rubra*, *Poa* species and *Trifolium repens*. *Poa* species appeared to have naturally colonised these sites as it was not part of the original seed mixture. At the 1986 site *Poa* species was replaced by *Agrostis stolonifera*. At the 1988 site *Agrostis stolonifera*, *Trifolium repens* and *Festuca* species were present. The latter may have been *Festuca rubra* however if the specimen sampled was in bad condition it may have made a positive identification impossible.

The *Festuca rubra*, *Agrostis stolonifera* and *Trifolium repens* species at these sites may have been the same as those originally sown. However this was unknown as detailed identifications were not undertaken.

The presence of *Trifolium repens* at each site was an encouraging sign. The relevance and importance of legume species in nitrogen fixation has already been discussed. Dancer, Handley and Bradshaw (1977) stated that *Trifolium* represented an efficient and inexpensive method of accumulating organic matter and nitrogen during reclamation.

Prendergast (1991) stated that *Trifolium repens* was usually sown with a companion grass and reported that, on low pH strip-mines, a mixture of *Trifolium repens* and *Festuca arundinacea* gave better soil protection and yield than *Trifolium repens* alone.

The presence of *Festuca rubra* at all sites and *Agrostis stolonifera* at two may have been attributed to them being tolerant to heavy metals. These species possess heavy metal tolerant populations. Their presence may have also been attributed to fertilisers complexing heavy metals, thus preventing inhibition of growth or it may have been due to organic matter forming stable complexes with metal ions thus preventing these ions being taken up by plant species.

The disappearance of *Agrostis stolonifera* in conjunction with the appearance of *Poa* species at the 1985 and 1987 sites may have been due to its uncompetitiveness at these sites. It may have also been due to conditions at these sites being unfavourable for this species survival. This in turn may have given *Poa* the opportunity to naturally colonise and force it out.

Lolium perenne formed part of the original seed mixture. Its disappearance from all sites may have been due to the fact that it was a normal agricultural grass intolerant to heavy metals. Smith and Bradshaw (1972) studied tolerant plant populations growing on mine waste in England, using *Lolium perenne* as a control. They found that all species, especially those in plots which were fertilised, grew well initially and that the tolerant species and control were still present after six months. At this stage of the study it appeared that *Lolium perenne* was a realistic alternative to tolerant populations however within one year it was dying out.

On re-examining the five sites 1985, 1986, 1987 and 1988 in 1992 (Figure 4.52 and Table 4.19) the following observations were made: There was an increase in species diversity since 1991. Species present at the 1986 and 1987 sites in 1991 were present. At the 1987 site *Poa trivialis* was identified however in 1991 a *Poa* species was present. Whether both were the same was unknown. Two of the three species at the 1985 site in 1991 were present, *Trifolium repens* was missing. Two of the three species at the 1988 site in 1991 were present, *Agrostis stolonifera* was missing. At this site *Festuca rubra, Festuca arundinacea* and *Trifolium* species were identified however in 1991 a *Festuca* species and *Trifolium repens* were present. Whether the 1991 and 1992 species were the same was unknown. *Poa* species which had colonised the 1985 and 1987 sites in 1991 had now colonised all sites.

Eight species were present at the 1985 site, six of them belonged to the Gramineae family. With regards to the *Agrostis* species identified, *Agrostis stolonifera* Seaside was originally sown however it was not identified in

1991. This may have been due to it being 'missed' when sampling or to the specimen being in poor condition thus preventing a positive identification. Alternatively this species may have actually disappeared sometime after sowing, this disappearance recorded in 1991. The species now present may have naturally colonised the site.

Williamson, Johnson and Bradshaw (1982) stated that *Dactylis glomerata* was an agricultural forage species. These species have been useful in waste stabilisation world-wide. Martin (1960) stated that this species was considered to inhibit clover development. *Trifolium repens* was absent from this site however it was unlikely attributed to *Dactylis glomerata* as it together with a *Trifolium* species were present at the 1986 site.

Williamson, Johnson and Bradshaw (1982) reported that *Festuca arundinacea* had a high fertility demand, was tolerant to neutral and calcareous pH's and had a low drought tolerance. *Festuca rubra* had a low fertility demand, was tolerant to neutral and calcareous pH's and had a high drought tolerance. *Poa pratensis* had a low fertility demand, was tolerant to acidic, neutral and calcareous pH's and had a high drought tolerance. Two other plant species present were *Ranunculus acris* and *Sorbus aucuparia*. The latter was a seedling and therefore may have had recently colonised this site. This species has a low fertility demand, is tolerant to acidic, neutral and calcareous pH's and its moisture tolerance is wet (Williamson, Johnson and Bradshaw, 1982). The absence of *Trifolium repens* from this site may have been due to it being forced out by other species.

At the 1986 site five species belonging to the Gramineae family were identified. Williamson, Johnson and Bradshaw (1982) reported that *Agrostis stolonifera* had a medium fertility demand, was tolerant to neutral and calcareous pH's and had a low drought tolerance.

A number of species belonging to the Leguminosae family were present at this site. They were *Trifolium pratense*, *Trifolium repens* and *Trifolium campestre* or *Medicago lupulina*. Williamson, Johnson and Bradshaw (1982) reported that *Trifolium pratense* and *Trifolium repens* preferred

neutral and calcareous soils. The presence of these three species was quite significant as members of the Leguminosae family are involved in nitrogen fixation. In relation to *Medicago lupulina,* another member of this genus *Medicago sativa* was estimated to fix between 148kg Nitrogen/Ha and 290kg Nitrogen/Ha.

Ranunculus acris, an unknown member of the Brassicacae family and *Salix atrocinerea* were also present at this site.

At the 1987 site three species belonging to the Gramineae family were present together with *Trifolium repens* and *Funaria hygrometrica*.

At the 1988 site the same grass species were present together with a *Trifolium* species.

5:1.4 Synopsis of Discussion

To summarise the pertinent factors from the five mine tailings sites it can be stated that:

5:1.4.1 ABBEYTOWN

Abbeytown mine tailings site is undergoing natural colonisation. This was reflected in the wide diversity of plant species on this site together with the presence of physical, chemical and microbiological parameters necessary for soil profile establishment. A number of these parameters were in variance with typical soil figures. However this did not appear to have a detrimental effect on plant species. As this ecosystem develops these parameters may reach levels similar to those found in soils.

The success of Abbeytown in attracting and maintaining plant species may be attributed to two factors: A layer of topsoil was spread over the mine tailings prior to colonisation. This layer may have supplied plant species with a non-toxic medium to initially root in, thus resulting in their successful establishment. Nutrients and organic matter, originating in the estuary, may be providing sustenance to the plant species. This factor may have played a vital role during the initial stages of colonisation.

5:1.4.2 GORTDRUM

Gortdrum mine tailings site, investigated in 1990/1991 and 1993, appears to be establishing a soil profile. Evidence of this establishment was indicated by the presence of physical, chemical and microbiological parameters in the top 4cm of most sites. This is the horizon of the soil within which most biological activity and plant rooting occurs. Many parameters, at times, compared closely with typical soil figures.

The presence of plant species on these sites indicated that soil profile development had reached a sufficient stage to sustain these species.

On visual observation of this mine tailings site it was felt that further rehabilitation work may be required before a "walk-away" scenario could be endorsed.

5:1.4.3 SHALLEE

Shallee mine tailings site, investigated in 1990/1991 and 1992, is undergoing natural colonisation. This was reflected in the presence of plant species together with physical, chemical and microbiological parameters in the top 4cm of each site. A number of these parameters were, at times, in variance with typical soil figures. This however did not appear to effect the growth of plant species.

The factors which initiated natural colonisation are unknown. One hypothesis is that metal-tolerant plant species may have colonised this site. This tolerance may have been genetically determined. These species may have built up a tolerance, over many generations, through colonising soils adjacent to the mine tailings site. These soils may have contained higher than average heavy metal values but lower heavy metal values than on the mine tailings site.

Managed rehabilitation may be required, on relatively bare areas of this mine tailings site, to encourage plant growth. The absence of species from these areas may have been attributed to motorbike scrambling that occurred there periodically. However natural colonisation may take place if this activity ceases completely.

5:1.4.4 SILVERMINES

Silvermines mine tailings site, investigated in 1990/1991 and 1992, is undergoing a process of rehabilitation. This was reflected in the physical, chemical and microbiological parameters in the top 4cm of sites together with an increase in species diversity since original seeding. A number of parameters, at times, were in variance with typical soil figures however this did not appear to effect plant growth or diversity.

Despite the findings at Silvermines, the time for a "walk-away" scenario has not been reached. There is still a lot of pyrite burn on the mine tailings site and there are several reported areas underwhich an iron pan has formed. As plant growth may be inhibited on such areas special rehabilitation techniques together with long term monitoring may be required to ensure long term stabilisation. Routine monitoring of areas with good plant covers should also be undertaken to ensure they don't fall susceptible to these conditions.

5:1.4.5 TYNAGH

Tynagh mine tailings site, investigated in 1990/1991 and 1993, appears to be establishing a soil profile. This was reflected in the presence of physical, chemical and microbiological parameters in the top 4cm of sites. Many parameters, at times, were in variance with typical soil figures. This however did not appear to effect the growth of plant species as a thick plant cover, of predominantly grass species, was observed on the rehabilitated section of the site.

On visual observation of this mine tailings site it was believed that further work was required to ensure long term stabilisation. Existing bare areas together with seemingly poor plant diversity, in contrast to Abbeytown and Shallee, may support this statement. Efforts should be made to determine if the barite area of the mine tailings site will be reworked. If not, rehabilitation of this area should begin to improve the appearance of the site.

5:2 Conclusions

Natural or managed rehabilitation is occurring on Abbeytown, Gortdrum, Shallee, Silvermines and Tynagh mine tailings sites. The degree of rehabilitation differs between each with those that are naturally rehabilitated appearing to be further along the stages of plant succession.

Abbeytown, which was naturally rehabilitated, appears to be the most successfully rehabilitated site. This was reflected in its wide diversity of plant species and abundance of growth. The success of this site may be attributed to its topsoil layer and to estuarine nutrients. These may have played a major role in the initial establishment and on-going maintenance of plant species. It is therefore felt that no management is required to maintain this mine tailings site.

The condition of the remaining sites dictate that managed rehabilitation policies be continued to ensure stabilisation at a par with Abbeytown. This policy could also be applied to the naturally rehabilitated Shallee site.

CHAPTER 6

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APPENDIX 1

CALCULATIONS USED IN PHYSICAL, CHEMICAL AND MICROBIOLOGICAL DETERMINATIONS

1a Calculation used in the organic matter determination - Loss on ignition method

$$\% \text{ Organic Matter} = \frac{A-B \times 100}{\frac{W}{1}}$$

A = Weight of porcelain crucible and sample (g) before ignition at 695°C to 700°C

B = Weight of porcelain crucible and sample (g) after ignition at 695°C to 700°C

W = Weight of sample (g)

1b Calculation used in the standardisation of ferrous ammonium sulphate used in the organic carbon determination - Walkley-Black method

Sample calculation

$$N_1 \times V_1 = N_2 \times V_2$$

N_1 = Normality of potassium dichromate (N) = 1

V_1 = Volume of potassium dichromate (cm^3) = 10.5

N_2 = Normality of ferrous ammonium sulphate (N) = ?

V_2 = Volume of ferrous ammonium sulphate (cm^3) = 52.4

$$N_2 = (N_1 \times V_1) \div V_2$$
$$= (1N \times 10.5cm^3) \div 52.4cm^3$$
$$= 0.20N$$

1c Calculation used in the organic carbon determination - Walkley-Black method

$$\% \text{ Organic Carbon} = \frac{(V_1 - V_2/5) \times 0.003 \times 100}{W}$$

V_1 = Volume of 1N potassium dichromate (cm^3)

V_2 = Volume of N/5 ferrous ammonium sulphate (cm^3)

W = Weight of sample (g)

1d Calculation used in the standardisation of hydrochloric acid used in the kjeldahl nitrogen determination - Kjeldahl method

Sample calculation

$$N_1 \times V_1 = N_2 \times V_2$$

N_1 = Normality of sodium hydroxide (N) = 0.02

V_1 = Volume of sodium hydroxide (cm^3) = 24.8

N_2 = Normality of hydrochloric acid (N) = ?

V_2 = Volume of hydrochloric acid (cm^3) = 25

$$N_2 = (N_1 \times V_1) \div V_2$$
$$= (0.02N \times 24.8cm^3) \div 25cm^3$$
$$= 0.02N$$

1e Calculation used in the kjeldahl nitrogen determination - Kjeldahl method

Sample calculation

$1cm^3$ 0.02N hydrochloric acid	= 0.28mg nitrogen
If $10cm^3$ of hydrochloric acid were used	= 2.8mg nitrogen
If 10g of sample were digested	= 2.8mg/10g sample
	= 28mg/100g sample
	= 0.028g/100g sample
	= 0.028%

1f Calculation used in the available phosphorus determination - 'Ag' method

Sample calculation

1. In the available phosphorus determination $30cm^3$ of Morgan's extracting reagent are added to 6g of sample to make a dilution of 1 in 5 with the sample. This suspension is shaken and filtered.
2. A calibration curve of absorbance readings at 880nm versus phosphorus (mg/L) is plotted using standards ranging from 0mg/L to 4mg/L.
3. On extrapolation from this graph the sample filtrate contains 2mg/L phosphorus.
4. Due to the dilution factor in Step 1 the actual phosphorus concentration in the sample is:

$$2mg/L \times 5 = 10mg/L$$

If 0mg/L to 20mg/L, taking into account the dilution factor, is plotted on the graph instead of 0mg/L to 4mg/L then the actual phosphorus concentration in the sample may be read directly of it.

5. If a further 1 in 10 dilution is required on the sample filtrate the phosphorus concentration in the sample will be:

2mg/L x 5 x 10 = 100mg/L

1g Calculation used in the exchangeable potassium determination - Flame photometer method

Sample calculation

1. In the exchangeable potassium determination 30cm^3 of Morgan's extracting reagent are added to 6g of sample to make a dilution of 1 in 5 with the sample. This suspension is shaken and filtered.
2. To 1cm^3 of sample filtrate is added 19cm^3 of 109.58mg/L lithium, as an internal standard, to make a dilution of 1 in 20 with the filtrate.
3. A calibration curve of emission readings versus potassium (mg/L) is plotted using standards ranging from 0mg/L to 20mg/L.
4. On extrapolation from this graph the sample filtrate contains 10mg/L potassium.
5. Due to the dilution factors in Steps 1 and 2 the actual potassium concentration in the sample is:

10mg/L x 5 x 20 = 1,000mg/L

If 0mg/L to 2,000mg/L, taking into account the dilution factors, is plotted on the graph instead of 0mg/L to 20mg/L then the actual potassium concentration in the sample may be read directly of it.

6. If a further 1 in 10 dilution is required on the sample filtrate the potassium concentration in the sample will be:

10mg/L x 5 x 20 x 10 = 10,000mg/L

1h Dry weight calculation used in microbiological determinations

Sample calculation

Aluminium tray 1

Weight of dried empty aluminium tray (g)	=	24.8687
Sample wet weight (g)	=	5.0063
Weight of aluminium tray and sample after drying (g)	=	27.6262

Weight of dried empty aluminium tray and sample wet weight (g)

29.8750

—

Weight of aluminium tray and sample after drying (g)

27.6262

=

Weight of water in sample (g)

2.2488

Therefore in 5.0063g of sample there are 2.2488g of water

In 1g of sample there is:

2.2488g ÷ 5.0063g = 0.4492g of water

The dry weight of the sample is:

1g - 0.4492g = 0.5508g

Aluminium tray 2

Weight of dried empty aluminium tray (g)	=	25.2093
Sample wet weight (g)	=	5.0127
Weight of aluminium tray and sample after drying (g)	=	28.0105

Weight of dried empty aluminium tray and sample wet weight (g)

30.2220

—

Weight of aluminium tray and sample after drying (g)

28.0105

=

Weight of water in sample (g)

2.2115

Therefore in 5.0127g of sample there are 2.2115g of water

In 1g of sample there is:

2.2115g ÷ 5.0127g = 0.4412g of water

The dry weight of the sample is:

1g - 0.4412g = 0.5588g

The average dry weight of the sample (g) = (0.5508 + 0.5588) ÷ 2

The average dry weight of the sample (g) = 0.5548

1i Calculation of Colony Forming Units (CFU)/g dry weight of soil

Sample calculation

Aerobic spore forming bacteria determination

Serial dilution	Count per plate
10^{-2}	97
10^{-2}	122
10^{-2}	101

Average = 106.7

$= 106.7 \times 10^2$ CFU/0.1cm^3

$= 106.7 \times 10^2 \times 10$ CFU/1cm^3

$= 1.067 \times 10^5$ CFU/1cm^3

$= 1.067 \times 10^5$ CFU/g wet weight

1g wet weight = 0.5548g dry weight (Appendix 1h)

$= 1.067 \times 10^5$ CFU/0.5548g dry weight

$= 1.067 \times 10^5 \div 0.5548$g

$= 1.92 \times 10^5$ CFU/g dry weight

APPENDIX 2

PHYSICAL, CHEMICAL AND MICROBIOLOGICAL RESULTS

TABLES

Explanations for abbreviations used in Tables 2a to 2w:

A = Top 3.5cm of sample core.

Aer. Spore Form. Bact. = Aerobic Spore Forming Bacteria.

Avail. P = Available Phosphorus.

Avail. P* = Available phosphorus levels are not averages for one sample core at the 270m and Background sites in Gortdrum, at all sites in Shallee, at the 1986 site in Silvermines and at all sites in Tynagh.

B = Bottom 3.5cm of sample core.

BD = Bulk Density.

BG = Background.

Bold results = One or more plate replicates in the microbiological determinations were outside the counting range.

C:N = Carbon to Nitrogen ratio.

Cl = Chloride.

Colony Forming Units/Gram Dry Weight* = Microbiological levels are not averages for one sample core.

Distance* = A and B are separate sample cores. This applies to the microbiological results for Gortdrum and the physical, chemical and microbiological results for Tynagh.

Exch. K = Exchangeable Potassium.

Exch. K* = Exchangeable potassium levels are not averages for one sample core at all sites in Abbeytown, at the 90m site in Gortdrum and at all sites in Shallee and Tynagh.

Exch. K** = Exchangeable potassium levels are averages for one sample core at all sites in Silvermines.

Kjel. N = Kjeldahl Nitrogen.

Kjel. N* = Kjeldahl nitrogen levels are not averages for one sample core at all sites in Abbeytown, at the 90m and 270m sites in Gortdrum, at all sites in Shallee, at the 1985 and Background sites in Silvermines and at all sites in Tynagh.

NA = Not Analysed.

ND = Not Detectable using stated method.

ND# = Taken to be Not Detectable.

NG = No Growth.

NR = No Result obtained.

Org. C = Organic Carbon.

Org. C* = Organic carbon levels are not averages for one sample core at all sites in Abbeytown, Shallee and Tynagh.

Org. C** = Organic carbon levels are averages for one sample core at all sites in Gortdrum and Silvermines.

Org. M = Organic Matter.

Org. M* = Organic matter levels are not averages for one sample core at all sites in Abbeytown, Shallee and Tynagh.

Org. M** = Organic matter levels are averages for one sample core at all sites in Gortdrum and Silvermines.

pH* = pH levels are not averages for one sample core at all sites in Abbeytown, Gortdrum, Shallee, Silvermines and Tynagh.

Site* = A and B are separate sample cores. This applies to the microbiological results for Shallee.

T. Bact. = Total Bacteria.

T. Fungi = Total Fungi.

T. Fungi (M) = Total Fungi (Moulds).

T. Fungi (Y/M) = Total Fungi (Yeasts and Moulds).

W/V = Weight/Volume.

Year* = A and B are separate sample cores. This applies to the microbiological results for Silvermines.

2a Physical and chemical distribution at 30m intervals along Abbeytown mine tailings site, Ballisodare, County Sligo in November 1992 and May 1994*.

Distance (m)	pH*	Org. M* (%)	Org. C* (%)	Kjel. N* (%)	C:N	Avail. P (mg/L)	Exch. K*(mg/L)	Cl (mg/L)*
0	7.62	25.24	8.50	0.6528	13.0:1	NR	>2000	87
30	7.65	12.65	3.26	0.1788	18.2:1	NR	2186	NA
60	7.50	9.73	2.70	ND	NR	NR	2287	NA
90	7.65	3.47	0.60	ND	NR	NR	911	<28
120	7.73	3.03	0.60	ND	NR	NR	631	<28
150	7.72	2.45	0.50	ND	NR	NR	805	<28
180	7.72	2.81	0.74	ND	NR	NR	699	114
210	7.89	1.54	0.26	ND	NR	NR	448	167
240	7.91	1.99	0.62	ND	NR	NR	786	358
BG	7.62	24.60	9.40	0.8520	11.0:1	NR	1984	NR

2b Physical and chemical distribution at specific sites where particular plant species were dominant along Abbeytown mine tailings site, Ballisodare, County Sligo in November 1992.

Site	pH*	Org. M* (%)	Org. C* (%)	Kjel. N* (%)	C:N	Avail. P (mg/L)	Exch. K* (mg/L)
A	7.86	11.84	3.43	ND	NR	NR	2402
B	7.45	14.56	3.53	ND	NR	NR	3614
C	7.63	12.83	3.10	ND	NR	NR	1997
D	7.70	9.61	1.93	ND	NR	NR	3412
E	7.43	5.96	1.47	ND	NR	NR	4624
F	7.57	4.24	0.92	ND	NR	NR	819
G	7.59	3.50	0.96	ND	NR	NR	391
H	7.71	3.47	0.87	ND	NR	NR	1416
I	7.87	2.22	0.58	ND	NR	NR	879
J	7.99	2.11	0.50	ND	NR	NR	1038
BG	7.43	31.13	11.40	1.0288	11.1:1	NR	3094

2c Microbiological distribution at 30m intervals along Abbeytown mine tailings site, Ballisodare, County Sligo in February 1992.

	Colony Forming Units/Gram Dry Weight*			
Distance (m)	T. Bact.	T. Fungi (M)	Actinomycetes	Aer. Spore Form. Bact.
0	2.28E+07	5.23E+04	7.99E+03	1.92E+05
30	7.05E+06	**1.12E+03**	**4.75E+03**	**2.97E+04**
60	2.32E+06	2.78E+03	5.39E+03	**3.14E+04**
90	3.16E+05	**7.59E+02**	6.59E+03	**1.48E+04**
120	1.98E+06	**1.03E+03**	**1.71E+03**	8.69E+03
150	7.49E+05	**3.02E+02**	**7.49E+02**	**5.25E+03**
180	1.12E+07	**5.49E+02**	**2.06E+03**	7.27E+03
210	3.57E+06	2.63E+03	**4.79E+02**	**1.94E+03**
240	2.38E+06	5.42E+03	**2.66E+02**	**2.13E+03**

2d Microbiological distribution at specific sites where particular plant species were dominant along Abbeytown mine tailings site, Ballisodare, County Sligo in March/April 1992.

	Colony Forming Units/Gram Dry Weight*			
Site	T. Bact.	T. Fungi (Y/M)	Actinomycetes	Aer. Spore Form. Bact.
A	1.23E+07	9.21E+03	**3.05E+05**	3.66E+05
B	1.30E+07	**9.46E+02**	**1.03E+03**	5.29E+04
C	8.82E+06	3.01E+03	**1.26E+03**	2.44E+04
D	3.49E+05	**1.10E+02**	**1.93E+03**	1.03E+04
E	4.95E+05	**4.74E+02**	5.64E+03	1.50E+04
F	2.24E+06	**3.29E+02**	**7.58E+02**	1.40E+04
G	3.16E+06	**1.40E+02**	**1.77E+03**	1.57E+04
H	**3.60E+05**	**4.91E+02**	5.00E+03	6.77E+03
I	2.72E+05	**2.35E+02**	4.22E+03	1.11E+04
J	5.89E+05	**1.76E+02**	**9.48E+01**	5.01E+03

2e Physical and chemical distribution at seven sites on Gortdrum mine tailings site, County Tipperary in 1990/1991.

Site	pH A	pH B	Org. M (%) A	Org. M (%) B	Kjel. N (%) A	Kjel. N (%) B	Avail. P (mg/L) A	Avail. P (mg/L) B	Exch. K (mg/L) A	Exch. K (mg/L) B
1	8.52	8.00	6.82	3.78	0.0526	0.0026	0.995	0.690	2650	1690
2	8.00	8.40	4.28	1.12	0.0353	0.0023	0.810	0.392	2630	600
3	7.95	8.38	4.07	2.45	0.0126	0.0083	0.595	0.960	1595	740
4	8.18	8.27	5.58	4.63	0.4500	ND#	0.995	0.265	1100	800
5	8.08	8.52	3.43	2.20	0.0506	0.0000	0.590	1.520	1000	625
6	8.02	8.40	6.44	4.57	0.0139	0.0000	0.000	0.000	2000	0
7	7.96	8.53	7.25	1.76	0.0424	0.0060	0.600	0.665	1130	820

2f Soil texture and classification at sites on Gortdrum mine tailings site, County Tipperary in 1990/1991.

Site	Clay (%)	Silt (%)	Classification
3	29	49	Clay Loam
5	16	9	Sandy Loam
6	NR	NR	NR

2g Physical and chemical distribution at 90m intervals along Gortdrum mine tailings site, County Tipperary in February 1993.

Distance (m)	pH*	Org. M** (%)	Org. C** (%)	Kiel. N* (%)	C:N	Avail. P* (mg/L)	Exch. K* (mg/L)
90	7.55	7.69	1.72	0.1372	12.5:1	8.789	1912
180	7.85	4.79	1.23	ND	NR	3.800	1502
270	7.87	5.61	1.07	0.0868	12.3:1	3.573	1310
BG	7.34	31.79	9.06	NR	NR	17.783	>2000

2h Microbiological distribution at 90m intervals along Gortdrum mine tailings site, County Tipperary in February 1993.

	Colony Forming Units/Gram Dry Weight*			
Distance* (m)	T. Bact.	T. Fungi (Y/M)	Actinomycetes	Aer. Spore Form. Bact.
90 A	1.56E+07	8.44E+04	4.09E+05	1.03E+05
90 B	NR	6.85E+04	1.34E+05	NR
180 A	2.37E+07	6.29E+04	1.18E+05	4.05E+06
180 B	NA	1.16E+04	1.60E+05	**4.65E+04**
270 A	1.18E+07	2.81E+03	**2.41E+03**	4.86E+03
270 B	NA	4.28E+03	3.05E+04	8.24E+03
BG A	1.20E+08	**2.64E+05**	7.36E+06	5.37E+04
BG B	NA	2.88E+05	4.58E+06	3.38E+05

2i Physical and chemical distribution at sites along Shallee mine tailings site, County Tipperary in 1990/1991.

Distance (m)	pH A	pH B	Org. M (%) A	Org. M (%) B	Kiel. N (%) A	Kiel. N (%) B	Avail. P (mg/L) A	Avail. P (mg/L) B	Exch. K (mg/L) A	Exch. K (mg/L) B
0	5.30	6.56	0.33	0.00	0.0224	0.0000	0.63	0.35	525	170
16	5.43	7.64	3.55	0.67	0.1422	0.0122	0.92	0.45	500	100
30	6.00	7.90	1.44	1.05	0.0000	0.0000	0.72	0.70	1500	400
60	6.18	7.80	8.27	2.40	0.0756	0.0000	0.88	0.00	1180	611
90	6.10	8.00	6.04	2.10	0.0660	0.0223	1.16	0.30	1566	187
120	6.01	6.68	9.75	1.50	0.1197	0.0000	3.30	0.49	1700	400
150	6.86	8.00	5.51	2.12	0.0000	0.0000	0.84	1.14	1615	500
165	5.03	7.87	1.10	1.09	0.0617	0.0000	0.27	1.08	500	200
180	5.12	8.03	1.00	0.74	0.0407	0.0000	0.16	0.30	400	170
200	7.29	8.10	1.40	0.70	0.0272	0.0081	0.96	1.55	290	90
220	6.09	7.11	1.22	7.24	0.1581	0.0161	4.56	0.39	1800	500

2j Soil texture and classification at sites along Shallee mine tailings site, County Tipperary in 1990/1991.

Distance (m)	Clay (%)	Silt (%)	Classification
16	8	10	Loamy Sand
30	31	39	Clay Loam
90	16	78	Silt Loam
150	76	20	Clay
165	9	14	Sandy Loam
180	36	15	Sandy Clay
220	NR	NR	NR

2k Physical and chemical distribution at vetch and willow sites on Shallee mine tailings site, County Tipperary in May 1992.

Site	pH*	Org. M* (%)	Org. C* (%)	Kiel. N* (%)	C:N	Avail. P* (mg/L)	Exch. K* (mg/L)
Willow	5.62	15.81	6.84	ND	NR	2.94	1148
Vetch	6.42	43.36	15.54	0.0070	2220:1	50.37	10473

2l Microbiological distribution at vetch and willow sites on Shallee mine tailings site, County Tipperary in May 1992.

	Colony Forming Units/Gram Dry Weight*			
Site*	T. Bact.	T. Fungi (Y/M)	Actinomycetes	Aer. Spore Form. Bact.
Willow A	7.17E+06	1.61E+03	4.33E+05	8.72E+04
Willow B	2.53E+06	4.09E+03	3.96E+05	1.27E+04
Vetch A	**5.04E+07**	3.90E+04	1.19E+06	2.70E+05
Vetch B	1.19E+06	**8.66E+01**	6.64E+03	**2.35E+03**

2m Physical and chemical distribution at sites on Silvermines mine tailings site, County Tipperary in 1990/1991.

Year	pH A	pH B	Org. M (%) A	Org. M (%) B	Kjel. N (%) A	Kjel. N (%) B	Avail. P (mg/L) A	Avail. P (mg/L) B	Exch. K (mg/L) A	Exch. K (mg/L) B
1985-Grass	7.20	7.35	8.97	6.51	0.0700	0.0000	0.545	1.095	3100	720
1985-Clover	7.67	7.63	7.62	7.08	0.0125	0.0047	0.380	1.310	1800	420
1986-60m	7.20	7.36	8.04	4.96	0.0517	0.0000	0.000	0.000	1650	550
1987-105m	7.38	7.35	6.24	4.58	0.0138	0.0027	0.574	0.255	1000	950
1988-135m	7.46	7.57	5.47	4.34	0.0000	0.0024	8.140	2.155	1800	760
1988-195m	7.26	7.37	6.70	5.00	0.1555	0.0000	0.565	0.260	3200	1600

2n Soil texture and classification at sites on Silvermines mine tailings site, County Tipperary in 1990/1991.

Year	Clay (%)	Silt (%)	Classification
1985	42	7	Sandy Clay
1985-Clover	20	4	Sandy Clay Loam
1986	44	22	Clay

Note
Year = Year of Rehabilitation

2o Bulk density distribution at 20m and 30m intervals along Good and Poorly* rehabilitated sections respectively of Silvermines mine tailings site, County Tipperary in 1990/1991.

Distance (m)	BD (g/cm3)	Distance (m)	BD (g/cm3)*
0	0.784	0	0.928
20	0.775	30	0.916
40	0.757	60	0.834
60	0.863	90	0.928
80	0.953	120	0.684
100	0.812	150	0.915
120	0.742		
140	0.848		
160	0.874		
180	0.952		
200	1.112		

2p Microbiological distribution at sites on Silvermines mine tailings site, County Tipperary in April 1991.

	Colony Forming Units/Gram Dry Weight		
Year	T. Bact.	T. Fungi	Actinomycetes
1985	2.09E+07	NG	3.91E+07
1986	8.10E+07	NG	1.42E+07
1987	1.06E+08	NG	ND#
1988	6.87E+07	NG	2.75E+07

Note
Year = Year of Rehabilitation

2q Physical and chemical distribution at sites on Silvermines mine tailings site, County Tipperary in May 1992.

Year	pH*	Org. M** (%)	Org. C** (%)	Kjel. N* (%)	C:N	Avail. P* (mg/L)	Exch. K** (mg/L)
1985	7.05	7.78	1.63	0.0162	100.6:1	17.09	1075
1986	7.12	9.16	2.22	0.0510	43.5:1	3.29	3888
1987	7.16	8.56	1.63	0.0328	49.7:1	1.95	1735
1988	7.16	4.45	3.36	0.0300	112:1	11.91	1403
BG	NR	25.29	7.33	0.0030	2443.3:1	5.99	1427

2r Microbiological distribution at sites on Silvermines mine tailings site, County Tipperary in May 1992.

	Colony Forming Units/Gram Dry Weight*			
Year*	T. Bact.	T. Fungi (Y/M)	Actinomycetes	Aer. Spore Form. Bact.
1985				
A	1.28E+07	1.59E+03	2.19E+06	1.45E+04
B	1.68E+07	2.70E+03	4.33E+05	1.59E+04
1986				
A	2.28E+06	**3.80E+02**	1.48E+04	**1.09E+03**
B	2.37E+06	**8.16E+02**	3.16E+04	**4.08E+01**
1987				
A	1.91E+06	1.81E+03	6.56E+04	**1.70E+03**
B	2.14E+06	**2.89E+02**	1.65E+04	**1.67E+03**
1988				
A	5.93E+05	**1.01E+02**	0.00E+00	**3.90E+02**
B	1.99E+06	**1.08E+02**	**1.65E+03**	**1.19E+03**
BG				
A	2.44E+07	4.49E+04	1.66E+06	1.51E+05
B	1.87E+07	4.47E+04	1.88E+06	1.47E+05

Note

Year = Year of Rehabilitation

2s Physical and chemical distribution at sites along Tynagh mine tailings site, County Galway in 1990/1991.

Distance (m)	pH A	pH B	Org. M (%) A	Org. M (%) B	Kjel. N (%) A	Kjel. N (%) B	Avail. P (mg/L) A	Avail. P (mg/L) B	Exch. K (mg/L) A	Exch. K (mg/L) B
0	7.19	8.20	0.00	0.00	0.0020	0.0069	3.120	0.570	1000	200
30	8.21	8.13	0.67	0.63	0.0057	0.0017	0.275	0.735	ND#	800
60	7.40	8.32	2.05	0.00	0.0054	0.0000	0.925	1.205	1700	480
120	7.98	8.27	0.64	0.44	0.0054	0.0000	0.485	0.970	1700	810
150	7.99	8.10	1.65	0.69	0.0000	0.0065	0.825	1.710	640	330
180	7.70	8.02	0.55	0.78	0.0194	0.0000	0.680	0.665	725	480
210	7.73	8.21	4.35	0.36	0.0127	0.0000	1.105	0.205	2100	120
250	7.37	7.97	0.00	0.00	0.0167	0.0000	1.645	1.220	660	240

2t Soil texture and classification at sites on Tynagh mine tailings site, County Galway in 1990/1991.

Distance (m)	Clay (%)	Silt (%)	Classification
0	49	17	Clay
30	37	0	Not Classified
60	18	5	Sandy Loam
120	38	0	Not Classified
150	49	15	Clay

2u Microbiological distribution at sites on Tynagh mine tailings site, County Galway in April 1991.

	Colony Forming Units/Gram Dry Weight		
Site	T. Bact.	T. Fungi	Actinomycetes
Rabbit Graze	4.99E+07	NG	2.43E+07
Good Grass	3.45E+07	NG	2.90E+08
Poor Grass	0.00E+00	NG	ND#
Mine Tailings	0.00E+00	NG	0.00E+00

2v Physical and chemical distribution at 30m intervals along Tynagh mine tailings site, County Galway in February 1993.

Distance* (m)	pH*	Org. M* (%)	Org. C* (%)	Kiel. N* (%)	C:N	Avail. P* (mg/L)	Exch. K* (mg/L)
30 - A	7.29	3.88	0.98	0.0478	20.5:1	43.002	1280
30 - B	7.23	4.33	1.20	0.0615	19.5:1	65.041	3499
60 - A	7.25	4.90	1.68	0.0676	24.9:1	67.590	1617
60 - B	7.40	3.69	1.16	ND	NR	62.879	1474
90 - A	7.29	2.92	0.97	0.0003	3233.3:1	114.030	851
90 - B	7.40	2.62	1.06	0.0437	24.3:1	82.729	943
BG - A	5.83	19.51	6.90	0.0154	448.1:1	6.743	6589
BG - B	5.66	21.23	7.32	0.0011	6654.6:1	26.200	15993

2w Microbiological distribution at 30m intervals along Tynagh mine tailings site, County Galway in February 1993.

	Colony Forming Units/Gram Dry Weight*			
Distance* (m)	T. Bact.	T. Fungi (Y/M)	Actinomycetes	Aer. Spore Form. Bact.
30 - A	7.73E+06	1.67E+04	1.51E+06	3.15E+04
30 - B	1.70E+07	2.65E+05	2.21E+06	1.16E+05
60 - A	1.49E+06	5.63E+03	7.69E+05	**1.34E+03**
60 - B	1.13E+06	7.65E+04	1.69E+06	**2.88E+03**
90 - A	1.90E+06	6.91E+04	1.30E+06	8.67E+03
90 - B	1.16E+06	**1.63E+05**	1.28E+06	6.91E+03
BG - A	3.76E+07	7.50E+04	1.78E+06	1.50E+05

APPENDIX 3

STATISTICAL TABLE

3a Values of the correlation coefficient, r, which differ significantly from 0 at 5%, 1% and 0.1% levels

d.f.	0·05	0·01	0·001	d.f.	0·05	0·01	0·001
1	0·9^{2}692	0·9^{2}877	0·9^{3}877	16	0·468	0·590	0·708
2	·9500	·9^{2}000	·9^{3}000	17	·456	·575	·693
3	·878	·9587	·9^{2}114	18	·444	·561	·679
4	·811	·9172	·9741	19	·433	·549	·665
5	·754	·875	·9500	20	·423	·537	·652
6	0·707	0·834	0·9249	25	0·381	0·487	0·597
7	·666	·798	·898	30	·349	·449	·554
8	·632	·765	·872	35	·325	·418	·519
9	·602	·735	·847	40	·304	·393	·490
10	·576	·708	·823	45	·288	·372	·465
11	0·553	0·684	0·801	50	0·273	0·354	0·443
12	·532	·661	·780	60	·250	·325	·408
13	·514	·641	·760	70	·232	·302	·380
14	·497	·623	·742	80	·217	·283	·357
15	·482	·606	·725	90	·205	·267	·338
				100	·195	·254	·321

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(Barrington and Willis, 1969)